Modelling the health impacts of urban transport changes in Africa

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Declaration

This thesis is the result of my own work and includes nothing which is the outcome of work done in collaboration except as declared in the preface and specified in the text. It is not substantially the same as any work that has already been submitted for any degree or other qualification except as declared in the preface and specified in the text. It does not exceed the 60000-word limit prescribed by the Clinical Medicine and Veterinary Medicine Degree Committee.

Abstract

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Lambed Tatah

Africa is rapidly urbanising and motorising, complicating its existing urban transport impacts such as high road traffic injuries, air pollution, and decreasing physical activity derived from walking and cycling. This situation highlights a need to develop healthy and sustainable urban transport systems on the continent. Modelling studies can help unpack the effects of urban transport plans and policies, thus facilitating evidence generation for policymaking. However, the use of modelling approaches in Africa is limited. This thesis aimed to increase understanding of the health impacts of changes in African urban transport systems through modelling.

I started by exploring travel and physical activity behaviours and their data sources in selected African cities to elicit the context and address some challenges related to model data inputs from surveys. Secondly, I explored health integration in urban transport policies to gauge the transport sector's commitment to supporting health goals and the range of meaningful modelling scenarios for engaging stakeholders in the African context. Thirdly, I reviewed modelling studies on transport health impacts to synthesise modelling approaches and guide model selection and adaptation. Finally, I modelled urban transport health impacts in five African cities for four scenarios: cycling, bus, car and motorcycle. Each scenario represented a 5% increase in the chosen transport mode.

Surveys using travel and time-use diaries were valuable sources of travel behaviour data. Travel behaviour case studies from four cities, Nairobi and Kisumu (Kenya), Yaoundé (Cameroon), and Accra (Ghana), showed a wide variation of immobility and daily travel duration across cities, with walking as the primary mode and privately owned small-capacity public transport as the second. Motorcycles were also an essential component of public transportation in some cities. The physical activity case study from Accra showed high levels of background physical activity with a substantial contribution from transport. However, there was a significant disagreement between the Global Physical Activity Questionnaire and travel diary physical activity measurements, signalling precaution when using these crucial data sources for modelling. The policy analysis from Cameroon showed the integration of physical activity and non-communicable diseases in the policies of some sectors but not the transport sector, suggesting that modellers need simple illustrative scenarios to pitch transport health benefits to the naive transport sector. The systematic review identified several models in different contexts and various scenarios. Studies on the application of models in low-and middle-income countries were scarce, but overall review findings could guide transport health impact modelling in African cities. The modelling study in five African cities showed reduced adverse outcomes from shifts towards cycling and bus for public transport, mainly from gains in physical activity and reduction in air pollution, as road traffic fatalities were significant for the cycling scenario in some cities. Comparatively, car and motorcycle scenarios showed increased adverse outcomes from air pollution and physical inactivity, with additional road injuries for the motorcycle scenario across cities.

The thesis sheds light on using relatively complex tools to elicit the health impacts of changes in urban transport in contexts with limited data, making a case for transport policies that favour active travel even in settings where active travel is already prevalent. It provides cross-city results, which help cities compare the effects of similar policies in different contexts, supporting collaboration amongst cities and increasing opportunities to learn from one another. Additionally, the thesis highlights our limited understanding of travel behaviour from available surveys and caveats in model adaptation as priority areas for future research.

Contributions and dissemination

Chapters 3-7 are based on research I led and have prepared for publication in collaboration with multiple authors, for whom I am a guarantor. The contents of these papers are reproduced in the corresponding chapters with minimal changes. Authors' contributions are reported according to the International Committee of Medical Journal Editors (ICMJE) criteria. Appendix 10.1 details additional research contributions made during my doctoral studies that are not part of this dissertation.

Chapter 3.1 is under second-round review in the Journal of Transport Geography. It is submitted as "Lambed Tatah, Louise Foley, Tolu Oni, Matthew Pearce, Charles Lwanga, Vincent Were, Felix Assah, Yves Wasnyo, Ebele Mogo, Gabriel Okello, Stephen Mogere, Charles Obonyo, James Woodcock. Travel behaviour characteristics and correlates in Nairobi and Kisumu, Kenya". The study was part of a work package in the Global Diet and Activity Research (GDAR) project, which received data through collaboration with the Japan International Cooperation Agency (JICA) and the Institute for Transportation and Development Policy (ITDP). Authors contributed as follows: Conceptualisation, LT, LF, MP, TO, VW, CL, YW, FA, EM, GO, SM, CO, and JW; methodology, LT, LF, and JW; formal analysis, LT; investigation, LT; resources, TO and JW; data curation, LT; writing—original draft preparation, LT; writing—review and editing LT, LF, MP, TO, VW, CL, YW, FA, EM, GO, SM, CO, and JW; supervision, CO and JW; project administration, LT; funding acquisition, TO, CO, and JW. All authors read and agreed to the revised version of the manuscript.

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Diary Transport-Related Physical Activity in Accra, Ghana. Int. J. Environ. Res. Public Health 2022, 19(12), 7346; https://doi.org/10.3390/ijerph19127346". Authors contributed as follows: Conceptualisation, LT, RG, FAAD and JW; methodology, LT, MP, RG, SB, FAAD, and JW; formal analysis, LT; investigation, FAAD; data curation, LT; writing—original draft preparation, LT; writing—review and editing, LT, MP, RG, SB, FAAD, and JW; supervision, FAAD and JW; project administration, FAAD and JW; funding acquisition, FAAD and JW. All authors read and agreed to the published version of the manuscript.

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Contents

Abbreviations

AP	Air pollution
AT	Active transport
BE	Built environment
CI	Confidence interval
COPD	Chronic obstructive pulmonary disease
CRA	Comparative risk assessment
CVD	Cardiovascular disease
DALY	Disability-adjusted-life years
DRF	Dose-response function
EDGAR	Emissions Database for Global Atmospheric Research
ERF	Exposure-response function
GBD	Global burden of diseases
GDAR	Global Diet and Activity Research Network
GHG	Greenhouse gases
GIS	Geographic Information Systems
GPAQ	Global Physical Activity Questionnaire
HEAT	Health Economic Assessment Tool
HIA	Health impact assessment
HIC	High-income country
IHD	Ischemic heart disease
IQR	Interquartile range
IPAQ	International Physical Activity Questionnaire
ITDP	Institute for Transport and Development Policy
ITHIM	Integrated Transport Health Impact Model
JICA	Japan International Cooperation Agency
LMIC	Low- and middle-income country
LQ	Lower quartile
MET	Metabolic equivalent of task
MMET	Marginal metabolic equivalent of task
MT	Motorised transport
NCD	Non-communicable disease
NMT	Non-motorised transport
PA	Physical activity
PAF	Population attributable risk
PIF	Potential impact fraction
$PM_{2.5}$	Particulate matter of less than 2.5 µm aerodynamic diameter
PM_{10}	Particulate matter of less than 10 µm aerodynamic diameter
PT	Public transport

RTI	Road traffic injuries
RR	Relative risk
SD	Standard deviation
SDGs	Sustainable Development Goals
SSATP	Africa transport policy programme
UN	United Nations
VoI	Value of information
WHO	World Health Organisation
YLL	Years of life lost

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1. Introduction

1.1. Overview

Urban transport—the ensemble of rules, infrastructure, and modes that enable the transfer of people and goods within the urban territory and its immediate suburban zones—is critical to city functioning. Beyond affecting all urban activities, it also influences population health through several pathways, such as road traffic injuries, air pollution, and physical activity gained from walking and cycling. Modelling the health impacts of changes in urban transport systems and policies provides evidence for healthy and sustainable urban transport planning. Such impact assessments are gaining ground in high-income countries, with recent studies showing net health gains for policies/interventions favouring active transport (walking and cycling). These approaches, however, are still timid in lower-income countries, especially in Africa, where urban transport development faces significant challenges, and there is a lack of evidence of the health impacts of transport systems. This thesis focuses on generating evidence and methods for promoting healthy and sustainable urban transport development in Africa.

The numerous shortcomings characterising African urban transport systems can negatively affect urban dwellers' health and well-being. Tail-pipe emissions from old, under-performing vehicles using dirty fuels, copious amounts of road dust in the dry seasons, and long traffic waits due to traffic congestion worsen peoples' exposure to unacceptable air pollution levels [1]. Road traffic injuries on the continent are among the highest in the world [2, 3]. Walking is purportedly high, but long walking distances under the sun and the lack of safe routes for walking and cycling make active transport unsafe, inconvenient, and unpopular, potentially limiting its contribution to physical activity and health. Policy actions to tackle these urban transport shortcomings are lacking, likely linked to multiple factors, including the gaps in evidence and evidence application in the African context.

One health indicator directly affected by urban transport shortcomings is non-communicable diseases (NCDs). NCDs kill over 41 million people in the world yearly, mainly (75%) through cardiovascular diseases (such as heart attacks and strokes), cancers, and chronic respiratory diseases (such as chronic obstructive pulmonary disease and asthma) [4]. The burden of NCDs has surged in sub-Saharan Africa over the past two decades [5]. They will likely overtake communicable, maternal, neonatal, and nutritional diseases, all combined, as the leading cause of mortality in sub-Saharan Africa by 2030 [6]. Urban transport factors, such as the high levels of air pollution and greenhouse gas emissions, the shortage of space for walking, cycling, and active living, and the changes in diet towards the consumption of highly processed foods accessible at transport stations, combine to transform African cities into NCDs epicentres. A re-think of how urban transport could contribute to slowing these rising epidemics in Africa is timely.

Africa is urbanising at one of the fastest rates globally (1.1% per year). The United Nations projects that more than two-thirds of the world's population will live in urban areas in the next 30 years, adding

2.5 billion new urban dwellers by 2050, with Africa and Asia absorbing over 90% of the new urban dwellers [7]. The rapid rise in urban population will put enormous pressure on all urban infrastructures and services and expose many people to all sorts of urban transport hazards. The need for well-planned urban environments to match the needs of the rapidly growing urban population on the continent has never been more urgent. The global community has a unique opportunity to guide urbanisation and significant urban development trends in Africa and other low- and middle-income contexts in ways that protect and promote future global health.

Beyond the precarious transport systems and rapid urbanisation, other unique features that characterise African urbanism can accentuate urban transport health impacts on the continent. The rapid urban growth on the continent is occurring in a context dominated by widespread corruption and poor governance, income poverty, inadequate urban planning, informal settlement proliferation in disaster-prone areas, and frequent disease and conflict outbreaks. These background factors can distract from needed developments and complicate the preservation and promotion of urban health in Africa. Any attempt to develop meaningful urban transport systems needs to consider these aspects.

First, urban growth in Africa is not mirrored by the expected economic transition, contradicting the long-held notion that urbanisation leads to economic growth [8]. Most African urban dwellers are poor and, hence, disproportionately exposed to urban health hazards [9]. Ideally, urban centres serve as engines to drive economic growth, poverty reduction and human development. The diverse, well-educated labour, the concentration of businesses, government services and infrastructure, and the economies of scale in urban centres facilitate entrepreneurship, technological innovations, knowledge transfer and sustainable provision of public goods such as roads, electricity and piped water. Well-managed urbanisation helps optimise the benefits of agglomeration. However, recent trends in Africa suggest that the urbanisation process aligns more with the demographic rather than the economic transition theory [10]. The demographic phenomenon partly explains the widespread urban poverty and overcrowding, which affect many aspects of urban life, including the constraint of living in poor neighbourhoods and using inefficient, unsafe transport modes.

Second, the demographic theory also explains the proliferation of informal settlements in Africa, another crucial determinant of urban health. Over 60% of African urbanites reside in informal settlements, with sub-Saharan Africa hosting one of the world’s highest count of residents in informal settlements (189 million) [11]. The non-durable or overcrowded housing, lack of access to improved water and sanitation, or more heightened insecurity against eviction that characterises informal settlements expose dwellers to environmental and health hazards. These hazards, such as violence and land pollution (from using roadsides as dumping grounds), compound those resulting from transportation in informal settlements.

Third, poverty and the propensity for informal settlements push many African urban dwellers to settle and operate economic activities in disaster-prone areas. Thus, they are more likely to experience the impact of climate change and transport-related disasters. Target residential areas usually include low-elevation coastal zones and river banks [12], prone to floods and road collapses. Economic activities such as open markets occur close to roads, heightening the risk of vehicles running into people. Globally, nearly 60% of cities with at least 300,000 inhabitants are at higher risk of at least one type of six natural disasters (cyclones, droughts, floods, earthquakes, landslides, and volcanic eruptions), and the number is growing [13]. In Africa, seasonal, temporary, and permanent urban migration is already among the strategies households utilise when faced with food and livelihood insecurity associated with climate variability. Climate-related migration could become more prevalent with the anticipated increase in frequency and intensity of adverse climate events [14]. This pattern induces a vicious cycle: climate-related migration, resettling into risky urban areas, contributing to urban poverty, and complicating urban planning, all negatively impacting urban population health.

Finally, the majority of African cities have fragile health systems that are overwhelmed by the triple health burden: infectious diseases (e.g. HIV/AIDS, tuberculosis, pneumonia, dengue fever, and diarrhoea), NCDs (e.g. heart disease, stroke, asthma and other respiratory illnesses, cancers, diabetes and depression), and intentional and unintentional injuries (e.g. violence and road traffic injuries). Poorer health outcomes are inevitable in such weak and overwhelmed health systems. For example, the chances of death from brain injuries resulting from road traffic injuries are higher if the emergency response system is not functioning correctly. Interventions addressing multiple prongs of the triad, such as those in the transport sector, can release significant pressure on the health systems by reducing disease prevalence and facilitating patient distribution to maximise the use of available health services.

Targeting urban health and well-being is strategically vital in improving global and regional human and economic development. Health is essential for building a productive workforce, fostering good urban livelihoods, and creating resilient and vibrant communities. Healthy and sustainable urban transport systems can improve health by providing access to essential opportunities like education, jobs, and health and social services. Inadequate transportation can lead to poorly connected urban centres, exacerbate inequity, and introduce new hazards, mainly through poor air quality, local and global climate change impacts, and lack of adequate housing. City managers can and should harness the inherent human mobility needs to improve physical and mental health by enabling access to active transport means, promoting social interactions, and protecting vulnerable people.

Current frameworks show that urban transport is causing premature mortality and a significant burden of morbidity through 14 key pathways: (1) motor vehicle crashes, (2) human physical inactivity, (3) climate change, (4) social exclusion, (5) community severance, and traffic-related environmental exposures including (6) air pollution, (7) noise pollution, (8) green space, blue space, and aesthetics reduction, (9) urban heat islands, (10) contamination, (11) lack of independence, (12) reduced access, (13) stress and (14) exposure to electromagnetic fields [15]. These exposures and their health effects are not proportionally distributed, notably varying by income and race, whereby lower-income populations are disproportionately negatively affected [16].

Commonly evaluated pathways in the literature are road traffic injury, air pollution, and physical activity pathways, partly because of the share of their burden relative to the others. Reducing road traffic injuries and air pollution directly improves health, but increasing transport physical activity may increase road traffic injuries and inhalation of pollutants. Understanding the health impacts of changes in transport-related physical activity is particularly important in Africa because walking rates are purportedly high on the continent, and there is a lack of evidence as to whether or not higher levels of active transport translate to overall healthy urban transport systems in these environments. Modelling these health impacts provides a way of understanding their differential effects and comparing urban transport policies. This approach can either complement conventional but limited economic and environmental transport impact assessments or serve as a standalone measure to guide policy choices.

Two of the leading modelling approaches are (i) the health economic assessment tool (HEAT) developed by the World Health Organization for assessing the health impact of cycling and walking (applied mainly in Europe and the USA, and now extended globally) and (ii) the Integrated Transport and Health Impact Modelling tool (ITHIM) developed at the University of Cambridge MRC Epidemiology Unit (applied in many cities in high-income countries and some cities in Latin America, Africa and India). Model developers have primarily relied on the HIC context for the conceptualisation, underlying assumptions, dose-response functions that link transport to health, data requirements, assessed policy scenarios, and output communication. Cities in Africa and other LMICs differ substantially from those in HIC with regard to the parameters used for model development, which limits the ability to use available models in LMIC settings. For example, the background levels of physical activity, road traffic injuries and air pollution are different for LMICs [17], which directly affect the dose-response functions of transport to health pathways. Current dose-response relationships rely on epidemiological studies to which only a few studies from LMICs contribute. It is also unclear how existing models will behave in settings with extreme inputs, such as the high RTI and walking shares typically observed in most African cities.

Developing contextually relevant models for LMICs requires input data for physical activity, road traffic injuries, air pollution, and travel behaviour. Travel behaviour data, for example, are essential because modellers use them to create scenarios and estimate vehicle mode share, travel-related PA, road traffic injuries and air pollution. Such data are scarce in most African cities; the existing bits are difficult to access. There are no benchmarks against which to compare new data. In addition to the challenges of data limitation, the use of evidence in policymaking in Africa is low [18]. The risk of generating evidence that does not contribute to better policymaking demotivates research. To an extent, minimal and poor allocation of resources leads to focusing on the short-term, shifting significant long-term problems for the future.

1.2. Problem statement

Researchers have made substantial advances in quantifying transport health impacts, especially in developing robust models for health impact assessments. These models have provided important insights into the health impacts of various urban transport policies and scenarios. However, most urban transport research and model development efforts concentrate on high-income countries, leading to tools and outputs that are mainly relevant to those settings. LMICs, especially those in Africa, are understudied despite the scale of the problem in these countries. The simultaneous rise in urbanisation, NCDs, and “motorcyclisation” (which particularly heightens the risk of fatal road traffic injuries) exacerbate the potential health impacts of urban transport in Africa. Harms from urban transport compound a precarious health situation threatened by infectious diseases and weak health systems. Consequently, there is an urgent need to facilitate healthy transport policymaking in Africa.

Multiple challenges preclude the direct application of existing evidence and models to understanding the health impacts of urban transport in Africa. These challenges range from the lack of routine data that serve as inputs for most models to the inherent contextual differences in demographics, urban typologies, and disease profiles that affect the parameterisation of the transport-to-health dose-response relationships. The relative inattention to this kind of evidence in policymaking in Africa has not helped the advancement of research in this field. These challenges also point to where research can leverage existing efforts to understand the health impact of urban transport. For Africa, the focus should include bridging the data gap, contextualising current models, and integrating evidence into policy.

1.3. Research aim

This research aims to understand the health impacts of changes in African urban transport systems. Through modelling, it focuses on the magnitude, direction, and policy implications of health impacts of changes in urban transport. The research relies on an adaptable model for evaluating the health impacts of urban transport in the African context, with attention to critical model features such as holistic health outcomes, dose-response functions and assumptions, consideration of model behaviour in settings with extreme inputs such as walking or road injury rates, data requirements, and the acceptability of model outputs by policymakers.

1.4. Research objectives

Using models to understand urban transport health impacts requires knowledge of existing models, their use cases, and data requirements. Modellers need information on baseline behaviours, especially those resulting from individual surveys that are more challenging to gather. Additionally, knowledge of the transport policy space (the freedom, scope, and mechanisms that authorities have to choose, design, and implement transport policies to fulfil their aims) is required to identify opportunities, enablers and constraints for integrating evidence of the health impact of transport into policies. These preliminary needs motivated the following specific research objectives:

1. To describe travel behaviours and their data sources in African cities.
2. To describe physical activity behaviour and its data sources in an African city.
3. To identify policy opportunities and constraints for integrating health into transport policies.
4. To explore use cases of transport health impact models and synthesise approaches of urban transport modelling.

5. To model and compare the health impacts of urban transport changes in selected African cities.

1.5. Scope of the thesis

This research only uses modelling to explore the health impacts of changes in urban transport in Africa. It relies on estimating the difference in disease burdens between urban transport scenarios, but calculating the disease burdens of transport systems is not the end goal. The actual health impact calculations do not explicitly use classical epidemiological approaches; these approaches have been instrumental in describing background behaviours and relationships between transport and health pathways. The research also does not explore the entire health impact assessment framework, which sometimes considers modelling as only one step. Although the aim is to describe findings relevant to Africa, the case studies are limited to the cities with available and accessible data. All pathways from transport to health have not had equal space in this research; the physical activity pathway dominates the thesis.

1.6. Significance of the thesis

This thesis has three intended outcomes. Theoretically, it sets out to demonstrate how context and population affect the health impacts of urban transport modelling. On a practical level, the thesis intends to adopt a model for quantifying the health impact of urban transport that is useful for researchers and urban planners in Africa. The final intended outcome is understanding the policy context that enables or constrains healthy urban transport planning.

This research contributes to African urban health and well-being. Healthy and sustainable urban transport policies, among other benefits, can be expected to increase or maintain travel-related physical activity (walking and cycling), mitigate exposure to air and noise pollution and road injuries, and reduce the emission of greenhouse gases. By targeting healthy and sustainable urban transport, the thesis simultaneously contributes to three of the 17 UN 2030 SDGs: Goal 3 (health and well-being), goal 11 (sustainable cities and communities), and goal 13 (climate action).

1.7. Structure of the thesis

The thesis consists of seven further chapters. In chapter 2, I provide a background to assessing the health impacts of urban transport in Africa, fleshing out the relevant themes and situating the research and gaps in the related literature. Chapter 3 uses survey data from different sources, including newly collected data, to explore and compare patterns in travel behaviours among African cities, presenting the results of travel behaviours from three countries. These travel behaviour data are central in transport health impact modelling: they serve as a basis for scenario creation and inform transport-related physical activity and population exposure to air pollution and road traffic injuries. Chapter 4 explores physical activity behaviour and data sources in Accra, Ghana. PA is the pathway of interest in this thesis and relies on individual survey data like travel surveys. I focused on exploring survey data because they are more challenging to source and usually serve as benchmarks for other data sources.

Policies need to integrate health goals to effect health-related changes. To understand the policy landscape and the extent to which these policies integrate health, chapter 5 explores how transport and other relevant sectors consider physical activity and NCDs as health indicators in Cameroon. I use findings from this study to gauge entry points for engaging transport stakeholders with health goals, propose urban transport policy scenarios, and evaluate them in chapter 7.

Chapter 6 addresses the fourth thesis objective by reviewing studies that modelled the health impacts of urban transport. The chapter identifies existing models, their use cases and their suitability for the African context; it provides information for adapting existing models for use in African settings. The outputs from this chapter also justify the need to target urban transport as a health determinant and the choice of the modelling approach used in this thesis.

Based on a preliminary scoping of transport health impact models, the Integrated Transport Health Impact Model (ITHIM) was considered a suitable starting model for this project. It has successfully generated outputs in pilot studies in Ghana, India and Latin American cities, and there is available support from the Public Health Modelling Group at the MRC Epidemiology Unit. ITHIM has two other advantages over the health economic assessment tool (HEAT) model (another prominent model). Firstly, HEAT focuses only on walking and cycling and does not fully consider public transport, which could become an important domain in LMICs. Secondly, it does not consider changes in car-driving or motorcycling on injury risk or air pollution. The data explored in chapters 3 and 4 align with the data requirements of the ITHIM model.

Chapter 7 combines work from the preceding chapters to model the health impact of urban transport in Africa. It uses data identified and processed in chapters 3 and 4, policy scenarios derived from chapter 5, and a model adapted with information from Chapter 6 to quantify and compare the health impacts of transport in selected cities. This chapter's sensitivity and uncertainty analyses indicate the model's robustness and priorities in the data gap and which data transformation processes require more research.

Chapter 8 critically examines results from preceding chapters in light of the previous evidence on the health impact of transport as outlined in the background and makes judgments regarding the contributions of this work, its strengths and limitations.

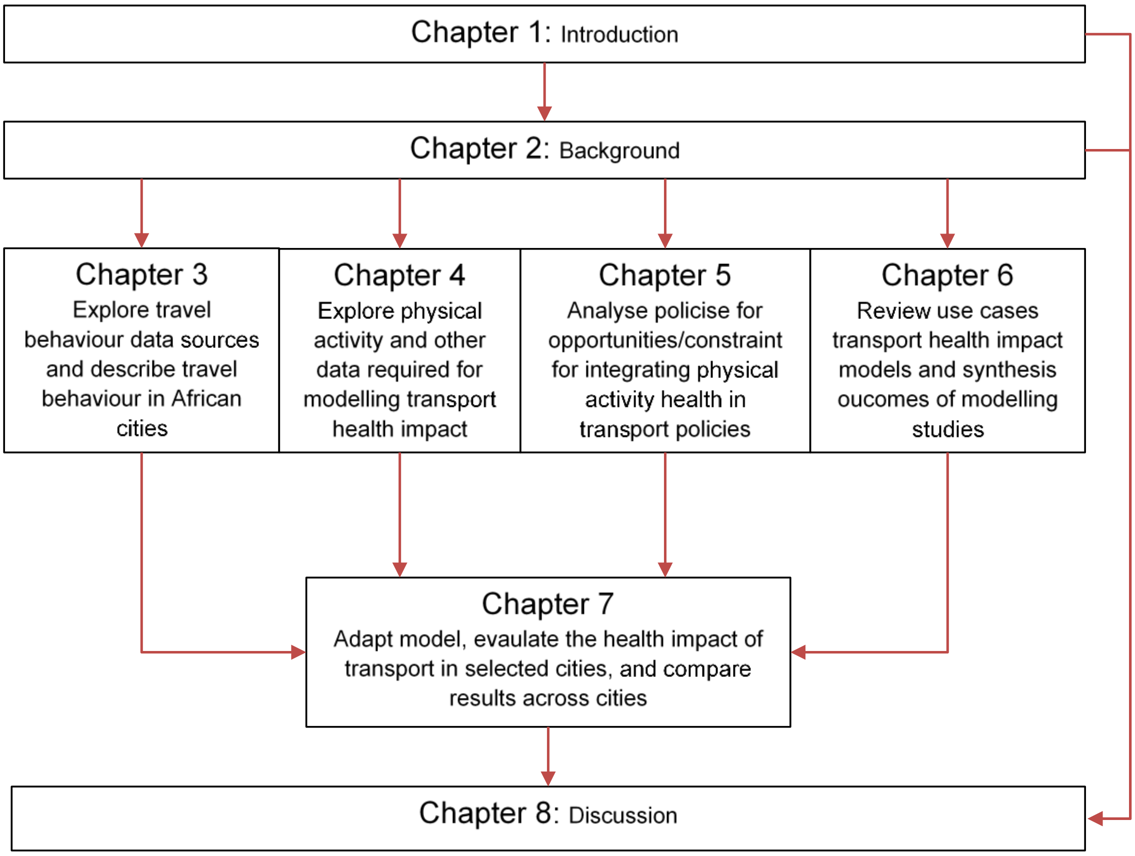


Figure 1.1 Interlinkages of thesis chapters

1.8. Key concepts used in the thesis

The three central concepts used throughout this thesis, urban transport, health impact, and modelling, need further contextualisation. Similarly, urban transport-related terminologies, such as public transportation, paratransit, mass transit, active transport, accessibility, and mobility, need to be defined.

Urban transport refers to the supply system that enables the movement of people and goods within a defined urban or metropolitan area. The system typically includes infrastructure (fixed installations and technology), vehicles, and operations. From a public authority perspective, transport supply is usually considered a two-dimensional system comprised of transport infrastructure and services. Transport infrastructure includes linear installations (roads, railways, and waterways) and terminals (such as railway stations, bus stations and truck terminals). Transport services include bus systems, taxi fleets and rail services. Ownership and operation of infrastructure and services can be in public, private or semi-private hands. Transport operations refer to how stakeholders operate infrastructure and vehicles and the enabling environment, such as financing, legal frameworks, policies, and data. Additionally, I adopt the following definitions for terminologies closely related to urban transport:

- *Public transport* refers to transport services available to the public (as opposed to private transportation). Public, private, or both operators can supply public transport services with or without predetermined schedules, routes, stops, fares and subsidies. Private operators of public transport services can be formal (officially recognised by the public authority) or informal, and the state of informality can range from 'illegal' and unregulated to 'legal' and regulated.

- *Paratransit* refers to public transport services supplied by informal private operators running small to medium-capacity vehicles (including motorcycle taxis, collective taxis, and minibuses) and usually relegated to the city periphery.
- *Mass transit* refers to high-capacity public transport systems, usually operated on dedicated infrastructure (railway or road-based), e.g. regional trains, subways or metros, light rail transit (LRT), tramways, and bus rapid transit (BRT).
- *Active transport (AT) or non-motorised transport (NMT)* refers to human-powered modes (mostly walking and cycling); *motorised private transportation* refers to all other personal vehicles (e.g. motorcycle, car, pickup truck). This thesis does not detail other semi-motorised transports, such as e-bikes.
- *Mobility* refers to the ability of people and goods to move, resulting in transport demand. It relates primarily to the demand side of a transport system. The term 'mobility' usually highlights the pre-eminence of people over infrastructure and vehicles. Mobility embraces concepts such as multi-modality (the principle of simultaneously considering all travel modes in a complementary way) and inter-modality (connecting various travel modes for consecutive use along the same trip). Transport infrastructure and services should answer current and future mobility needs. These needs include commuting to work or school, travelling to medical appointments, accessing shopping centres, and other daily activities. Mobility needs vary depending on age, income, disability, and location. Meeting these needs requires various transportation options, including public transit, active transportation (walking and cycling), and private vehicles.
- *Accessibility* measures the ease with which people and goods can reach different places. The capacity and the arrangement of transport infrastructure and services are crucial in determining accessibility [19]. Accessibility is an important concept because the overarching aim of any sustainable urban transport policy should be to provide and improve accessibility towards and within a particular area. Providing efficient transport infrastructure and services is only a means to that end, not the aim itself.

Health impact refers to a quantifiable change in health status, mainly at a population level. It relies on the calculation of disease burdens from different urban transport systems. The health indicators include disease incidence, morbidity, mortality or a combination of disability-adjusted life years (DALY) and years of life lost (YLL).

Modelling aims to reduce particular parts or features of the world to levels that are easier to understand, define, quantify, visualise, or simulate by referencing it to existing and usually commonly accepted knowledge. In urban transport health impact modelling, the relationships between urban transport and health are generally expressed in mathematical equations using dose-response functions derived from epidemiological studies.

2. **Background to quantifying the health Impacts of transport in African cities**

African urban transport systems exhibit many features that may significantly affect health. Urban contexts also influence the extent of the health effects of urban transport. Knowledge of the transport systems and contexts is needed to understand how to quantify the health impacts of urban transport. This chapter provides this background knowledge. First, I describe features of the African urban context that might influence how urban transport affects health. Next, I describe the characteristics of African urban transport systems while focusing on components relevant to healthy and sustainable urban transport systems. I also review the evidence of linkages between urban transport and health to elucidate the quantifiable pathways researchers can consider during transport health impact calculations. Finally, I discuss the efforts and challenges in quantifying the health impacts of urban transport in Africa while highlighting the critical gaps addressed in this PhD.

2.1. The African urban context

The African urban context influences how urban transport systems affect health. Beyond the well-acknowledged widespread problems of civil unrest, conflicts, and corrupt governance, the other main contextual features influencing the urban transport-health relationship include rapid urbanisation, a high level of informal settlements, and a triad of health burdens (infectious diseases, NCDs, violence and injuries) in fragile health systems. I have hinted at these features in chapter 1. Now, I provide an in-depth description of the attributes to bring into perspective the potential health impacts of urban transport in Africa.

2.1.1. Rapid urbanisation

Urbanisation—the process by which rural communities grow into urban ones and, by extension, the growth and expansion of urban communities [20]—is arguably the world's most important trend in the 21st century. It induces rapid physical, social, and economic changes, which unavoidably but malleably affect peoples' lives. Thus, it is an essential determinant of health, acting through multiple pathways. These health effects depend on urbanisation drivers, mechanisms, and speed.

Different factors have driven urbanisation throughout history. By c.5000 BCE, the world was largely rural. Prosperous and efficient villages started to attract resettlements from less successful neighbours. They grew into earlier cities such as Uruk and Ur in ancient Mesopotamia (4300-3100 BCE), marking the beginning of urbanisation. Earlier cities centred on agricultural activities near fertile riverbanks quickly disappeared once soil fertility declined and farming outputs could no longer support the swelling population. Religion and commerce also led to early human agglomeration. The growth of urban areas was generally slow until the industrial revolution in the late 18th century and the later green revolution in the mid-20th century, which caused many cities to sprout around mines and factories. The improved agriculture and transport technology increased food production and supply to growing populations in distant urban centres. Rural-urban migration still drives urban growth, but a new form of urbanisation specific to Africa has emerged. Urban agglomerations are rapidly emerging in densely populated, traditionally rural areas [21]. Due to population growth, many villages and small towns are growing into metropolitan centres. Africa's urbanisation also exhibits city sprawling, with unplanned high-density peripheral settlements occurring at remote locations that necessitate motorised transport for residents to pursue livelihoods and fulfil household needs.

Urban growth has continued faster as technology and innovation continue to improve and spread across the globe. The UN estimates that 30% of the world's population lived in urban areas in 1950. Today, the proportion has increased to 55% and will likely grow to 68% by 2050. This projection translates to 2.5 billion new urban dwellers expected from rural to urban transition, migration and urban population growth [7]. With the lowest proportion of urbanites (40%), Africa has consistently maintained the fastest urbanisation rates since 1950. It has an average annual rate of change of urban dwellers of 1.1%, which is higher than the world's average of 0.75% and many times higher than the slowest region (Oceania) with 0.07%. The UN projects that Africa will stay at the top of the urban growth chart until the end of the century. Over 90% of new urban dwellers globally will diffuse into cities and urban centres in Africa and Asia.

The effects of rapid urbanisation are likely to be felt the most in Africa for two reasons. The large share of the global urban population that Africa will absorb implies that many people will experience a myriad of urban challenges on the continent. Secondly, compared to regions that have urbanised for centuries, Africa has little experience managing urbanisation challenges. It seems less prepared to deal with the woes of urbanisation. Under such conditions, poorly managed urbanisation abounds, manifested through the rapid growth of urban poverty and informal settlements in large and intermediate African cities.

Most humans agglomerate in urban areas with the reasonable expectation of benefiting from rapid economic growth, poverty reduction, human development, and access to health and social services. At the same time, some urban environment features are harmful and can deprive residents of fundamental human rights. The natural and built environments (housing, transportation, parks, and urban design) and the socio-economic environments (the availability of education, jobs, and social support) can influence health behaviours (such as diet, exercise, tobacco use, and unhealthy alcohol and drug use). These tend to be important determinants of health in addition to the availability of medical care, which has often been the primary focus of global and national health policies [22]. The public policies and political environments that shape urban health determinants, including the societal impact of discrimination (both from within and outside these societies), have far more significant effects on health than individual factors alone. Figure 2.1 illustrates the main determinants of urban health, further detailed in Table 2.1.

Figure 2.1 Determinants of health in urban environments.

Table 2.1 Determinants of urban health

Urban health determinant	Health effects
Housing	Housing conditions are associated with many significant health conditions, including respiratory infections, asthma, lead poisoning, injuries, childhood development and nutrition, and mental health [23]. Most urban poor live in informal and squatter settlements, which tend to be unregulated, precarious, overcrowded, and often located in hazardous areas such as riverbanks and water basins subject to flooding, steep hillsides, busy roads and industrial zones.
Water and sanitation	Clean water is crucial for preventing diarrheal diseases. Globally, over 3% of all deaths are due to diarrhoeal conditions caused by unsafe drinking water and poor hygiene and sanitation [24]. Although 94% of urban residents in developing countries use improved water sources, these are often at risk of contamination and shortage. A third of developing city dwellers lack access to improved sanitation, with over half a billion urban dwellers living in households that share sanitary facilities with other families [25].

Food and nutrition	Safe and sufficient food reduces the prevalence of many diseases. Inadequate food intake is typical and reduces defence against infections, leading to frequent diseases, especially for slum dwellers whose environments constantly have pathogenic microorganisms. The urban poor often rely on cheap, processed, fast or street foods, which are associated with myriads of other health problems, including obesity and diabetes, cardiovascular diseases, vitamin/mineral deficiencies and dental issues.
Community cohesion	Social environments can promote or damage health. Social pressures can cause health-damaging behaviour such as drug abuse and violence, and high social stressors such as social isolation and extreme poverty are problematic. Interpersonal violence is fast becoming a significant security and public health issue. Faster-growing and larger cities experience higher levels of violence. In urban areas, young males aged 15 to 24 commit the most violent acts and are the principal victims of violence. The lives and health of city dwellers are at risk during wars and conflicts.
Health sector	The urban poor typically have limited access to health services. Even when these services are free regarding medications and supplies, their location and operation hours are usually inconvenient, and the quality of care is poor. The result is low utilisation of even the most basic preventative and curative health services.

The effects of urban transport on health are distinctly significant in the context of rapid urbanisation because urban transport can affect physical activity, air pollution, road traffic injury, noise pollution and climate change. Since current systems focus on providing motorised transport infrastructure, with little attention to walking and cycling, rapid urban population growth will likely overwhelm those infrastructures and lead to more traffic congestion, air pollution, and greenhouse gas emissions. Many people will continue to unwillingly walk for long distances, risking their lives in polluted and injury-prone environments. Therefore, urban transport systems must ensure convenient and safe walking and cycling infrastructure for growing urban dwellers.

On the other hand, rapid urbanisation and the emergence of new cities may present opportunities for healthy and sustainable urban transport infrastructures. Authorities may not often recognise these opportunities, leading to the growing mismatch between infrastructure requirements and the ability of city authorities to provide the requisite financial resources in fast-growing cities. The cost and challenges of delivering better infrastructure are higher when old, sophisticated ones need demolishing. Most African cities are new, less refined, and have inadequate infrastructure and backlogs. They will require minimal destruction; this can be an opportunity to improve and rebuild new transport infrastructures. A known feature of African urban growth which allows space for new urban transport development is in-situ urbanisation—the transformation of rural into urban areas by increased population density without necessitating migration.

2.1.2. High informal settlements

Informal settlements or slums are self-built urban communities rarely recognised officially, and officials typically deny them life-supporting services and infrastructure [26]. They are prolific in Africa. Many health outcomes are worse in informal settlement residents than in neighbouring urban or rural areas [27, 28]. Drivers of poor health in slums are highly complex, and identifiable root causes include inadequate or inappropriate urban and transport planning as well as spatial and material deprivation and pervasive discrimination. These inequalities within cities and the disproportionate burden of urban transport mainly harm the urban poor in informal settlements. Unfortunately, people blame poor health in informal urban settlements on poor residents' behaviours. Poor sanitation and hygiene practices, such as open defecation and waste management, can spread infectious diseases in slums.

Dwellers in informal settlements make up most of the urban poor who likely travel on foot or utilise casual paratransit options such as minibuses, rickshaws and motorcycles. These modes vary widely in coverage, safety and performance. Paratransit users typically comprise the largest group of victims after pedestrians [29]. The disproportionate impact of urban transport on the poor makes the problem less likely to be given serious attention since those in power and making most of the cities' decisions may not feel directly affected. Safe routes can foster a sense of place and enhance the social, economic and spatial integration of slums into the entire fabric of the city. Improved planning for non-motorised transport can reduce injuries, provide safe spaces for walking and cycling, and perhaps provide organised spaces for street-level vendors [30]. Public and non-motorised transport can also enhance air quality, foster neighbourhood vitality, and promote physical activity (cycling and walking), all contributing to reducing non-communicable diseases.

The general poor transport infrastructure within informal settlements can limit access by emergency vehicles, discourage mobility, slow economic growth and perpetuate poverty. The intense mixed-use of streets with the encroachment of vendors could also act as a barrier for walking and cycling and increase the risk of road injuries if authorities poorly plan and manage streets. The expected transformation of slums must consider the benefits and unintended harms of improved transport. Improving road conditions can enhance vendors' livelihoods, manufacturing workshops and others who rely on streets for income-generating activities [11]. Examples from Latin America indicate that improving streets, pavement, or public transport can generate multiple health benefits for informal areas. In Acayucan, Mexico, street asphalting in an informal settlement increased residents' wealth, appliance ownership, and home improvements [31]. In Medellín, Colombia, cable cars ('Metrocables') constructed in the poorest neighbourhoods (districts) linked previously segregated and impoverished areas with the entire city. The results were improved economic status for the poor residents, significant reductions in gun homicides and improvements in social cohesion [32].

2.1.3. The triple health burden

Most African health systems are fragile, underfunded, and constantly under pressure from a triple health burden: infectious diseases with high maternal and child mortality, NCDs, and injuries. Health consequences from poorly planned transport systems will likely result in worse outcomes as there are almost no resources for treatment.

Infectious diseases such as HIV/AIDS, tuberculosis, malaria and hygiene-related diseases have been the leading cause of mortality for decades in LMICs. Additionally, these settings still have high maternal and childhood morbidity and mortality. These conditions have understandably masked the even more harmful emerging NCDs that the continent will succumb to soon. Africa's rapid urbanisation is accompanied by a quick epidemiological transition, characterised by a shift from disease profiles dominated by infectious, maternal and childhood diseases to NCDs. The distribution of disease burden will change by 2030, with NCDs overtaking all the other diseases combined [5]. The rise in NCDs primarily stems from the increasing incidence of cardiovascular diseases and their risk factors, such as diabetes, dyslipidemia, hypertension, obesity, unhealthy diets, physical inactivity and air pollution [5]. In 2013, WHO Africa reported that NCD control ranked among the lowest regarding integrating social participation and dialogue into interventions that address risk factors and the determinants of priority public health conditions [33]. Together with high rates of intentional and unintentional injuries, these conditions exert enormous pressure on healthcare systems.

African urban transport systems, in their current state, are far from contributing to NCD and injury prevention/reduction, at least without causing severe harm. Most countries have poorly organised public transport, and cycling for transportation is generally low and inexistent in many cities. Walking and cycling may expose travellers to a higher risk of road injuries and air pollution and negate the potential physical activity gains. Ill-health conditions resulting from inadequate transport planning will likely have poor prognoses from the overwhelmed healthcare systems.

2.2. Urban transport in Africa

Describing African urban transport systems is challenging as the continent is large and diverse, and each urban transport system is unique. The fabric of every city and its transport system result from specific geographical, political, economic, historical, and cultural situations. These multiple and dynamic components are sometimes tricky to appraise since a proper assessment of a transport system will need a deeper understanding of a broad range of dimensions and stakeholders. Unfortunately, data on African urban transport demand, supply, and impact are scarce, with only a few unharmonised data sources available, rendering syntheses and comparisons complex among African cities.

A relatively comprehensive description of African urban transport systems emerges from work undertaken by the African Transport Policy Program (SSATP), Africa's leading transport policy development forum with 42 active member countries [34]. SSATP promotes sustainability, accessibility, and mobility policies in African urban areas. In the past five years, they have conducted literature reviews and consulted with African stakeholders using systemic approaches that consider the technical aspects of urban transport supply, its governance framework, and its impacts. They have implemented new experimental guidelines to improve urban transport planning in 12 African countries (Senegal, Guinea, Côte d'Ivoire, Ghana, Nigeria, Rwanda, Kenya, Ethiopia, Mali, Burkina Faso, Togo, and Benin). Thus, they have an authoritative voice on transport affairs in Africa.

The emerging characteristics of the African urban transport systems fall into three main dimensions: governance, which lays the framework for the development and operation of urban transport systems; transport systems themselves, which include the infrastructure and services; and the impacts of urban transport, including travel behaviours which represent an intermediary step between the transport systems and other transport impacts. These dimensions vary among countries and cities within the same country. However, many settings share similar features.

2.2.1. Governance of urban transport

The concept of urban transport governance varies [35]. Here, it refers to the framework within which urban transport development and operation occur. It includes the legislative, policy, administrative, and financial frameworks defining urban transport systems. Generally, national, state and local institutions are involved in either planning, regulating, issuing licences, allocating resources or monitoring and enforcing compliance, with frequent overlaps among institutions. In most cases, national governments are responsible for setting the frameworks across all sectors in the country, determining the main investment programmes and the distribution of resources within the country.

African urban transport policies, planning and regulations are generally thought of as weakly articulated and confusing, a situation that cuts across multiple sectors. The World Bank views this as the root cause of urban transport failures on the continent, highlighting that institutions at the municipal level are weak and inadequately staffed, and jurisdiction and functional impediments prevent policy integration [36]. Another limitation is the lack of autonomous agencies with overarching responsibility for urban transport. Only a few African cities, such as Abidjan (Agence des Transports Urbains—AGETU), Bamako (Direction de la Régulation de la Circulation et du Transport Urbain—DRCTU), Dakar (Conseil Exécutif des Transports Urbains—CETUD), and Lagos (Lagos Metropolitan Area Transport Authority—LAMATA), have functional agencies. Even these lack executive powers to implement their vision and must work through other agencies [37]. The regulatory frameworks, which include controlling new operators' entry into markets, allocating routes, licensing new vehicles and drivers, and establishing tariffs, are light-handed. Syndicates of transport operators often enjoy a significant degree of autonomy and a wide ambit for self-regulation [37].

Beyond basing urban transport plans on outdated ideas previously used by now-developed cities, the decisions around which urban transport infrastructure to build often lie in the hands of external sponsors and their interests. Investments often prioritise inter-urban transport infrastructure to establish trade networks linking cities and countries, mainly to transfer goods [38]. The development trajectory of urban transport in most African towns still prioritises cars over non-motorised or public transport, aiming to improve the flow of (mostly private) vehicles rather than people. These development approaches persist despite the knowledge that improved non-motorised transport planning can reduce injuries, make active travel more convenient, and perhaps provide safe spaces for street-level vendors in systems dominated by the informal sector [30]. Safe pedestrian and cyclist spaces can foster a sense of place and enhance the socioeconomic and spatial integration of informal settlements into the entire fabric of the city. Such integration is also a recognised urban health determinant, and governments cannot afford to ignore the opportunity [28].

Integrating health into transport policies seems to be a distant goal for African cities. The "Health in all policies" declaration stipulates the need for systematic consideration of the health impact of policies in all sectors [39]. Many stakeholders of African urban transport have still not embraced this approach. A WHO survey in 2013 reported that only 15% of African health stakeholders mentioned the Ministry of Transport as a critical sector for health policies, ranking the transport sector lowest among many sectors considered [33]. The ill-consideration of health in urban transport policies could result from the lack of health impact assessments to inform policymakers of the health contributions of different sectors. Until 2019, no study had reported a transport health impact assessment from Africa [40].

Governance challenges for building the desired urban transport systems across Africa may be glaring. Still, some cities are making progress, proving that transport health benefits are not far-fetched with the correct determination. These cities are taking advantage of new opportunities in the political arena, specifically in political and economic reforms in urban governance, with a new generation of mayors and political leaders in Uganda, South Africa, and Ghana actively involved in health and sustainable urban transport development. The national, city and municipal governments are primarily responsible for developing their jurisdictions; they often receive support from international and local stakeholders, who provide resources, guidance and cross-pollinating good initiatives among cities. Key organisations supporting African urban transport development include the Institute for Transportation and Development Policy (ITDP), UN-Habitat, World Health Organisation Urban Health Initiative (WHO-UHI), C40 Cities, the World Resource Institute (WRI), African Transport Policy Programme (SSATP), Transformative Urban Mobility Initiative (TUMI), and International Association of Public Transport (UITP) (Table 2.2).

Table 2.2 Organisations that support African urban transport governance

Organisation	Relevant scope
African Transport Policy Programme (SSATP)	It comprises 42 African member countries and focuses on advising governments on transport policy and strategy development, coordinating initiatives and sponsoring links between global and African institutions, and building capacity through training programs and establishing institutional frameworks. In the past five years, SSATP has produced and implemented guidelines and roadmaps for establishing Public Transport Authorities in African cities, conducted urban transport studies and strategic policy papers in 12

	African cities, and created a roadmap for improving informal public transport.
Institute for Transportation and Development Policy (ITDP)	Over the years, ITDP Africa has worked with African cities in designing and implementing high-quality bus rapid transit (BRT) systems, bike networks, and pedestrian projects. These include the Dar es Salaam BRT, which opened as the first world-class BRT in East Africa in 2016; Johannesburg's silver-standard Rea Vaya BRT; and Cape Town's bronze-standard MyCiTi BRT. It has an African head office in Nairobi and works throughout Africa.
World Health Organization - Urban Health Initiative (WHO-UHI)	It is an implementation framework aiming to reduce the deaths and diseases caused by unhealthy urban environments. It equips decision-makers, public health experts and other stakeholders with health-based tools to identify and assess the impacts of unsustainable urban policies. It has piloted urban transport initiatives in Accra, Ghana.
C40 Cities	14 African cities are now part of C40 cities, a network of mayors of nearly 100 world-leading cities collaborating to deliver the urgent action needed to confront the climate crisis. The network idealises foot, bicycle and shared modes of transportation in cities. In May 2022, Abidjan, Accra, Addis Ababa, Dakar, Ekurhuleni, Freetown, Johannesburg, Lagos, Nairobi and Tshwane joined Durban to sign the air declaration act. The target actions include creating low or zero-emission areas; supporting walking/cycling; implementing vehicle restrictions or financial incentives/disincentives, such as road-use or parking charges; reducing truck, non-road machinery and city-owned vehicle emissions.
World Resource Institute (WRI)	WRI, together with Agence Française de Développement (AFD), is a steering committee member of the Digital Transport for Africa (DT4A) Initiative. DT4A is a network of various city governments, residents, universities, civic technology companies and collectives committed to building digital commons for sustainable urban mobility and access.
African Network of Walking and Cycling (ANWAC)	ANWAC is a space for organisations and experts to collaborate and promote safe, healthier, and comfortable walking and cycling in African countries.

2.2.2. Urban transport infrastructure

Urban transport infrastructure comprises roads, rails, stations, car parks and bays, and the technological infrastructure that facilitates the flow of goods and people in urban areas. Today's urban transport infrastructure in many African cities is a product of colonialism (and apartheid in the case of South Africa), continued or slightly modified by later local policies and international funding models. Towns in the colonial era developed around central points, with networks for resource extraction to the sea rather than local and regional integration, and comprised limited public transport infrastructure to cater to privileged groups rather than the general population. Both new and older cities now face similar infrastructure problems. The road networks are generally sparse and contain multiple incomplete, unconnected roads. The ongoing erection of houses in a largely unplanned manner, without adequate transport and other infrastructure planning and the low density in the periphery of most cities increases the challenge of providing suitable transport infrastructure.

The overall road network constitutes less than 7% of the land area in most African cities compared to 25–30% coverage in developed cities [41]. Paved roads account for only one-third of all city roads, although the range is wide: barely 10% in Kinshasa and Kigali to more than 70% in Kampala. The average paved road density in urban areas in Africa is 300 m per 1000 inhabitants (close to 2 km/km^2), far lower than the average for developing cities worldwide, with an average of 1000 m per 1000 inhabitants, according to the UN Millennium Cities Database. The average national road density in Africa is 204 $km/1000\ km^2$, with only one-quarter paved, and dirt roads with poor drainage are the norm since a big part of aid has been directed to building roads without accounting for maintenance costs. This density lags far behind the world average of 944 $km/1000\ km^2$, with more than half paved [42, 43]. Congestion seems to ensue from the low road density with limited alternate roads in the fast-growing African cities; this impacts economic development, pollution, and accidents in a rather complex relationship. Almost everyone is stuck when a crash or other blockage occurs on a single stretch of road. Other aspects of the infrastructure that could improve and facilitate transport have also received little attention. Dedicated bus, cycling or pedestrian lanes to improve passenger flow and safety are limited or absent altogether. Bus stops, bus shelters, and other passenger facilities are scarce and in poor condition. Interurban bus terminals are often at the heart of many cities, worsening city congestion.

Though timid, the focus on developing infrastructure for motorised vehicles has caused most cities to ignore pedestrians' and cyclists' needs. Sidewalks were missing from around 65% of the road networks of 14 African cities studied [37], so pedestrians, cyclists and motorised vehicles must share the same space. Where they exist, sidewalks are poorly maintained, contain open drains, and expanding adjoining properties tend to encroach and overtake them. Pedestrian crosswalks and bridges are not provided, except in the city centre. The only facilities afforded to pedestrians are crosswalks without signals; these are rarely respected by motorists or enforced by the police. Cycling facilities are almost non-existent in most cities.

2.2.3. Urban transport services

Africa has the lowest level of motorisation in the world. However, the growth of cars and motorcycles is increasing rapidly as the proportion and aspirations of the middle-class increase and public transport deteriorates. Factors such as lack of investment, poor planning, competition from other modes of transport, inefficiency and corruption, and political instability have contributed to a decline in the quality and availability of public transportation in many African cities. The current average is 42 vehicles/1000 inhabitants compared to the world's average of 182 vehicles/1000 persons [44]. The purchase of new cars in Africa accounts for only 1% of global sales, with new vehicles making up only 10% of the overall purchase in Africa. The low level of motorisation makes Africa a lucrative, untapped target market [45]. The growth in internal production and aggressive intrusion by external car manufacturers will further increase Africa's motorisation levels [44]. However, this rise in motorisation does not help health, sustainability, and climate change causes.

From a car-centric perspective, the low levels of motorisation and a decline in organised public transport systems have led to an unmet demand for motorised transport. The gap has resulted in rapid growth in alternative public transport means, initially provided by minibuses and shared taxis and vans, and more recently by commercial motorcycles. Motorcycle use has increased significantly over the past decade, offering transport advantages such as easy manoeuvrability, travel on poor roads, and demand responsiveness. But such growth has also led to increased road traffic injuries, traffic management problems, pervasive noise and increases in local air pollution and greenhouse gas emissions.

It will be complex for cities to balance the desired renovations and upgrades in public transport with the anticipated growth in vehicles and the proliferation of motorcycles. The rise in these transport modes has economic and social implications for the cities. For example, equitable conventional public transport has the potential to uplift many people from poverty [46], while commercial motorcycles are already providing employment and transportation for a significant share of the urban poor. A holistic understanding of the health impacts of transport can help cities optimise transport services for well-being.

Some large African cities have introduced new (often foreign-funded) public transportation like Bus Rapid Transit (BRT) and Light Rail, based on their success in Latin America and Asia. However, a significant share of public transport consists of paratransit, or informal, unscheduled, privately owned transport services, generally offered by small-scale operators on a for-profit basis. For cities where data is available, paratransit's share of road-based public transport ranges from 65% in Yaoundé (Central Africa) and 72% in Johannesburg (Southern Africa) to 82% in Algiers (Northern Africa), 86% in Accra (Western Africa) and 98% in Dar es Salaam (Eastern Africa) [47]. The vehicles involved in paratransit include motorised four-, three- and two-wheelers, non-motorised rickshaws, bicycle taxis and animal-drawn carts. Together, they outweigh the mode shares of formal public transport (buses, trains and BRT) in most African cities. Many city authorities do not formally recognise most paratransit transport; they fail to regulate it and even develop anti-paratransit policies like the central city Boda-Boda Free Zone in Kampala, Uganda.

2.2.4. Travel behaviour

Urban travel behaviours reflect the situations of the urban transport systems, which are themselves shaped by urban transport governance. Thus, travel behaviour is an intermediate step for transport impact. A general lack of data on urban travel behaviours in African cities hinders our understanding of urban travel, and there is a tendency to generalise across heterogeneous and changing contexts. Only a few transport authorities on the continent have embarked on extensive travel surveys. They merely cover capital or primary cities, leaving out the smaller towns which dominate African urbanisation. This inadequacy of data contributes to the scantiness of the literature. Our recent systematic review on the socioeconomic and gendered inequities in African travel behaviour elucidates this literature gap [48]. Only three countries (Nigeria, Ghana and South Africa) out of 54 have more than 15 studies on travel behaviour characteristics, and 20 countries with an aggregate population of over 225 million had no traceable published literature. Repeated travel surveys, which are the primary data source for most settings, are rare and were only traceable in two cities Cape Town (2001, 2013, and 2021) and Nairobi (2004, 2013). The limited data explains why insights on African urban travel primarily emerge from small-scale, one-time surveys that may not adequately represent the relevant population.

It is often reported that many trips in urban Africa are on foot, albeit the quality of the walking environment is poor. There is a lack of dedicated pedestrian space and prioritisation, and pedestrians compete for space with two-wheelers and street vendors. Travel surveys report walking trip mode shares close to 70% in many cities, including Douala (Cameroon), Conakry (Guinea), Dakar (Senegal), Niamey (Niger), Addis-Ababa (Ethiopia), Lusaka (Zambia), Kampala (Uganda), and Kisumu (Kenya) [49–51].

The second often-discussed feature is that congestion occurs at low levels of car ownership, resulting in long, unpredictable trip durations and daily travel durations for motor vehicle users. While consistent multi-city data on congestion levels do not seem to exist, there are examples of congested cities; it is, however, unclear if they are representative of a single country, let alone the continent. For instance, in Nairobi, traffic models estimate that vehicle speeds are 8.3 km/h and 7.6 km/h during the morning and evening peaks, respectively [52]. In Dar es Salaam, average daytime speeds are 8–15 km/h [53], and the duration of a 30-minute trip can increase six-fold depending on the traffic conditions in the city [54]. Gonzales et al. (2011) [52] argue that congestion occurs in these cities because the road networks are much smaller than in the towns with similar populations in higher-income settings. Metz (2018) argues that congestion in urban areas is inevitable and should be embraced and managed efficiently rather than trying to eliminate it [55]. Thus, the goal may be to manage congestion with pricing, land-use policies, and technology solutions such as intelligent transportation systems rather than building new roads that may never meet the ever-growing transport needs.

Finally, there are gender and socioeconomic differences in mobility patterns in Africa. Females make fewer trips and are less likely to travel by car, motorbike (as a driver) or bicycle (as a rider) but more likely to travel by walking and paratransit [48]; their perceived barriers to travelling include violence and household responsibilities [48, 56]. Lower-income households live on the urban periphery and face more travelling challenges [57]. Individuals with lower socioeconomic status are more likely to travel by walking, paratransit, and bike and less by private vehicle [58, 59]. There is some limited evidence that lower-income households are less likely to travel or more likely to make fewer trips; it is unclear if total travel time differs by socioeconomic status [48].

Overall, African urban transport systems have huge limitations, but urban mobility systems continue to function, albeit sub-optimally. People still go to work, school, or markets every day. The suboptimal nature of transport signifies that people travel in less safe modes than they need or deserve. This low-quality transportation imposes avoidable burdens and costs and impedes the city's progress. The systems could be improved, especially by making them healthier and more sustainable. There are unfolding opportunities in the political arena, with the rapidly growing informal transport sector and south-south learning for addressing African urban transport needs.

2.3. Evidence of the linkages between urban transport and health

Urban transport affects health through several pathways. Researchers have explored the quantitative health impacts of only a few of these pathways, partly due to the advancement of research on pathway exposures and the significance of their associated health burden. Injuries cause direct harm; air and noise pollution stem from emissions from specific vehicles; and physical activity results directly from walking and cycling. Robust and quantifiable evidence is available for these exposures. Empirical studies linking and quantifying the health effects of urban transport on access to jobs, markets, education, healthcare, and other services are scarce. New evidence is emerging to clarify and establish relationships between urban transport and health. Changes in the health effects of one pathway may also affect the outcomes of another. For example, active transport increases physical activity but may also increase road traffic injuries. Figure 2.2 and Table 2.3 summarise 14 tracks with evidence linking urban transport to health, followed by additional details for five popular pathways.

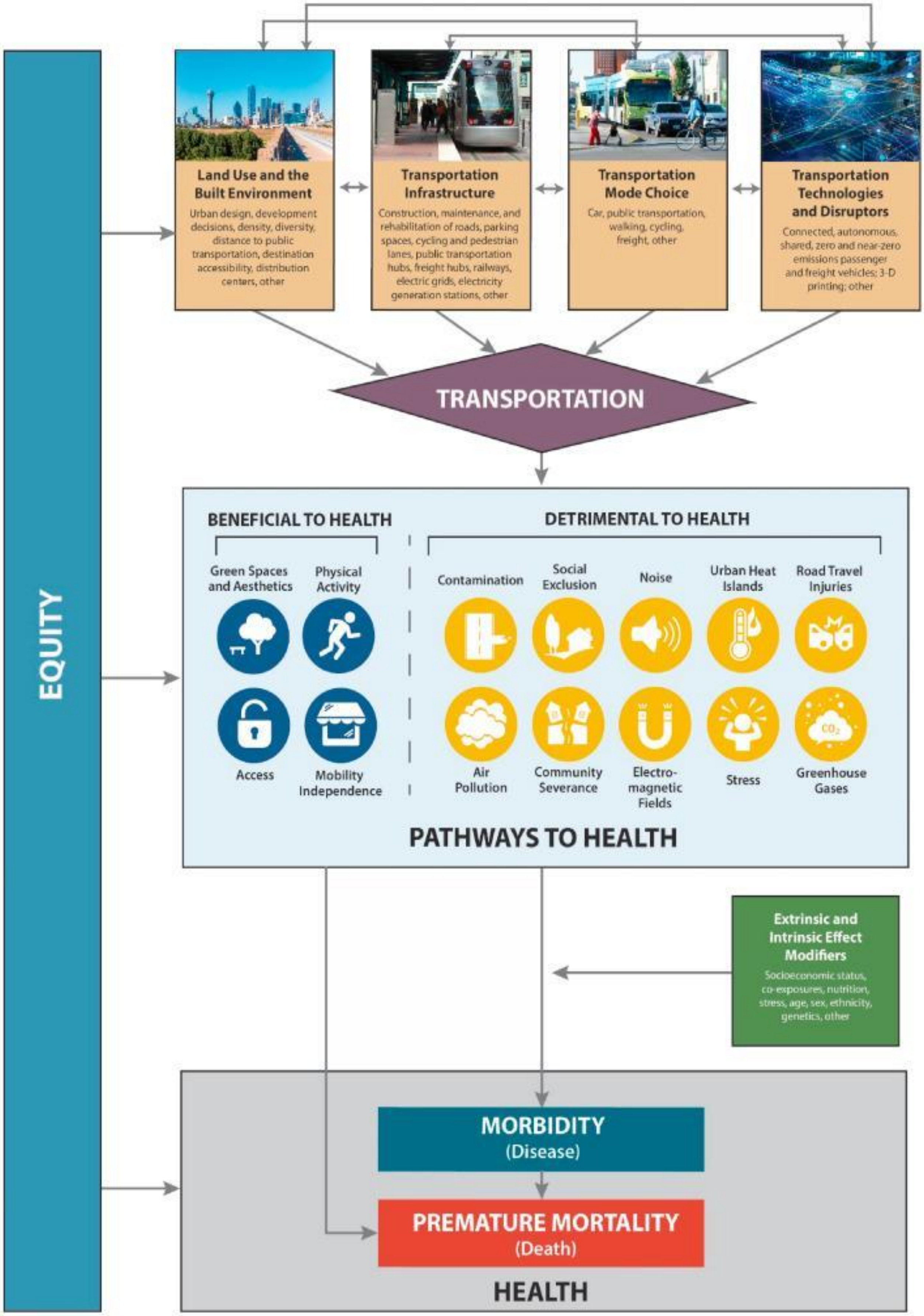


Figure 2.2 Fourteen pathways from transport to health (Glazener et al. 2021[16])

Table 2.3 Pathways between urban transport and health (adapted from Khreis et al., 2017 [59])

Pathway	Source of exposure	Health effects
Motor vehicle crashes	Crashes	Premature mortality, injuries, traumas, post-traumatic stress, and other indirect impacts, including less active travel and outdoor play/physical activity due to perceived unsafety (see health effects of physical inactivity), e.g. road traffic causes over 1.5 million deaths and 79.6 million injuries [60, 61].
Air pollution exposure	Motor vehicle exhaust and non-exhaust emissions, secondary air pollutants formation, underground, metro, and rail exposures	Premature mortality, e.g. 184,000 deaths globally, including 91,000 deaths from ischemic heart disease, 59,000 deaths from stroke, and 34,000 deaths from lower respiratory infections, chronic obstructive pulmonary disease, and lung cancer [60, 62]
		Lung cancer incidence [63, 64]
		Cardiovascular disease incidence [65]
		Asthma incidence [66]
		Reduced lung function in children [67]
		Reduced cognitive function [68]
		Respiratory infections during early childhood [69]
		Low birth weight [70]
		Premature birth [71]
		Diabetes [72]
		Obesity [73]
Noise exposure	Motor vehicle engine, tyre/ road contact, operational noise	Premature mortality, e.g. one million healthy life years are lost every year from traffic-related noise in Western Europe (conservative estimates), including 61 000 years for ischaemic heart disease, 45 000 years for cognitive impairment of children, 903 000 years for sleep disturbance, 22 000 years for tinnitus and 654 000 years of annoyance [74].
		Cardiovascular mortality and morbidity [75]
		Annoyance and sleep disturbance [76]
		High blood pressure in children [77]
		Reduced cognitive function in children [78]
		Adverse reproductive outcomes [79]
		Type 2 diabetes [80]
Increased urban		Premature mortality and cardiorespiratory morbidity [81]
		Hospital admissions [82]

temperature exposure	Urban heat island effect, tailpipe and evaporative heat and emissions	Children's mortality and hospitalisation [83]
Lack of green space and biodiversity loss	Land acquisition for infrastructure, depletions of green space, partition or destruction of wildlife from infrastructure	The immune system, allergies and asthma, Mortality and longevity [84]
		Cardiovascular disease [85]
		Self-reported general health [86]
		Mental health [87]
		Behavioural problems in children [88]
		Cognitive function [89]
		Sleep patterns [90]
		Recovery from illness [91]
Physical inactivity	Reliance on motor vehicle travel and lack of active travel	Five million deaths yearly are attributable to insufficient physical activity [92]. Premature mortality [93].
		Cardiovascular disease [94]
		Diabetes [95]
		Dementia [94]
		Breast cancer [96]
		Colon cancer [97]
Climate change	Extreme weather events, effects on the ecosystem and species, sea-level rise, salination of coastal land and seawater, environmental degradation	Thermal stress, premature deaths (150,000–250,000 annually), illness and injury from floods, storms, cyclones, etc., food poisoning, unsafe drinking water, changes in vector-pathogen host relations, and infectious disease geography/seasonality, impaired crop, livestock, and fisheries yield and inadequate nutrition, health, survival, changes in air pollution, loss of livelihoods, displacement, leading to poverty and adverse mental and physical health [98, 99].
Social exclusion and community severance	Lack of access to active and public transport, healthy food, recreation facilities, healthcare, work, and social interaction due to severance caused by transport infrastructure or perceived risk of motor vehicle crashes	Mental health and well-being, premature mortality, lack of physical activity (e.g. active transport and children's play; see effects of physical inactivity), and stress [100]

2.3.1. Physical activity

Physical activity embodies all bodily movement produced by skeletal muscles that require energy expenditure, not just exercise (the planned, structured form of physical activity). It encompasses all actions undertaken during leisure time, work, household chores and transport to and from places, be it of light, moderate or vigorous intensity. Therefore, individuals' total daily physical activity can come from multiple sources. Active transport (using large muscle groups to walk, cycle, or similarly exert oneself to get from place to place) is essential since people have to move for various reasons. It provides a valuable opportunity to accumulate physical activity.

The links between physical activity and numerous health outcomes have been known over millennia [101]. Epidemiological studies have established that physical activity reduces cardiovascular diseases, cancers, type 2 diabetes, obesity, respiratory illnesses, mental illness, and musculoskeletal disorders (Table 2.4). Some recent evidence suggests that those who participate in active commuting have a reduced risk of cardiovascular disease (coronary heart disease, stroke and heart failure) compared to those who participate in other forms of physical activity [102–105]. However, there is insufficient evidence to differentiate the effect of different domains of physical activity on every health outcome. A possible reason for the difference is that active commuting involves regular travel to a specific destination with two journeys for each trip (arrival and departure).

In terms of overall burden, physical inactivity accounts for 5 million deaths globally each year, mainly by increasing the prevalence of major diseases and their risk factors [106]. It further burdens society through the hidden and rising cost of medical care and loss of productivity. WHO valuations from 2016 showed that physical inactivity costs the health system some US$54 billion and results in US$14 billion in economic losses, approximating that 1 to 3% of national healthcare expenditures in both high- and low-income countries are attributable to physical inactivity [106]. There is also variation in physical activity levels and burdens across populations. Only one in five adolescents and three in four adults worldwide achieve the recommended physical activity levels. Women and girls are generally less active than boys and men, while older adults and people with disabilities are even less likely to be involved. Urban transport can increase physical activity, as it proves to be one of the most effective ways to incorporate PA into people's daily lives through walking and cycling [107, 108].

Despite being a source of physical activity, active transport has some drawbacks to health that need highlighting, although the onus should not be on active travellers. Pedestrians and cyclists have higher respiratory rates and may inhale more air pollutants than car users, depending on their route (park paths versus main roads), traffic conditions, weather, emissions, time of the day, and background air pollution concentrations. Pedestrians and cyclists lack protective shields and other safety features like seatbelts or airbags, so they are more likely to be injured or killed in collisions with other vehicles than vehicle occupants. In addition, drunkenness and mobile devices that obstruct auditory cues of necessary safety information are less controlled in the pedestrian and cyclist population, increasing their risk of RTI [109]. Notwithstanding, in cities where air pollution is comparatively lower, pedestrian/cycling paths are well-defined, or streets have pedestrian/cycling priority, the benefits of active transport outweigh the risks [110–113].

Furthermore, active transport is an outdoor activity that exposes people to sunlight. Although sunlight stimulates the production of vitamin D, which further reduces the risk of Type 2 diabetes, cardiovascular diseases, and some cancers, it increases the risk of heat stroke and skin cancer [114]. Appropriate protection is needed to ensure that active travel does not lead to high exposure to ultraviolet radiation and increases the risk of skin cancer.

Table 2.4 Transport-related physical activity health outcomes

Physical activity health outcome	Evidence of effects
Cardiovascular Diseases (CVD)	CVDs are a group of diseases that affect the heart and blood vessels. They include coronary heart disease, cerebrovascular disease, and other conditions. Physical inactivity is a known risk factor for CVDs, and other risk factors include hypertension, diabetes, elevated cholesterol, overweight and obesity. Physical activity's role in preventing CVDs is central because it directly reduces the risk of CVDs and other CVD risk factors (hypertension, diabetes, elevated cholesterol, overweight and obesity) [115]. Studies have demonstrated that people who accumulate higher amounts of total physical activity have reduced CVD risk, irrespective of whether other risk factors are present [116, 117]. When the relationship between physical activity engagement and CVD disease is isolated, relative risk reductions for CVD attributable to physical activity are between 20 and 35% [118]. Transport-related physical activity influences CVD risk factors such as hypertension, overweight/obesity, and high triglycerides. For example, compared to those who use motorised transport, people who walk to work are likelier to have normal-range blood pressure, body mass, and blood lipid profiles [103, 104].
Cancers	Regular physical activity has protective effects against some cancers. The evidence is most substantial for colorectal, breast and endometrial cancers, with some support for oesophageal, liver and lung cancers [119]. In addition, physical activity plays an essential role in reducing many other cancers by reducing obesity [120], which is a risk factor for numerous cancers [119]. For the effect of physical activity on site-specific cancers, the reduction in relative risk for cancer in sufficiently active people, compared with those who are inactive, is colon cancer – 30 to 40%; breast cancer – 20 to 30%; lung cancer – 20% [121, 122]. Further research is needed to develop relative risk reduction profiles for other cancers. Specific to active transport and cancer, a case-controlled study on Chinese adults showed that the risk of colon cancer is significantly lower in those who engaged in active transport than those who commute by motorised modes and accumulate the same level of physical activity through recreation. The effect was more

	pronounced for those who commuted by active transport modes for longer durations (>35 years) [102]. In other words, active transport is more effective in reducing risks than recreational activities.
Type 2 diabetes	Physical inactivity is a significant risk factor for type 2 diabetes [123], with data showing that the chance of developing diabetes is reduced by 26 - 53% in sufficiently physically active people [124]. This relationship holds for people who only walk or cycle [95, 125]. The relationship between active transportation and type 2 diabetes comes from a landmark study that followed 14,290 Finnish adults for 12 years. Those who engaged in moderate to high levels of occupational, active transportation, or leisure-time physical activity showed a reduced risk of developing type 2 diabetes compared to the general population [123].
Obesity	It is a recognised risk factor for many conditions, including all-cause mortality, CVD, some cancers, musculoskeletal disorders, and poor mental health. Its high prevalence makes its prevention even more critical. A World Health Organization report estimates that approximately 1.9 billion adults (18 years and older) are overweight globally. Of these, over 650 million are obese [126]. Physical activity is key to preventing obesity, and people who are overweight or obese can reduce the risks of many health conditions by engaging in physical activity [127]. People who walk or cycle to work [3] or school [128] are more likely to have an acceptable body mass index (a measure of obesity) when compared to those who commute by motorised transport. Commuting by active transport is also critical for preventing obesity because car use increases the risk of obesity. Research reports that every additional hour per day spent commuting by car is associated with a 6% increase in the odds of becoming obese [129]. Conversely, each extra kilometre walked per day is associated with a 4.8% reduction in the odds of becoming obese. A 5% increase in neighbourhood walkability is associated with a 32% increase in active transport and a 0.23-point decrease in body mass index (BMI) in US adults [130].
Chronic respiratory diseases	These are long-term conditions affecting the airways and lung structure. Chronic obstructive pulmonary disease (COPD) and asthma are common diseases in this category. In patients with COPD, there is an inverse relationship between physical activity levels and the magnitude of lung function decline. However, evidence of lower physical activity levels and faster lung function decline is inconsistent [131]. Physical activity can reduce 46% of admissions in COPD patients [132]. In patients with stable asthma, physical training can improve maximum oxygen uptake, although it has no effects on other measures of pulmonary functions [133]. Acute respiratory diseases such as the common cold and influenza have a different relationship with physical activity than chronic respiratory diseases.

	However, moderate physical activity levels are associated with a lower risk of upper respiratory tract infections (URTI) [134]. A reduction in the severity of URTIs probably has implications for sick days. It is plausible that increased physical activity could reduce some of the morbidity and health sector costs related to COPD and URTI, with further research required to establish the dose-response relationships.
Mental illness	Regular physical activity has preventive and therapeutic effects on various mental illnesses, including anxiety and depression [135, 136], the two most common mental disorders [137]. Other beneficial effects are stress, phobias, panic disorders and schizophrenia reduction [138, 139]. Physical activity enhances perceptions of happiness and self-esteem, improves mood states, reduces state and trait anxiety, increases resilience to stress, and improves sleep [140]. The domain in which physical activity occurs also influences the relationship between physical activity and mental health. Transport and leisure physical activity and school sports show inverse associations with mental ill-health, while work-related physical activity positively correlates with mental ill-health. Household activity and participation in physical education do not seem to affect mental ill-health [141].
Musculoskeletal Disorders	These include osteoporosis, osteoarthritis, and lower back pain. These conditions cause severe disability and loss of functionality. Weight-bearing physical activity can increase bone and muscle mass, preventing osteoporosis and the risk of falls and associated fractures in older adults [142]. Moderate-intensity aerobic exercises, such as walking, also benefit patients with osteoarthritis [143] and lower back pain [144] by improving the healing process and reducing pain-causing stiffness. Despite known mechanisms, I found no study evaluating the effects of active transport on musculoskeletal disorders. Research to establish such relationships would allow for the quantification of health benefits.
Infectious diseases	Infectious diseases have an unclear relationship with physical activity. Moderate-intensity physical activity stimulates the immune system and prevents stress-induced immunosuppression, helping prevent contagious diseases [145, 146]. On the other hand, vigorous-intensity activity may exacerbate infectious disease episodes by depressing the immune system and increasing the susceptibility to these diseases [147, 148]. Although specific relationships between active transport and infectious disease are unestablished, the scale of burden induced by contagious diseases (e.g., the current COVID-19 pandemic) dictates that research keeps them on the radar.

2.3.2. Air pollution

Air pollution results from the release of harmful substances into the air due to human and earth's activities. The transport sector contributes a large and increasing share of urban air pollutants from the combustion of fuels, especially in old, poorly performing diesel vehicles. Transport-related air pollutants include particulate matter, nitrogen oxides, ozone, carbon monoxide, and benzene. These are associated with mortality, allergic and non-allergic respiratory diseases, cardiovascular diseases, cancers, and adverse reproductive outcomes [149].

Small particulate matter (PM_{10} with less than 10 microns aerodynamic diameter) and fine particulate matter ($PM_{2.5}$ with less than 2.5 microns aerodynamic diameter) are the most closely linked to public health outcomes. A particulate matter may comprise elemental carbon, carbon compounds, heavy metals, sulphurs, and carcinogens such as benzene derivatives. Its mass per volume of ambient air is considered the best indicator of potential damage to health for risk reduction purposes [150]. When inhaled, it bypasses the body's defence against dust and lodges in the respiratory system. It accumulates over long periods and causes a reduction in lung function, increased frequency of respiratory diseases, and ultimately reduced life expectancy [150]. Annual average concentrations of particulate matter of 8 μg/m^3 ($PM_{2.5}$) and 15 μg/m^3 (PM_{10}) have correlated with adverse health outcomes [151]. Short-term exposure to $PM_{2.5}$ is associated with increased daily mortality and hospital admissions, mostly from chronic respiratory and cardiovascular conditions [151].

Like particulate matter, nitrogen oxides, such as Nitrogen dioxide (NO_2), also reduce lung functions. At concentrations exceeding 200 μg/m^3, NO_2 causes significant airway inflammation, reducing lung function and increasing bronchitis symptoms in asthmatic children. In the presence of ultraviolet light, NO_2 forms ozone [151], which also causes airway inflammation and reductions in lung function. NO_2 has a higher spatial variation than other traffic-related air pollutants, and it is the primary source of nitrate aerosols, which form an essential fraction of $PM_{2.5}$.

The WHO estimates that 7 million people worldwide die from air pollution yearly [17]. Ambient air pollution accounts for 4.2 million deaths, and people die mainly from strokes, heart disease, lung cancer, and acute and chronic respiratory diseases. Transport contributes 12 and 70% of $PM_{2.5}$ in developing and developed cities [49]; up to 98% of carbon monoxide and nitrogen oxides come from transportation [152]. Serious and quantifiable health damages occur at typical air pollution levels in developed and developing cities today. A drop in $PM_{2.5}$ levels from 35 μg/m^3 (a range observed in most cities) to 10 μg/m^3 will reduce pollution-related mortality by 15% [17]. Nine out of ten people live in areas where air pollution is higher than levels recommended by the WHO guidelines, and residents of low- and middle-income countries suffer from the highest exposure. The average air pollution concentration in developing cities in Asia, Africa, and the Middle East significantly exceeds that of developed cities, and these settings have limited air monitors.

Transport-related air pollution affects active travellers, people close to the streets, and the general population. Active transporters and motorcyclists are exposed to above background ambient air pollution [152] because such transport primarily occurs near motorised vehicles. Active transport users are likely to commute longer than faster-moving motorised vehicles and thus inhale more air pollutants. The volumes of inhaled air pollutants also increase with an increased respiratory rate in active travellers. Cyclists could breathe 2.3 times as much air as car riders during commuting, inhaling more NO_2 when travel distances are equated [153]. Frequency and duration of stopping at traffic intersections, temperature, wind speed, and travel through dusty environments can affect the volume of pollutants inhaled [154]. Some researchers have argued that people travelling in cars and buses could inhale higher levels of air pollution than active travellers [154]. They say the air intakes of vehicles lie directly in the path of emissions from surrounding vehicles. Those who travel by motorised modes are subject to emissions from their vehicles. However, new cars with good filters provide cleaner microenvironments when windows are closed and can lessen this effect, but as noted earlier, most vehicles in Africa are not new. Adverse health consequences of exposure while using the road have included CVDs and respiratory diseases [152]. People living near major busy roads have increased exposure to traffic-related air pollution, correlating with poor child and adult health and increased death rates [149]. Children's health is particularly at risk from ambient air pollution [155]. Studies have shown that children in metropolitan areas experience more adverse health effects when NO_2 levels increase, even in cases where the overall city-wide NO_2 level is low.

2.3.3. Road traffic injuries

The link between urban transport and health through road traffic injuries (RTI) is direct. RTIs kill 1.35 million people globally every year and cause non-fatal injuries to 50 million other people with varying levels of disability [156]. RTI could rank as the third-highest burden of diseases by 2030 and will account for 5% of the global disease burden at that time [156]. Children and young adults between 5 and 29 are at higher risk of RTIs. Over 90% of all deaths occur in LMICs, which have less than 60% of world vehicles, although the rate of motorisation is rising rapidly. In Africa, road traffic fatalities per 100,000 people are 32.2, with only 7.2 deaths reported. Traffic fatalities in Africa are almost double the global estimates of 18.2 deaths, with 10.1 per 100,000 people registered [157].

Two major risk factors of RTI are vehicle kilometre travel (VKT) and vehicle speed. Settings with higher VKT experience more RTI. VKT strongly correlates with reduced road traffic injuries, such that some suggest it as a proxy for RTI since data on RTI are often incomplete [158]. The higher the speed of a car, the higher its kinetic energy, which translates to injury severity during a collision. Pedestrians are eight times more likely to die if struck in a 50 km/h than in a 30 km/h collision [156]. Higher traffic volumes are a vital risk factor for child pedestrian injury [159]. Walkers and cyclists in most cities are more likely to be injured than vehicle occupants [159]. Over half of RTI mortality worldwide comes from pedestrians, cyclists and two/three-wheelers, without correcting for the under-reporting that is likely to occur in cyclists and pedestrians who do not have insurance coverage [156]. Motorcyclists are increasing at significant rates in LMICs. Like pedestrians and cyclists, motorcyclists lack the protection of an enclosed vehicle and vehicle safety features like seatbelts or airbags. They travel at even higher speeds, making them more likely to be injured or killed in a collision. Drivers' use of alcohol, medicinal and recreational drugs, and hand-held mobile phones; road users' disregard for personal protective equipment such as helmets and seat belts; poor street designs with no pedestrian and cycling spaces; or poor enforcement of regulation all culminate in the increased risk of RTI.

Road injuries are predictable and preventable by modifying human behaviours [159], designing traffic in ways that help users cope with increasingly demanding conditions and putting the vulnerability of the human body as the limiting parameter for traffic design. Interventions to calm down traffic, such as the 20 km/h urban residential zones, and physical barriers, such as speed bumps and pavement designs, have significantly reduced injury rates [160]. Speed limits can also remove safety barriers to active travel. Public transport options can improve safety in transport systems since buses and trains are often the safest transport modes per passenger kilometre [161].

Perceived danger from motor vehicle collision is a potential barrier to active transport [162], especially cycling [163]. This perception also affects the selection of children's commute modes. However, an increased number of active travellers may also lead to a safety-in-numbers effect since higher walking and cycling rates are associated with lower per capita injury risks for pedestrians and cyclists [164]. One potential mechanism of the safety-in-numbers phenomenon is that motorists become increasingly aware and drive more cautiously when there are higher levels of active transport. Researchers observed that doubling the cycling rates in Australia reduced injury risk per kilometre by 34% while halving the cycling rates doubled the injury risk per kilometre cycled [165]. The observed associations could also be due to improved environments (reduced vehicle volume and speed). The total number of injuries may still increase as the volume of walkers and cyclists increases since they remain at a higher risk than car drivers [166]. Thus, increasing walking and cycling requires concrete environmental steps (vehicle speeds and volumes) to prevent injuries among walkers and cyclists.

2.3.4. Noise pollution

Transport is a significant source of noise in urban environments—the growing demand for mobility and increasing urban freight intensify urban traffic noise high [167]. The perceived traffic noise is a function of traffic volume, speed, and human proximity to traffic. The average noise level near a street with a traffic volume of 100 cars per hour is around 55 dBA, with approximate peak levels of up to 70 dBA [168]. If background noise levels are 40–45 dBA, these street noise levels result in a high signal-to-background noise ratio. A difference as small as ten dBA between background and peak noise levels can trigger autonomous reactions [169]. In zones with high signal-to-noise ratios, research shows that the "startle response" can be reduced if the signal-to-noise ratio stays below 15 dBA [170]. Overall, the health effects of high community noise exposure range from general annoyance and stress to increased blood pressure.

Typical transport-related noise in modern cities is an ambient/environmental stressor, mainly affecting the nervous system [171]. Noise-related stress is associated with an increased risk of cardiovascular diseases and mental ill-health [172, 173]. Although one can live and adapt to noise to some extent, the efforts to cope with noise come with some costs. Even in the short term, after-effects will occur [174]. Estimates from Western European countries suggest that annoyance, sleep disturbance, heart attacks, learning disabilities and tinnitus resulting from traffic noise account for one million healthy years of life lost annually to ill health, disability, and death. Adverse birth outcomes have also been associated with traffic noise, although evidence is inconclusive [79, 80, 175, 176].

2.3.5. Climate change

Transport contributes significantly to climate change, which has far-reaching health effects. Vehicles generate up to a third of greenhouse gases (carbon dioxide and others) through the combustion of fossil fuels. Energy consumed in vehicle production and powering electric vehicles is also a significant source of greenhouse gases. These gases trap heat in the atmosphere, causing global warming and driving climate change. Climate change affects many social and environmental determinants of health, including clean air, safe drinking water, food security and secure shelter. Extreme weather events such as heat waves, floods, droughts, and storms are critical pathways through which climate change affects health. These events are instead becoming frequent [177]. Climate change also affects the geographical distribution of most vector-borne infectious diseases, such as malaria, dengue and schistosomiasis. The burdens of these diseases have been increasing, especially in atypical locations. Climate-induced water and food shortages in drought-prone areas of Africa have direct health consequences. The WHO estimates that between 2030 and 2050, climate change will cause over 250,000 additional deaths per year. The leading pathways to mortality will be malnutrition, malaria, diarrhoea, and heat stress. Transport plays a crucial role as a top contributor to GHG emissions that drives climate change. Interventions to reduce the damaging effects of climate change due to transport emissions will yield co-benefits because such interventions will lead to a concomitant reduction in urban air pollution.

2.4. Quantifying the health impacts of urban transport in Africa

Studies quantifying the health impacts of urban transport in Africa are scarce, with only three traceable attempts in the literature: a cost-benefit analysis in Cape Town, South Africa, a case study in Port Louis, Mauritius, and a pilot study in Accra, Ghana [178–180]. Cooke et al. (2017) [178] piloted a tool for analysing the cost-benefit of non-motorised transport in Cape Town, with health as one among multiple pathways. While this approach provided some insights into the health impacts of transportation in a data-scarce context, the economic focus of cost-benefit analyses does not allow for sufficient health outcome exploration. Thondoo *et al*. (2020) [179] and Garcia *et al*. (2021) [180] trialled health outcomes calculations on the continent. These studies have elucidated some of the main limitations in quantifying the health impacts of urban transport in Africa, including the lack of methods/tools, data, and technical capacity on the supply side and policy uptake of model outputs on the demand side. I discuss these limitations in further detail in the following section.

2.4.1. Methodological challenges

Researchers and planners can comprehensively assess the health impacts of urban transport using the Health Impact Assessments (HIA) framework. The framework combines mixed research methods and allows assessors to systematically judge the potential population health effects of policies, programmes, and projects [181]. Modelling approaches can determine which transport system yields the most quantitative benefits and the least harm; thus, modelling can be part of an HIA or a standalone assessment. Modelling is ideal for studying the health impacts of transport because it allows for an integrated evaluation of health outcomes from multiple pathways using disparate epidemiological data in ways that are not practical with classical epidemiology. Besides, modelling identifies priority research areas for empirical data collection based on the value of information on reducing the uncertainties of results.

So far, researchers have applied a few models in restricted settings, mainly in high-income countries. An example is the Compact City Model used in Melbourne, London, Boston, Copenhagen, Delhi and São Paulo [61]. The Urban Transport Planning Health Impact Assessment, UTOPHIA, is another model example developed and applied in Barcelona by the Barcelona Institute for Global Health [182]. The two widely used models are the health economic assessment tool (HEAT), developed and maintained by the WHO Regional Office for Europe for assessing the health impact of cycling and walking (validated for Europe with ongoing work for a global model) [183], and the Integrated Transport and Health Impact Modelling tool (ITHIM) developed by the University of Cambridge MRC Epidemiology Unit for evaluating health impacts from general mode shifts, and greenhouse gas emissions.

HEAT for cycling and walking [183] estimates the economic value of reduced mortality from regular walking or cycling changes. It primarily serves as part of a comprehensive cost-benefit analysis of transport interventions or complements existing tools for economic valuations of transport interventions, such as emission or congestion evaluation tools. Fewer technical professionals who can use the approach include transport planners, traffic engineers, and special interest groups working on transport, walking, cycling, or the environment. The default parameters were initially only valid for the European context, but the current version includes parameters for worldwide countries. Users can adapt model parameters to fit specific situations. The model has successfully generated health impact estimates of several cycling and walking projects in European and US cities [65]. However, this model focuses on cycling and walking and does not yet fully consider public transport and driving changes on RTI and AP. Although it provides premature mortality counts, these are primarily valued in monetary terms using the value of statistical life (VSL) approach to be compatible with other economic endpoints resulting from cost-benefit analyses; this raises ethical questions. Overall, HEAT answers questions in the following form: if X people cycle or walk Y distance on most days, what is the monetary value of mortality rate improvements?

ITHIM [184], on the other hand, allows for a comprehensive, integrated assessment of the health impacts of transport scenarios and policies on urban and national populations, not just focusing on active travellers. The health impacts are a summation of the health gains from physical activity (through public transport, walking and cycling) and losses from RTI and AP to active and non-active travellers. Some versions of ITHIM also predict changes in CO_2 emissions. The model can be used alone or combined with other transport, health, and economic models. It estimates health outcomes in years of life lost (YLL) and the number of attributable deaths using background burden data from

Global Burden of Disease studies. The monetary evaluations of health outcomes are not ITHIM's primary endpoints. Researchers have applied the model in the UK, USA, Canada, Malaysia, Brazil, and India cities. The model developers have recently piloted it in Accra with support from the WHO. Although the model has some LMIC-relevant parameters, its underlying functions result from studies in high-income settings. A large amount of input data is not realistic for most African cities.

ITHIM and HEAT share several features. Both models evaluate impacts through AP, PA, RTI and CO_2 pathways. They rely on the comparative risk assessment (CRA) approach for estimating PA and AP health impacts. In this approach, the risk of interest (premature deaths or morbidity) is compared between two cases: the reference case and a comparison case (sometimes referred to as the counterfactual case). The impact of interest is the difference in mortality between the two cases. This difference results from the contrast in physical activity from regular walking/cycling or exposure to different levels of air pollution between the two cases. Both models apply a safety-in-numbers approach to road traffic injury estimation. This approach accounts for the reduction of injury risk over time as drivers become more aware of and accustomed to cyclists, more drivers become cyclists themselves, and cyclist advocacy becomes more effective. Infrastructure and other safety improvements may also play a role. Users can adjust (reduce) the road crash risk estimate if they consider that exposure changes over time. There is safety-in-numbers if the number of accidents increases less than proportionally to traffic volume (for motor vehicles, pedestrians and cyclists). Based on meta-analyses, Elvik and Bjornskau (2017) reported the following regression coefficients as safety-in-numbers values for traffic volumes: 0.50 for motor vehicle volume, 0.43 for cycle volume and 0.51 for pedestrian volume [185]. The generalisability of these values is yet to be established. Notwithstanding, the models exhibit significant differences, especially in the detailed inputs and outputs (Table 2.5).

Table 2.5 Comparison of some critical features between HEAT and ITHIM

Aspect	HEAT	ITHIM
Latest version as of February 2023	HEAT v5.0.6 (5th iteration since 2007) (https://www.heatwalkingcycling.org/#homepage)	ITHIM Global (3rd iteration since 2009) (https://github.com/ITHIM/ITHIM-R)
Developer	WHO	University of Cambridge
Principle	Scientifically robust, user-friendly, transparent assumptions, conservative approach, adaptable to local contexts, and modular	Scientifically robust, transparent assumptions, adaptable to local contexts, and modular
Primary purpose	To assess the economics of the health effect of walking or cycling. The intended inputs and outputs are relatively simpler and accessible to less technical analysts.	To assess the health and climate impacts of changes in transport policies through changes in travel behaviour. The inputs and outputs are relatively detailed, and model

		manipulation requires more technical skills.
Scope	Initially Euro-centric. The current version includes parameters for most WHO countries, but no use case from an LMIC yet exists.	It started by looking at HIC but quickly included LMICs with multiple use cases in Latin America, India and recently Africa.
Pathways	PA, AP, RTI and CO_2 for active travellers only	PA, AP, RTI and CO_2 for the study population
Health impacts	Only all-cause mortality (monetised); no morbidity, system, or organ outcomes	Allows the estimation of mortality for all causes and organ-specific systems
Scenario approach	Simple scenarios of changes in average walking/cycling rates without considering the plausibility of such changes	Creates scenarios through a synthetic population that is representative of the study population. This process allows investigators to understand the source of trips for scenarios; hence, proposed changes are likely plausible.
PA approach	It uses a comparative risk assessment approach and linear dose-response functions, capping risk reductions at 447 and 460 minutes for walking and cycling, respectively. Calculates relative risks for groups	It uses a comparative risk assessment approach and non-linear dose-response functions without caping. Uses non-transport PA levels to account for PA changes comprehensively. Calculates relative risks for individuals in the synthetic population
AP approach	It uses a comparative risk assessment approach with linear dose-response functions and caping exposures at 50µg. Do not consider background air pollution changes due to changes in mode shares.	It uses a comparative risk assessment approach and linear dose-response functions with more extreme AP concentrations. It considers changes in background air pollution due to changes in mode shares. Considers health effects in the general population
Road traffic injury approach	It uses a basic approach by applying national cycling fatality rates per distance cycled to local distance cycled (does not yet include fatalities for drivers and pedestrians). It also allows for non-linear risk reduction by applying the safety-in-numbers parameter.	It uses an interactive approach, where a mode’s risk depends on interaction with other modes. It estimates mode fatality rates using mode distance travelled, safety-in-numbers, gender and age in a poisson regression. This approach implies a higher burden in terms of user-provided input data.

CO_2 approach	Estimates carbon emission and its social cost based on operational vehicle cost, energy supply cost and vehicle life-cycle emissions.	Essentially similar to the HEAT approach

The use of a recent meta-analysis [186] in the ITHIM PA pathway sets apart the ITHIM from HEAT. HEAT relies on a 2014 meta-analysis for linear mortality relative risk values for walking and cycling [187]. The 2022 meta-analysis estimates dose-response associations between non-occupational PA and multiple chronic disease outcomes (all-cause mortality, total cardiovascular disease, coronary heart disease, stroke, heart failure, total cancer, and site-specific cancers (head and neck, myeloid leukaemia, myeloma, gastric cardia, lung, liver, endometrium, colon, breast, bladder, rectum, oesophagus, prostate, kidney), neurological disorders (all-cause dementia, Alzheimer's disease, Parkinson's disease and vascular dementia), and depression (depression, elevated depressive syndrome and major depression)) in the general adult population. The study pooled 194 articles from 94 cohorts, and dose-response functions are shown in Figure 2.3. Although this approach requires more data (individual transport and non-transport PA) and not simple average walking/cycling rates as required by the HEAT, it allows analysts to reflect on the plausible source of walking and cycling rather than some exaggerated changes. Secondly, the new meta-analysis contains relative risks for various outcomes other than walking and cycling-specific relative risks, allowing for extensive output presentation.

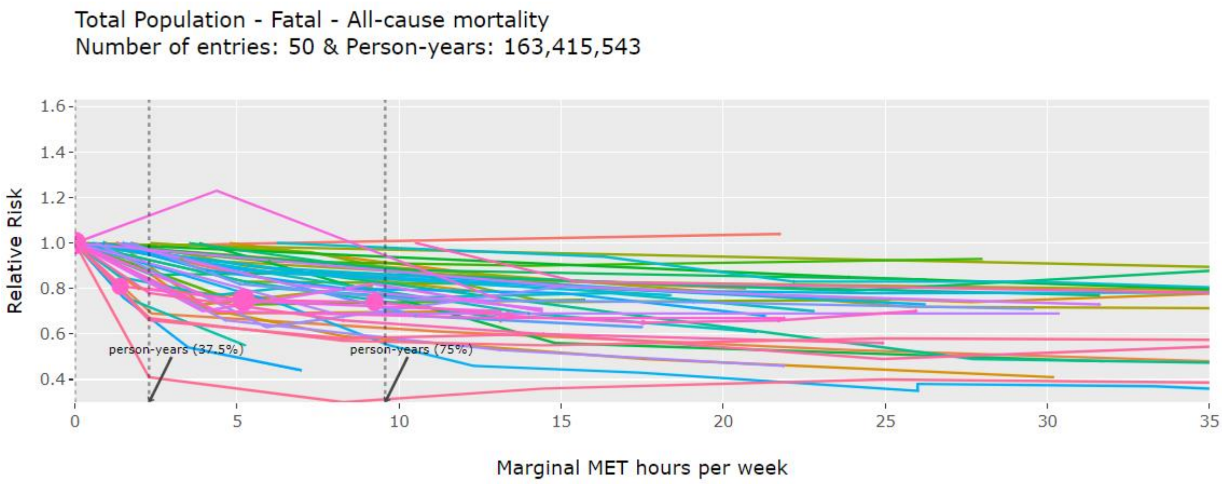


Figure 2.3 Non-occupational physical activity and risk of cardiovascular diseases, cancer, and mortality outcomes: a dose-response meta-analysis of large prospective studies [185].

Figure 2.4 shows a schematic structure of a model for assessing urban transport health impact based on ITHIM. It illustrates a flow from input data for the three pathways (PA, AP and RTI) to health outcomes. Noticeably, travel behaviour information plays a central role as it informs travel-related physical activity and the population exposed to air pollution and road injuries based on travel mode shares.

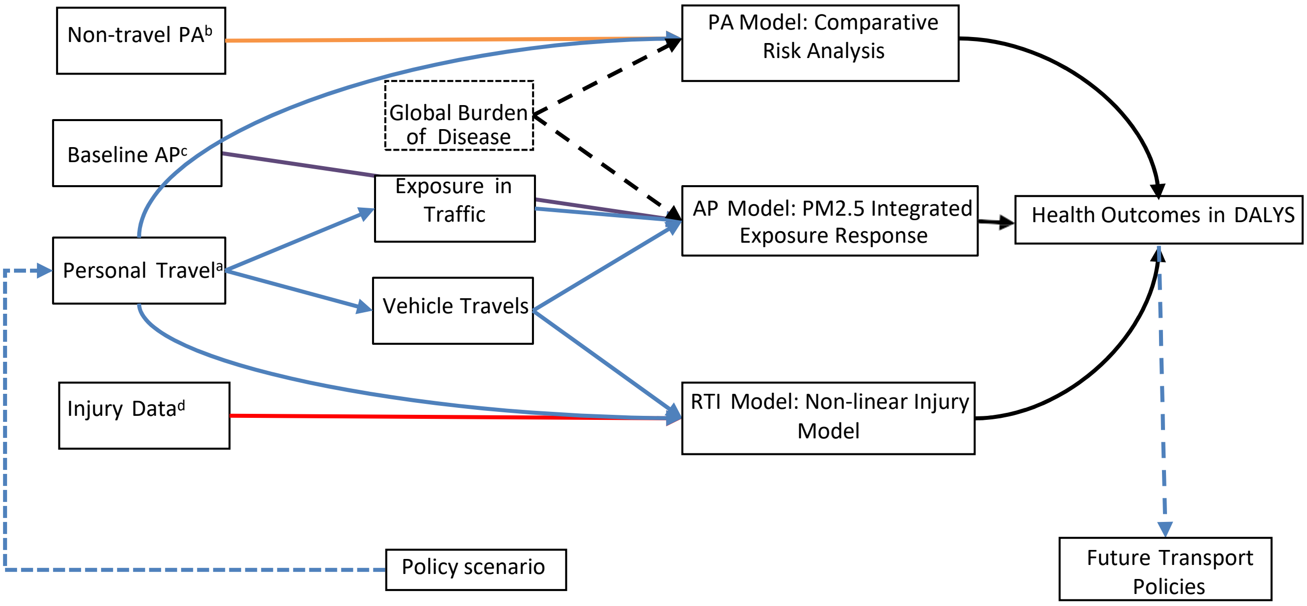


Figure 2.4 Schema of model based on ITHIM

	Typical data sources	Points of contact
[a]Travel Patterns	Travel surveys, censuses, time use surveys, predictions from Google Street Views, mobility indicator of Multiple Indicator Surveys / Demographics and Health Surveys	GDAR partners and WHO focal points
[b]Physical Activity	WHO steps, published work, new data collection	GDAR partners
[c]Air Pollution	Local measurements, WHO site Emissions Database for Global Atmospheric Research (EDGAR).	WHO, GDAR partners
[d]Road Traffic Injury	Traffic police, the global repository of injury data	GDAR & WHO

Africa's rapid urban growth, rise in NCDs, and motorisation will lead to complex situations that require model thinking to unravel urban policy health impacts. However, African cities are diverse and have several specificities that limit the direct use of existing models. The underlying dose-response functions used in current transport models result largely from high-income settings. When the dose-response relationships result from global estimates, only a few articles from LMICs contribute to the assessments. Researchers have also not stress-tested these models in settings with inputs that might be extreme to the models, such as the high road injuries in LMICs. Walking trip mode shares in Africa can also be higher, with some settings reporting walking shares of up to 80% of daily trips [188].

In addition, the policy targets for African cities need to be different. High walking in Africa is often out of necessity. Some people walk too far under inconvenient conditions of high temperatures and rain. Changing facilities after walking and cycling, adequate sidewalks or signalled and safe intersections, and accessibility to public transport stations are inadequate. Where they exist, motorists or street vendors often usurp the road intersections and pedestrian pathways. People often report that cycling is socially unacceptable in many settings [188]. African cities must, therefore, aim to preserve walking while reducing walking distances and improving walking conditions. They must also increase PT services and normalise cycling by providing infrastructure and behavioural change. These are not goals that cities in high-income settings will necessarily pursue.

Most methodological issues, especially those related to dose-response functions and safety-in-numbers, need new empirical studies and their synthesis to obtain setting-relevant estimates. These studies are unlikely to be achieved in a single thesis, but the caveats of using models with such biases must be mentioned upfront.

2.4.2. Data

The lack of data for modelling, as is often the case for other data in Africa, is a fundamental challenge for modelling the health impacts of urban transport. Data availability is pivotal because the kinds of available data can determine what models are possible, and available models can also inform the types of new data researchers should collect. Routine data collection is poor in most African countries; where they are collected, they are poorly processed and not readily accessible. For example, travel behaviour influences many pathways to health outcomes, but few countries in the African region collect and manage such data. Similarly, data on road traffic injuries is scanty and often of low quality [157]. There are often significant disparities in results from data collected for the same exposures in Africa.

Data scarcity likely stems from the lack of resources but mainly from the lack of coordination of statistical activities such as the systematic collection of population, health and travel surveys; these may all boil down to a lack of political will or knowledge. The chief economist of the World Bank for Africa summed these as "Africa's Statistical Tragedy" [189, 190]. The multiple pathways through which urban transport affects health imply that data are required from various sources, increasing the data challenge. There are budding initiatives to grow data science in LMICs. Still, there is little understanding of using the currently available data for modelling, for example, how to pool and harmonise data across settings. Efforts to increase modelling for Africa must first consider the kinds of data available and how to make these data available and applicable.

2.4.3. Technical capacity

Technical capacity is the third crucial factor on the supply side of urban transport health impact modelling after data and modelling tools. Technical capacity is needed to source the correct data and build and use models for urban transport health impact assessments. Limitations range from very few training institutions and poorly equipped facilities to unreliable energy supplies and internet connectivity. Interdisciplinary collaboration for integrated transport health impact modelling is required, but this adds another layer of complexity for countries with low technical capacity.

2.4.4. Policy

Using health impact assessment outputs in policymaking creates demand for modelling tools to enhance urban transport health impact assessments. Studies report that evidence in policymaking in most African settings is low [18], although what counts as evidence varies. Policies borrowed from Western European countries and, more recently, from the US and China, which do not fit the context, are often preferred. Researchers and developers can easily be discouraged if they develop tools to facilitate evidence-based policymaking, but policymakers ignore evidence from their hard work. To some extent, the minimal resources and poor resource allocation force policymakers to focus on apparently significant current problems in ways that ignore long-term critical issues or postpone them at the very least. Researchers need knowledge of how policymakers can use model outputs in African decision-making.

2.4.5. Gaps addressed in this PhD

In light of the challenges associated with quantifying the health impact of transport in African cities, this PhD addresses five main gaps. Firstly, it extends the literature on travel behaviour in African cities using different data sources. Secondly, the PhD explores physical activity behaviour and data in African cities to unveil the nature of baseline data for the selected exposure pathway. The third gap relates to the policy landscape and the extent to which transport policies currently consider health. Fourthly, it reviews methods for quantifying transport health impacts and synthesises evidence of transport health impacts from modelling studies. Finally, it models the health impacts of transport in selected African cities.

3. **Travel behaviours and data sources in African cities**

Travel behaviour is critical information for modelling the health impacts of transport. It is central because it reflects the situation of transport systems, and altering it can represent desired or likely changes in transport systems and policies. However, knowledge of urban travel behaviour is limited in low- and middle-income countries (LMICs), especially in Africa [48, 191]. Literature often reports that most people walk in African cities, but how this varies and how much of urban travelling is done by cycling, motorcycling, or informal mini-buses is simply unclear—people generalise across the large continent. In addition, there is limited knowledge of how well different data sources capture travel behaviour.

Routine surveillance of travel and other essential population behaviours is particularly challenging in resource-constrained settings [192]. In these circumstances, it is imperative to piece together disparate data sources to help understand and monitor key population behaviours. For travel behaviour, information sources include travel diary surveys, time use surveys, censuses, and activity tracking on mobile phones and personal devices such as fitness trackers. Some of these data sources are available in Africa but often include varying degrees of information relevant for evaluating population travel behaviour. For example, housing and population censuses, albeit at relatively lower frequency in Africa, generally capture coarse travel information such as household vehicle ownership. Mobile phone penetration in Africa is high [193], and some researchers have used this source to describe travel behaviour [194, 195].

Among the available data sources, travel diaries and time-use surveys are the most common sources that provide comprehensive information on travel behaviour characteristics. A travel diary survey collects information on movement (including time, mode, and purpose) using questionnaires that capture trip details on reference days. On the other hand, a time-use survey records daily activities (including movements) on a pre-coded grid with multiple slots per hour. These two methods yield significantly different travel behaviour estimates in European settings. For example, Hubert *et al.* (2008) [196] reported parallel but considerably lower percentages of immobility and longer travel times in the time-use surveys of Great Britain, France, and Belgium compared to their national travel diary surveys. Perhaps this makes sense because participants need to report their activities at every time point in the time-use survey, leading to more travel activities, while participants in travel surveys could choose not to report travel activities, leading to soft refusal. A similar pattern of differences was observed in German surveys [197]. How travel behaviour estimates from these two sources compare in LMICs is unknown.

In this chapter, I present three case studies using travel diaries and time-use surveys in three countries to extend the literature and compare data sources on travel behaviour in Africa (Table 3.1). The first study presents travel diary data from two Kenyan cities, while the second presents new data from a time-use survey in Cameroon. The third study compares time-use and newly collected travel diary data from Ghana.

Table 3.1 Travel behaviour case studies from different data sources

Case study	City	Travel diary	Time-use diary
Case study 1	Nairobi	✓	x
	Kisumu	✓	x
Case study 2	Yaoundé	x	✓
Case study 3	Accra	✓	✓

I conceived these studies, analysed the data, and drafted the manuscripts, but I also received support from team members in many essential areas. Data for case study 1 were obtained through GDAR's collaboration with the Japan International Cooperation Agency (JICA) (2013 Nairobi travel survey) and the Institute for Transportation and Development Policy (ITDP) (2016 Kisumu travel survey). Data for case study 2 came from a GDAR work package. I designed and coordinated this study remotely and was assisted in the fieldwork by an onsite team in Cameroon. Dr Fidelia Dake collected the Accra travel survey data reported in case study 3. I supported the field team remotely and managed the collected data. Collaborators provided feedback to this chapter's three case study manuscripts, shaping the outputs presented here. I have used the royal "we" in this and other result chapters to acknowledge collaborators' contributions to the manuscripts on which I base these chapters.

3.1. Case study 1: Using travel diaries to compare travel behaviour in Nairobi and Kisumu (Kenya)

3.1.1. Abstract

We used travel diary data to compare travel behaviour characteristics and their correlates in two Kenyan cities (Nairobi and Kisumu). We analysed data from 16,793 participants (10,000 households) in a 2013 Japan International Cooperation Agency (JICA) household travel survey in Nairobi and 5,790 participants (2,760 households) in a 2016 Institute for Transportation and Development Policy (ITDP) household travel survey in Kisumu. We used the Heckman selection model to explore correlations. The proportion of individuals reporting no trips was far higher in Kisumu (35% vs 5%). For participants with trips, the mean number [IQR] of daily trips was similar (Kisumu (2.2 [2-2] versus 2.4 [2-2] trips), but total individual daily travel times were lower in Kisumu (65 [30-80] versus 116 [60-150] minutes). Walking was the most common trip mode in both cities (61% in Kisumu and 42% in Nairobi), followed by motorcycles (19%), matatus (minibuses) (11%), and cars (5%) in Kisumu; and matatus (28%), cars (12%) and buses (12%) in Nairobi. In both cities, females were less likely to make trips, and when they did, they travelled for shorter durations; people living in households with higher incomes were more likely to travel and did so for longer durations. Gender, income, occupation, and household vehicle ownership were associated differently with trip making, use of transport modes and daily travel times in cities. These findings illustrate marked differences in reported travel behaviour characteristics and their correlates between two cities within the same

country, indicating setting-dependent influences on travel behaviour. More sub-national data collection, data harmonisation and use of alternative data sources like time-use surveys are needed to build a more nuanced understanding of patterns and drivers of travel behaviour in African cities.

3.1.2. Background

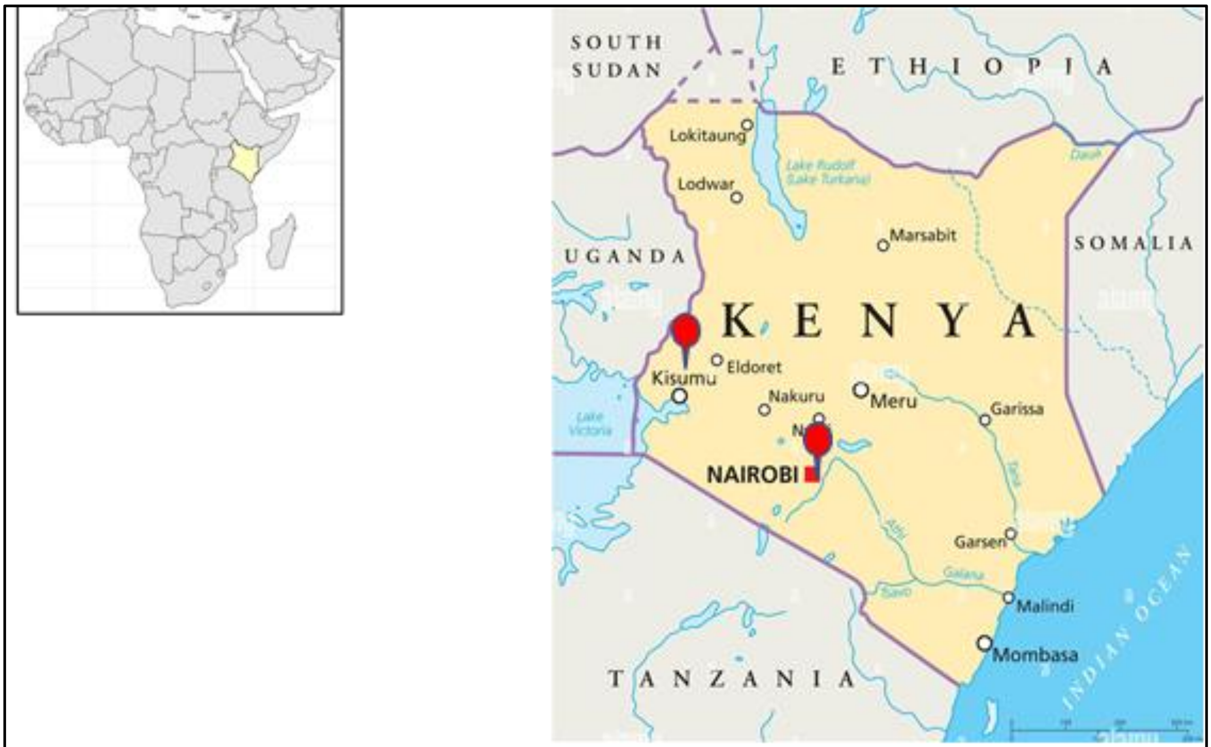
The lack of literature on African urban travel behaviour stems primarily from limited routine survey data and inadequate exploitation of the few available data. As discussed in section 2.2.4, the sparse literature provides indicative insights into transport challenges in some thematic areas, such as gender and socioeconomic inequities in mobility. Still, these are generally not based on representative survey data. Moreover, the available literature mainly reports summary statistics such as vehicle ownership, transport mode shares and expenditure on transport, which are limited in terms of travel duration, who is travelling and for what purpose [49, 198–200]. Crucially, there is a lack of comprehensive explanatory analyses to show the correlates of travel behaviour characteristics and how these vary across diverse African cities.

This study compares and correlates travel behaviour characteristics from travel diaries in two Kenyan cities: Nairobi (the capital city) and Kisumu (the third-largest city in Kenya). Travel behaviour characteristics include trip number, mode, duration, and purpose [201], and correlates refer to sociodemographic characteristics. The study addresses three specific questions: What are the travel behaviour characteristics and correlates in Nairobi and Kisumu? How do travel behaviour characteristics and correlates differ between the two cities? How is the travel environment perceived in Kisumu (where data were available)?

Like most African cities, Nairobi and Kisumu (Figure 3.1 and Figure 3.2) are experiencing rapid transportation changes, including rapid vehicle ownership growth. According to the Kenyan National Bureau of Statistics (KNBS), the number of cars, motorcycles, and all vehicles registered in Kenya in 2012 were 644,805, 610,056 and 1,789,789. The five-year growth from 2008 to 2012 was 9%, 30% and 12%, respectively. The average number of vehicles per capita was 0.076 in 2019, up from 0.024 in 2010.

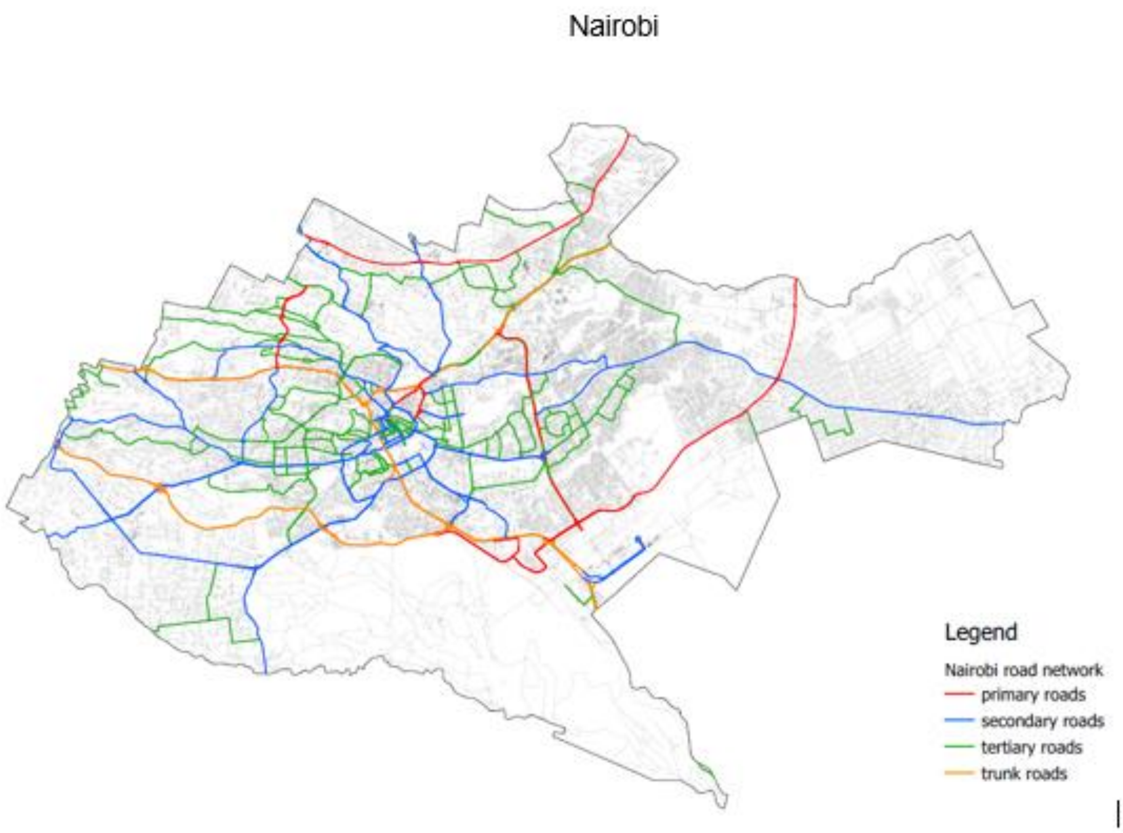
Nairobi, the nation’s capital, is densely populated and located in the country's central highlands. Based on the 2009 Kenyan household census, the city had an estimated population of 3.1 million people and a density of 4,515 people/km^2 in 2013. As Kenya's largest city, it attracts many people from other urban and rural areas in search of better economic and livelihood opportunities. This migration has led to rapid and uncontrolled urban growth, congestion of streets and residential areas, and proliferation of slums, with 60%–70% of Nairobi’s population currently living in slums [202]. Most of Nairobi’s population lives on the outskirts and commutes to the city centre daily [203]. The primary public transport modes include matatus (minibuses), motorcycles (bodaboda), and walking. Walking is a common aspect of journeys, both as the primary mode and as part of other journeys, weaving through busy roads, dodging open drains, potholes, street vendors and speeding vehicles. Private cars have become aspirational to avoid the discomfort associated with matatus, and even though car use remains low when compared to high-income countries, traffic congestion and associated harms are increasing.

The city of Kisumu is the third most populous city in Kenya. It is located in the west and borders Lake Victoria. Based on the 2009 Kenyan household census, Kisumu had an estimated population of 490,079 and a density of 297 people/km^2 in 2013. Like many African cities, Kisumu is starting to experience mobility challenges characterised by increasing car traffic, inefficient public transport, inadequate walking and cycling facilities, and poor traffic and parking management. These challenges contribute to air and noise pollution, congestion, and safety concerns, impacting the city's attractiveness and liveability.



General Info	Nairobi	Kisumu
Population	3138369	490079
Area in Sq. Km	695	297
Density (population per Sq. Km)	4515	1650
GDP per Capita	6344	3356

Figure 3.1 Map of Kenya showing Nairobi and Kisumu and city characteristics (numbers scaled to 2013 projections; per capita GDP estimated USD (1USD = 85 Kenyan Shillings (KES)))



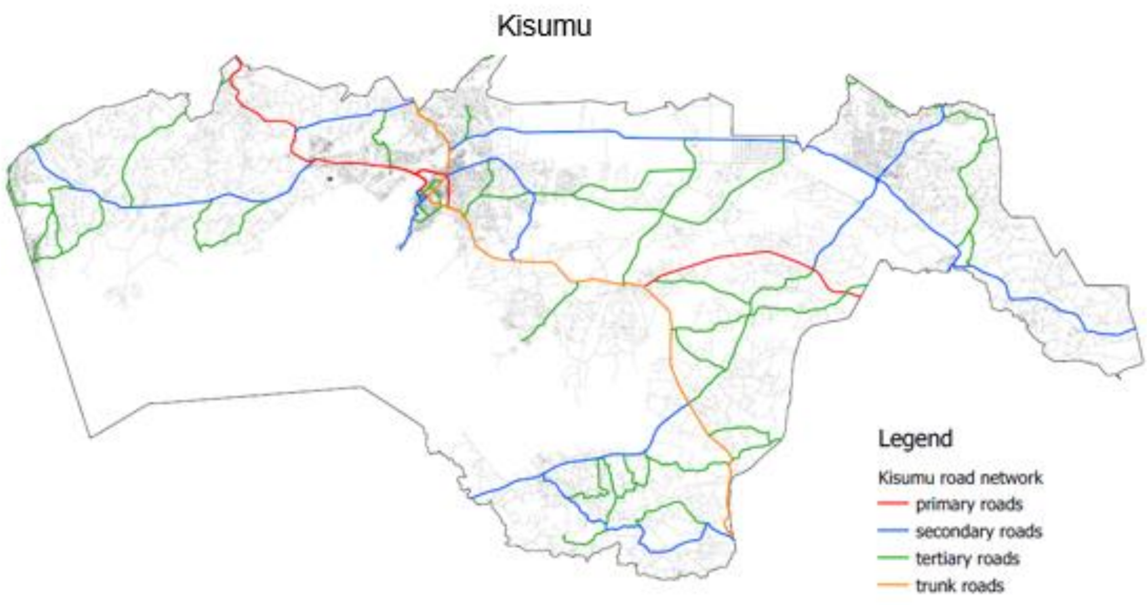


Figure 3.2 Maps showing road networks and density in Kisumu and Nairobi, Kenya (drawn from the Open Street Map)

3.1.3. Methods

3.1.3.1. Study design, participants and data

We used two cross-sectional travel diary surveys from two cities in Kenya (the 2013 Japan International Cooperation Agency (JICA) household travel survey in Nairobi and the 2016 Institute for Transportation and Development Policy (ITDP) household travel survey in Kisumu) to describe and compare travel behaviour characteristics and correlates between Nairobi and Kisumu. To ensure we captured all the relevant survey elements, we reported the study following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [204].

Participants in both surveys were members of selected households aged five years and above. The surveys considered individuals as household members if they were usual residents or visitors who had spent the previous night in the homes. Households were selected from established sampling frames as described below.

The two primary data sources for this study were collected by JICA in 2013 in Nairobi and ITDP in 2016 in Kisumu. A third data source, by the World Bank (2013 Kenya - State of the City Baseline Survey), was used to compare key indicators in the JICA and ITDP data.

JICA surveyed 10,000 households and 16,580 individuals in Nairobi in 2013 [205]. To obtain this sample, the JICA team used a small zone system to stratify the city into 106 zones. The team based their household sampling rate on the 2009 population housing census. With 985,016 households in Nairobi, the estimated sampling rate for a size of 10,000 was 1.02% per zone. The survey was conducted in person in the selected households. Questions covered variables related to household income and assets and sex, age, education, and travel information for all household members aged five years and above. The survey response rate was not reported.

ITDP surveyed 2760 households and 5970 individuals in Kisumu in 2016. The team based their household sampling on the 2009 population housing census. Their sampling strategy also comprised a small zone system stratifying the city into 104 zones. The survey was conducted in person in the selected households, and questions covered variables related to household income and assets, as well as sex, age, education, and travel information for all household members above the age of five. The survey response rate was not reported.

Both surveys included household questions on household composition, income, and vehicle ownership; individual questions on demographics, income and occupation; and 24-hour trip diaries covering the number of trips taken, trip stages, modes, purposes and costs. Additional questions in Kisumu covered perceptions of the travel environment and opinions on improving city travel.

To account for differences that potentially stemmed from comparing datasets collected by two different institutions at different locations and times, we compared commute characteristics from the two analysis datasets with those from the 2013 World Bank survey in Kenya. The World Bank survey collected baseline data on the state of the cities in Kenya, including data on usual commutes to school and work.

3.1.3.2. Variables

Predictor variables included household and individual characteristics. Household characteristics included household size (number of individuals in each household), monthly household income, and vehicle ownership. Individuals' characteristics included age, age group (5-14, 15-24, 25-34, 35-44, 45-54, 55-64, 65+ years), sex, monthly income, and occupation (no work, employed, housekeeper, student, other). Individual monthly income was grouped into three categories to reflect the minimum monthly wage in Kenya, which was less than 10,000 KES (Kenya Shilling) between 2013 and 2016 (<10,000 KES, 10,000-30,000 KES and >30,000 KES) [206]. One Kenyan Shilling was equivalent to an average of $0.01 between 2013 and 2016. In Kisumu alone, where data were available, we included individual perceptions of travel environments (degree of agreement on access to transport modes and quality of travel environment) and opinions on improving travel modes (scored a list of options on improving transport modes).

Outcome variables included individual trip characteristics. The survey defined a trip as one journey undertaken by a participant from origin to destination for a single purpose during the reference day. 'No trip' was defined as not making a trip on the reference survey day. A trip could have multiple stages, denoting the different stops to change transport modes. The trip mode was defined as the most significant transport mode used during the trip, while the stage mode was the transport mode used in each trip stage. Transport modes included walking, cycling, motorcycle, tricycle, car, taxi, matatu (minibus), truck, and train. Matatu refers to privately owned small-capacity (14-30) minibuses used as shared taxis, while a bus refers to a publicly owned larger-capacity vehicle running on fixed routes and schedules. I grouped these transport modes into non-motorised transport (NMT) (walking and cycling) and motorised transport (MT) (motorcycle, tricycle, car, taxi, matatu, bus, and train). Motorised transport was further grouped into private MT (car, private motorcycle, private tricycle) and public MT (commercial motorcycle or tricycle, taxi, matatu, and bus). Public MT was also grouped into formal public MT (bus) and informal public MT (commercial motorcycle or tricycle, taxi, and matatu). The trip duration was the sum of stage durations within one trip, and the daily travel duration was the sum of all trip durations for trips travelled by an individual. Trip purposes included travel for work, school, recreation, shopping, personal business, and returning home.

3.1.3.3. Statistical analysis

For our exploratory analysis, we used a combination of summary statistics and plots to check for missingness, normality, zero inflation, and near-zero variance in data variables. With a total of 3% and 5% of observations with missing data points in the Nairobi and Kisumu travel datasets, respectively, we excluded missing records from each relevant analysis. Our variables of interest did not show near-zero variance (categorical variables) nor zero inflation (number of trips). Total daily travel duration and travel duration by mode were right-skewed; these were log-transformed.

We summarised and compared household and participant characteristics for each site. We also summarised and compared travel behaviour characteristics (trip frequency and time, use of different transport modes, mean (lower - upper quartile) travel times by mode and trip purposes) by age group and sex for each study site. We used the mean (lower - upper quartile) to summarise variables with higher proportions of zeros, which could otherwise be all zeros if we used the median (interquartile range). Our descriptive statistics were weighted using post-stratification weights derived from sex and age distribution. These demographic distributions came from the 2014 population demographic data, which was a projection from the 2009 national population census.

We used a Toby type 2 Heckman selection modelling framework to evaluate correlates of trip making, use of different transport modes (NMT, informal PT and private MT), daily travel duration and travel durations in transport modes. The choice of the model framework was motivated by the high frequencies of unobserved zeros, especially in the Kisumu dataset. The model framework comprised two equations. The first equation was a probit model that evaluated the likelihood of making a trip and using a transport mode. The probit model also generated the inverse mill's ratios (imr) to parameterise the second equation. The second equation was an ordinary least squares (OLS) model that evaluated the correlates of the log-transformed daily travel durations. In addition, we used a Poisson regression to predict correlates of trip frequencies. All analyses were performed in the R software, notably using the “sampleSelection” package (version 1.2-12) for our modelling.

We reported the outputs of the probit model as average marginal effects (AME), indicating the change in probability for any unit change in predictor variables. The outputs of the Poisson regression were reported as rate ratios. We reported the outputs of the OLS as per cent change in the daily travel time for a unit change in the predictors since the dependent variable was log-transformed. We reported the point estimates and their 95% confidence intervals for each dependent variable.

3.1.4. Results

3.1.4.1. Characteristics of the study sample

We analysed data from 10,000 households and 16,794 participants in Nairobi and 2,760 households with 5,790 participants in Kisumu. Household and participant characteristics are summarised in Table 3.2. Compared to Nairobi, a higher proportion of households in Kisumu registered no response to household income (32% vs 1%). A higher proportion of households in Kisumu owned bicycles (15% vs 10%, p<0.001), while ownership of all forms of motorised vehicles was lower in Kisumu. Participants from Kisumu were younger and comprised more females, students, and people with no employment.

Table 3.2 Characteristics of households and participants surveyed in Nairobi (2013) and Kisumu (2016), Kenya

	Nairobi Unweighted	Nairobi Weighted	Kisumu Unweighted	Kisumu Weighted
Household characteristics	N=10,000		N=2,760	
Median household size [IQR]	2.6 [1-3]	..	2.1 [1-3]	..
Household income in KES/month (%)				
<10,000	2,000(20)	..	1,049(38)	..

10,000 – 30,000	4,100(41)	..	607(22)	..
>30,000	3,700(37)	..	221(8)	..
No response	100(1)	..	883(32)	..
Households with vehicles (% (count %))				
Bicycle	10 (12)	..	15 (17)	..
Motorcycle	5 (6)	..	11 (13)	..
Car	19 (27)	..	8 (12)	..
Motorised vehicle	24 (35)	..	12 (16)	..
Any vehicle	30 (47)	..	25 (33)	..
Participant characteristics	N =16794	N= 16794	N=5790	N=5790
Average age (SD)	30 (11)	27 (13)	27 (15)	25 (18)
Age group in years (n, %)				
5-14	1276 (8)	3398 (20)	1161 (20)	1870 (32)
15-24	3418 (20)	4585 (27)	1475 (26)	1557 (27)
25-34	7276 (43)	4827 (29)	1743 (30)	1000 (17)
35-44	3268 (20)	2308 (14)	800 (14)	530 (9)
45-54	1183 (7)	1065 (6)	306 (5)	376 (7)
55-64	285 (2)	395 (2)	197 (3)	233 (4)
65+	88 (1)	216 (1)	108 (2)	224 (4)
Female (n, %)	8456 (50)	8181 (49)	2612 (45)	2966 (51)
Occupation (n, %)				
No work	959 (6)	983 (6)	590 (10)	458 (8)
Student	2572 (15)	4929 (29)	1551 (27)	1981 (34)
Employed	12009 (72)	9802 (58)	2779 (48)	2311 (40)
Homemaker	1071 (6)	879 (5)	448 (8)	358 (6)
Other	183 (1)	201 (1)	422 (7)	682 (12)
Participants per household income groups (n, %)				
<10000	5328 (32)	6042 (36)	1622 (28)	13156 (23)
10000-30000	5586 (33)	4499 (27)	666 (12)	498 (7)
>30000	3634 (22)	2860 (17)	125 (2)	108 (2)
No response	2246 (13)	3393 (20)	3377 (58)	3867 (67)

KES= Kenyan Shilling; SD= standard deviation; IQR= interquartile range

3.1.4.2. Travel behaviour characteristics

The trip characteristics in each study site are summarised in Table 3.3. Compared to Nairobi, the proportion of participants reporting no trip in the 24-hour trip diary period was far higher in Kisumu (47% vs 5%). The overall mean number of trips per survey participant was lower in Kisumu (1.2; IQR:0-2 vs 2.3; IQR:2-2; p<0.001), but when participants with no trips were excluded, the mean number of trips per participant with trips was similar in both cities (2.2; IQR:2-2 in Kisumu vs 2.4;

IQR:2-2 in Nairobi; p<0.001). The mean duration per trip, total travel time per survey participant (including participants with no trips), and whole travel time per survey participant (excluding participants with no trips) in Kisumu were half those in Nairobi.

Table 3.3 Characteristics of trips reported in the 24-hour trip diary in Nairobi (2013) and Kisumu (2016), Kenya

Trip Characteristics	Nairobi	Kisumu
Participants reporting no travel (%)	5	47
Total number of trips	37779	6892
Mean [IQR] number of trips per survey participant	2.3 [2-2]	1.2 [0-2]
Mean [IQR] number of trips per participant with trips	2.4 [2-2]	2.2 [2-2]
Mean [IQR] number of stages per trip	2.1 [1-3]	1.3 [1-1]
Mean [IQR] trip time in minutes per trip	49 [30-60]	24 [10-30]
Mean [IQR] total travel minutes per survey participant	110 [60-150]	50 [10-70]
Mean [IQR] total travel minutes per participant with trips	116 [60-150]	65 [30-80]

IQR= Interquartile range

Walking was the most common trip mode in both cities for both sexes, with women more likely to make a trip by walking (Table 3.4). Compared to Nairobi, the proportion of trips on bi/tri/motorcycles was higher, while the proportion of trips in cars, matatus or buses was lower in Kisumu. In both cities, most bi/motorcycle, car, and bus trips were undertaken by males, while matatu trips were evenly distributed between sexes.

Walking was the transport mode for more than 50% of trips and more often for females than males in both cities (Table 3.4). The mean travel time was shorter in Kisumu and for females in both cities.

When we grouped transport modes, NMT and informal public MT were the predominant modes, with similar transport mode shares in both cities (Table 3.4). The use of formal public transport modes was lower in Kisumu (1% vs 9.5%).

The primary trip purposes for both cities were for work, school, personal business and home return. Kisumu had lower proportions and shorter durations of work commute trips compared to Nairobi. All other trip purposes followed similar patterns in both cities (Table 3.4).

Table 3.4 Trip mode and purpose share and duration by sex in Nairobi (2013) and Kisumu (2016), Kenya

	Nairobi						Kisumu					
	Mode share (%)			Mean duration (IQR) in minutes			Mode share (%)			Mean duration (IQR) in minutes		
	Both sexes	Male	Female	Overall	Male	Female	Both sexes	Male	Female	Overall	Male	Female
	N=37779	N=19475	N=18322				6892	3447	3445			
Main trip mode												
Walk	41.7	36.6	47.2	33(15-30)	34(15-30)	32(15-30)	61.1	54.6	67.5	20(10-26)	20(10-26)	20(10-28)
Bicycle	1.4	2.4	0.4	43(20-60)	42(20-60)	48(30-60)	4.6	7.2	1.9	20(10-30)	20(10-28)	21(10-30)
Motorcycle	3.4	3.5	3.3	38(25-45)	42(25-60)	34(20-40)	2.7	2.4	3	27(15-35)	28(15-35)	27(18-35)
Tricycle	1	0.9	1.2	49(30-60)	47(30-60)	50(30-60)	14.9	16.9	12.9	19(10-25)	18(10-20)	21(10-25)
Car	11.7	15.3	7.9	54(30-60)	56(30-60)	51(30-60)	4.8	6.7	2.9	24(10-30)	25(10-30)	23(15-30)
Matatu	27.7	27.7	27.8	60(30-70)	62(30-75)	57(30-60)	10.5	10.4	10.6	41(25-50)	42(25-50)	40(22-50)
Bus	11.8	12.4	11.3	59(30-70)	59(30-75)	58(30-70)	1	1.3	0.7	42(15-45)	52(25-45)	22(15-30)
Other	1.1	1.2	1	49(30-60)	57(30-60)	39(20-45)	0.5	0.5	0.5	47(10-50)	80(24-95)	12(8-10)
Overall	100	100	100	46(25-60)	49(30-60)	44(20-60)	100	100	100	23(10-30)	23(10-30)	22(10-30)
Grouped modes												
NMT	43.1	39	47.5	33(15-30)	34(15-30)	32(15-30)	65.6	61.9	69.4	20(10-28)	20(10-28)	20(10-30)
Informal PT	32.1	32	32.2	57(30-60)	59(30-70)	55(30-60)	23.3	22.4	24.3	30(15-37)	30(15-39)	30(15-35)
Formal PT	12.1	12.7	11.4	59(30-75)	60(30-75)	58(30-72)	1	1.3	0.7	42(15-45)	52(25-45)	22(15-30)
Private MT	11.8	15.4	8	54(30-60)	56(30-60)	51(30-60)	9.6	14	5.2	22(10-30)	21(10-25)	23(15-30)
Other	0.9	1	0.9	43(30-45)	53(30-60)	32(20-30)	0.5	0.5	0.5	47(10-50)	80(24-95)	12(8-10)
Overall	100	100	100	46(25-60)	49(30-60)	44(20-60)	100	100	100	23(10-30)	23(10-30)	22(10-30)
Trip purpose												
Work	24.9	29.1	20.5	50(30-60)	52(30-60)	47(30-60)	12.7	16.3	9	28(10-30)	28(10-30)	28(10-30)
Education	15.3	14.7	15.9	37(20-45)	37(20-45)	37(20-45)	17.5	18.7	16.2	19(10-25)	19(10-25)	19(10-30)

Personal	6.2	6	6.4	43(20-60)	44(20-60)	43(20-60)	12.2	12.4	12.1	26(10-30)	25(10-30)	27(10-35)
Recreation	2.1	2.1	2.1	49(20-60)	48(20-60)	51(20-60)	1.3	1.5	1.1	23(10-30)	21(10-30)	25(10-30)
Shopping	5	2.5	7.7	35(15-45)	37(15-50)	35(15-40)	8.6	3.7	13.5	16(5-20)	15(5-20)	17(5-20)
Return	44.9	44.1	45.7	49(30-60)	53(30-60)	46(25-60)	46.3	46.1	46.5	23(10-30)	23(10-30)	23(10-30)
Other	1.6	1.5	1.7	43(15-45)	43(15-55)	42(15-45)	1.4	1.3	1.6	26(10-30)	35(10-37)	19(7-25)
Overall	100	100	100	46(25-60)	49(30-60)	44(20-60)	100	100	100	23(10-30)	23(10-30)	22(10-30)

MT = motorised transport; NMT = non-motorised transport; PT = public transport

- Walking and cycling

The proportion of participants with walking stages during any trip in Kisumu was half of that in Nairobi (40% vs 83%) (Table 3.5). Among trips including at least one walking stage, most (77%) of the trips included only walking in Kisumu compared to Nairobi (43%), where walking was more common as part of a multimodal trip. For any given trip, including at least one walking stage, walking was most likely combined with using matatus (over 60%) in both cities. The mean walking duration of trips that used matatus in another stage was double that of motorcycles in both cities.

The proportion of participants who cycled any trip in Kisumu was double that of Nairobi (4% vs 2.1%). These trips were predominantly (90%) cycled all the way. In Nairobi, cycling was sometimes one stage for other primary modes, mainly buses, matatus, and motorcycles.

Table 3.5 Characteristics of walking and cycling trips undertaken in Nairobi (2013) and Kisumu (2016), Kenya

	Nairobi (N=16,793)		Kisumu (N = 5,790)	
	Walking	Cycling	Walking	Cycling
Number of participants	13862	335	2292	130
% of participants	83	2.1	40	4
Number of trips in mode	31559	626	4740	262
% of trips as the main mode	43	93	77	98
Number (%) accompanying modes				
bicycle	97 (1)	..	24 (2)	..
car	1117 (6)	3 (7)	12 (1)	00
bus	4046 (23)	5 (12)	17 (2)	00
matatu	11557 (65)	26 (63)	692 (63)	2 (33)
motorcycle	711 (4)	5 (12)	189 (17)	00
tricycle	171 (1)	2 (5)	152 (14)	00
taxi	00	00	6 (1)	00
other	32 (0)	00	5 (0)	4 (66)
Median (IQR) walking time associated with other modes				
bicycle	11(6-12)	..	10(7-10)	..
car	15(8-20)	..	7(5-6)	..
bus	17(10-20)	..	10(5-15)	..
matatu	17(10-20)	..	12(5-15)	..
motorcycle	10(6-12)	..	8(5-10)	..
tricycle	14(6-20)	..	10(5-15)	..
taxi	…	..	14(5-25)	..
other	19(9-26)	..	7(5-7)	..

3.1.4.3. Correlates of trip making, transport mode usage, and travel time

- Individual trip-making, trip frequency, and daily travel time

Table 3.6 shows the correlates of trip making and total travel time in Nairobi and Kisumu. In Nairobi, the likelihoods of making a trip on the reference survey day were lower among females (compared to males), 05-14 and >65 age groups (compared to 35-44 years), homemakers and people with no work (compared to those employed), and individuals living in households with motorised vehicles (compared to no vehicles). The likelihoods of making trips were higher among higher-income earners and students. This pattern was similar in Kisumu, except that there was no gender influence in trip-making in Kisumu. Similar sociodemographic factors were associated with the number of trips made in each city.

For those with at least one trip on the reference day in Nairobi, females (compared to males), younger participants, and homemakers and those with no work (compared to those employed) had shorter total travel times. Higher-income earners and students travelled for longer durations. In Kisumu, females and homemakers travelled for shorter durations, while older people were likely to travel for longer durations.

Table 3.6 Correlates of individual trip-making and daily travel time in Nairobi (2013) and Kisumu (2016), Kenya

	AME (95%CI) likelihood of trips		Rate Ratio (95%CI) of daily trips		%Δ (95%CI) Daily travel time	
	Nairobi	Kisumu	Nairobi	Kisumu	Nairobi	Kisumu
Female	-0.03 (-0.03, -0.02)	-0.01 (-0.03, 0.02)	0.96 (0.94, 0.98)	0.96 (0.92, 1.01)	-9 (-11, -6)	-7 (-13, -2)
Age group (ref: 35 – 44 years)						
05-14	-0.03 (-0.04, -0.02)	0.03 (-0.02, 0.08)	0.91 (0.86, 0.97)	0.85 (0.75, 0.96)	-45 (-48, -42)	-20 (-37, 1)
15-24	0.00 (0.00, 0.01)	0.06 (0.02, 0.10)	0.96 (0.93, 1)	1.07 (0.98, 1.17)	-11 (-15, -7)	-3 (-13, 9)
25-34	-0.01 (-0.03, 0.00)	0.01 (-0.05, 0.07)	1.03 (1, 1.06)	1.12 (1.04, 1.21)	-6 (-8, -3)	-4 (-18, 13)
45-54	0.01 (-0.01, 0.02)	-0.04 (-0.10, 0.02)	1 (0.96, 1.05)	1.06 (0.94, 1.18)	1 (-3, 6)	26 (10, 44)
55-64	-0.03 (-0.06, 0.00)	0.09 (0.01, 0.16)	0.97 (0.89, 1.05)	1.19 (1.03, 1.36)	-8 (-15, 0)	38 (5, 81)
65+	-0.06 (-0.12, -0.01)	-0.01 (-0.11, 0.10)	0.89 (0.76, 1.04)	1.03 (0.82, 1.29)	-3 (-17, 14)	35 (3, 76)
Income (ref: <10000KES/month)						
10000-30000	0.04 (0.03, 0.05)	0.15 (0.11, 0.19)	1.09 (1.06, 1.12)	1.24 (1.15, 1.33)	13 (9, 18)	4 (-27, 48)
>30000	0.04 (0.03, 0.05)	0.23 (0.18, 0.27)	1.13 (1.09, 1.17)	1.44 (1.3, 1.59)	25 (20, 31)	-7 (-47, 63)
No response/NA	0.00 (-0.01, 0.01)	-0.28 (-0.31, -0.24)	1 (0.96, 1.05)	0.55 (0.52, 0.6)	10 (6, 15)	25 (-40, 157)
Occupation (ref: Employed)						
Homemaker	-0.10 (-0.12, -0.08)	-0.02 (-0.07, 0.03)	0.81 (0.77, 0.85)	1.01 (0.92, 1.11)	-21 (-29, -12)	-25 (-33, -15)
No work	-0.12 (-0.15, -0.10)	-0.01 (-0.06, 0.03)	0.75 (0.71, 0.79)	0.97 (0.89, 1.06)	-13 (-22, -2)	-4 (-13, 7)
Student	0.02 (0.01, 0.03)	0.04 (0.00, 0.09)	1.06 (1.01, 1.11)	1.21 (1.1, 1.34)	10 (4, 16)	-6 (-23, 15)
Others	-0.04 (-0.08, 0.00)	-0.19 (-0.25, -0.13)	0.89 (0.79, 1.01)	0.56 (0.48, 0.64)	0 (-12, 13)	-3 (-48, 81)
Household vehicle (ref: No vehicle)						
Any vehicle	0.00 (-0.01, 0.01)	-0.02 (-0.05, 0.01)	0.99 (0.95, 1.03)	1 (0.93, 1.06)	-1 (-5, 3)	-1 (-10, 9)
Motorised vehicle	-0.03 (-0.04, -0.01)	-0.04 (-0.08, 0.00)	1.01 (0.96, 1.06)	0.94 (0.87, 1.02)	-3 (-7, 2)	-4 (-15, 9)
Inverse Mills Ratio	..	..	..	..	-19 (-44, 17)	-34 (-87, 228)
N	16735	5767	16735	5767	15887	3072
R^2 (pseudo)	..	..	0.03	0.20	0.98	0.96

AME: Average Marginal Effects; %Δ: per cent change in travel time

- Individual daily use of NMT and daily time spent in NMT

Table 3.7 shows the correlates of NMT use and total time spent in NMT. In Nairobi, the likelihoods of using NMT were lower among homemakers, those with no work (compared to those employed), and those who earn >30,000 KES (compared to <10,000 KES) monthly. The likelihoods of NMT use were higher among those earning 10,000 – 30,000 KES monthly (compared to <10,000 KES) and students (compared to those employed). In Kisumu, the pattern for NMT use was similar to Nairobi, except those living in households with vehicles were less likely to use NMT. For those who used NMT, females travelled for shorter durations in NMT than males in both cities. Higher earners and motorised vehicle owners were likely to travel for shorter durations in NMT modes in Nairobi but not in Kisumu.

Table 3.7 Correlates of individual use of, and daily travel time in, non-motorised transport modes in Nairobi (2013) and Kisumu (2016)

	AME (95%CI) likelihood of NMT		%Δ (95%CI) daily NMT time	
	Nairobi	Kisumu	Nairobi	Kisumu
Female	0.00 (-0.01, 0.01)	0.02 (-0.01, 0.04)	-6 (-8, -3)	-18 (-26, -8)
Age group (ref: 35 – 44 years)				
05-14	-0.02 (-0.04, 0.00)	0.06 (0.01, 0.10)	1 (-6, 8)	-4 (-18, 14)
15-24	0.02 (0.01, 0.03)	0.06 (0.02, 0.10)	-3 (-8, 1)	-17 (-36, 8)
25-34	-0.04 (-0.06, -0.02)	0.03 (-0.03, 0.09)	-4 (-7, 0)	-17 (-36, 9)
45-54	-0.06 (-0.10, -0.03)	0.02 (-0.04, 0.07)	5 (-1, 12)	13 (-9, 40)
55-64	-0.04 (-0.08, 0.00)	0.09 (0.02, 0.17)	-3 (-14, 8)	2 (-34, 58)
65+	-0.11 (-0.19, -0.04)	0.05 (-0.06, 0.15)	27 (2, 57)	52 (6, 119)
Income (ref: <10,000KES/month)				
10,000-30,000	0.03 (0.01, 0.04)	0.06 (0.02, 0.11)	-11 (-14, -7)	-30 (-46, -10)
>30,000	-0.12 (-0.14, -0.10)	-0.22 (-0.28, -0.15)	-15 (-20, -9)	13 (-55, 182)
No response/NA	-0.02 (-0.04, 0.00)	-0.24 (-0.28, -0.21)	4 (-1, 9)	101 (-26, 441)
Occupation (ref: Employed)				
Homemaker	-0.14 (-0.17, -0.11)	0.02 (-0.03, 0.07)	-2 (-9, 7)	-11 (-24, 4)
No work	-0.16 (-0.19, -0.13)	0.01 (-0.03, 0.06)	5 (-4, 15)	0 (-12, 14)
Student	0.05 (0.03, 0.07)	0.06 (0.01, 0.11)	-11 (-16, -6)	-11 (-35, 22)
Others	-0.05 (-0.11, 0.02)	-0.17 (-0.23, -0.12)	28 (11, 48)	69 (-31, 313)
Household vehicle (ref: No vehicle)				
Any vehicle	-0.01 (-0.03, 0.01)	-0.05 (-0.09, -0.02)	10 (5, 15)	28 (1, 63)
Motorised vehicle	-0.20 (-0.22, -0.18)	-0.15 (-0.19, -0.11)	-16 (-26, -4)	42 (-28, 180)
Inverse Mills Ratio	..	..	-22 (-41, 3)	-83 (-98, 78)
N	16735	5767	14012	2432
R^2 (pseudo)	..	..	0.96	0.94

AME: Average Marginal Effects; %Δ: per cent change in travel time

- Individual use of informal PT and time spent in informal PT

Table 3.8 shows the correlates of informal PT use and daily travel time in informal PT. In Nairobi, the likelihoods of using informal PT were lower among participants living in households with a vehicle (compared to no vehicle). The likelihoods were higher among students, higher-income earners, and those employed. The pattern for informal PT was similar in Kisumu. In addition, females were more likely to use informal PT in Kisumu. For those who used informal PT in Nairobi, total travel time in informal PT was susceptible to sociodemographic factors. That was not the case in Kisumu, where only people without work (compared to those employed) travelled longer. The difference in the travel times in informal PT could highlight a difference in city congestion patterns.

Table 3.8 Correlates of individual use of, and travel time in, informal public transport in Nairobi (2013) and Kisumu (2016)

	AME (95%CI) likelihood of informal public transport trips		%Δ (95%CI) daily informal public transport time	
	Nairobi	Kisumu	Nairobi	Kisumu
Female	0.00 (-0.01, 0.02)	0.03 (0.01, 0.05)	-9 (-12, -6)	-21 (-43, 9)
Age group (ref: 35 – 44 years)				
05-14	-0.02 (-0.04, 0.01)	-0.02 (-0.05, 0.02)	238 (20, 857)	227 (-69, 3388)
15-24	0.04 (0.02, 0.06)	0.03 (0.00, 0.07)	-1 (-7, 5)	11 (-12, 40)
25-34	-0.08 (-0.12, -0.05)	0.01 (-0.04, 0.06)	-16 (-22, -9)	-14 (-36, 15)
45-54	-0.37 (-0.40, -0.34)	-0.16 (-0.20, -0.12)	31 (9, 57)	23 (-2, 53)
55-64	-0.13 (-0.19, -0.07)	0.05 (-0.02, 0.12)	51 (11, 105)	26 (-24, 107)
65+	-0.12 (-0.23, -0.02)	-0.11 (-0.19, -0.03)	77 (23, 156)	198 (-29, 1156)
Income (ref: <10,000KES/month)				
10,000-30,000	0.17 (0.15, 0.19)	0.20 (0.16, 0.24)	-39 (-56, -15)	-58 (-90, 83)
>30,000	0.07 (0.05, 0.09)	0.06 (0.00, 0.12)	-17 (-29, -4)	-16 (-53, 50)
No response/NA	0.00 (-0.03, 0.03)	-0.08 (-0.10, -0.05)	8 (1, 16)	81 (-23, 328)
Occupation (ref: Employed)				
Homemaker	-0.15 (-0.19, -0.12)	-0.10 (-0.13, -0.06)	57 (8, 128)	121 (-35, 651)
No work	-0.16 (-0.19, -0.13)	-0.03 (-0.07, 0.00)	67 (13, 147)	51 (2, 125)
Student	0.14 (0.11, 0.17)	0.04 (0.00, 0.08)	-37 (-52, -16)	-32 (-58, 9)
Others	-0.12 (-0.20, -0.04)	-0.08 (-0.12, -0.03)	46 (4, 105)	106 (-24, 460)
Household vehicle (ref: No vehicle)				
Any vehicle	-0.06 (-0.09, -0.04)	-0.10 (-0.12, -0.07)	23 (7, 42)	97 (-29, 450)
Motorised vehicle	-0.10 (-0.14, -0.07)	0.02 (-0.02, 0.05)	38 (9, 74)	-5 (-28, 24)
Inverse Mills Ratio	..	..	-83 (-95, -49)	-90 (-100, 225)
N	16735	5767	7475	1204
R2 (pseudo)	..	..	0.98	0.95

AME: Average Marginal Effects; %Δ: per cent change in travel time

- Individual use of private MT and daily travel time in private MT

Table 3.9 shows the correlates of using private MT and daily travel time in private MT. In Nairobi, the likelihoods of using private MT were lower among females (compared to males), most of the age groups (compared to 35-44), homemakers and those with no work (compared to those employed). The likelihood was higher among those with a higher income and those living in households with motorised vehicles. In Kisumu, the likelihoods of using private MT were lower among females (compared to males) and homemakers but higher among those earning >10,000 KES/monthly (compared to <10,000 KES) and those living in households with a vehicle (compared to none). For those who used private MT in Nairobi, the total travel time in private MT was shorter among females (compared to males) and children. No individual characteristic was associated with travel time in private MT in Kisumu. Therefore, private MT use in both cities is dominated by males and the wealthy.

Table 3.9 Correlates of individual use of, and daily travel time in, private motorised transport in Nairobi (2013) and Kisumu (2016), Kenya

	AME (95%CI) likelihood of private car trips		%Δ (95%CI) Private car travel time	
	Nairobi	Kisumu	Nairobi	Kisumu
Female	-0.02 (-0.03, -0.02)	-0.03 (-0.04, -0.01)	-16 (-22, -9)	7 (-23, 50)
Age group (ref: 35 – 44 years)				
05-14	-0.08 (-0.09, -0.06)	-0.02 (-0.04, 0.01)	-50 (-66, -26)	-24 (-70, 94)
15-24	-0.03 (-0.04, -0.02)	0.01 (-0.01, 0.02)	-16 (-38, 13)	37 (-2, 92)
25-34	0.03 (0.01, 0.05)	-0.01 (-0.04, 0.01)	-6 (-14, 3)	7 (-12, 30)
45-54	-0.08 (-0.11, -0.06)	-0.05 (-0.08, -0.03)	-3 (-11, 7)	20 (-11, 62)
55-64	0.04 (0.01, 0.08)	0.02 (-0.02, 0.06)	-10 (-22, 4)	6 (-27, 56)
65+	0.01 (-0.05, 0.07)	-0.04 (-0.09, 0.00)	-21 (-39, 3)	-8 (-74, 219)
Income (ref: <10000KES/month)				
10,000-30,000	0.01 (0.00, 0.02)	0.04 (0.01, 0.06)	9 (-4, 23)	9 (-26, 60)
>30,000	0.18 (0.16, 0.20)	0.26 (0.21, 0.32)	16 (-22, 71)	5 (-72, 292)
No response/NA	-0.01 (-0.02, 0.01)	-0.03 (-0.04, -0.01)	16 (-3, 40)	36 (-18, 124)
Occupation (ref: Employed)				
Homemaker	-0.06 (-0.08, -0.04)	-0.04 (-0.06, -0.02)	-26 (-47, 2)	-33 (-71, 50)
No work	-0.04 (-0.07, -0.02)	-0.02 (-0.04, 0.01)	15 (-21, 68)	-16 (-46, 30)
Student	0.03 (0.00, 0.05)	-0.01 (-0.04, 0.01)	-16 (-34, 6)	-29 (-53, 8)
Others	-0.01 (-0.06, 0.04)	0.00 (-0.04, 0.03)	15 (-25, 78)	-7 (-41, 48)
Household vehicle (ref: No vehicle)				
Any vehicle	0.00 (-0.02, 0.02)	0.06 (0.04, 0.08)	-15 (-32, 6)	13 (-52, 165)
Motorised vehicle	0.18 (0.16, 0.20)	0.06 (0.04, 0.08)	41 (-20, 150)	-30 (-64, 34)
Inverse Mills Ratio	..	..	1 (-40, 69)	-32 (-86, 224)
N	16735	5767	2314	441
R2 (pseudo)	..	..	0.98	0.95

AME: Average Marginal Effects; %Δ: per cent change in travel time

3.1.4.4. Travel environment in Kisumu

- Perception of travel environment

Most participants perceived their access to commercial bi/motorcycles and public transport as easy (Figure 3.3). Most participants did not consider traffic in their neighbourhoods to be high. Many participants were not satisfied with the quality of street lighting and footpaths. The crime rate was perceived as high in neighbourhoods. Thus, while access to transport modes does not seem to be an issue, multiple barriers that can still discourage mobility exists. These provide possible starting points for investigating the causes of low mobility in Kisumu.

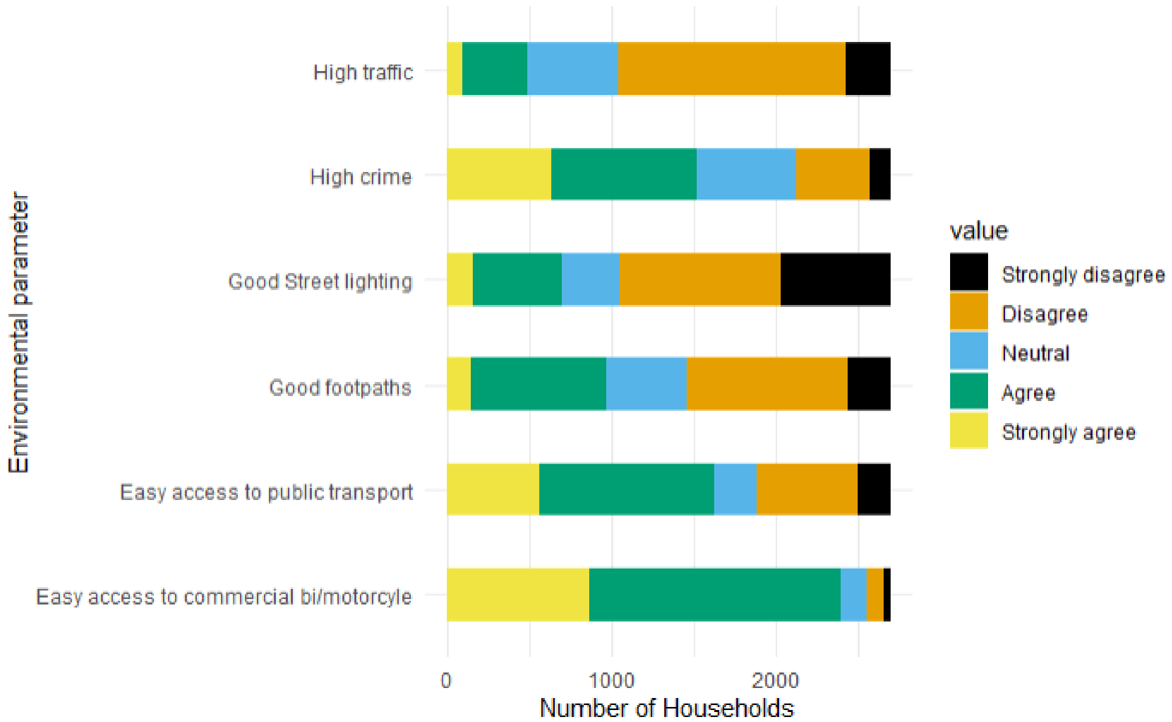


Figure 3.3 Characteristics of the travel environment in Kisumu (2016)

- Opinions on improving transport in Kisumu

It is innate for people to prioritise their safety, but highlighting it in a survey as the number one priority in a context with many transport inconveniences and shortcomings speaks to people's concerns about road safety. Participants prioritised addressing safety issues associated with the different transport modes as a key strategy for improving those modes. For example, 25% of participants suggested improved bus safety, safe driving (reducing the risk of cars hitting motorcycles), and safe pedestrian crossings. Many participants also suggested the improvement of footpaths, separate cycle tracks and provision of helmets for motorcycle passengers as ways to improve the respective modes (Figure 3.4). The “other” category comprised a variety of opinions for different transport modes. For example, “other” for public transport included less overcrowding and lower fares.

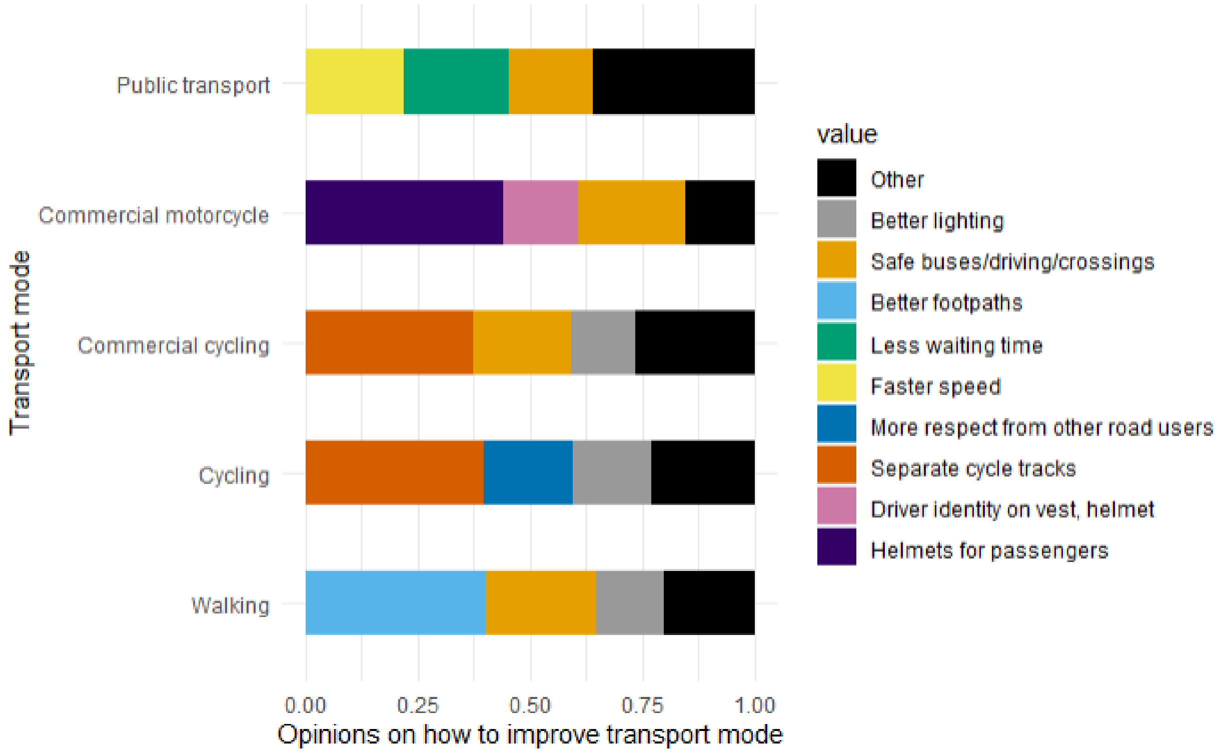


Figure 3.4 Main opinions on strategies to improve main transport modes in Kisumu (2016). The 'other' category comprises a broad range of mode-dependent strategies.

3.1.4.5. Comparing data sources with the World Bank sources

The Nairobi (2013) and Kisumu (2016) travel surveys and the World Bank (2013) baseline surveys of usual travel modes showed similarities and substantial differences in terms of work and school commute characteristics (Table 3.10). All three surveys imply that walking and cycling rates are higher in Kisumu than in Nairobi, while car and matatu use is higher in Nairobi than in Kisumu, although the mode shares differ. The World Bank (2013) baseline survey reported that the predominant work and school commute modes (~90%) in both cities are walking and matatus. Nairobi (2013) reported the same dominant commute modes accounting for 67% of trips, while Kisumu (2016) reported different predominant commute modes (walking and use of motorcycles) accounting for 68% of trips (Table 3.10). For Nairobi, matatu and bicycle shares are comparable, while walking, bus, and car shares are widely different between the two surveys. For Kisumu, bus and bicycle shares are similar, while the other modes are widely different between the two surveys.

Regarding commute time by mode, the World Bank data showed that apart from cars, commute times for all modes were higher in Kisumu than in Nairobi. On the contrary, when using the Nairobi (2013) data and the Kisumu (2016) data, commute times were higher for all modes in Nairobi than in Kisumu. Although commute times were generally lower in the World Bank data, the time difference was more pronounced with the Nairobi (2013) data than with the Kisumu (2016) data.

Overall the Kisumu travel survey closely matches the World Bank estimates in terms of commute duration and mode shares for NMT but not other modes. Similarly, the Nairobi travel survey closely matches the World Bank estimates in terms of NMT shares but significantly deviates when it comes to commute durations.

Table 3.10 Comparing work and school commute mode shares and travel times from the Nairobi (2013) and Kisumu (2016) travel surveys and the World Bank (2013) baseline survey

	Nairobi			Kisumu		
	Share (%)	Median (IQR)	Mean (SD)	Share (%)	Median (IQR)	Mean (SD)
World bank data	**N=1940**			**N=1535**		
Walk	52.4	15(5-20)	17(1)	59.8	15(10-30)	20(1)
Bicycle	1.7	10(4-20)	15(2)	3.8	20(15-30)	22(2)
Bicycle taxi	0.5	7(7-20)	12(3)	4.6	15(7-20)	15(1)
Car	4	30(15-45)	76(36)	1.9	10(10-20)	24(7)
Matatu	37.5	30(20-60)	49(3)	26.8	30(20-40)	48(5)
Taxi shared	0.1	10(10-10)	10(0)		..	..
Taxi vehicle	0.1	10(10-10)	10(0)	0.1	30(30-30)	20(5)
Bus	0.4	10(10-60)	33(14)	0.8	12(10-60)	97(38)
Other	3.3	7(0-20)	26(9)	2.2	10(7-25)	32(14)
Overall	100	20(10-30)	31(2)	100	20(10-30)	28(1)
Travel survey data	**N= 15169**			**N= 2076**		
Walk	37.7	30(15-30)	31(1)	60.3	15(10-30)	21(1)
Bicycle	1.6	30(20-60)	42(2)	4.5	18(10-30)	19(1)
Motorcycle	3.6	30(25-45)	38(1)	17.2	15(10-20)	18(1)
Tricycle	1	40(30-60)	46(2)	2.4	25(18-35)	28(2)
Car	13.1	45(30-60)	52(1)	1.5	33(25-50)	59(25)
Matatu	28.8	50(30-60)	57(1)	7.4	35(25-45)	38(2)
Bus	12.7	50(30-60)	55(1)	6.1	20(10-25)	25(4)
Other	1.5	40(30-60)	50(3)	0.6	24(10-95)	72(37)
Overall	100	30(30-60)	45(0)	100	20(10-30)	23(1)

3.1.5. Discussion of case study findings

In summary, we found a higher rate of immobility in Kisumu compared with Nairobi (35% vs 5%), with double the average number of trips per survey participant in Nairobi (2.3; IQR:2-2 vs 1.2; IQR:0-2). The mean trip duration and daily travel time in Nairobi were double those in Kisumu. Walking was the most common mode of transport, followed by matatus in both cities. Most walking (53%) was undertaken with other modes in Nairobi, whereas walking was the sole transport mode in most walking trips in Kisumu (77%).

Gender, income, occupation, and household vehicle ownership were variedly associated with individual trip making; use of NMT, informal PT, and private MT; and personal daily travel durations in different transport modes. For example, in Nairobi, females, compared to males, were less likely to make trips (AME = -0.03; 95%CI=-0.03 to -0.02), and those who made trips travelled for shorter times (% difference = -9; 95%CI= -11 to -6). In Kisumu, gender was not associated with trip making; for those who travelled, females travelled shorter times than males (% difference = -7; 95%CI= -13 to -2). Females and people living in households with higher monthly incomes travelled for shorter durations in NMT modes and had higher chances of using informal PT in both cities. Living in households earning more than 10,000 KES ($100) per month was associated with a higher probability of trip-making and longer daily travel times in both cities.

The two main problems identified in the travel environment (only for Kisumu, where data were available) were the poor quality footpaths and streetlights. Participants frequently requested improvements in the safety of transport modes, for example, improving safety on buses, safe driving (to reduce the risk of cars hitting motorcycles), and safe crossings for pedestrians.

Other relevant studies in the literature focused on testing advanced travel survey designs [49], analysis methods [199], and the use of public transport [198], with none of these studies using representative data. Salon et al. (2019) recently conducted two analyses on travel patterns from representative surveys in Kenyan cities: one based on a 2004 travel survey in Nairobi [200] and the other based on the 2013 World Bank data on commuting in major Kenyan towns [191]. However, the 2004 data are likely outdated, while the 2013 data reports only commuting. This study, therefore, provides comprehensive and relatively timely findings that respond to a critical gap in the literature and inform transport policies.

Despite filling an important gap in the literature, this study has limitations that must be acknowledged to support the complement of findings. Firstly, because the datasets originated from different organisations, collected at different times and for slightly different purposes, with possible contextual adaptations, there are likely inherent differences between the data sources. To account for differences resulting from data types, we explored our two main datasets and compared them with other available data. In Nairobi, four other representative surveys with travel-related questions have been conducted since 2004. One of these surveys was conducted by the Japan International Cooperation Agency (JICA) in 2004. The second survey was by the Kenya Institute for Public Policy Research and Analysis (KIPPRA) in 2004; the third survey in 2010 by the African Centre of Excellence for Studies in Public and Non-Motorised Transport (ACET), and the fourth survey was conducted by the World Bank in 2013. Many parameters were found to substantially differ among these surveys, with JICA surveys reporting higher car mode share, fewer walkers and longer travel durations compared to all the other surveys [191]. There is consistency in the travel duration of motorised travel and the fraction of walking time in these surveys [191]. In Kisumu, apart from the ITDP data, only the World Bank collected data with travel variables, but these two datasets have not been previously compared. Our triangulation of the two main datasets with a third dataset that covered both settings provided a lens through which our findings were interpreted. Travel surveys are prone to recall bias and ‘soft refusal’ (participants reporting no travel to avoid filling out the rest of the questionnaires), as surveys entail recalling multiple travel activities, estimating travel times, and filling out relatively lengthy questionnaires. The reports on the administration of both surveys provide confidence in the steps taken to ensure correct data. However, the trip rate in Kisumu is low and warrants further investigation.

- Trip-making and daily travel time

The two cities have very contrasting rates of reporting no trips on the survey day (5% Nairobi vs 35% Kisumu). These values deviate substantially from the reported 8 to 12% of the population that will be captured as immobile at some point [207], even if this global figure varies substantially across age groups, zones of residence, and days of the week. One also notes that the trip rates in Kisumu are similar for men and women. A possible explanation for the high no-trip rates in Kisumu is ‘soft refusal’ or participants omitting shorter trips if interviewers did not skilfully prompt their inclusion [207]. On the other hand, the very high reported participation rates in Nairobi could signal that people without trips were somehow excluded. The case for possible overestimation of travel behaviour characteristics in Nairobi is strengthened by the very long travel times reported in the city. However, the large observed differences strongly suggest considerable differences in participation and travel times between two major cities in the same country.

Being female did not seem as much of an impedance to travel in Kisumu as in Nairobi. Our findings that females were less likely to make trips, and when they travelled, they travelled for shorter times than males support recent claims on gender inequity in travel in Africa [48]. In addition, mobility increases with household income, highlighting a possible financial barrier to motorised transport for many. A link could not yet be made between the inclusive mobility observed in Kisumu and the recent changes in transport policies supported by NGOs such as the ITDP and the city’s campaign to host major events such as the Africities Summit in 2022.

- NMT

The high use of NMT modes is expected in most African cities, and cities with higher NMT use, such as Kisumu, have taken steps to preserve NMT in their mobility plans with actions including education and advocacy for NMT, the introduction of car-free days, and improving private car parking facilities to create space for public transport and NMT use. Participants aged 45 years and above and those living in households with monthly incomes above 30,000 KES or with motorised vehicles were less likely to use NMT modes in both cities. This observation is consistent with the expectation that some people earn more, purchase vehicles, and abandon NMT modes of transport as they get older. In terms of physical activity accumulated from NMT modes, over half of the participants engaged in moderate physical activity in the form of walking and cycling for more than 30 minutes on the survey day. The importance of travel as a source of physical activity in lower-income countries is corroborated by Strain et al. (2020) in their work on domain-specific physical activity in 104 countries [208]. Although most of NMT comes from walking, cycling is significant in Kisumu, ranking high among the global cycling cities, albeit dominated by men [209, 210]. The difference in cycling rates between Nairobi and Kisumu could result from multiple factors, including historical and built environmental factors. For example, Nairobi's built environment is denser because of the city’s large population and role as the capital.

- Perception of environment and opinions on improving travel modes

In Kisumu, most participants report acceptable neighbourhood public transport, low road traffic, high crime rates, inadequate footpaths, and street lighting. The observed low mobility means that the high crime rates, inadequate footpaths and poor lighting could be substantial barriers to mobility. Therefore, the perception of a good transport environment regarding access and low traffic does not imply high mobility. Page *et al.* (2010) [211] reported how the perception of a physical environment relates differently to physical activity behaviours. Young girls but not boys engage in outdoor play when they perceive less risk in road traffic accidents, while boys but not girls increased active commuting to school if they perceived easy accessibility.

The findings from this study have important implications. The high proportion of participants without trips in Kisumu needs further exploration, especially using improved data, but highlights the importance of consistent study designs with attempts to overcome soft refusals in travel surveys. From the lenses of income, gender, adolescence, and age, travel in Kisumu was more inclusive and equitable when people were mobile. The low number of people with trips raises concerns about potential immobility in smaller towns and cities that comprise most of Africa's urban areas. Most African cities are slightly smaller than Kisumu in size and stage of urban development, with over 97% of the urban areas in Africa having fewer than 300,000 inhabitants [21]. Much of Africa's projected rapid urban growth will occur in these small and medium-sized cities [21].

The observed growth in motorcycles shares concerns from two perspectives. First, motorcycle trips seem to pull from NMT and other public transport modes such as matatus. This trip pulling reduces opportunities for active travel and obscures the demand for further development of walking, cycling and public transport infrastructure. Secondly, motorcycle riders and passengers typically face high injury risks and pose a high risk to pedestrians. Notwithstanding, motorcycles are more space efficient than cars, as cars require lots of road space.

Kisumu's relatively higher cycling uptake indicates the possible success of promoting cycling in similar settings. Encouraging and consolidating high cycling levels would need investments. Still, a movement in that direction will reduce danger and increase the mode's safety, as reflected by the participants’ opinions on improving the safety of the different transport modes. Efforts to increase cycling must also consider the competition induced by the rapid increase in motorcycling.

The data challenges encountered in this study, including limited datasets, gross disparities in estimates, and omission of critical variables, highlight known problems with data that inform travel behaviour. Travel data from cities worldwide have often posed challenges that impede comparing and monitoring travel patterns. These challenges include the frequently unclear definition of trips, inconsistent inclusion of short trips, poor selection of travel days to adequately capture weekly and seasonal variation, the granularity of travel time estimates, and the designation of trip modes. Efforts to harmonise and triangulate travel data are necessary to paint more complete pictures of travel behaviour and the evolution of travel patterns.

In conclusion, our findings show that the proportion of individuals travelling is very high in Nairobi and very low in Kisumu; also, the travel durations are longer in Nairobi and shorter in Kisumu. Higher household income is associated with more travel in both cities, while the female gender is associated with less travel in Nairobi and shorter travel times in both cities. The safety of different transport modes is considered an essential strategy for improving mode usage in Kisumu. The marked differences in travel behaviour characteristics and correlations between cities in the same country indicate setting-dependent travel behaviour correlations. This variation suggests more sub-national data collection, harmonisation, and the use of alternate data sources like time-use surveys to build a more nuanced understanding of travel behaviour profiles, patterns, and drivers in African cities.

3.2. Case study 2: Using time-use diaries to investigate travel behaviour and barriers to active travel in Yaoundé, Cameroon

3.2.1. Abstract

We conducted a cross-sectional household telephone time-use survey on 1334 participants to investigate travel behaviour and barriers to active travel (walking and cycling) in Yaoundé, Cameroon. We found that two-thirds of all participants reported at least one trip; the median (IQR) numbers of trips per capita and participants with trips were 2 (0–3) and 2 (2–3), respectively. The main trip modes were shared taxis (46%), walking (27%), private cars (11%), and motorcycle taxis (10%), with 25%, 56%, and 45% of all participants reporting the use of active, motorised, and public transport, respectively. The mean (IQR) trip duration was 48 (30–60) minutes; for participants who reported trips, the daily overall and active travel durations were 121 (60–150) and 28 (0–45) minutes, respectively. Women were less likely to travel, making fewer and shorter trips when they travelled. Participants in less wealthy households were more likely to travel. The stated barriers to walking and cycling were the fear of road traffic injuries and the inconvenience of active travel modes. Local urban transport authorities must improve the safety and convenience of active mobility and promote gender equity in transport. Restrictions to movements during the COVID-19 pandemic and the relatively small survey sample might have biased our results; thus, a representative travel survey could improve current estimates. More generally, high-quality research on travel behaviours and their correlates is needed in low-resource settings.

3.2.2. Background

Cameroon, which has just over 26 million people, is one African country that exemplifies the sparseness of information on urban travel behaviour. The country has had only one travel survey from one city (Douala) in almost two decades [50]. This lack of data raises the question of what evidence guides current urban transport policies in the country. At the same time, the available indicators do not reflect adequate transport planning. For example, there are high and increasing rates of road traffic injuries [212], physical inactivity [213], and air pollution concentrations [214]. These poor transport-related indicators and the lack of basic information on urban travel behaviour and barriers to active travel underscore the need to gather new data and research on urban travel in Cameroon.

We surveyed the travel behaviour characteristics and barriers to active travel (i.e., walking and cycling) of residents of Yaoundé, the capital city of Cameroon. Our specific objectives were, firstly, to describe the individual travel behaviour characteristics of residents of Yaoundé. Secondly, we examined how travel behaviour characteristics differed by demographic and socioeconomic groups. The third objective was to describe the main self-reported factors influencing active travel among residents of Yaoundé.

The study was based in Yaoundé (Figure 3.5), Cameroon's political capital and second-most populous city. Its 2021 population was around 4 million. Similarly to most African cities, Yaoundé has a transport landscape that is changing to cope with its increasing size (population and land area), changing land use and urban settlement patterns, and the distribution of socioeconomic activities. Researchers [215] described urbanisation in Yaoundé as being largely uncontrolled and characterised by the spontaneous development of settlements in multiple locations without respect for urban planning rules. The new unplanned human settlements easily strain public goods and services. The main economic activities in Yaoundé are trade, public service, and diplomatic services. Its GDP per capita is USD 1529, with 58 cars and 18 motorcycles per 1000 inhabitants [216].

The city is spread around seven major hills. Although it is near the equator, the temperatures are moderate and relatively constant (average temperature is 27 °C) because of its high elevation of 750 m above sea level. It has a tropical wet and dry climate, with dusty roads in the dry season when precipitation is at its minimum (19 mm in January) and torrential rains in the wet season when precipitation is at its highest (294 mm in October).

In 2010, the Yaoundé Urban Council estimated that the city had a surface area of 300 square kilometres and a total road network mileage of 2536 km (Figure 3.5). The urban road network was 752.75 km and is divided as follows: 61 km of national roads, 159 km of main roads concentrated in the city centre, 57 km of secondary roads connecting the city centre to surrounding areas, and 478 km of tertiary roads connecting the surrounding areas. Secondary and primary roads are concentrated in the city’s core, extending from the Central Business District (CBD) to the periphery.

The residents of Yaoundé travelled mainly by personal transport modes such as walking, private cars, and motorcycles or by public transport modes such as motorcycles and shared taxis. Motorcycle taxis typically transport one or two passengers and run on secondary and tertiary roads, although they often encroach into the CBD. The shared taxis are four-seat vehicles that run mainly on primary and secondary roads. Taxis are often shared by up to five passengers, who board and alight at different points and negotiate fares based on distances. Other less frequent transport modes include minibuses and four-seat cars (opeps) used for longer commutes between the CBD and nearby towns.

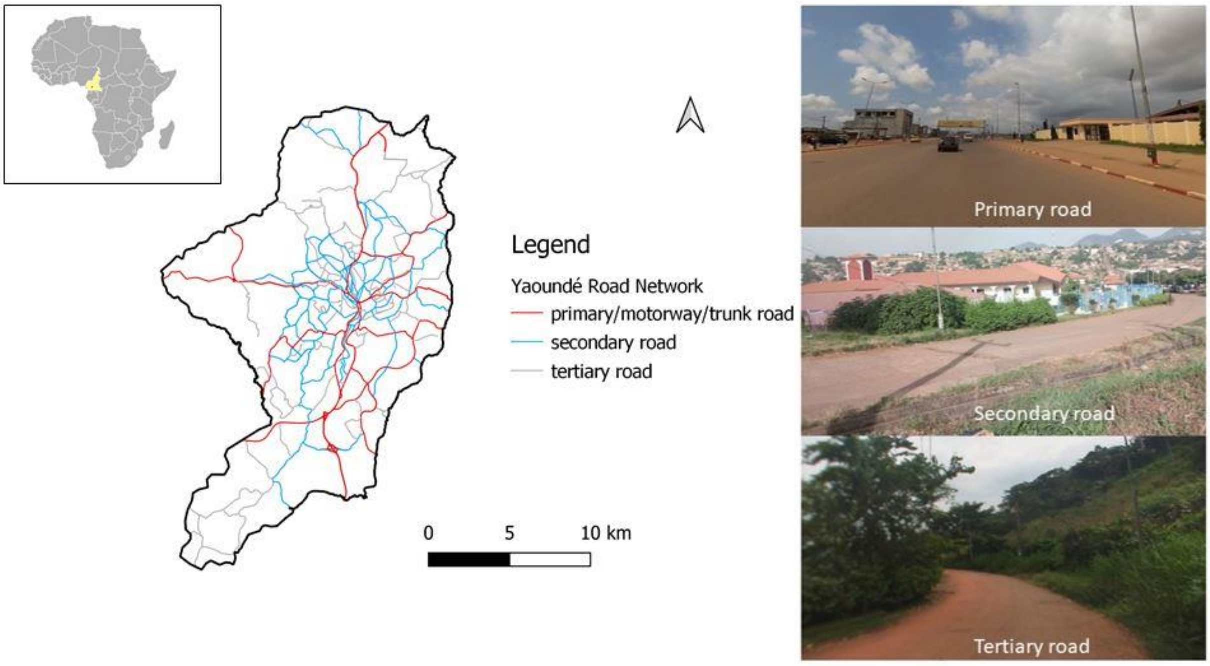


Figure 3.5 Network of larger roads on a background of residential roads in Yaoundé (2022). (Source: drawn from OpenStreetMap and obtained pictures of sample roads from Google Street Views)

3.2.3. Methods

3.2.3.1. Study design, participants and sampling

We conducted a cross-sectional household telephone survey in Yaoundé (Cameroon) in August and September 2021. Using a 24-hour time-use diary and Computer-Assisted Telephone Interviewing (CATI), we captured the time people spent on different activities, including travel activities and modes used for travelling. In addition, we captured information related to the perception of active travel infrastructure and barriers to active travel. The study protocol was approved by the Centre Regional Committee of Ethics for Research on Human Health (Yaoundé) (reference CE No. 2179 CRERSHC/2021). We report the results according to the STROBE guidelines [217].

The study population comprised members of households in Yaoundé. We considered individuals as household members if they regularly shared meals, lived together, and pooled all or part of their monetary or other resources. All adult members in households aged 18+ years who consented to the study were interviewed. We excluded households headed by children under the age of 18 years and potential participants who could not be reached by telephone after three attempts.

Since budget often constrains the sample size of household travel surveys, and there is no consensus on sample size estimation for travel surveys, we considered that a sample size of 1,000 households was acceptable for Yaoundé, which has approximately 4 million inhabitants. With an estimated response rate of 50% for telephone surveys in Africa [218], we aimed to contact a minimum of 2,000 households.

We sampled participants and collected data in collaboration with the National Institute of Statistics (NIS), a Cameroonian government agency. Samples were proportionate to the size of the municipality and selected from each of the seven municipalities in Yaoundé. The sampling frame was based on the Fourth Cameroon Household Survey (EC-ECAM4), conducted in 2015 and the Cameroonian DHS-2018 database. We sampled the phone numbers and addresses of 2,000 households. Research assistants contacted the households by telephone to obtain consent for participation in the survey.

3.2.3.2. Data Collection and survey instruments

Trained research assistants who had previously collected data for other NIS surveys contacted adult family members to obtain their consent. Once the participants consented, the research assistants set a day with the participants to administer the questionnaires by telephone using CATI built on the CSPro 7.4 platform. The NIS has previously used this platform to collect and clean survey data. The data were extracted for further management and analysis in the R statistical software.

Participants provided information on household assets, individual sociodemographic characteristics, and perceived barriers to active travel, as well as completing a 24-hour time-use diary.

Previous-day time-use diaries (Table 3.11) were completed on the day of the appointment. Each diary started at 7 am and covered a full 24-hour period in 30-minute time slots. For each time slot, the participant reported one primary activity they undertook ("Activity" variable). The "Duration" variable captured how many minutes the activity lasted within the 30-minute slot since some activities lasted for less than 30 minutes or were started in one slot and ended in another. The participant also reported their location ("Location" variable) for each time slot, for example, home, work, or travelling. If they were travelling, the mode of travel was reported under the "Mode of travel" variable. All responses were coded into individual codes a priori.

Table 3.11 Example from the time-use diary used in the survey in Yaoundé, Cameroon (2021).

Time	Activity	Duration (minutes)	Location	Mode of Travel	Who with
	1. Sleep 2. Leisure Physical Activity 3. Leisure Screen 4. Self-Care 5. Paid Work/Study 6. Household Chores/Care 7. Travel 8. Other		1. Home 2. Someone's House 3. School/College 4. Workplace 5. Other 6. Travelling	1. Walking 2. Bicycle 3. Private Car 4. Private Motorcycle/Scooter 5. Mototaxi/Boda Boda 6. Public Bus 7. Taxi 8. Train 9. Opep Minibus/Matatu 10. Opep Cars 11. Tuk Tuk 12. Boda Boda (Bicycle) 13. Skateboard/Rollerblade 14. Other	1. On Own 2. Child 3. Other Family Members 4. Friend 5. Work Colleague 6. Other

				15. Not Travelling	
7:00– 7:30					
7:30– 8:00					
…					

3.2.3.3. Variables

The household characteristics were household size (number of persons and continuous), sex of household head (male and female), age of household head (years), education of household head (≤primary, middle, secondary, and ≥high school), occupation of household head (not employed/not applicable, employed, student, and other), and household socioeconomic status (SES).

We assessed household SES using a household wealth index. We composed the wealth index from 15 household asset variables using principal component analyses. The household asset variables were quality of water supply (high, medium, or low), quality of toilet facility (high, medium, or low), quality of cooking facility (high, medium, or low), and own (yes/no) dwelling, electricity, radio, television, landline telephone, computer, refrigerator, watch, mobile phone, bicycle, motorcycle, and car. We used a limited number of variables compared to the DHS [219]. Still, we could adequately represent the wealth index for LMICs as recommended by validity studies using shortened, simplified household asset questionnaires [220, 221]. We ranked the wealth indices into tertiles (poorer, middle, and richer).

Individual demographic and socioeconomic characteristics included age (years), age group (less than 25, 25–34, 35–44, 45–54, and 55+ years), sex (male, female), occupation (not employed/not applicable, employed, student, and other), education (≤primary, middle, secondary, and ≥high school), and marital status (never married, formerly married, living together, and married).

Trip characteristics were trip duration and trip mode. We defined a trip as one travel activity or a block of travel activities occurring over contiguous 30-minute slots; it could comprise multiple stops and changes of transport modes. The transport modes were walking, bicycle, personal motorcycle, motorcycle taxi, personal car, taxi, bus, and minibus (opep). Only one transport mode was reported for each 30-minute slot, and this was the largest vehicle used by the participant during that slot. The trip duration was defined as the total time (minutes) for an entire trip. That resulted from summing the durations of the different legs within a trip. The trip mode was the transport mode used for the most extended duration during the trip.

Individual travel characteristics were aggregates of individual trip characteristics for the survey day. These included the number of trips (continuous and categorical: 0, 1, 2, 3, or 4+); daily travel duration, defined as the sum of all trip durations by an individual (minutes/day); use of active transport (walking/cycling) (yes/no) and time spent in active transport (minutes/day); use of motorised transport (motorcycle, tricycle, car, taxi, mini-bus, and bus (yes/no)) and time spent using motorised transport (minutes/day); and use of public transport (yes/no) and time spent using public transport (minutes/day). Daily time spent in each transport mode was the sum of all the travel durations during the day.

Perceived barriers to active travel were perception of the adequacy of primary, secondary, and neighbourhood roads for walking and cycling (very good, good, fair, poor, and very poor). Participants ranked the importance of key barriers to active travel (safety, infrastructure, convenience, time, and weather) from one through five.

3.2.3.4. Statistical Analysis

We reported the frequencies, means, medians, and interquartile ranges of variables for our summary statistics. We reported the means instead of the medians of most skewed variables to avoid uninformative all zero estimates, which could result from the high zero prevalence in many variables. We reported estimates per capita, where the denominator was all survey participants and per participants who travelled, where the denominator was only participants who reported at least one trip. We weighted our estimates using post-stratification weights. We derived these weights using population age and sex distributions from the 2018 Cameroon Demographic and Health Surveys. We conducted all analyses in R statistical software using the “svryr” package (version 0.3.1), which allows for weighted survey analyses.

3.2.4. Results

3.2.4.1. Characteristics of Survey Households and Participants

We surveyed 1199 households in Yaoundé (the survey response rate was not recorded). The median (IQR) household size was three (1–4) persons. Most (72%) of the households were headed by males; 64% of household heads were employed, and 47% of them had at least a high school education. A third (35%) of the households had access to a vehicle (i.e., at least one household member owning a vehicle) (Table 3.12). Compared to the 2018 Cameroon Demographic and Health Surveys, our survey captured a smaller median household size (3 (1–4) vs 6 (4–8)), the same proportion of households headed by males (72%), and a higher household vehicle ownership (8% vs 5% for bicycles, 12% vs 8% for motorcycles, 21% vs 18% for cars, and 35% vs 25% for any vehicle).

A total of 1334 participants were interviewed; most were males (54%). About half (49%) of the participants were married or living with partners, two-thirds had at least a secondary education, and 55% were employed (Table 3.12). The mean (standard deviation) age of participants was 36 (13) years, with over three-quarters of participants in the <45 years age group.

Table 3.12 Characteristics of households and participants in the 2021 time-use survey in Yaoundé, Cameroon.

Summary of Household Characteristics		Summary of Individual Characteristics		
			Unweighted	Weighted
n	1199	*n*	1334	1334
Household size (median (IQR)	3 (1–4)	Female (%)	505 (38)	616 (46)

Household head is females = Yes (%)	302 (28)
Education of household head (%)	
Primary school or less	130 (12)
JHS/middle school	227 (21)
SHS/secondary school	224 (20)
High school	515 (47)
Occupation of the house heads (%)	
Employed	696 (64)
Student	102 (9)
Not employed or not applicable	119 (11)
Other	179 (16)
Household vehicle ownership	
Any vehicle	415 (35)
Car	256 (21)
Motorcycle	139 (12)
Bicycle	96 (8)
Household Wealth	
Poorer	400 (33)
Middle	400 (33)
Richer	399 (33)

Age (mean (SD))	38 (12)	36 (13)
Age group (%)		
≤24 years	85 (6)	255 (19)
25 to 34 years	523 (39)	491 (37)
35 to 44 years	385 (29)	287 (22)
45 to 54 years	197 (15)	157 (12)
≥55 years	144 (11)	144 (11)
Education (%)		
Primary school or less	164 (12)	172 (13)
JHS/middle school	278 (21)	269 (20)
SHS/secondary school	282 (21)	273 (21)
High school	610 (46)	621 (47)
Marital status (%)		
Never married	458 (34)	561 (42)
Formerly married	127 (10)	126 (9)
Living together	280 (21)	263 (20)
Married	469 (35)	384 (29)
Occupation (%)		
Employed	815 (61)	735 (55)
Student	141 (11)	218 (16)
Not employed	177 (13)	204 (15)
Other	201 (15)	177 (13)
Relationship to head (%)		
Head	1096 (82)	1015 (76)
Spouse	149 (11)	161 (12)
Son or daughter	51 (4)	96 (7)
other	38 (3)	63 (5)
Any vehicle in house = Yes (%)	471 (35)	434 (33)
Cars/motorcycles in house = Yes (%)	424 (32)	388 (29)
Household Wealth		
Poorer	435 (33)	479 (36)
Middle	450 (34)	444 (33)
Richer	449 (34)	411 (31)

3.2.4.2. Trip Characteristics

One thousand three hundred thirty-four (1334) individuals reported a total of 2153 trips. Weighted estimates showed that taxis were the most popular trip mode (46%), followed by walking (27%), car (11%), and motorcycle taxi (10%). Compared to males, females were more likely to use taxis and motorcycle taxis but were less likely to use private cars and motorcycles. Walking shares were similar in both sexes. The mean (IQR) trip duration was 48 (30–60) min and was higher in males compared to females (50 (30–60) vs 45 (30–60) min, $p < 0.001$) (Table 3.13). A high proportion of trips were unimodal, with over 80% of shared taxi and motorcycle trips having no other mode. Only 15% of walking trip stages accompanied different modes (Table 3.14).

Table 3.13 Summary of trips reported in the 2021 time-use survey in Yaoundé, Cameroon

	Both Sexes		Females		Males	
Trip Mode	Share (%) (*n* = 2153)	Mean (IQR) Minutes	Share (%) (*n* = 907)	Mean (IQR) Minutes	Share (%) (*n* = 1245)	Mean (IQR) Minutes
Walk	26.6	41 (30–60)	27.5	40 (30–60)	25.9	43 (30–60)
Bicycle	0.2	36 (30–30)	…	…	0.3	36 (30–30)
Motorcycle	5	42 (30–60)	0.8	49 (20–90)	8	41 (30–60)
Motorcycle taxis	10.3	39 (30–30)	11.8	37 (30–30)	9.2	41 (30–30)
Car	10.6	59 (30–60)	4.8	49 (30–60)	14.8	62 (30–60)
Taxi	45.7	50 (30–60)	54	48 (30–60)	39.7	51 (30–60)
Public bus	0.6	146 (60–210)	0.1	360 (360–360)	1	129 (60–210)
Opep	0.8	55 (30–60)	0.9	30 (30–30)	0.7	78 (30–120)
Other	0.3	52 (30–80)	…	…	0.5	52 (30–80)
Overall	100	48 (30–60)	100	45 (30–60)	100	50 (30–60)

Table 3.14 Characteristics of walking and modes contributing to walking in Yaoundé.

Characteristic	Percentage
Participants (N = 1334)	
% People reporting walking	25%
Walking trip stages (N = 845)	
% Of walking as the main mode	85%
% Of walking accompanying taxi	12%
% Of walking accompanying motorcycle	2%
% Accompanying other modes	1%
Shared taxi trips (N = 999)	
% Accompanied by walking	6%
% Accompanied by motorcycle	2%
% Accompanied by other modes	3%
% Unaccompanied by other modes	89%
Motorcycle taxi trips (N = 207)	
% Accompanied by walking	6%
% Unaccompanied by other modes	83%

3.2.4.3. Individual Travel Behaviour

- Number of Trips

Overall, just above a third (37%) of all participants reported no travel (zero trips). Compared to participants reporting any travel, those reporting no travel were more likely to be females, have a partner, and be from a household with a vehicle or richer households but less likely to be employed (Table 5).

Of the 847 (66%) participants who reported trips, 13%, 48%, 20%, and 19% reported 1, 2, 3, and 4+ trips, respectively. The median (IQR) trips per capita and per participant who reported trips were 2 (0–3) and 2 (2–3), respectively. Males were more likely to report more trips than females, and residents of poorer households were more likely to report more trips than their more affluent counterparts (Table 3.15).

Table 3.15 Trip making and the number of trips by population subgroup

	Made Trip			Number of Trips Made			
	No	Yes	*p*	1 Trip	2 Trips	3 Trips	4+ Trips
n(%)	487 (37)	847 (63)		108 (13)	409 (48)	172 (20)	153 (19)
Female (%)	54	42	0.00	48	46	32	39
Age group (%)			0.00				
≤24 years	25	16		17	17	19	8
25 to 34 years	29	42		41	39	44	46
35 to 44 years	22	21		19	20	18	28
45 to 54 years	11	12		11	12	13	12
≥55 years	12	10		11	12	6	6
Education (%)			0.66				
≤ Primary school	14	12		9	12	13	13
Middle school	20	20		20	20	20	21
Secondary school	21	20		24	22	18	17
≥High school	45	48		46	47	49	49
Marital status (%)			0.32				
Never married	40	43		43	39	49	49
Formerly married	11	9		7	9	6	11
Living together	21	19		15	19	22	16
Married	28	29		35	32	23	24
Occupation (%)			0.00				
Employed	44	62		54	65	58	62
Student	19	15		16	16	15	9
Not employed	18	14		20	9	18	16
Other	19	10		11	9	9	13
Relationship (%)			0.00				
Head	67	81		73	75	90	92
Spouse	19	8		13	12	2	3
Son or daughter	9	6		9	8	5	3

Other	6	4		6	5	3	1
Any vehicle (%)	41	28	0.00	31	29	24	27
Car/motorcycle (%)	36	25	0.00	29	26	22	24
Household Wealth			0.00				
Poorer	27	41		35	37	50	47
Middle	34	33		38	32	30	35
Richer	39	26		28	31	21	18

- Use of Active, Motorised, and Public Transport Modes

Any active travel and active travel exceeding 30 minutes were reported by only 25% and 19% of all participants, respectively. Walking was the main mode of active travel (24.7% of all participants), while cycling was reported by a very small proportion of participants (0.1%). The total active travel rate among participants who reported any form of travelling was 38%. The individual characteristics of participants who reported no active travel were similar to those of participants reporting no travel, except that participants with no active travel were more likely to be employed than participants with any active travel (Table 3.16).

Motorised transport use was reported in over half (56%) of all participants, with 39%, 15%, 10%, and 2% of participants reporting the use of taxis, motorcycles, private cars, and public buses, respectively. Less than 1% of participants reported using minibuses (opeps). Compared to participants who did not report using a motorised vehicle, those who did were more likely to be males, have higher education, and be employed; still, they were less likely to be from wealthier households or households with vehicles (Table 3.16).

Public transport use was reported by 44% of participants. Compared to those who did not use public transport, users were more likely to be younger, more educated, employed and lived in households without vehicles. Participants in poorer households were likelier to report public transport (Table 3.16).

Table 3.16 Travel in different modes by population subgroup in the 2021 time-use survey in Yaoundé, Cameroon.

	Any Active Travel			Active Travel ≥ 30 min			Motorised Transport			Public Transport		
	No	Yes	*p*	No	Yes	*p*	No	Yes	*p*	No	Yes	*p*
n (%)	1001 (75)	333 (25)		1078 (81)	256 (19)		636 (48)	698 (52)		753 (56)	580 (44)	
Female (%)	47	42	0.18	47	42	0.20	52	41	0.00	46	46	0.93
Age group (%)			0.30			0.10			0.00			0.00
≤24 years	19	20		18	22		26	13		23	14	
25 to 34 years	35	42		35	43		30	43		29	48	
35 to 44 years	23	18		22	19		20	23		23	20	
45 to 54 years	12	11		13	9		11	13		13	10	
≥55 years	11	10		12	7		13	9		13	8	
Education (%)		0	0.10			0.67			0.00			0.00

≤ Primary school	12	16		12	15		17	9		16	9	
Middle school	19	23		20	20		21	20		22	18	
Secondary school	21	18		21	18		20	21		20	21	
High school	48	43		46	47		43	50		43	52	
Marital status (%)	0		0.00			0.00			0.12			0.04
Never married	37	57		37	63		45	39		41	44	
Formerly married	10	8		10	6		10	9		9	10	
Living together	22	13		22	11		19	20		18	22	
Married	31	22		31	20		26	31		32	25	
Occupation (%)			0.06			0.06			0.00			0.00
Employed	56	53		56	51		43	66		48	64	
Student	16	19		15	21		21	12		18	14	
Not employed	14	19		14	19		19	12		18	12	
Other	15	10		14	9		16	11		16	10	
Relationship (%)			0.01			0.00			0.00			0.13
Head	74	82		74	83		69	82		73	80	
Spouse	14	5		14	4		15	9		14	10	
Son or daughter	7	7		8	5		9	6		8	6	
Other	4	6		4	8		7	3		6	4	
Any vehicle (%)	36	21	0.00	35	22	0.00	36	30	0.02	45	17	0.00
Car/Motorcycle (%)	33	18	0.00	32	17	0.00	32	27	0.07	41	14	0.00
Household Wealth			0.00			0.00			0.09			0.00
Poorer	30	53		31	56		34	38		31	43	
Middle	35	29		35	27		32	34		31	36	
Richer	35	18		34	17		34	28		38	22	

- Overall Travel Duration and Duration in Active, Motorised, and Public Transport

The mean (lower–upper quartile) daily travel durations per capita and per participant who travelled were 77 (0–120) and 121 (60–150) minutes. Males and participants living in households with no vehicles reported longer travel durations. Participants in poorer households travelled for longer durations (Table 3.17).

Active travel times per capita and per participant who reported travel were 18 (0–0) and 28 (0–45) min, respectively. The active travel time was longer in males, younger participants, and those living in households with no vehicles. Participants in poorer households reported longer durations of active travel (Table 3.17).

Motorised travel durations per capita and per participant who travelled were 56 (0–90) and 88 (30–120) minutes, respectively. Motorised travel time was longer in males, older participants, participants with higher education and employment, and those in households with cars and motorcycles. Participants in middle-wealth households travelled longer in motorised transport (Table 3.17).

Public transport travel duration per capita and per participant who travelled were 43 (0–60) and 67 (0–90) minutes, respectively. Public transport duration was longer among those in households without vehicles. Participants in richer households travelled for a shorter duration on public transport (Table 3.17).

Table 3.17 Daily travel durations in various modes for population subgroups in the 2021 time-use survey in Yaoundé, Cameroon

	All participants				Participants who travelled			
Characteristics	Overall	Active	Motorised	Public	Overall	Active	Motorised	Public
All	77 (0–120)	18 (0–0)	56 (0–90)	43 (0–60)	121 (60–150)	28 (0–45)	88 (30–120)	67 (0–90)
Sex								
Male	88 (0–120)	18 (0–30)	66 (0–90)	44 (0–60)	129 (60–150)	27 (0–40)	96 (40–120)	65 (0–90)
Female	63 (0–90)	16 (0–0)	45 (0–60)	41 (0–60)	110 (60–150)	29 (0–60)	78 (30–120)	71 (10–120)
Age group (years)								
≤24 years	49 (0–80)	18 (0–30)	28 (0–60)	27 (0–60)	95 (60–120)	35 (0–60)	55 (0–60)	51 (0–60)
25 to 34 years	87 (0–120)	19 (0–30)	64 (0–90)	54 (0–90)	121 (60–150)	27 (0–40)	90 (30–120)	75 (30–120)
35 to 44 years	84 (0–120)	12 (0–0)	68 (0–100)	47 (0–60)	135 (60–150)	20 (0–30)	109 (60–120)	75 (0–120)
45 to 54 years	82 (0–120)	18 (0–0)	60 (0–90)	36 (0–60)	126 (60–150)	27 (0–30)	93 (50–120)	56 (0–90)
≥55 years	73 (0–120)	21 (0–0)	49 (0–60)	33 (0–60)	127 (60–150)	35 (0–60)	85 (0–120)	58 (0–90)
Education								
≤Primary school	74 (0–120)	30 (0–30)	41 (0–60)	32 (0–60)	125 (60–150)	51 (0–60)	70 (0–90)	54 (0–90)
Middle school	77 (0–120)	22 (0–30)	52 (0–90)	39 (0–60)	123 (60–150)	34 (0–60)	83 (30–120)	62 (0–100)
Secondary school	70 (0–120)	16 (0–0)	50 (0–60)	37 (0–60)	111 (60–150)	26 (0–30)	79 (30–120)	59 (0–90)
High school	80 (0–120)	13 (0–0)	65 (0–90)	50 (0–90)	124 (60–150)	20 (0–30)	99 (60–120)	77 (0–105)
Occupation								
Employed	82 (0–120)	16 (0–0)	63 (0–90)	47 (0–85)	116 (60–150)	23 (0–30)	89 (45–120)	67 (0–100)
Student	62 (0–90)	20 (0–30)	39 (0–60)	38 (0–60)	110 (60–120)	36 (0–60)	69 (0–90)	66 (0–90)
Not employed	73 (0–120)	22 (0–30)	47 (0–90)	37 (0–60)	129 (60–180)	39 (0–60)	83 (0–120)	65 (0–120)
Other	76 (0–120)	14 (0–0)	59 (0–90)	37 (0–60)	156 (60–180)	29 (0–30)	121 (60–150)	76 (0–120)
Marital status								
Never married	77 (0–120)	23 (0–30)	51 (0–80)	45 (0–60)	117 (60–150)	36 (0–60)	77 (0–120)	68 (0–90)
Formerly married	67 (0–120)	18 (0–0)	48 (0–90)	39 (0–60)	117 (60–150)	31 (0–60)	83 (40–120)	68 (30–105)
Living together	76 (0–120)	13 (0–0)	61 (0–90)	48 (0–90)	126 (60–150)	21 (0–30)	100 (60–135)	80 (30–120)
Married	80 (0–120)	12 (0–0)	64 (0–90)	38 (0–60)	124 (60–150)	19 (0–20)	99 (60–120)	58 (0–90)
Vehicle in house								
No vehicle	79 (0–120)	22 (0–30)	55 (0–90)	52 (0–90)	117 (60–150)	32 (0–60)	80 (30–120)	76 (30–120)
Any vehicle	71 (0–120)	9 (0–0)	59 (0–90)	24 (0–0)	131 (60–160)	17 (0–30)	109 (60–150)	45 (0–60)
Car/Motorcycle	72 (0–120)	7 (0–0)	62 (0–90)	23 (0–0)	132 (60–160)	13 (0–15)	113 (60–150)	43 (0–60)
Household Wealth								
Poorer	85 (0–120)	27 (0–60)	55 (0–90)	50 (0–80)	117 (60–150)	38 (0–60)	76 (10–120)	69 (0–100)

Middle	79 (0–120)	15 (0–0)	61 (0–90)	47 (0–90)	126 (60–150)	24 (0–30)	97 (60–120)	75 (0–120)
Richer	65 (0–90)	9 (0–0)	52 (0–90)	30 (0–45)	121 (60–150)	17 (0–15)	97 (60–120)	55 (0–90)

3.2.4.4. Barriers to active travel

- Perception of active travel infrastructure

Figure 3.6 shows the perception of the suitability of different road categories for walking and cycling. For walking, over a third of participants perceived primary roads as poorly or very poorly designed for walking. They perceived smaller roads as the more suitable ones, with almost no participants perceiving that their neighbourhoods had poor walking infrastructure. These perceptions were similar in both males and females, but compared to those who reported no active travel, those who reported perceived the roads to be in better condition. The perceptions were in the opposite direction for cycling, with over a quarter of participants perceiving primary roads as poorly or very poorly designed for cycling. Participants perceived smaller roads as less suitable for cycling, with about 60% perceiving that their neighbourhoods had poor or very poor cycling infrastructure. The perceptions of the state of roads for cycling were similar in both males and females, but compared to those who reported no active travel, those who reported active travel perceived roads as less suitable for cycling.

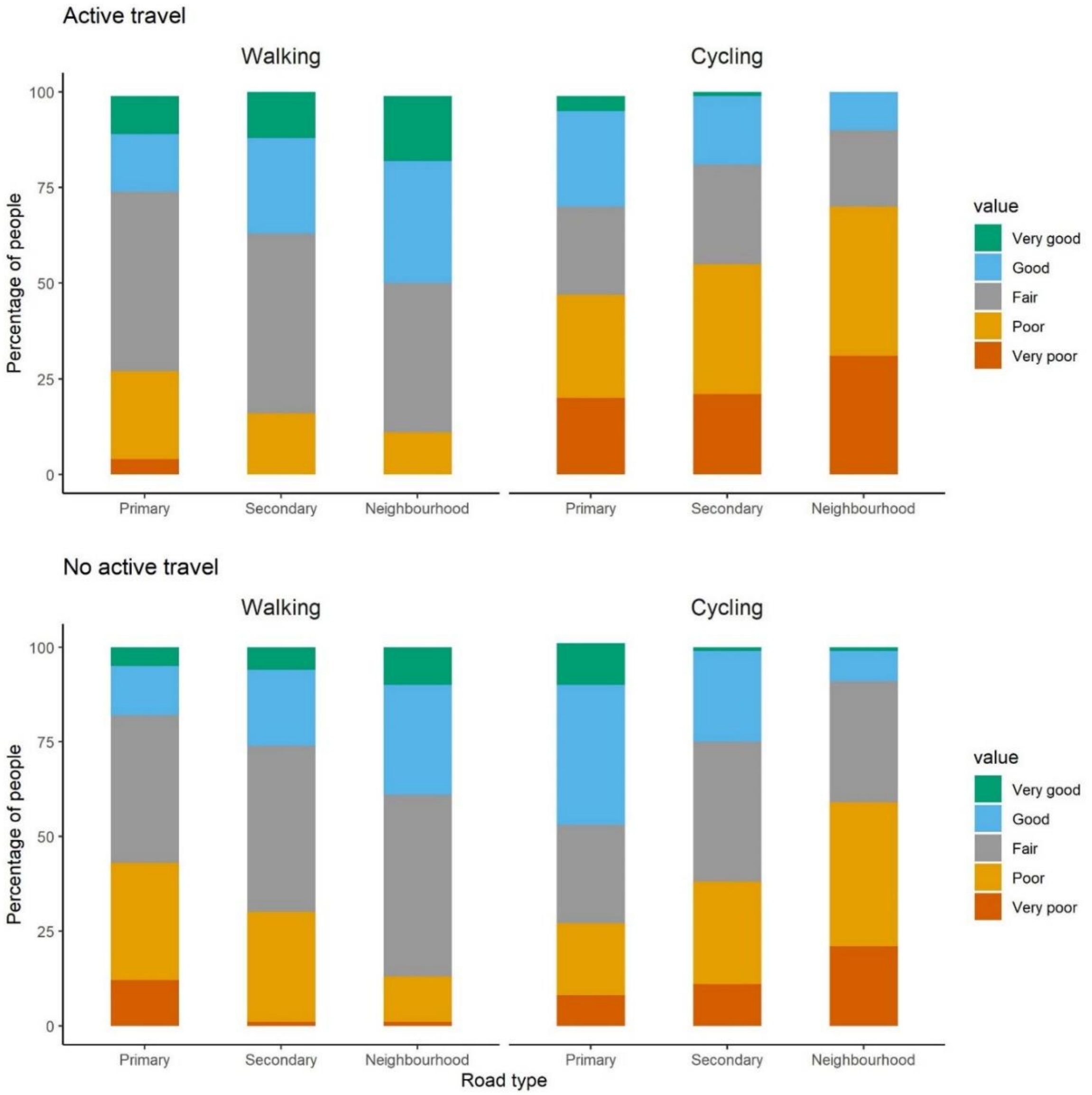


Figure 3.6 Perception of the suitability of different road types for walking and cycling in Yaoundé, Cameroon (2021).

- Perception of Key Barriers to Active Travel

Figure 3.7 shows the perception of major barriers to walking and cycling by sex and active travel status. For walking, participants ranked road injury safety as the primary concern among the key barriers to walking, with almost a quarter of all participants ranking safety concerns in the first position. Females were marginally more concerned about road injury safety for walking than males, and the patterns were similar for those who reported active travel and those who did not. The ranking of barriers was similar for cycling, albeit there was more concern about the cycling infrastructure. The judgment of cycling in a context with very low cycling levels might be biased.

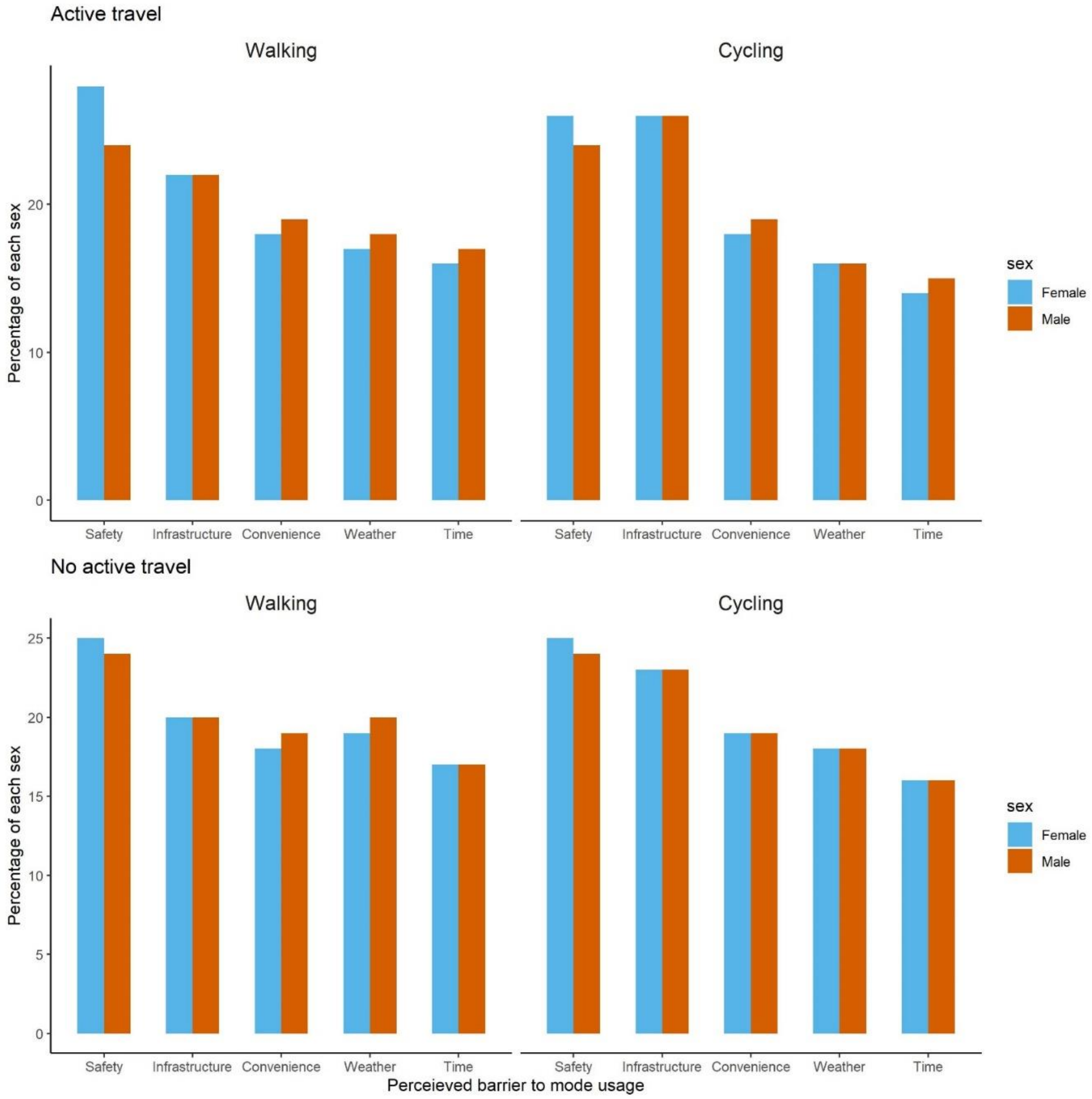


Figure 3.7 Ranking of key barriers to walking and cycling in Yaoundé, Cameroon (2021)

3.2.5. Discussion of case study findings

This study is the only second detailed account of travel behaviour in a Cameroonian city in nearly two decades. Two-thirds of all participants reported at least one trip per day. The main trip modes were taxi (46%), walking (27%), private cars (11%), and motorcycle taxis (10%), with only a quarter of the participants reporting active travel (almost exclusively walking) on that day. The daily travel time per capita was 77 (0–120) minutes, and the active travel time was 28 (0–45) minutes in participants who reported trips.

Females were less likely to report trips, and when they did, they reported fewer and shorter-duration trips. Their trips were more likely to be made by taxis and motorcycle taxis but less likely by private cars and motorcycles. Overall, females were less likely to use motorised transport, and there was no gender difference in active and public transport use. Males reported longer daily travel durations overall, but their daily travel durations were shorter when we looked at active and public transport.

Participants in richer households were likelier than those in poorer households to report overall travel and travel in active, motorised, and public transport modes. They also reported more trips and longer daily travel durations in all modes except motorised ones. Participants in vehicle-owning households were less likely to report travel, even in motorised modes.

Safety from road traffic injuries was the most common concern for walking and cycling. There were opposite trajectories for the perception of the state of the road for walking vs cycling, with participants perceiving that the larger roads were less suitable for walking but more suitable for cycling. In comparison, smaller roads were more suitable for walking but less suitable for cycling.

The study had limitations. First, the lockdown of cities and the restriction of movements and social interactions to control the COVID-19 pandemic limited peoples' activities and the use of some transport modes. This could affect the estimation of routine trips and the use of modes, particularly for public transport modes. Although we allowed an ample buffer time of one-year post-lockdown before launching our data collection, the ongoing pandemic likely continued to affect people's behaviour. Second, despite ensuring the maximum sample size allowed by budget, our sample size was relatively small and could misrepresent population estimates. Our sample had more males and fewer younger participants than the representative 2018 demographic and health surveys. After weighting our survey with the demographic and health survey estimates, our sample still had higher vehicle ownership. Third, the time-use design (compared to a traditional travel survey) likely impacted how trips were captured. The time-use diary prioritised one among multiple activities within the same time slots, and some activities may be more interesting for the participants to report to the detriment of travel activities. It is also more difficult to differentiate trips in the time-use surveys on whether, for instance, multiple travel activities are legs of the same trips or if they are independent trips. Furthermore, we used 30-minute slots in our diary instead of the 10–15-minute slots commonly used in other surveys; this coarse time resolution could miss short trips and overestimate trip duration. Short walking trips (particularly walking to access other modes) are likely to be missed in this coarse resolution as participants are more likely to prioritise other modes. Third, we only captured trip frequency and duration but no trip distance, despite having no prior knowledge of travel distances in the city. As such, our study offers little information about travel speeds and road traffic congestion in the city. Finally, the survey was relatively lengthy and relied on recalling a large amount of information; thus, it was prone to soft refusal and recall bias.

Our findings can be interpreted in light of the current literature. The finding that only one-quarter of all main trip modes were on foot contradicts our expectation of a high proportion of walking trips since high walking rates have been reported from travel surveys in some African cities, including those in Cameroon. For example, studies with varying definitions of trips report that walking rates can be as high as 70% in cities such as Douala (Cameroon), Conakry (Guinea), Dakar (Senegal), Niamey (Niger), Addis-Ababa (Ethiopia), Lusaka (Zambia), Kampala (Uganda), and Kisumu (Kenya) [49–51]. The only analysis for time-use survey data we are aware of (our analysis of the 2009 Accra time-use survey) showed high walking trip rates of 58% [222]. The observed low walking trip rates could result from under-reporting trip stage modes, especially walking as a component of public transport trips.

One indication of possible under-reporting of walking comes from the gap between walking and public transport trip rates—public transport trips almost double walking trips. One would expect most residents to walk to public transport in cities with road networks like Yaoundé. Thus, the walking rate should be closer to or higher than the public transport rate. This analysis shows that almost 90% of shared taxi trips do not have any accompanying mode. If all shared taxi trips were to be accompanied by a walking stage, stage mode shares would increase from 22% to 44%. Even when motorcycle taxis (which tend to provide doorstep transport services) are high, walking rates might be expected to be higher than the rates we observed. For example, in Ouagadougou (Burkina Faso), 39% of trips were on motorcycles, and 42% were still on foot [50]. As hinted earlier, the 30-minute time slot in the time-use survey could encourage the under-reporting of short walking trips. Nonetheless, low walking rates have been reported in African cities, with about one-third of daily trips being walking in Nairobi and Mombasa (Kenya) [191, 223] and one-quarter in Cape Town (South Africa) [49]. Outside of Africa, this walking stage mode share in Yaoundé is similar to 21% in London, United Kingdom [224] but higher than 14% in Canberra, Australia [225].

Active travel is the second most important source of physical activity after work-related physical activity in LMICs [206]. With relatively low levels of daily walking and practically non-existent cycling, only one-fifth of the population travels actively for ≥30 min daily. Low levels of physical activity have already been highlighted as a problem in Cameroon, with one-third of adults not meeting the recommended levels of physical activity. Suggested interventions by participants for active travel included improving active transport infrastructure, making active transport safer from road traffic injuries, and making it more convenient to use. These should serve as a starting point for improving physical activity in the transport sector in Cameroon since the sector has not previously expressed physical activity goals in its policies [226].

The high share of public transport modes (mainly shared and motorcycle taxis) is a logical observation since walking is low in a context with low use of private vehicles. Large buses are nearly absent (less than 2%). The taxi trip mode share of 46% is the highest reported in Africa, and the second is Abidjan (Côte d'Ivoire) with only 30%; trip mode shares are usually around 10% in most cities, including Douala [37]. The average motorcycle share in urban Africa is 12% and goes up to 58% [37]. The 9% for motorcycle taxis observed in Yaoundé is similar to the reported average motorcycle trip mode share in urban Africa. Other public transport modes such as buses and minibuses that contribute an average of 7 and 30% of trips in African cities are nearly absent in Yaoundé. The predominant modes in Yaoundé have important implications on the transport indicator. The shared taxis have low-carrying capacities; although higher than private cars, it adds to the problem of road congestion. The motorcycles are suitable for navigating smaller neighbourhood roads but are associated with increased road traffic injuries.

We note a longer daily travel duration of 83 min/capita/day compared to the global average of 60 min/capita/day [227]. While the time-use survey could overestimate the time, travel duration in African cities is generally considered long and unpredictable. This is partly associated with the congestion patterns for motorised trips, the unavoidable long walks, and poor land-use planning. The general tendency of car-centric transport planning is to decrease travel times. Tranter (2010) [228] argues that access and not speed should be crucial and that travelling faster causes more health harms beyond road traffic fatalities and should not be the development goal.

Our finding of gender differences in mobility patterns is consistent with results from other African studies. Females make fewer trips and are less likely to travel by car, motorbike (as the driver), and bicycle (as the operator) but more likely to travel by walking and paratransit. Some perceived barriers to female travel have included male violence, patriarchal beliefs that travelling can increase promiscuity, and household responsibilities [48, 229]. For example, Salon and Gulyani (2010) [56] showed that women in Nairobi’s slums were less likely to use motorised modes, even after accounting for differences between men and women in childcare responsibilities and education levels. The gender disparity in travel calls for gender-responsive urban design interventions to support active travel.

In Yaoundé, lower economic households were more likely to travel and use different modes. That contrasts with findings from multiple studies summarised in our recent systematic review [48]. The review looked at socioeconomic inequities in travel behaviour in Africa and found that lower-income households tend to live peripherally and face more challenges in travelling. Although evidence from the review is not conclusive in most instances, it shows some limited evidence that lower-income households are less likely to travel and more likely to make fewer trips. It also indicates limited and mixed evidence that total travel time differed by socioeconomic status. While high income might increase opportunities for travelling, as people become wealthier, they might relocate to places where less travel is needed.

In conclusion, we have used a time-use survey to detail the main travel patterns and barriers to active travel in Yaoundé, Cameroon, as one example of the many African cities that lack a description of their travel behaviours. Our study highlights low walking and high use of shared and motorcycle taxis in Yaoundé. It also shows gender and socioeconomic inequity in mobility, illustrated by the more downward mobility and higher use of “low-class” modes in females and by higher trip frequency and durations in the poor. Safety from road traffic injuries is the most common concern for walking and cycling. These findings suggest that African urban transport authorities must consider interventions that improve active mobility and gender equity in mobility, especially road safety interventions and public transport development. Good public transport improvement will also cater for the needs of females and poorer residents who rely on this mode of transportation. The COVID-19 pandemic, the relatively small survey sample size, and the lengthy recall diary might have biased our observations from a time-use survey. A representative travel survey is needed to triangulate the current findings in this setting. High-quality data from well-designed surveys are necessary to describe African urban travel behaviours accurately.

3.3. Case study 3: A comparison of time-use and travel diaries in the assessment of travel behaviour in Accra, Ghana

3.3.1. Abstract

Travel behaviour explorations from time-use and travel-diary surveys highlight the need to complement analyses with data from either source. To understand the influence of data sources on estimates of travel behaviour, we conducted a travel diary survey in 2020/2021 and extracted travel information from the 2009 national time use survey in Accra (Ghana). We described and compared travel behaviour from these two surveys. We found that two-thirds of the 1159 participants in the travel survey reported trips; the mean number (IQR) of trips per capita was 1.4 (0-2); trip duration was 37 (10-40) minutes and daily travel time per capita was 51 (0-70) minutes. The main trip modes were walking (65%), and trotro (minibus) (17%), and the main trip purposes were work (12%) and services (30%). In comparison, the time-use survey reported similar trip duration and predominant trip modes and purposes but higher trip rates (84%), trips per capita (3.1 (2-4)), and daily travel durations (101 (30-130) minutes). Bicycle and motorcycle trips grew from less than half to 1%, paralleling household ownership of bi/motorcycles. Females were less likely to report trips and longer travel durations in both surveys. These findings highlight patterns of high walking and informal public transport use and the growing use of motorcycles. Travel diary and time use surveys report similar distributions of trip modes shares, durations and purposes but lower trip rates, number of trips and daily travel durations in the travel diary. However, the COVID-19 travel restrictions and the time lapse between surveys might have accentuated the observed differences.

3.3.2. Background

Differences in travel behaviour estimates from travel diaries and time use surveys have been associated with methodological and technical variations [230]. For example, unlike in travel diary surveys, where trips are more easily identified, tracing trips in time-use data can lead to errors in trip identification. Kimbrough (2019) [231] outlines practical approaches to reduce errors in measuring commuting in time-use surveys by tracing trips from start to end and excluding stops greater than 30 minutes. Some researchers argue that the approach to capture all activities with a 10-minute resolution in the time-use survey will likely remind respondents of the trips they may have failed to report in the travel survey [197]. Another cause of survey differences is that a substantial share of respondents exhibit "soft refusal" by incorrectly claiming not to have left the house [207]. "Soft refusal" and other errors could affect time-use surveys differently, given the length of time-use questionnaires. In addition, some of the differences in survey estimates could be context-dependent, given that societies shape peoples' behaviours. These differences notwithstanding, there is limited knowledge of how estimates from different data sources compare in low- and middle-income settings.

This study aimed to compare the estimates of travel behaviour characteristics from time use and travel diary surveys in Accra, Ghana. The study addressed three specific objectives. Firstly, we described the household characteristics and individual travel behaviours such as trip making, travel time budget and the number of trips from a travel diary and a time use survey. Secondly, we evaluated the correlation between travel behaviour characteristics and individual demographic and socio-economic characteristics such as age, gender, education, and occupation in each survey. The third objective was to compare travel behaviour characteristics and correlations between the surveys.

Accra is the capital of Ghana. Accra is one of the fastest urbanizing cities in Africa, with an annual population growth rate of around 2% since the mid-2000s [232], with a daily influx of 2.5 million business commuters [233]. Accra usually represents a broader area of 12 districts. Still, the city of Accra refers only to the Accra Metropolitan District, the central business district whose administrative boundaries and hence, its population have continually been redefined due to political restructuring. Table 3.18 summarises relevant characteristics of the city of Accra, highlighting changes between 2009 and 2021, with growth in population and GDP per capita and the significant COVID-19 pandemic in 2021.

Table 3.18 Characteristics of the City of Accra in 2009 and 2021

City Characteristics	2009	2021
Population	1,665,086 [234]	2,052,341 [235]
Pop density (residents/Km^2)	8,325	10261
GDP per Capita (USD) [206]	[1234]	$3,388 (2019) [1848] [235]
Vehicles registered (‘000)	710	890 [236]
Significant event	…	COVID-19 lockdown and transport restrictions in 2020

Like most cities in the world, Accra (Figure 3.8) suffered the effect of the COVID-19 pandemic that led to lockdowns and travel restrictions, mainly in 2020/2021. Early in the pandemic, many governments instituted restrictions on the movements of persons and goods to reduce the spread of the SARS-CoV-2 (COVID-19) virus. The Government of Ghana implemented a partial lockdown on March 30, 2020, in its two most populous cities, Accra and Kumasi, which security agencies enforced. A stay-at-home order applied to almost all people in the two cities and most activities. Exceptions included individuals providing or accessing food, water, beverages, public toilets and baths, health services, electricity, banking, and those in key institutions, such as the media, Members of the Executive, the Legislature, and the Judiciary. The Government lifted the lockdown after the third week of its implementation despite rising numbers of new cases of COVID-19. Movement of people continued to be affected after the lifting of the lockdown in Ghana, as restrictions on gatherings continued, and people were only allowed essential activities.

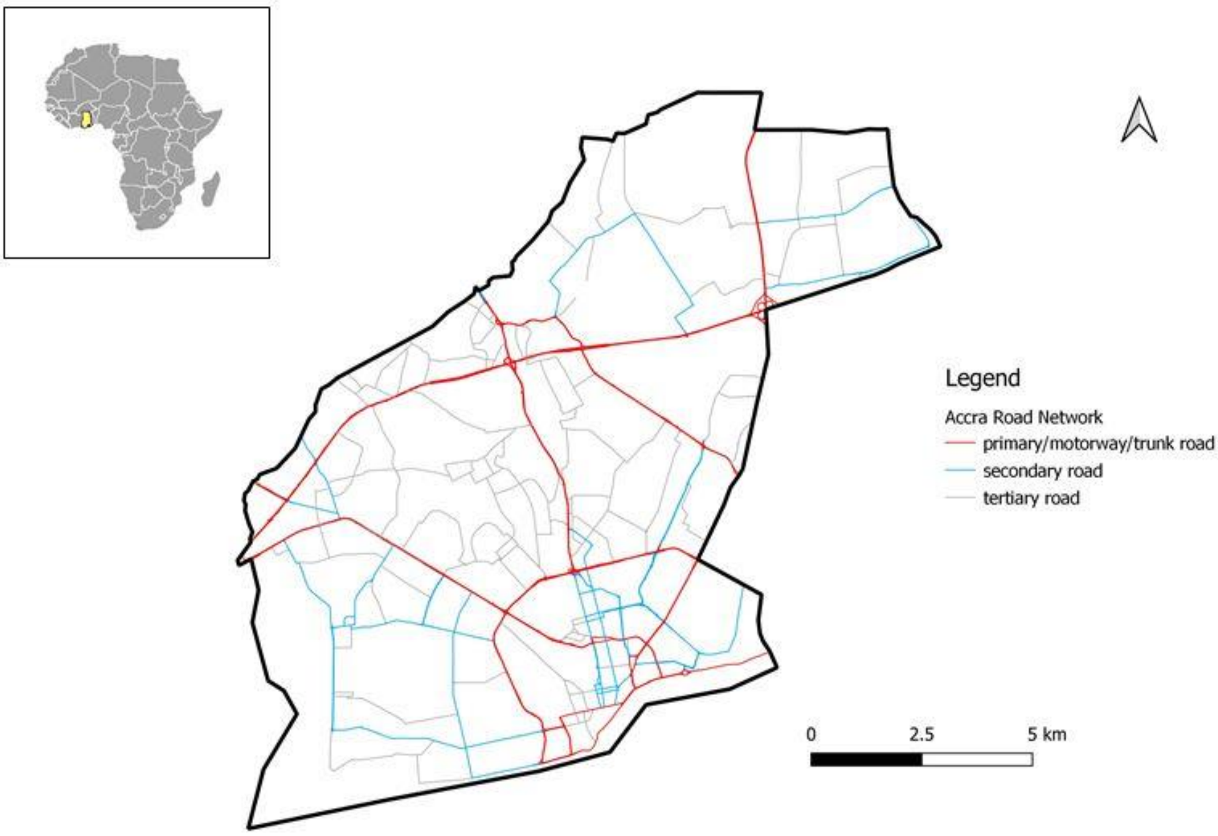


Figure 3.8 Road network of Accra, Ghana (drawn from OpenStreetMap)

3.3.3. Methods

3.3.3.1. Study design and data

We conducted a cross-sectional household travel survey to capture travel behaviour characteristics in Accra, Ghana. We collected data through face-to-face interviews from May 2020 to April 2021. We also extracted travel information from a 2009 national time use survey conducted by the Ghana Statistical Service. We analysed and compared travel behaviour characteristics from the travel and time use surveys. Our comparison focused on differences in trip rates, use of transport modes and correlates of travel behaviour characteristics from the two surveys. We reported the study following the STROBE guidelines [217]. The Ethics Committees for the Humanities (ECH), University of Ghana (ECH 036/19-20) approved this study protocol.

We used two datasets in this study: a 2020 - 2021 travel diary survey collected purposely for this study and a 2009 national time use survey compiled by the Ghana Statistical Service (Table 3.19). We used the time use data because estimates of travel behaviour characteristics from the survey have not been previously reported in the literature and provided an alternative lens for understanding travel behaviour characteristics captured around the time of a pandemic.

- Travel diary survey

We conducted a cross-sectional household-based travel diary survey in the urban areas of Accra, with data collection from May 2020 to April 2021. The survey sample selection was designed to estimate Accra's travel indicators. We used a two-stage stratified sampling design to select participants for the survey. At the first sampling stage, we selected 47 enumeration areas based on the 2010 Population and Housing Census frame to form the primary sampling units. The primary sampling units were allocated into the various districts in Accra using probability proportional to population size. We systematically selected 10 to 15 households in the PSUs in the second sampling stage to form the secondary sampling units. All eligible individuals in the selected households who were available for interviews were surveyed. Survey respondents were consenting household members aged five years and above. A household member was anyone who usually lived in the household, including visitors who had spent the previous night in the household. Eligible household members who were absent after three visits to the household during the interview period were not interviewed and thus were not included in the survey. Data collection for the travel survey was done around the global COVID-19 pandemic. The duration of data collection was protracted because of the lockdown and travel restrictions amidst the pandemic.

We used a face-to-face interviewer-led approach for our data collection. Interviewers used structured household and individual questionnaires to capture household and individual travel and trip characteristics. Household information was collected from household heads or proxies who were adult (18 years+) members with detailed knowledge about the household. Household questions covered household size, household assets and vehicle ownership. Individual household members and their proxies answered individual questionnaires that covered sociodemographic characteristics and trip information, including trip number, duration, mode and purpose.

- Time use survey

The 2009 national time use survey, conducted by the Ghana Statistical Service, collected data on daily activities from members of selected households aged ten years and above [237]. Households were selected through a two-stage stratified, clustered, systematic sampling representative at national, regional, and urban/rural levels. Survey clusters (the enumeration areas) were based on the 2000 household population census, and the strata were the districts and regions. In this analysis, we selected all enumeration areas corresponding to urban Accra. The survey captured five activities per one-hour slot on a 24-hour grid. Activities included house chores, work and travel. Participants also reported transport modes for corresponding travel activities.

Table 3.19 Characteristics of the 2009 time use and the 2021 travel surveys in Accra, Ghana

Characteristics	Time use (2009)	Travel diary (2020 - 2021)
Data collection	Face-to-face interview	Face-to-face interview
Period under review	From June 2009 - August 2009.	From May 2020 – April 2021. Intermittent due to COVID-19 lockdowns and travel restrictions

Number of interviews per household	All household members aged ten years and above	All household members aged five years and above
Respondent sample size	910 respondents in 402 households	1159 respondents in 602 households
Type of questionnaire	Activities agenda filled by the interviewer	Questionnaires filled out by the interviewer
Unit of time	15 minutes interval (e.g. 14h00 to 14h15: activity)	Continuous time (e.g. Trip from 14h13 to 14h18)
Activity	Open description of activities which motivated trips	Reasons for travel are pre-coded within a list of types of activities
Geography	Poor geographical indications	Precise locations
Mode of transport	Mode of transport included for travel activities	Descriptions of various means of transport used successively
Day of interview	One day is chosen at random by the interviewer	Trips made by the respondent in the last 24 hours preceding the survey

3.3.3.2. Variables

Variables of interest included household, individual and trip characteristics. Household characteristics included household size, sociodemographic characteristics of the household heads and household vehicle ownership. Individual characteristics included sociodemographic characteristics, including age and age group in years, sex, education and occupation. Trip characteristics included the number of individual trips, trip modes, duration, and trip purposes.

3.3.3.3. Statistical analysis

For our exploratory analysis, we used a combination of summary statistics and plots to check for missingness, normality, zero inflation, and near-zero variance in data variables. We log-transformed non-normal outcome variables, regrouped variables with near-zero variance, and excluded observations with missing outcome data points from the analysis when necessary. We summarised household and individual characteristics by survey type. We also summarised travel behaviour characteristics by age group, sex, and survey type. Specifically, we reported a combination of means and lower and upper quartiles for skewed variables with high-zero frequency to avoid all estimates being zero and uninformative.

We used a two-part regression analysis for our explanatory analysis to determine factors associated with trip-making and the individual daily travel duration. The first part of the model comprised a logistic regression model that evaluated the correlates of no travel. In the second part, we used a linear regression model to assess the correlates of log-transformed individual daily travel durations.

3.3.4. Results

3.3.4.1. Characteristics of households and participants

We surveyed 602 households and 1159 participants in the 2020-2021 travel survey. Over 60% of the study participants were females. Females headed a little over a third of households (38%), and 50% of all household heads had completed at least secondary education. Fourteen per cent of households had at least one bicycle, 5% had motorcycles, and 12% had cars. Participants' mean (standard deviation) age was 29 (18) years, and 15% reported no occupation. Most of the household characteristics in 2021 were similar to those in 2009 (Table 3.20). Differences included a higher proportion of females (53% vs 61%), household bicycle (6% vs 14%) and motorcycle (1% to 5%) ownership in 2021. In addition, participants were about four years younger and marginally less educated in 2021.

Table 3.20 Characteristics of households and participants surveyed in the 2009 Time use and 2021 Travel diary survey in Accra, Ghana

Characteristics	2009 Time use survey	2020 - 2021 Travel survey
Households (n)	402	602
Household size (median [IQR])	3 [3]	3 [3]
Household headed by females = Yes (%)	33	38
Age of household head mean [SD]	43 [15]	45 [14]
House head's education ≥ secondary education (%)	49	50
Households vehicle owned (% (number per 100))		
Bicycles	11 (NA)	14 (18)
Motorcycles	1 (NA)	5 (6)
Cars	13 (NA)	12 (14)
Individuals (n)	910	1159
Sex = female (%)	53	61
Age in years (mean [SD])	32 [17]	29 [18]
Age groups in years (%)		
05-14	14	26
15-24	25	22
25-34	23	18
35-44	15	15
44-54	10	9
55+	13	11
Education ≥ secondary education (%)	40	38
Occupation = No occupation (%)	8	15
Access to any vehicle = Yes (%)	24	21
Access to motorised vehicle = Yes (%)	13	15

3.3.4.2. Travel characteristics

- Trips

Nearly a third (34%) of all participants in the travel diary reported no trip on the reference survey day. We recorded a total of 1591 trips, resulting in a mean number (IQR) of trips per capita and per participant who reported trips of 1.4 (0-2) and 2.2 (2-2), respectively. Of the participants who reported trips, 65% reported only one trip, and 24%, 7%, and 2% reported two, three, and four trips, respectively, with the same distribution of trip frequency across sex and age groups.

Fewer participants (16%) reported no trip in the time-use survey. For the 2830 trips recorded, the number of trips per capita and per participant who reported trips was 3.1 (2-4) and 3.7 (2-4), respectively. Of the participants who reported trips, only 5% reported one trip; 38%, 15%, and 18% reported two, three, and four trips, respectively, with the same distribution of trip frequency across sex and age groups.

Participants reporting no trip in the travel diary were likelier to have lower than secondary education and no occupation. In the time-use survey, those who reported no trip were more likely to be females, older participants above 45 years, and those with less than secondary education (Table 3.21).

Table 3.21 Characteristics of participants reporting trips compared to those reporting no trip in the 2009 Time use survey and 2021 Travel diary survey in Accra, Ghana

	2009 Time Use Survey		2020 - 2021 Travel Survey	
	Trip (775)	No trip (135)	Trip (731)	No Trip (428)
Sex = female (%)	386 (50)	99 (73)	442 (60.5)	265 (62)
Age in years (mean [SD])	32 (16)	38.00 (25)	29 (17)	28 (20)
Age groups in years (%)				
05-14	111 (14)	18 (13)	158 (22)	138 (32)
15-24	205 (27)	24 (18)	171 (23)	88 (21)
25-34	180 (23)	29 (22)	150 (21)	59 (14)
35-44	119 (15)	19 (14)	123 (17)	49 (11)
44-54	73 (9)	14 (10)	64 (9)	37 (9)
55+	87 (11)	31 (23)	65 (9)	57 (13)
Education ≥ secondary education (%)	301 (42)	32 (27)	281 (40)	135 (33)
Occupation = No occupation (%)	61 (8)	9 (8)	91 (12)	84 (20)
Access to any vehicle = Yes (%)	189 (24)	30 (22)	129 (22)	49 (17)
Access to motorised vehicle = Yes (%)	102 (13)	17 (12)	96 (17)	34 (12)

- Travel times

Table 3.22 summarises the daily travel times of participants who reported trips by their socio-demographic characteristics. The mean (lower quartile – upper quartile) trip duration was 37 (10-40) minutes in the travel diary survey and 33 (10-45) minutes in the time use survey. The daily travel time per capita in the travel survey was half that of the time use survey (51 (0-70) vs 101 (30-130) minutes). The overall daily travel times were far higher in the time use survey. In both surveys, travel times were higher in adults in the 25-44 age groups, those with at least a secondary education, and those living in households with vehicles. Participants with no occupation travelled longer in the time-use but shorter times in the travel surveys.

Table 3.22 Mean daily travel times of different socioeconomic groups in the 2009 Time use and 2021 Travel diary surveys in Accra, Ghana.

	Mean daily travel times (in minutes)	
Individual characteristics	2009 Time Use Survey	2020 - 2021 Travel Survey
Overall	119 (50-145)	80 (27-97)
Females	113(50-135)	81(20-95)
Males	125(50-150)	79(30-103)
05-14 years	79(45-100)	53(20-60)
15-24 years	109(50-135)	77(28-90)
25-34 years	152(50-171)	96(35-108)
35-44 years	136(50-168)	101(30-134)
45-54 years	114(55-145)	85(38-126)
55+ years	105(42-134)	76(20-110)
Below secondary education	114(45-135)	79(23-90)
Secondary education and above	131(59-165)	84(30-110)
No occupation	148(50-180)	64(20-85)
Named occupation	116(50-140)	83(30-100)
No access to a vehicle in household	117(50-140)	85(30-100)
Access to any vehicle in household	126(45-160)	95(30-135)
Access to a motorised vehicle in household	141(45-165)	102(30-146)

- Trip modes

Both surveys' predominant trip modes were walking and trotro (Table 3.23). Higher walking, bicycle, motorcycle, and taxi shares but lower trotro and car shares were reported in the 2020/2021 travel diary compared to the 2009 time use survey. Females were more likely to walk and use a trotro in both surveys. They walked for longer durations but used a trotro for shorter durations in both surveys. On the other hand, males were more likely to cycle and drive in both surveys. The use of bicycles and motorcycles paralleled the increased access to these modes between 2009 and 2021.

- Trip purposes

The travel diary recorded 39% of return-to-home trips, whereas the time use survey recorded no trip in the return-to-home category. The proportions of commute trips for work, school and recreation in the time use were almost double those of the travel survey, suggesting that only outgoing trips were reported for those categories in the travel survey. Proportions of trips for these purposes in the time use almost doubled when return-to-home was excluded from the travel survey (work = 24%, school = 9%, and recreation = 20%). Work commute time was almost double the trip times for other purposes in both surveys. More males commuted for work and longer durations than females in both surveys, except in the travel survey, where females' work commute was more prolonged. Commute to school was similar for both sexes in both surveys.

Table 3.23 Share and trip duration for trips by modes, purposes, and gender in the 2009 Time use and 2021 Travel diary surveys in Accra, Ghana.

	2009 Time use						2020 - 2021 Travel survey					
	Both sexes		Females		Males		Both sexes		Females		Males	
	% share (N=2830)	Mean trip time (IQR)	% share (N=1302)	Mean trip time (IQR)	% share (N=1528)	Mean trip time (IQR)	% share (N=1591)	Mean trip time (IQR)	% share (N=937)	Mean trip time (IQR)	Share (%) (N=654)	Mean trip time (IQR)
Trip mode												
Walk	58.3	21(10-30)	60.6	24(10-30)	56.4	19(8-30)	64.9	29(10-30)	68.1	32(7-30)	60.4	26(10-30)
Bicycle	0.5	19(5-30)	0.1	5(5-5)	0.8	20(5-30)	1.8	28(7-25)	0.1	20(20-20)	4.3	28(7-25)
Motorcycle	..	..	..	..	..	..	1.4	36(14-38)	0.3	23(18-27)	3.1	38(12-40)
Tricycle	..	..	..	..	..	..	0.1	10(10-10)	0.1	10(10-10)		
Car	8.4	38(15-60)	6	40(15-60)	10.5	37(18-60)	5.8	38(18-45)	2.7	36(20-50)	10.4	38(17-45)
Taxi	6	45(25-60)	4.5	35(20-48)	7.2	51(30-60)	7.8	39(20-50)	8.2	36(15-45)	7.2	44(30-60)
Trotro	25.5	53(30-60)	27.9	52(30-60)	23.4	53(30-60)	17.2	61(32-80)	19.9	59(30-70)	13.5	66(39-90)
Train	0.1	34(8-50)	0.1	0(0-0)	0.1	50(33-68)	..	..	..	..	..	..
Other	1.2	45(18-60)	0.8	47(30-60)	1.6	44(14-60)	0.9	106(22-90)	0.6	133(34-90)	1.2	86(28-71)
Overall	100	33(10-45)	100	33(10-45)	100	32(10-45)	100	37(10-40)	100	38(10-40)	100	35(10-40)
Trip purpose												
Work	28	44(15-60)	27	42(15-60)	29	45(20-60)	12	62(20-64)	10	67(16-59)	15	57(25-70)
School	10	30(15-35)	11	30(15-38)	10	30(15-34)	6	30(15-40)	5	31(15-40)	6	29(15-40)
Services*	31	27(10-30)	39	28(10-30)	23	25(5-30)	30	30(10-33)	33	29(8-30)	26	31(10-40)
Recreation	27	28(10-40)	21	34(15-48)	33	25(10-30)	10	31(10-30)	8	35(10-30)	12	27(10-30)
Other	4	33(10-60)	2	26(5-52)	5	35(20-60)	4	63(10-85)	5	73(10-90)	2	33(10-30)
Return home	..	..	..	..	..	..	39	35(10-40)	39	36(10-40)	39	33(10-40)
Overall	100	33(10-45)	100	33(10-45)	100	32(10-45)	100	37(10-40)	100	38(10-40)	100	35(10-40)

*services included providing services, errands, accompanying children and others, and shopping; IQR = Interquartile range (lower quartile - upper quartile)

3.3.4.3. Correlates of travel behaviour characteristics

- Trip making

Being female was associated with lower odds of making trips in both surveys while having at least a secondary education (compared to those with lesser than secondary education) in the time use survey and having no occupation (compared to having an occupation) in the travel diary survey was associated with higher odds of making trips (Table 3.24).

- Travel time

In the travel survey, being a female was associated with 17% lower daily travel time. Younger adults in the age groups between 25-44 years travelled for longer times compared to children (05-14 years) in the time-use surveys. Education, occupation, and household vehicle access were not associated with daily travel time (Table 3.24).

Table 3.24 Factors associated with travelling and travel time on a reference day in 2009 Time use and 2021 Travel diary survey in Accra, Ghana

	Trip making		Daily travel time	
	Time use	Travel diary	Time use	Travel diary
	OR (95% CI)	OR (95% CI)	% Change (95%CI)	% Change (95%CI)
Female	0.4 (0.3-0.7)	0.7 (0.5-0.9)	-2 (-14-12)	-17 (-30--1)
Age group (ref: 5-14 years)				
15-24	1.0 (0.5-2.1)	0.5 (0.0-3.8)	23 (-1-53)	11 (-57-189)
25-34	0.8 (0.4-1.7)	0.7 (0.0-4.6)	41 (12-78)	39 (-47-262)
35-44	0.9 (0.4-1.9)	0.6 (0.0-4.2)	42 (11-82)	46 (-44-282)
45-54	0.7 (0.3-1.7)	0.4 (0.0-3.0)	29 (-3-71)	42 (-46-274)
55+	0.5 (0.2-1.0)	0.3 (0.0-2.3)	19 (-9-57)	10 (-59-194)
≥ Secondary education (ref: below)	1.6 (1.0-2.6)	0.9 (0.7-1.2)	9 (-6-26)	-3 (-18-15)
Has an occupation (ref: none)	0.8 (0.4-1.4)	0.5 (0.6-0.7)	-5 (-21-13)	-19 (-36-4)
In a house with any transport	1.2 (0.6-2.4)	1.0 (0.5-1.9)	-8 (-25-13)	-15 (-40-22)
In a house with motorised transport	0.8 (0.3-1.9)	1.6 (0.8-3.6)	20 (-7-57)	33 (-10-96)

3.3.5. Discussion of case study findings

In the 2020/2021 travel dairy survey, two-thirds of participants reported trips. The mean number of trips per capita (lower – upper quartile) was 1.4 (0-2) trips; 65% and 24% of participants with trips reported one and two trips, respectively; the trip duration was 37 (10-40) minutes; and the daily travel time per capita was 51 (0-70) minutes. The main trip modes were walking (65%) and trotro (17%), and the main trip purposes were work (12%) and services (30%), including shopping, offering services, and accompanying children and others. Participants with less than secondary education and no occupation were likelier to report no trip. Compared to the travel diary, the 2009 time use survey captured a higher proportion of participants reporting trips (84%), number of trips per capita (3.1 (2-4)), and daily travel time per capita (101 (30-130) minutes), but a similar trip duration and predominant trip modes and purposes. Participants reporting no trip in the time use survey were likelier to be females, older, and less educated. There was a growth in bicycle and motorcycle trips, paralleled by the change in household ownership of the respective modes between 2009 and 2021. Walking rates and taxi use increased with a corresponding decrease in private cars and trotros between 2009 and 2021. Being female was associated with lower odds of trip-making and shorter daily travel times in both surveys.

Limitations of this study are primarily associated with the datasets and the COVID-19 context. Firstly, the COVID-19 pandemic affected data collection in two main ways. (i) The several lockdowns of cities limited people's movements and the usual use of transport modes. This situation could affect the approximation of routine trips and the use of particular modes such as public transport, but over-approximation of private modes. Although we allowed ample buffer time post-lockdown before relaunching data collection, behaviours might not have reverted to pre-2019 levels at the time of data collection, given that the disease continued to affect people's behaviour for several months and years. (ii) Social distance instituted to reduce the spread of COVID-19 post-lockdowns limited participation in the face-to-face interviews and could lead to response bias, although the use of facemasks and strict respect for COVID-19 prevention measures by field researchers reassured and encouraged many participants. Secondly, we compared estimates of travel behaviour characteristics between surveys separated by a decade but did not formally control for differences from time. We also did not have access to longitudinal survey data from other sources to help gauge the changes that might have occurred over time. Thirdly, despite ensuring the maximum sample sizes allowed by budget, our sample sizes were relatively small and could misrepresent population estimates. Finally, both surveys were reasonably lengthy and relied on the recall of a large amount of information; thus, both were prone to soft refusal and recall bias.

The proportion of participants reporting no trip in the travel diary (34%) is far higher than the proportions reported in other LMIC cities: 13% in Bamako (Mali), 11% in Conakry (Guinea), 13% in Dakar (Senegal), 7% in Douala (Cameroon), 9% in Niamey (Niger), and 10% in Ouagadougou (Burkina Faso) [50]. The no-trip rate in the time-use survey (16%) closely matches the estimates from other LMIC cities. The divergence of the travel survey estimates would raise questions about the validity of the travel survey estimates if the effect of COVID-19 were to be excluded. Madre et al. (2007) [207] have determined that immobility is expected to range from 8 -12% in standard travel surveys, irrespective of the context. However, extremes in trip rates from travel surveys are not uncommon in LMICs. For example, our recent analysis comparing travel behaviour characteristics in two Kenyan cities showed very high trip rates in Nairobi (95%) and very low trip rates in Kisumu (63%) [223].

Low trip rates can sometimes be observed in travel surveys in LMICs because of how surveys are conducted. Travel surveys usually involve face-to-face interviews in which interviewers ask about participants' previous day's activities without allowing for sufficient household preparation. High survey costs and lack of a postal sampling frame in most LMIC contexts could limit household preparation before travel surveys. Where surveys are adequately planned, more thorough methods are used. For example, letters are first sent to the households introducing the survey and questionnaires and inviting household member(s) to participate in the survey; researchers then visit households to describe how to fill the survey forms; the households receive reminders, and the individuals fill their questionnaires on the appointed day. When these preparatory steps are skipped, participation and trip rates can be affected.

The travel time budget of 51 minutes in the travel survey matches estimates from other LMIC cities: 62 minutes in Bamako, 88 minutes in Conakry, 58 minutes in Dakar, 88 minutes in Douala, 63 minutes in Niamey, 66 minutes in Ouagadougou [50]. The time budget of 102 minutes from the time use survey is more than double that of the travel survey. An analysis of a 2001 travel and 2003 time use survey from the United States showed rather marginally higher travel times in the travel survey [238]. Hubert et al. (2008) [196] reported parallel but significantly lower percentages of people not reporting trips and longer travel times in the time-use surveys of Great Britain, France, and Belgium compared to their national travel diary surveys. A similar pattern of differences was also observed in German surveys [197].

The similarities observed between the time use and travel surveys in terms of trip duration, mode, and purpose indicate an opportunity to enhance the data collection process of each survey for multiple uses. Closer similarities have been noted in other studies [238]. For the African context, travel diaries could be improved to reduce soft refusal and retain more trips, while time-use surveys could further clarify time spent for actual travel activities. In that way, time-use surveys could confidently be used to inform transport demand, while surveys could also be used to inform time use [239].

In conclusion, this study highlights patterns of high walking and use of informal public transport, low use of private cars, and growing use of motorcycles consistent with broad-brush estimates from project reports in Africa. Travel diaries and time-use surveys similarly capture trip modes, durations and purposes. Still, estimates of trip-making rates, trip numbers and daily travel duration tend to be lower in the travel diary survey. However, COVID-19 travel restrictions and the time lapse between the two surveys might have accentuated the difference. Collecting travel diaries and time-use surveys simultaneously in the same population would improve our understanding of the relationship between instruments.

3.4. Synthesis of findings from case studies

- Data sources

The primary sources of travel behaviour data in African cities are travel diaries and time-use surveys, which are unfortunately infrequent. Other potential sources, such as mobile devices and street views, are yet to receive sufficient attention. Travel behaviour estimates from data using similar instruments differed across settings, as travel diary estimates from Nairobi, Kisumu, and Accra showed variations in mobility rates and travel durations. Time-use diaries from Yaoundé and Accra showed equal differences in mobility rates and travel durations. A comparison of travel diary and time use data from Accra shows that travel diary and time use surveys similarly capture trip modes, durations and purposes. Still, estimates of trip-making rates, trip numbers and daily travel duration tend to be lower in the travel diary survey. These surveys highlight the contextual variation of travel behaviours and their dependence on questionnaire types. These factors must be considered when exploiting surveys for health impact modelling. Other cross-cutting points from the surveys include the following:

- Travel rates and times

Travel behaviour estimates across four African cities show essential variations in most travel behaviour characteristics. The proportion of participants reporting no trips ranges from 5% in Nairobi to 35% in Kisumu. The no-trip rate in Accra is 33% (travel survey) and 15% (time-use survey), while Yaoundé has a no-trip proportion of 33% (time-use survey). The number of trips per survey participant ranged from 1.2 in Kisumu to 3.1 in Accra (time-use). Daily travel duration per capita also varies widely: 77 (0–120) minutes in Yaoundé, 51 (0-70) minutes (travel diaries) and 101 (30-130) minutes (time-use survey) in Accra.

- Active transport (walking and cycling)

Walking is the most common trip mode in most cities: 42% in Nairobi, 61% in Kisumu, and 65% in Accra, although only 27% in Yaoundé, where it is the second most common trip mode. These percentages are considerably less than the purported higher values in Africa (>70% in many cases). The contribution of data sources to this difference is unclear. Cycling is almost inexistent in some cities like Yaoundé and Accra, while Kenyan cities show encouraging cycling rates of up to 5% of trips in Kisumu.

- Public transport

The private sector essentially runs public transport. The primary public transport modes are minibuses and shared taxis. These are small-capacity vehicles. Minibuses are the second most popular mode of transportation in Nairobi, Kisumu and Accra (17%), while shared taxis are the most popular mode of transportation in Yaoundé (46%).

- Private cars and motorcycles

Private cars represent less than 10% of all trip modes in African cities (and about 5% for smaller towns like Kisumu). Up to 10% of trips may be undertaken on motorcycles, although motorcycle use is far lower in Accra.

A notable limitation emerges concerning the lack of information on survey response rates. This omission is significant as response rates are a critical metric in assessing the representativeness of survey data. High response rates generally indicate a lower risk of nonresponse bias, enhancing the credibility and generalizability of the findings. Conversely, low response rates might suggest potential biases and limitations in the representativeness of the data, which could affect the robustness of the conclusions drawn from the surveys. The absence of this information in our case studies necessitates a cautious approach to interpreting the data. It underscores the need for comprehensive documentation in future surveys to ensure a more thorough understanding and evaluation of travel behaviours in African cities. This gap in the data highlights an area for improvement in survey methodologies. It emphasizes the importance of transparency and completeness in reporting survey metrics to accurately interpret and apply research findings.

The findings from the diverse case studies examined in this chapter show that the methodologies and approaches in conducting surveys across different African cities present unique challenges and opportunities. This diversity underscores the need for a set of refined, context-sensitive recommendations for future surveys in African urban settings.

Firstly, there is a crucial need for standardisation in survey methodologies to allow for more meaningful comparisons across different cities and time periods. This standardisation should encompass aspects such as question formats, data collection techniques, and the definition of key metrics like trip types and travel modes.

Secondly, future surveys should aim for greater inclusivity in participant selection to ensure that diverse demographic groups, including underrepresented populations, are adequately captured. This would enhance the representativeness of the data and provide insights into the travel behaviours of all societal segments.

Thirdly, leveraging data collection technology could significantly enhance the efficiency and accuracy of future surveys. The use of mobile devices, GPS tracking, and digital diaries should be considered to supplement traditional survey methods. These technologies can provide more precise data and reduce the reliance on self-reported information, which is often subject to recall biases.

Additionally, there is a need for increased transparency in reporting survey methodologies and response rates. This transparency is vital for assessing the reliability and generalizability of the survey findings. Clear documentation of these aspects would aid in the critical evaluation of the data and foster trust in the research outcomes.

Lastly, considering the dynamic nature of urban environments in Africa, surveys should be conducted at regular intervals. This regularity will capture the evolving travel behaviours and patterns, which are influenced by factors like urban development, economic changes, and shifts in public policy.

4. **Physical activity and comparison of GPAQ and travel diary physical activity in Accra, Ghana**

This chapter describes physical activity behaviour and compares data from routine physical activity and transport questionnaires. Similar to travel behaviour explored in the previous chapter, knowledge and baseline data on transport health impact pathways are also limited in Africa. While all the pathways are essential, I lean towards clarifying physical activity data since a central theme of this thesis is exploring whether or not the health effects of changes in urban transport in purportedly higher active transport environments are similar to observations from other settings. In addition, physical activity estimates result from individual survey data, which, like travel surveys, are more challenging to obtain than data from the other pathways that can be extracted from registries and other databases. I conceived this study, analysed the data, and wrote the manuscript. Dr Fidelia Dake collected the data reported in this study and, with other collaborators, provided feedback to the case study, shaping the output presented in this chapter.

4.1. Abstract

There is a lack of data on physical activity (PA) and the comparison of PA measuring instruments in low-resource settings. This paper aims to describe PA behaviour and the agreement of walking estimates from the Global Physical Activity Questionnaire (GPAQ) and the travel diary in a low-resource setting. We used a cross-sectional survey design to capture data from Accra (Ghana) residents between May 2020 and March 2021. Of the 863 participants aged 15+ years, 65% were females, and 86% reported PA. The median weekly PA was 18 (IQR: 5–75), the metabolic equivalent of task hours, with 50% of females and 37% of males achieving low PA levels. In the GPAQ, 80% of participants reported weekly walking; the mean number of days walked was 3.8 (standard deviation (SD): 2.5); hence, 54% of participants reported walking on any day, and the mean daily walking duration was 51 (SD: 82) minutes. In the diary, 56% of participants reported walking for over 24 h, with a mean walking duration of 31 (SD: 65) minutes. The correlation of walking duration between instruments was weak (rho: 0.31; 95% Confidence Interval: 0.25–0.37); the mean bias was 20 min, with GPAQ estimates being 0.1 to 9 times higher than diary estimates. We concluded that low PA is prevalent in Accra, and while the travel diary and GPAQ estimate similar walking prevalence, their walking duration agreement is poor. We recommend accompanying PA questionnaires with objective measures for calibration.

4.2. Background

Regular physical activity (PA) has well-established health benefits [240, 241], but the literature describing PA behaviour in low-resource settings is sparse. A 2008 systematic review on the prevalence of PA in two low- and middle-income countries (LMICs) identified no study on PA in Ghana and only four in Nigeria [242]. A recent scoping review in 2022 corroborates this gap and highlights the lack of recent high-quality data in all 17 articles identified on PA in Ghana, with multiple studies recycling the 2007/2008 World Health Organisation Study on global ageing and adult health [243]. This sparse literature on PA behaviour in LMICs hinders efforts to control non-communicable diseases (NCDs)—the leading global cause of disability and mortality—since PA is a major NCD risk factor and LMICs bear the highest burden of NCDs [4].

Transport PA (primarily walking and cycling, including while accessing public transport) is a major contributor to total daily PA [244], especially in LMICs [208, 210]. Population levels of transport PA are commonly captured through surveys that either use domain-specific questionnaires such as the Global Physical Activity Questionnaire (GPAQ) [245] or travel diaries [246]. However, it is unclear how PA estimates from questionnaires compare to those in travel diaries, and this can be problematic for research seeking to use PA estimates from different sources—for example, in modelling the health impact of transport or comparing PA across places and time.

The GPAQ estimates PA from work, leisure, and transport domains and is used in many LMICs [247–249]. Travel diaries capture travel behaviour—how people move to places in terms of modes, such as walking and cycling, duration of travel, and purpose for doing so—but are less commonly used in LMICs [48, 191]. Both instruments attempt to capture daily active travel duration but accomplish this differently. The GPAQ records the number of days per week of walking or cycling for ≥10 min continuously and the total time spent walking or cycling on a typical day [250]. On the other hand, travel diaries aim to record every segment of walking and cycling for transport during a reference day; the sum of these is the daily active travel duration.

Using these different instruments will typically lead to different estimates of transport PA. The GPAQ places the burden of recalling travel information on the responders by asking them to aggregate and average their daily active travel time. The travel surveys rather guide responders through their daily transport events; they vary in how well they capture leisure trips purely since walking and cycling are not always for or a result of travelling. In addition, travel diaries rarely count walking inside building complexes. The GPAQ, therefore, tends to provide coarser aggregated estimates of all PA compared to the higher time-resolution data of some transport PA captured by travel surveys. Both types of instruments suffer from recall and social desirability biases. High-income settings have sought to reduce recall bias by allowing participants to fill their travel diaries as days progress and by introducing better control mechanisms. Control mechanisms that ensure the correct completion of questionnaires have included pre-survey visits to introduce the survey and questionnaires and follow-up phone calls to remind participants and clarify doubts. These approaches are often seen as too costly for most LMICs, so survey data from these settings may contain higher biases, substantially affecting the comparison of survey instruments.

Although the GPAQ is widely used, its validity for total PA is poor when compared to accelerometers, pedometers, and PA logs [250–252]. Bull et al. (2009) [245] investigated the reliability and validity of the GPAQ from nine countries and showed a moderate to substantial strength of reliability (0.67 to 0.73), a moderate to strong concurrent validity compared with the International Physical Activity Questionnaire (IPAQ) (0.45 to 0.65), and a poor to fair criterion validity (0.06 to 0.35). Fewer studies have examined transport surveys' corresponding reliability and validity for PA, even in high-resource settings [244, 246]. Adam et al. (2014) [246] report fair reliability of transport PA questionnaires for walking (ICC = 0.59) and cycling for transport (ICC = 0.61); they report a strong agreement for vigorous physical activity ($r = 0.72$, $p < 0.001$) and a fair agreement for moderate physical activity ($r = 0.24$, $p = 0.09$) when compared with accelerometers. The focus of these studies has been on high-income settings, limiting the generalisation of findings. It is important to understand the level of agreement between estimates of transport PA from different instruments in multiple contexts to aid comparisons between studies or settings and facilitate data harmonisation.

This study investigates PA behaviour and the agreement between transport PA estimates derived from the GPAQ and travel diary among residents of Accra, Ghana. The specific objectives were to (i) describe the distribution of overall and domain-specific PA by gender and age group and (ii) compare the agreement of walking estimates between the GPAQ and the travel diary. Our main hypothesis is that both instruments measure the same latent PA behaviour and, therefore, agree highly.

4.3. Methods

4.3.1. Study Design, Setting, and Data

We undertook a cross-sectional survey of residents of Accra, the capital city of Ghana, to describe their PA behaviour and compare walking estimates between the GPAQ and travel diary. Our data collection lasted from May 2020 to March 2021. The Ethics Committees for the Humanities (ECH), University of Ghana (ECH 036/19-20) approved the study protocol. The data collection for this study is detailed in chapter 3.3, and only aspects relevant to this case study are described here. We reported our study following the STROBE guidelines [253].

4.3.2. Data Summary

Survey details are presented in section 3.3.3.1. Briefly, we collected data using the computer-assisted personal interview (CAPI) approach. We used a household questionnaire and an individual questionnaire to gather information. The household questionnaires captured information on household ownership of any vehicle (yes/no) and a motorised vehicle (yes/no). Individual questionnaires captured information on sex (female, male), age (years in seven categories), education (preschool, primary, middle, secondary, tertiary), occupation (none, student, domestic, paid work), and marital status (never married, formerly married, married). Individual questionnaires included both the GPAQ and the travel diary. The GPAQ questions were used mostly in their original form [10], with a slight modification of questions on transportation: we separated walking and cycling, and different questions were asked regarding these two methods of transportation (Figure 4.1, upper panel). Travel diary questions were adapted from multiple surveys to suit the local context, especially vehicle categories and names (Figure 4.1, lower panel).

NOW I WOULD LIKE TO ASK YOU ABOUT TRAVELING OR MOVING FROM ONE PLACE TO ANOTHER			
The next questions exclude the physical activities at work that you have already mentioned. Now I would like to ask you about the **usual way** you travel to and from places. For example to work, school, for shopping, to market, to place of worship etc.			
15.	Do you **walk** for at least 10 minutes continuously to get to and from places? 1=YES 2=NO	☐	**IF CODE 2 SKIP TO Q18**
16.	In a typical week, on how many days do you **walk** for at least 10 minutes continuously to get to and from places?	☐ **Days**	
17.	How much time do you usually spend on one of those days walking for travel on a typical day?	☐☐ **Hours** ☐☐ **Minutes**	
18.	Do you use **a bicycle** for at least 10 minutes continuously to get to and from places? 1=YES 2=NO	☐	**IF CODE 2 SKIP TO Q21**
19.	In a typical week, on how many days do you cycle/use a bicycle for at least 10 minutes continuously to get to and from places?	☐ **Days**	
20.	How much time do you usually spend cycling for travel on a typical day?	☐☐ **Hours** ☐☐ **Minutes**	

SECTION 5: 24-HOUR TRAVEL DIARY (TO BE ADMINISTERED TO ALL HOUSEHOLD MEMBERS OF SCHOOL-GOING AGE AND OLDER)

The next set of questions relates to all the trips you made in the last 24 hours/previous day. Please mention **all the trips you made outside your home the previous day** including movement within your community/neighbourhood. **Please start with the first trip you made from 4 am the previous day to 4 am today.**

29. Did you go out of your home yesterday? 1=YES ☐ 2=NO ☐ IF NO, WHY? ....

Line No.	Trip No.	Purpose of trip[1]	Stage of trip	Mode of travel[2]	Start time **hrs: mins**	Start location (Specify address/common landmark)	End time **hrs: mins**	End Location (Specify address/ common landmark)	Total trip time **hrs: mins**	Distance covered **if known**	No. of accompanying persons
										…… km DK ☐	……….. Line No(s): ☐ ☐
										……. km DK ☐	……….. Line No(s): ☐ ☐
										…… km DK ☐	……….. Line No(s): ☐ ☐

Figure 4.1 Excerpts of survey questionnaires. The GPAQ (upper panel, which captures data on a typical day and week) shows separate questions for walking and cycling. The travel diary (lower panel, captures data on a specific day, say yesterday)

4.3.3. GPAQ Variables

We used data from the GPAQ to estimate minutes per day of moderate-to-vigorous physical activity (MVPA) in total and by PA domain (work, leisure, transport). MVPA referred to any activity ≥3 MET and included walking, cycling, running, hiking, and playing football. Sedentary behaviour was collected in hours per day and converted into minutes per day. Examples of sedentary activities included watching television, playing video games, using a computer, sitting at school or work, and sitting while commuting. The duration of walking or cycling for transport on a typical day was multiplied by the number of days walked or cycled per week and divided by 7 to give the average minutes per day of walking and cycling. Duration of moderate and vigorous physical activity was multiplied by intensity expressed in METs (metabolic equivalent of task) to estimate the total physical activity volume in MET-hrs/day. Physical activity volume was also categorised as high, medium, and low, following the GPAQ guidelines [254].

4.3.4. Travel Survey Variables

We estimated the minutes per day of walking and cycling from the travel diaries by summing all durations of walking and cycling trips performed by individuals during the survey day. The total transport PA was the sum of minutes per day of walking and cycling.

4.3.5. Statistical Analysis

Our exploratory analysis involved using a combination of summary statistics and plots to check for missingness, normality, zero inflation, and near-zero variance. No data were imputed for missing data. Non-normal dependent variables were log-transformed, while variables with near-zero variance were regrouped when possible.

We used Pearson's correlation coefficient to evaluate the relationship between active travel duration estimated using the GPAQ and travel diary. Absolute agreement of estimates from the two instruments was assessed by calculating the mean bias and 95% limits of agreement and by plotting the difference between estimates against their mean in Bland–Altman plots [255].

To examine if the time frame difference between methods (7 days vs 1 day) impacted the correlations, we randomly assigned individuals into groups of seven (n = 40 draws), with each group containing individuals reporting in their trip diary on different days of the week, and then compared between-group correlations with individual-level correlations.

4.4. Results

4.4.1. Characteristics of Participants

We surveyed 1159 participants in 602 households in Accra. Eight-hundred and sixty-three (75%) survey participants aged 15+ years were retained for this analysis. The characteristics of these participants are shown in Table 4.1. The majority (65%) of the participants were females. Compared to males, a lower proportion of females had completed at least a secondary education (61% versus 45%); a higher proportion of females were not working (20% versus 15%); a lower proportion of females were living in households with any vehicle (32% versus 14%) or with a motorised vehicle (21% versus 12%).

Table 4.1 Characteristics of participants surveyed for travel behaviour and physical activity stratified by sex in Accra, Ghana (2020/2021).

	Overall	Female	Male
Number (%)	863 (100)	557 (65)	306 (35)
Mean age (standard deviation)	35 (16)	35 (15)	37 (17)
Age group (%)			
15–24	259 (30)	162 (29)	97 (32)
25–34	209 (24)	146 (26)	63 (21)
35–44	172 (20)	118 (21)	54 (18)
45–54	101 (12)	65 (12)	36 (12)
55–64	68 (8)	36 (7)	32 (11)
65+	54 (6)	30 (5)	24 (8)
≥Secondary school (%)	416 (51)	236 (45)	180 (61)
No occupation (%)	159 (18)	112 (20)	47 (15)
Household has any vehicle (%)	178 (21)	80 (14)	98 (32)
Household has a motorised vehicle (%)	130 (15)	67 (12)	63 (21)

4.4.2. GPAQ Estimates of Physical Activity

Table 4.2 shows the distribution of MVPA by sex and age groups. Eighty-six per cent of participants engaged in at least some MVPA, and the median (low-upper quartile) PA was 18 (5–75) MET-hrs/week. The proportion of participants engaging in some MVPA was similar for females and males, and females' median PA was half that of males (14 (4–58) vs 28 (8–120) MET-hrs/week). Almost half (45%) of all participants were categorised as having low PA volume (4 (0–8) MET-hrs/week), with a higher proportion of low PA levels in females than in males (50% vs 37%, $p < 0.001$). Low PA volume was predominant in all female age groups, while high PA volume was predominant in males younger than 55.

Table 4.2 Physical activity volume by age and gender from GPAQ in the city of Accra

	Female (Number = 557)			Male (Number = 306)		
	High PA	Medium PA	Low PA	High PA	Medium PA	Low PA

Median MET—hours/week (Lower – upper quartile)	178 (96–258)	23 (14–42)	4 (0–8)	158 (104–302)	26 (16–42)	5 (0–9)
Age group (*n* and row % by gender)						
15–24	29 (18)	50 (31)	83 (51)	37 (38)	26 (27)	34 (35)
25–34	37 (25)	46 (32)	63 (43)	28 (44)	17 (27)	18 (29)
35–44	31 (26)	36 (31)	51 (43)	20 (37)	19 (35)	15 (28)
45–54	11 (17)	19 (29)	35 (54)	13 (36)	10 (28)	13 (36)
55–64	7 (19)	9 (25)	20 (56)	10 (31)	7 (22)	15 (47)
65+	1 (3)	4 (13)	25 (83)	0 (0)	7 (29)	17 (71)
Total (gender row%)	116 (21%)	164 (29%)	277 (50%)	108 (35%)	86 (28%)	112 (37%)

MET: Metabolic equivalent of task

Participants spent on average (low–upper quartile) 127 (11–150) minutes engaging in MVPA, with females in all age groups reporting fewer minutes than males overall (110; 9–120 vs 157; 17–208) and in each PA domain. Participants in the 35–44 years age group reported the highest duration of MVPA (Table 4.3). Work and travel domains contributed the most to the total daily MVPA duration (65; 0–14 and 54; 6–60 min). More time was spent walking than cycling in the travel domain. The daily walking time was 51 (6–60) minutes. Recreational activity contributed the least to total daily MVPA (23%). Females spent more time on sedentary behaviours than males (276; 120–360 vs 261; 150–300).

Table 4.3 Total and domain-specific durations of MVPA and sedentary behaviour by age and sex from GPAQ in Accra, Ghana

Domain	Age Group (Participants in Age Group)	Participants Reporting (% of 863)	Mean (LQ-UQ)			Median (IQR) (Only Those with PA)		
			Both Sexes	Female	Male	Both Sexes	Female	Male
All MVPA (minutes/day)	15–24 (259)	230 (30)	108 (13–129)	80 (9–90)	154 (18–176)	32 (116)	26 (81)	47 (158)
	25–34 (209)	187 (24)	149 (13–210)	129 (11–148)	196 (26–304)	43 (197)	36 (137)	86 (278)
	35–44 (172)	151 (20)	159 (13–239)	157 (12–278)	163 (26–209)	64 (226)	51 (266)	86 (183)
	45–54 (101)	86 (12)	123 (11–129)	103 (10–111)	157 (17–209)	34 (117)	26 (101)	55 (192)
	55–64 (68)	59 (8)	139 (10–157)	105 (12–108)	177 (8–212)	29 (147)	26 (95)	36 (204)
	65+ (54)	33 (6)	24 (0–21)	22 (0–14)	26 (0–33)	7 (21)	4 (14)	11 (33)
	Total (863)	746 (86)	127 (11–150)	110 (9–120)	157 (17–208)	34 (139)	30 (111)	54 (191)

Work MVPA (minutes/day)	15–24 (259)	42 (5)	33 (0–0)	27 (0–0)	43 (0–0)	163 (312)	60 (317)	214 (309)
	25–34 (209)	72 (8)	87 (0–69)	80 (0–71)	104 (0–58)	214 (280)	208 (259)	266 (404)
	35–44 (172)	65 (8)	93 (0–132)	98 (0–148)	82 (0–116)	214 (270)	257 (320)	154 (283)
	45–54 (101)	29 (3)	72 (0–15)	60 (0–14)	92 (0–45)	227 (231)	231 (270)	227 (129)
	55–64 (68)	19 (2)	88 (0–64)	48 (0–0)	133 (0–180)	283 (291)	279 (231)	351 (311)
	65+ (54)	3 (0)	2 (0–0)	3 (0–0)	0 (0–0)	9 (32)	9 (32)	NA
	Total (863)	230 (27)	65 (0–14)	60 (0–13)	74 (0–14)	208 (290)	206 (296)	214 (309)
Transport MVPA (minutes/day)	15–24 (259)	221 (26)	65 (10–62)	50 (9–58)	90 (13–120)	30 (75)	26 (46)	43 (111)
	25–34 (209)	171 (20)	51 (6–60)	45 (6–58)	66 (13–69)	30 (56)	27 (50)	40 (64)
	35–44 (172)	139 (16)	60 (6–103)	56 (6–99)	69 (11–103)	39 (104)	30 (107)	60 (90)
	45–54 (101)	77 (9)	44 (4–51)	40 (0–43)	51 (10–64)	26 (64)	25 (56)	29 (62)
	55–64 (68)	57 (7)	47 (8–35)	53 (12–34)	40 (3–42)	26 (39)	22 (26)	26 (34)
	65+ (54)	31 (4)	16 (0–20)	12 (0–12)	21 (0–27)	13 (21)	11 (19)	26 (17)
	Total (863)	696 (81)	54 (6–60)	47 (6–51)	66 (11–77)	30 (65)	26 (56)	36 (80)
Walking (minutes/day)	15–24 (259)	220 (25)	61 (10–60)	49 (9–58)	80 (13–114)	29 (71)	26 (46)	30 (111)
	25–34 (209)	171 (20)	50 (6–60)	44 (6–51)	63 (11–69)	30 (56)	27 (47)	40 (66)
	35–44 (172)	137 (16)	59 (6–103)	56 (6–99)	66 (8–100)	39 (105)	30 (107)	60 (91)
	45–54 (101)	76 (9)	42 (3–43)	39 (0–34)	48 (9–54)	26 (53)	25 (56)	27 (45)
	55–64 (68)	57 (7)	43 (7–34)	53 (12–34)	32 (3–31)	26 (39)	22 (26)	26 (39)
	65+ (54)	31 (4)	16 (0–20)	12 (0–12)	21 (0–27)	13 (21)	11 (19)	26 (17)
	Total (863)	692 (80)	51 (6–60)	47 (6–51)	60 (9–64)	29 (64)	26 (52)	30 (73)
Cycling (minutes/day)	15–24 (259)	26 (3)	4 (0–0)	0 (0–0)	10 (0–0)	13 (17)	6 (9)	13 (17)
	25–34 (209)	6 (1)	1 (0–0)	0 (0–0)	4 (0–0)	20 (30)	43 (0)	12 (20)
	35–44 (172)	7 (1)	1 (0–0)	0 (0–0)	3 (0–0)	17 (28)	9 (0)	26 (26)
	45–54 (101)	6 (1)	2 (0–0)	1 (0–0)	3 (0–0)	28 (11)	24 (6)	28 (14)
	55–64 (68)	4 (0)	4 (0–0)	0 (0–0)	9 (0–0)	30 (54)	NA	30 (54)
	65+ (54)	0 (0)	0 (0–0)	0 (0–0)	0 (0–0)	NA	NA	NA
	Total (863)	70 (8)	2 (0–0)	0 (0–0)	6 (0–0)	17 (26)	17(19)	17 (27)
Recreation MVPA (minutes/day)	15–24 (259)	70 (8)	10 (0–4)	3 (0–0)	21 (0–21)	17 (29)	9 (16)	26 (56)
	25–34 (209)	48 (6)	11 (0–0)	4 (0–0)	26 (0–17)	17 (36)	13 (21)	26 (49)
	35–44 (172)	31 (4)	5 (0–0)	2 (0–0)	13 (0–16)	17 (17)	17 (18)	26 (26)
	45–54 (101)	24 (3)	7 (0–0)	3 (0–0)	14 (0–17)	17 (24)	9 (11)	26 (24)
	55–64 (68)	12 (1)	4 (0–0)	4 (0–0)	4 (0–0)	17 (14)	13 (37)	17 (9)
	65+ (54)	11 (1)	6 (0–0)	6 (0–0)	5 (0–9)	9 (17)	95 (91)	9 (13)

	Total (863)	196 (23)	8 (0–0)	4 (0–0)	17 (0–17)	17 (26)	13 (21)	26 (36)
Sedentary behaviour (minutes/day)	15–24 (259)	256 (30)	270 (120–360)	276 (124–360)	261 (120–330)	240 (229)	240 (214)	240 (218)
	25–34 (209)	206 (24)	244 (120–330)	249 (120–360)	232 (120–240)	210 (232)	225 (240)	180 (120)
	35–44 (172)	170 (20)	238 (120–300)	246 (120–352)	222 (120–300)	180 (180)	210 (240)	180 (180)
	45–54 (101)	98 (11)	320 (180–420)	336 (180–480)	291 (180–315)	300 (262)	300 (300)	240 (135)
	55–64 (68)	67 (8)	276 (120–360)	282 (165–368)	268 (120–360)	270 (225)	300 (202)	240 (225)
	65+ (54)	54 (6)	378 (240–480)	381 (218–480)	373 (300–435)	330 (240)	360 (262)	300 (135)
	Total (863)	851 (99)	271 (120–360)	276 (120–360)	261 (150–300)	240 (240)	240 (240)	240 (158)

LQ–UQ: lower quartile to upper quartile; IQR: interquartile range.

4.4.3. Travel Diary Estimates of Physical Activity

Just above half (56%) of the participants reported transport PA (walking or cycling). Walking was the main source of transport PA, as only 1% of individuals reported cycling. The average daily transport PA duration was 32 (0–40) minutes, and the daily walking duration was 31 (0–40), equal for both sexes (Table 4.4).

Table 4.4 Total and mode-specific transport physical activity by age and gender from the travel diary in Accra, Ghana

Domain	Age Group (Participants in Age Group)	Participants Reporting (% of 863)	Mean (LQ-UQ)			Median (IQR) (Only for Travellers)		
			Both Sexes	Female	Male	Both Sexes	Female	Male
Transport PA (minutes/day)	15–24 (259)	160 (19)	34 (0–40)	27 (0–35)	45 (0–50)	35 (40)	30 (32)	40 (61)
	25–34 (209)	127 (15)	38 (0–50)	44 (0–50)	24 (0–42)	40 (40)	40 (50)	36 (38)
	35–44 (172)	97 (11)	36 (0–40)	40 (0–30)	29 (0–49)	30 (40)	28 (44)	40 (35)
	45–54 (101)	51 (6)	20 (0–35)	21 (0–35)	18 (0–35)	35 (40)	38 (40)	35 (30)
	55–64 (68)	34 (4)	24 (0–20)	20 (0–20)	29 (0–16)	20 (33)	20 (26)	30 (40)
	65+ (54)	20 (2)	17 (0–14)	6 (0–4)	31 (0–52)	32 (50)	20 (14)	60 (55)
	Total (863)	489 (57)	32 (0–40)	32 (0–39)	32 (0–44)	35 (40)	30 (44)	40 (40)
Walking minutes/day)	15–24 (259)	160 (19)	34 (0–40)	27 (0–35)	45 (0–50)	35 (40)	30 (30)	40 (61)
	25–34 (209)	125 (14)	37 (0–47)	44 (0–50)	22 (0–38)	40 (40)	40 (50)	36 (39)
	35–44 (172)	94 (11)	36 (0–36)	40 (0–30)	27 (0–44)	30 (43)	28 (44)	40 (35)

	45–54 (101)	51 (6)	20 (0–35)	21 (0–35)	17 (0–35)	35 (40)	38 (40)	35 (24)
	55–64 (68)	32 (4)	18 (0–20)	20 (0–20)	15 (0–10)	20 (30)	20 (26)	20 (25)
	65+ (54)	20 (2)	17 (0–14)	6 (0–4)	31 (0–52)	32 (50)	20 (14)	60 (55)
	Total (863)	482 (56)	31 (0–40)	32 (0–39)	30 (0–40)	35 (40)	30 (44)	38 (41)
	15–24 (259)	1 (0)	0 (0–0)	0 (0–0)	0 (0–0)	20 (0)	20 (0)	<NA>
	25–34 (209)	2 (0)	0 (0–0)	0 (0–0)	1 (0–0)	42 (18)	<NA>	42 (18)
	35–44 (172)	2 (0)	1 (0–0)	0 (0–0)	2 (0–0)	30 (15)	<NA>	30 (15)
Cycling minutes/day)	45–54 (101)	1 (0)	0 (0–0)	0 (0–0)	0 (0–0)	15 (0)	<NA>	15 (0)
	55–64 (68)	2 (0)	6 (0–0)	0 (0–0)	14 (0–0)	220 (170)	<NA>	220 (170)
	65+ (54)	0 (0)	0 (0–0)	0 (0–0)	0 (0–0)	0 (0)	<NA>	<NA>
	Total (863)	8 (1)	1 (0–0)	0 (0–0)	2 (0–0)	30 (30)	20 (0)	40 (29)

LQ–UQ: lower quartile to upper quartile; IQR: interquartile range.

4.4.4. Comparison of GPAQ and Travel Diary Estimates of Transport Physical Activity

Only 70 (8%) participants reported cycling in the GPAQ and 8 (1%) in the travel diary. Therefore, we focused the rest of our comparison of transport PA only on walking because the number of cyclists was small.

The number of participants reporting walking in each instrument is shown in Table 4.5. In the GPAQ, 694 (80%) participants reported walking over a typical week. The mean number (standard deviation) of days walked per week was 3.8 (2.5); thus, the expected proportion of participants walking on any given day in the GPAQ was 54% (95% CI: 51–58%). In comparison, 482 (56%) participants reported walking for over 24 hours in the travel diary. The proportion of participants reporting walking in the travel diary was, therefore, similar to the proportion of participants expected to report walking on any given day in the GPAQ. Of the participants reporting walking on any day in the GPAQ, almost two-thirds (63%) reported walking in the diary. The proportion was only slightly higher (70%) among those who reported walking for five or more days. In both instruments, we found no association between the reporting of walking and age, occupation, education, and household vehicle access.

Table 4.5 Walking in the travel diary compared to walking in the GPAQ

	GPAQ			
	No Walk (n = 169)	Walked for ≥1 Day (n = 694)	Walked for ≥5 Days (nr = 414)	Walked for 7 Days (n = 181)
Travel Diary No walk (number = 381)	126	255	124	54

Walked (number = 482)	43	439	290	127

Table 4.6 compares daily walking duration from the GPAQ and travel diary. The overall mean bias in daily walking duration for the GPAQ minus travel diary was 20 (95% agreement limit: –151 to 192) minutes; the bias increased with the number of days walked in the GPAQ and almost tripled in participants who reported walking for all seven days in the GPAQ (57; –179 to 294 min). The bias was stronger in males (31; –136 to 197 min) compared to females (15; –158 to 188 min) and in those with lower than secondary education (25; –163 to 213 min) compared to those who had at least a secondary education (16; –139 to 172).

Table 4.6 Comparison of daily walking duration (minutes) between GPAQ and travel diary

Participant Group	GPAQ Mean Daily Walking Duration (Standard Deviation)	Diary Mean Daily Walking Duration (Standard Deviation)	Bias (95% Limits of Agreement)	Percentage of GPAQ > Diary	Rho (95% Confidence Limits)
All participants	51 (82)	31 (65)	20 (–151 to 192)	54	0.31 (0.25 to 0.37)
Walk ≥ 1 day GPAQ	64 (87)	36 (69)	28 (–157 to 213)	68	0.29 (0.22 to 0.35)
Walk ≥ 5 days GPAQ	87 (101)	45 (79)	45 (–175 to 265)	70	0.24 (0.15 to 0.33)
Walk = 7 days GPAQ	98 (102)	40 (77)	57 (–179 to 294)	73	0.11 (–0.04 to 0.27)

The Bland–Altman plots (right panel of Figure 4.2) show substantial disagreement between the GPAQ and the trip diary daily walking durations. The plots are on a log scale since the original scale showed significant heteroscedasticity. When transformed from the log back to the original scale, the limits of agreement for individual GPAQ and trip diary daily walking durations were 0.1 and 9.0, implying that GPAQ estimates could be between 0.1 and 9 times the travel diary estimates. When daily walking duration is capped at three hours, GPAQ estimates could be as high as six times the trip diary estimates.

The overall correlation between the GPAQ and travel diary walking duration was weak (rho = 0.31; 95% confidence interval: 0.25 to 0.37) and decreased as the number of days walked in the GPAQ increased (Table 4.6). Compared to males, the correlation was weaker in females (42; 32 to 50 vs 28; 20 to 35).

When we randomly sampled individuals in groups of seven, such that each group contained individuals who were interviewed for their trip diaries on different days of the week, we saw no significant between-group correlation (rho = 0.11, 95% CI: −0.22 to 0.40) compared to a significant within-group positive correlation (rho = 0.29, 95% CI: 0.16 to 0.38). The left panel of Figure 4.2 shows the deviation of lines of best fit from the line of unity, with a nearly random distribution of group means.

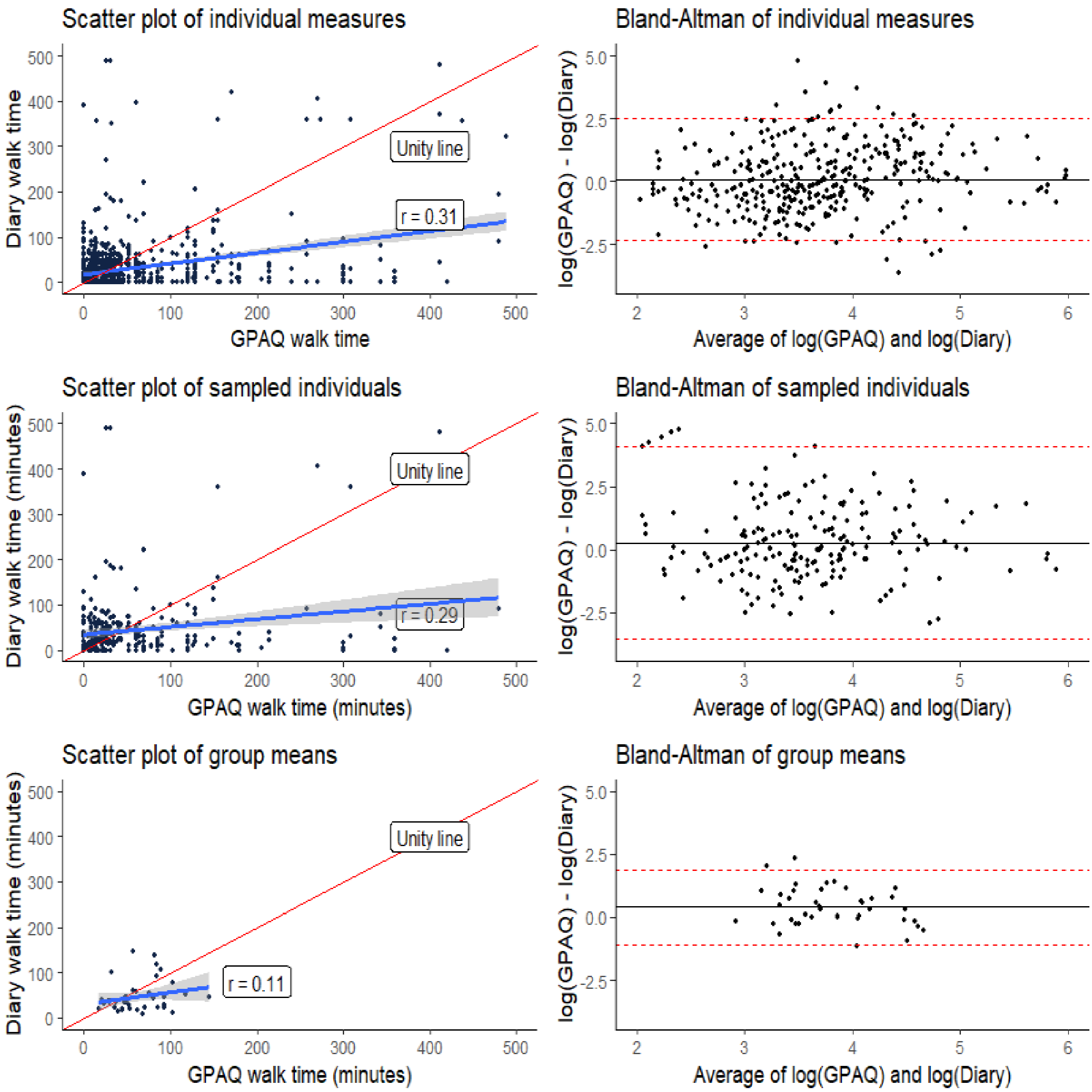


Figure 4.2 Comparison of walking duration in the GPAQ and travel diary. The left panels show the degree of deviation of the line of best fit from the unity line in the original data (top), in the sampled individuals (middle), and the group means of groups of seven.

4.5. Discussion

4.5.1. Main Findings

To our knowledge, this is the first study evaluating the agreement of a GPAQ and a travel diary in a low-resource setting. We analysed the PA of 863 participants aged 15+ years; 65% of them were females, and 86% engaged in some PA. The median PA was 18 (IQR: 5–75), the metabolic equivalent of task hours per week, with 50% of females and 37% of males having low PA levels. A total of 80% and 56% of participants reported walking in the GPAQ and travel diary surveys, respectively. The proportion of participants expected to report walking on any given day in the GPAQ was 54% (95% CI: 51–58), similar to the travel diary. The mean (standard deviation) daily walking time was 31 (65) minutes in the diary and 51 (82) minutes in the GPAQ. The mean bias error in daily walking time (GPAQ minus diary) was 20 minutes (95% limits of agreement: –151 to 192). The bias was stronger in males and participants with lower than secondary education. The correlation of walking time between the instruments was low (r = 0.31; 95% CI: 0.25–0.37), and there was substantial disagreement between the instruments, with daily walking time estimates in the GPAQ corresponding to between 0.1 and 9 times the estimates from the travel diary.

4.5.2. Interpretation of findings

We observed similarities in the proportions of participants reporting daily walking and in the average daily walking time between the travel diary and the GPAQ when we scaled down the GPAQ to expected daily walking levels. This is an important finding from the point of reporting and monitoring population levels of transport-related PA, especially in the context of limited data, where estimates from one survey would be sufficient. For example, estimates of active travel from a travel diary could inform population levels of transport PA, an important contributor to total PA in LMICs [208], and scaled PA estimates from a GPAQ can inform active travel. Although population PA estimates from either instrument may deviate from objective measurements, validity studies argue a place for these instruments in population PA evaluations [245, 246, 256].

On the other hand, we observed a poor correlation and a substantial disagreement in walking time estimates between the two instruments. One could expect a poor correlation and disagreement between instruments in a low-walking context. Marked differences will result in such contexts because the daily walking time in the GPAQ is an average across one week, while the travel diary reports for a single day. As a result, many people will have daily walking times in the GPAQ but zero walking time in the travel diary. However, a higher correlation and agreement are expected in a context with high walking rates, such as Accra.

The disagreement between instruments was different across population subgroups, with the absolute mean difference in daily walking time (GPAQ minus travel diary) being higher in males and those with lower education. The reason for population subgroup differences in PA reporting is unclear, but there is some evidence about gendered differences in memory, with females tending to exhibit better recall of activities than males [257, 258]. A low level of education has been associated with lower validity of reported physical activity [259].

Studies report conflicting results on the validity and reliability of PA questionnaires with regard to their timeframes. PA questionnaires targeting a usual week within a quarter-year or year seem to have better test-retest reliability than those targeting an actual week, as the usual week questionnaires control for week-to-week variation in PA patterns [260]. Minimal seasonal influence has been reported on PA questionnaires that target a one-year time frame [261]. A systematic review by Doma et al. (2017) [262] further shows that the test-retest reliability of actual and usual week PA questionnaires is rather comparable, partly because of the different reliability cut-offs used in the studies. Similar to the usual vs actual week comparison, weeklong PA questionnaires can seem to average day-to-day variations in PA patterns, but we did not see any significant between-day correlation to suggest that the survey day affected the correlation between average daily walking time in the GPAQ and the travel diary. This observation allows us to conclude that large day-to-day fluctuations do not primarily influence the degree of agreement between these two assessment methods.

Overall, a plausible explanation for the observed bias is that people inconsistently overestimate walking when asked the “usual behaviour in a week” question in GPAQ—of course, it could also be that they underestimate walking in the travel diary, but this would be less likely as the diary is an easier recall task. It could also be that people might be walking within larger complexes/buildings or do not consider some kinds of walking as trips. This observation underscores the need for objective PA measures alongside these survey instruments, at least in the survey subsample. Readily available tools such as pedometers and smartphones would provide basic data for triangulation. In addition, qualitative studies might clarify how people interpret these questions.

4.5.3. Study Limitations

Our study does have largely data source-related limitations. Firstly, the GPAQ and travel diary are susceptible to different levels of recall bias. The GPAQ asks about daily and weekly walking/cycling times above 10 min, which triggers a different trip recall and averaging process in responders, compared to the travel diary that focuses on a preceding day and aids trip recall by associating the purpose for leaving home. Secondly, the data collection was conducted around the time of the COVID-19 pandemic, which affected urban mobility in most cities worldwide in many ways. While responders would report routine walking/cycling based on their activities before the pandemic in the GPAQ, the dairy reported the preceding day’s walking/cycling, which was more likely affected by COVID-19. The measures implemented to reduce the spread of the COVID-19 pandemic in Accra, such as the stay-at-home orders, travel restrictions, and social distancing, could lead to increased walking and cycling as these became the most convenient/available means for movement, albeit with an overall reduction in walking. Finally, our data findings are only relevant for those aged 15+ years (as constrained by the GPAQ) and may not apply to children and adolescents (<14 years), for whom travel PA is crucial for long-term behaviour.

In light of the findings from this study, there are several avenues for future research that can strengthen our understanding of PA patterns in low-resource settings and enhance the accuracy of self-reported survey instruments. First, future studies should consider incorporating objective measures of PA to validate and calibrate self-reported data from questionnaires. These measures could include the use of wearable technology such as accelerometers, pedometers, and GPS devices. Accelerometers provide detailed information on the intensity and duration of physical activities, while pedometers are useful for counting steps, offering a straightforward measure of walking activity. GPS devices can track the geographical location and movement patterns of participants, providing valuable contextual data about the physical activity environment. Additionally, integrating mobile health (mHealth) applications and smartwatches could offer an innovative approach to tracking PA. These technologies are increasingly accessible and can provide real-time data collection with minimal respondent burden. The data gathered from these objective measures can be used to calibrate and validate responses from traditional questionnaires like the GPAQ and travel diaries, providing a more comprehensive understanding of PA patterns.

Furthermore, qualitative research methods, such as interviews or focus groups, could be employed to explore how participants perceive and report their physical activities. Understanding the subjective interpretations and potential biases in self-reporting can inform the design of more effective and accurate questionnaires.

To address the limitations of cross-sectional designs often used in PA research, longitudinal studies could provide insights into changes in PA behaviours over time, especially in response to urban development, policy changes, or interventions aimed at promoting physical activity.

4.6. Conclusions

Low PA is prevalent in Accra, Ghana, particularly among females. The travel diary and GPAQ had similar population-level walking estimates when we scaled down the GPAQ to expected daily walking. However, there is poor correlation and agreement between individual daily walking durations from both instruments, with the GPAQ reporting higher walking durations. The degree of agreement does not seem to be primarily influenced by large day-to-day fluctuations in travel durations. These findings have important implications for reporting and monitoring population-level transport-related PA, especially in contexts with limited data availability, and for using both data sources to model transport health impacts. Our findings also underscore the need to accompany PA questionnaires with objective measures to help calibrate the questionnaires.

5. **Opportunities and constraints for integrating physical activity into urban-relevant policies in Cameroon: implications for the transport sector**

Transport health impact models can help researchers and practitioners identify healthier transport scenarios and policies. The model outputs are most helpful if policymakers recognise, and are willing to improve, the contribution of transport to health. Focusing on physical activity and non-communicable diseases as health outcomes, I analysed Cameroon's sectoral policies (including transport policies) to understand the extent to which different sectors explicitly integrate physical activity and non-communicable diseases in their policies. The study findings, therefore, inform the opportunities and constraints of adopting transport health impact models in African cities. The case study presented in this chapter was part of a GDAR work package. The work package targeted policy analyses for NCD prevention at global, national and local levels. I focused on the Cameroon case study, sourcing and screening articles, extracting data, analysing and synthesising them, and writing the manuscript. A work package team member assisted me in double-screening the abstracts and full texts. The other team members provided feedback on the case study, shaping the output presented in this chapter.

5.1. Abstract

Physical inactivity is increasing in low- and middle-income countries (LMICs), where non-communicable diseases (NCDs), urbanisation and sedentary living are rapidly growing. Increasing active living requires the participation of multiple sectors, yet it is unclear whether physical activity (PA)-relevant sectors in LMICs are prioritising PA. We investigated the extent to which sectors that influence PA integrate PA into their policies in a LMIC such as Cameroon. We systematically identified policy documents relevant to PA and NCD prevention in Cameroon. Using the Walt and Gilson policy triangle, we described, analysed, and interpreted the policy contexts, contents, processes, and actors. We found 17 PA and NCD policy documents from 1974 to 2019 across seven ministries. Thirteen (13/17) policies targeted infrastructure improvement, and four (4/17) targeted communication for behaviour change, all aiming to enhance leisure domain PA. Only the health sector explicitly acknowledged the role of PA in NCD prevention. Notably, no policy from the transport sector mentioned PA. These findings highlight the need for intersectoral action to integrate PA into policies in all relevant sectors. These actions will need to encompass the breadth of PA domains, including transport while emphasising the multiple health benefits of PA for the population. The lack of explicit mention of PA in transport policies further implies that more groundwork is required before policymakers can exploit outputs of transport physical activity impact models.

5.2. Background

Physical activity (PA) from all domains (occupational, domestic, leisure, and travel) [263] is known to reduce the risk of morbidity and premature mortality significantly. It is crucial for preventing non-communicable diseases (NCDs)—mainly cardiovascular diseases, cancers, diabetes, and chronic respiratory diseases—which are rising and cause over 70% of global deaths [4]. Yet levels of insufficient PA remain high globally and are increasing in rapidly urbanising low- and middle-income countries (LMICs). In 2016, 28% of adults worldwide and 18% in sub-Saharan Africa were estimated to have insufficient PA levels [264]. Given that the majority of health behaviours that persist in adulthood are shaped during adolescence, the fact that over 80% of global adolescents also have insufficient PA levels [265, 266] has severe implications for future adult PA behaviour and health [267]. To address this challenge, the World Health Organization (WHO) has urged countries and communities to take the necessary actions to increase their citizens' PA levels. The WHO's 2013–2020 Global Action Plan for the Prevention and Control of NCDs highlights PA as a priority area [268]; and the Global Action Plan for Physical Activity (GAPPA) 2018–2030: more active people for a healthier world, outlines in detail the steps needed to increase PA [240].

The predominance of infectious diseases, poverty, weak health systems, conflicts, and governance issues in LMICs makes the control of NCDs more challenging and their prevention more urgent. The prevention of NCDs is particularly crucial for LMICs, where three-quarters of all NCD-related deaths, four-fifths of NCD premature deaths, and the highest loss of disability-adjusted life years occur [4]. In addition, LMICs suffer significant human, social and economic consequences from NCDs, with unaffordable disease management costs for most individuals, families, communities, and states. The decreased economic productivity associated with NCDs also perpetuates the vicious cycle of poverty [269].

Cameroon, similar to most LMICs, has a weak, underfunded health system overwhelmed by infectious diseases such as HIV/AIDS, malaria and tuberculosis, and high maternal and child mortality. It also faces challenges in governance, conflict and insecurity that are common in many LMICs. These challenges present opportunity costs to building healthy, active, and sustainable communities. A 2014 NCD report showed that NCDs accounted for 31% of all deaths in the country, with a 20% risk of dying from one of the main NCDs between the ages of 30 and 70 years and a 35% risk for people aged 50 years and above [270]. The rapid rise of NCDs and their consequences in the country are driven partly by an ongoing socio-economic transition, characterised by improved standards of living and rapid (but mostly unplanned) urbanisation with increasing air and noise pollution [271]. The country's long-term strategic development plan, "Cameroon Vision 2035" of 2009, elaborates policy actions aimed at socio-economic transformation, including poverty reduction, industrialisation, and urban growth. The vision also describes how the country's regional and urban policies contributed to the rapid uncontrolled urbanisation and its associated problems, which need addressing. Examples of policy actions that fuelled the observed urbanisation included (i) the construction of roads linking most medium-sized towns and opening of landlocked areas, (ii) the setting up of basic social amenities (education, water supply, electricity, hospitals and health centres, telecommunications, and trade centres) in potential towns; and (iii) border area development.

These transitions significantly impact two critical determinants of NCDs, PA and diet, as more people tend to adopt the consumption of unhealthy and obesogenic diets, as well as the shift from an active rural to a sedentary urban lifestyle associated with insufficient PA [271]. Whilst PA and diet are distinct determinants, they are integrally interrelated and contribute to unhealthy, obesogenic environments that affect different socio-economic groups. In 2018, it was estimated that a third of Cameroonian adults were not achieving the recommended PA levels, and limited access to safe urban spaces for PA is a purported contributor [264].

Increasing PA requires collective efforts across different sectors and disciplines with socially and culturally relevant approaches. These approaches emphasise the need for intersectoral actions that integrate PA in all relevant sectors of society while respecting the needs and beliefs of communities. Such efforts should be underscored by stakeholders' communication that acknowledges and emphasises the importance of PA for NCD prevention and overall health to bolster the argument for integrating PA goals into all relevant policies. Examples of such intersectoral actions include efforts by the urban planning sector to promote the development of public spaces to encourage PA and the transport sector to promote safe walking, cycling, and the use of public transport in cities. Urban planning and transport are particularly crucial as these influence transport-related PA, the second highest contributor to daily PA after work-related PA in most LMICs [208]. Developing public spaces to encourage PA aligns with the principle of placemaking, which emphasises the collective reimagination and reinvention of public spaces as the heart of every community and city [272]. Other key sectors in the PA policy space include the health sector, which emphasises the role of PA in the prevention/management of NCDs, as well as the general health and wellbeing benefits of PA; the physical education and sport sector, which primarily focuses on promoting sports and physical education; and the education sector that incorporates physical education and sport in most curricula. These holistic intersectoral approaches have been emphasised in the 2018–2030 framework for implementing the global action plan on PA in the WHO African region [240].

In Cameroon, as in many LMICs undergoing rapid urbanisation and epidemiological transition, there is limited knowledge of the extent to which different sectors exert influence on PA to integrate the goals of promoting PA and mitigating NCDs into their policies. This study sought to explore how PA-relevant sectors incorporated PA and NCDs in their policies in Cameroon. This analysis was conducted as part of a broader set of retrospective policy analyses exploring global, African regional, and selected national policy environments for promoting PA and diet interventions for NCD prevention. The analyses form part of the work conducted by the Global Diet and Activity Research (GDAR) network [16], funded through the National Institute for Health Research Global Health Research initiative. The overall aim of the GDAR network is to contribute to the co-creation of interventions for reducing NCDs in LMICs. Other aspects of the GDAR research involve primary data collection to explore lived experiences, environmental exposures, and behavioural risk factors of NCDs.

5.3. Methods

We used an instrumental case study that systematically identified policy documents relevant to PA and NCD prevention in Cameroon. We then used the Walt and Gilson policy triangle framework, widely used for health policy analysis in LMICs and remains a valuable framework for gaining insight into the multi-dimensional aspects of policy [273, 274], to guide our policy document analysis. It allowed us to describe, analyse, and interpret the policy context, content, process, and actors of PA policies in Cameroon. We focused in detail on the content of these policies to understand whether and how they purposively incorporated health goals related to NCDs. We report our findings following suggestions from Kayesa and Shung-King (2021) on document analysis in health policy analysis studies in low and middle-income countries [275].

5.3.1. Document Search

For this study, we focused on formal, national government and written policy documents. Whilst we recognise that policies comprise much more than formally written documents and are sometimes expressed as practices in the absence of written policies, our scope was limited to written documents. We defined policy documents as Government policies, laws, strategies and plans of action, policy guidelines, policy roundtable discussion reports, policy declarations, statements of intent and other relevant documents.

Figure 1 summarises the inclusion and exclusion of policy documents. The inclusion criteria for policy documents were the following: (i) Written documents that were adopted by June 2020. We anticipated only a few documents, so we included all available documents up to the time of the research, June 2020. (ii) Documents that had implications for PA, such as addressing issues related to walking, cycling, physical education, and sport. These also included documents that targeted placemaking interventions, i.e., interventions that sought to improve environments through urban design. In addition, we included (iii) documents that were from PA-relevant sectors. The PA-relevant sectors were identified and purposefully selected by the GDAR senior researchers who have experience in PA promotion based on the known (direct and indirect) sector influence on PA and NCD prevention. The following Government sectors (including those specified by the framework for improving PA in Africa [240]) were selected: health, housing and urban development, decentralisation (local governance), transport, sport, education, security, culture, entertainment, and youth affairs. In addition, we included cross-sectoral governmental institutions (Offices of the Prime Minister, President, and Parliament), research institutions, non-governmental organisations, and civil society organisations. Our exclusion criteria comprised written documents that were still being developed and not yet adopted and documents for which the full text could not be found.

In the initial phase of the document search, we aimed to screen all the documents that articulated policy intentions from all the relevant sectors/ministries. Two researchers independently hand-searched the websites of the relevant ministries between March and June 2020 to compile a list of potentially relevant policy documents from each sector. During the same search period, relevant databases were queried for articles and reports that referenced relevant policy documents in Cameroon. Databases included PAIS Index, Sabinet Legal database, PubMed, Google Scholar and Science Direct databases and the Google search engines. We used various combinations of the following search terms to identify sentinel documents on the internet search: “non-communicable diseases”, “NCDs”, “cancer”, “diabetes”, “heart disease”, “obesity”, “NCDs policies”, “physical activity”, “physical inactivity”, “sedentary”, “physical education”, exercise”, “sport,” “walking”, “cycling”, “public transport”, “built environment”, “urban planning”, “Cameroon”, and “health policies”. The search terms were translated into French, and when the websites had information in both French and English, we conducted searches in both languages.

The initial list served as a guide for two trained research assistants to retrieve and screen policy documents from the ministries' archives. The research assistants also asked archive attendants and key ministry informants about relevant documents that could meet the inclusion criteria. Our initial search from all sources identified 600 potentially relevant policy documents. Upon screening the document titles, executive summaries (abstracts), and table of contents, 580 were excluded because they did not meet the inclusion criteria (these had no specific relevance to PA and NCDs). Two documents were further excluded because they were still being developed. One document was excluded for lack of full text. Seventeen documents were included for the final data extraction.

5.3.2. Data Extraction and Analysis

We reviewed full texts of the documents that explicitly mentioned PA or NCDs for data extraction. Data extraction and analysis were iterative. Two researchers independently coded data into the NVivo 12 software [276]. We combined a top-down (deductive) thematic coding guided by the Walt and Gilson policy triangle [274] with a bottom-up (inductive) coding that allowed us to identify new themes not initially thought of as part of the deductive coding framework. The research assistants reviewed full texts of identified policy documents in Government ministries and organisations and identified documents that explicitly mentioned PA or NCDs for data extraction. We based our initial coding on a pre-designed codebook developed by the Global Diet and Activity Research Network developed for the overarching global policy analysis on diet and physical activity [277]. The following variables were initially coded from each policy document: title, year of publication, the level at which the document was produced (national, subnational, local), producing agency, primary ‘ownership’ of the document, stated purpose of the document, intended target audience(s) of the document, intended timespan, framing and beliefs specific to PA, PA related NCDs, the role of the state, the policy process, the context, the actors involved, and specific proposals on transport and urban planning (given their significant contribution to the travel domain of PA). We compared and amended our extractions.

We used global and regional recommendations on NCDs and PA policies [240, 278] to highlight gaps in the policy landscape and identify opportunities for improving policies in Cameroon. Based on Walt and Gilson’s policy triangle [273], we analysed and interpreted the different policy contexts, processes, actors, and content as stated in the policy documents. The contexts included the country’s relevant socioeconomic and political situation, the challenges of the healthcare system, and the epidemiology of NCDs and PA. The policy process component captured reference to how policy proposals were made, while the actors referred to the stakeholders involved in the policy process. The content referred to any proposals to promote physical activity and prevent NCDs and the implementation and financing of these proposals. The policy proposals were grouped into themes using an inductive process. These themes were based on the proposed targets and if the proposal had a level of complexity that necessitated intersectoral actions.

To ensure the quality of the research, we held weekly meetings during the project design, data coding, analysis, and write-up phases to agree on data collection tools and share progress and preliminary findings. We used critiques and insights from other GDAR researchers during these meetings to refine our analysis and synthesis of findings. Figure 5.1 shows the flowchart for document selection.

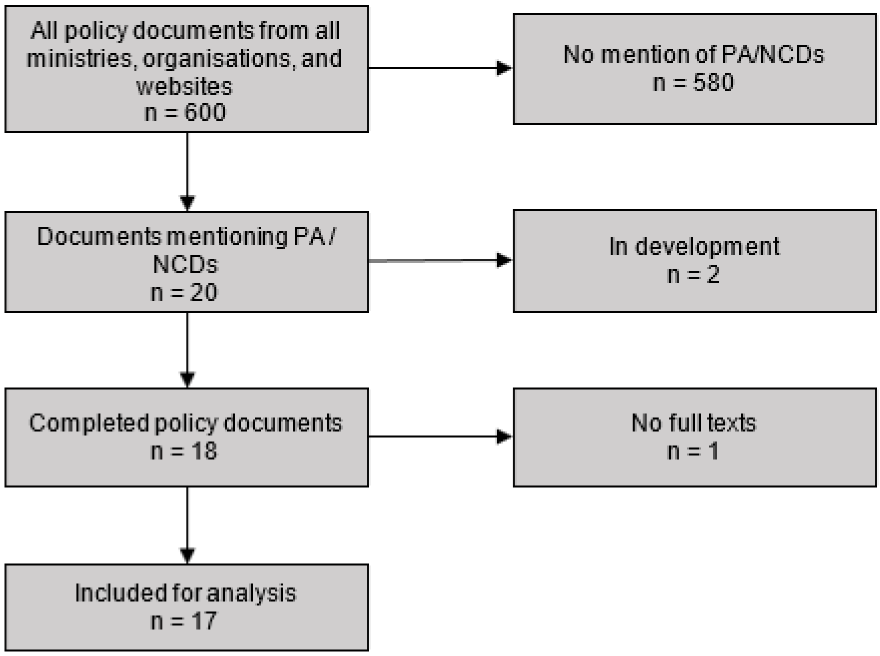


Figure 5.1 Flowchart of policy documents analysed for PA and NCD policies in Cameroon.

5.4. Results

We identified 17 policy documents explicitly mentioning PA and NCDs in Cameroon (Table 5.1). The documents spanned from 1974 to 2019 across seven ministries: Office of the Prime Minister, Sport and Physical Education, Health, Decentralisation (Local Governance and Development), Urban Development, Youth Affairs, and Education. The documents included eight laws, three executive orders, five strategic/action plans, and one policy document. Most records were from the Ministries of Sport and Physical Education (n=4), Health (n=4), and Decentralisation (n=4). While we found 58 policy documents from the transport sector, none mentioned PA or NCDs, so they were not included in the analysis. Seven documents (from the Office of the Prime Minister and Ministries of Decentralisation and Sport and Physical Education) focused on PA as the sole purpose of the document. In contrast, the rest of the documents considered actions relevant to PA promotion within actions that addressed sector-specific issues. Only one document, the National Integrated and Multi-sector Strategic Plan for the Control of Chronic NCD (NIMSPC-CNCD) of 2011–2015 [279], explicitly focused on NCDs. Below, we describe these policies' contexts, actors, processes, and contents.

Table 5.1 Physical activity-related policy documents in Cameroon (until 2020).

Year	Policy document	Type	Producing agency	Ownership
1974 ✓	Law No. 74/22 of December 5, 1974, on sport and socio-educational equipment [280]	Law	Parliament	Ministry of Sports and Physical Education
1996 ✓	Law No. 96/09 of August 5, 1996, establishing the Charter of Physical and Sporting Activities [281]	Law	Parliament	Ministry of Sports and Physical Education
1998	Law No. 98/004 of April 4, 1998, on the orientation of education [282]	Law	Parliament	Ministry of Education
2001	Health Sector Strategy 2001-2015 [283]	Strategic document	Ministry of Health	Ministry of Health
2004	Law No. 2004/003 of 21 April 2004 for urban planning in Cameroon [284]	Law	Parliament	Ministry of Housing and Urban Development
2004	Decentralisation law 2004 [285]	Law	Parliament	Ministry of Decentralisation
2008 ✓	Order No 048 / PM / CAB March 19, 2008 on Interministerial Committee for the Supervision of the National Program for the Development of Sports Infrastructures [286]	Executive order	Office of the Prime Minister	Office of the Prime Minister (Including Ministries of Sports, Finance, Planning, Public Works, Land Tenure, Urban Planning and Territorial Administration)
2010	Growth and Employment Strategy Paper (GESP) [287]	Strategic document	Office of the Prime Minister	Office of the Prime Minister (cross-ministry)
2011*	The National Integrated and Multi-sector Strategic Plan for the Control of Chronic NCD (NIMSPC-CNCD) of 2011–2015 [279]	Action Plan	Ministry of Health	Ministry of Health

2011 ✓	Law No. 2011/018 of 15 July 2011 on the organization and promotion of physical and sporting activities [288]	Law	Parliament	Ministry of Sports and Physical Education
2012 ✓	Decree N° 2012/0881/PM of 27 March 2012 to lay down the conditions for the exercise of certain powers devolved by the State to councils in matters of sports and physical education [289]	Executive order	Office of the Prime Minister	Office of the Prime Minister and Ministry of Sports and Ministry of Decentralisation
2012 ✓	Order No. 14/CAB/PM of 24 September 2012 on organization and functioning of Parcours Vita [290]	Executive order	Office of the Prime Minister	Office of the Prime Minister and Ministry of Sports and Ministry of Decentralisation
2015	National Youth Policy [291]	Policy document	Ministry of Sports	Ministry of Youth Affairs
2016	Health Sector Strategy 2016-2027 [292]	Strategic document	Ministry of Health	Ministry of Health
2016	National Health Development Plan 2016-2020 [293]	Action Plan	Ministry of Health	Ministry of Health
2018 ✓	Law No 2018/014 on the promotion of physical activity and sport in Cameroon [294]	Law	Parliament	Ministry of Sports and Physical Education
2019	Law No 2019/024 of 24 December 2019 on the general code of decentralized territorial authorities [295]	Law	Parliament	Ministry of Decentralisation

✓ Explicit focus on PA; * explicit focus on NCDs.

5.4.1. Context

The local social, cultural, economic, health, and political contexts that influenced PA-related policies in Cameroon varied over the four decades covered by the documents. In general, policies converged towards addressing infrastructural barriers and contextual needs for promoting culture, health and wellbeing, and competitiveness in sports. Expressions of PA were largely confined to physical education, exercise, and sport. Temporal evolution in PA policies was discernible, where a shift from focusing on competitive sports to exercise and physical education and health was observed.

"ARTICLE 1 - (1) Physical activities and sports contribute to the balance in health, education, culture, and development of the individual. They are of a general interest in nature… (Law No. 96/09 of August 5, 1996, establishing the Charter of Physical and Sporting Activities – Sport and Physical Education)" [281].

"Article 18 - Traditional games and sports are the expression of the richness of the national cultural heritage (Law No 2018/014 on the promotion of physical activity and sport in Cameroon - Sport and Physical Education)" [285].

From a socio-economic perspective, underdevelopment, as reflected by the insufficient and uneven distribution of resources and infrastructure, is captured in the background section of several policy documents. In the documents, the lack of infrastructure is reportedly perceived to be a barrier to the practice of physical activity, especially by youth. The majority of policies sought to address this need by developing infrastructure for physical education, exercise, and sports. The importance of excelling in sports was expressed as a cultural priority with a desire to display national talents and culture.

"Youths do not generally practice enough sports and physical education enough because of poor valuation of physical education at school, poor enforcement of existing laws, insufficient and uneven distribution of financial, material, and human resources, alongside infrastructural barriers (National Youth Policy 2015 – Youth Affairs)" [291].

Although health was considered broadly in some policies, it was not until 2010 that NCDs, and their risk factors, were highlighted in health policy documents as needing PA interventions. The 2011–2016 National integrated multisectoral plan for the control of NCDs included a focus on chronic diseases and expressed concerns about the increasing prevalence of NCDs, sedentary living, insufficient infrastructure for PA, rapid urbanisation, and poor implementation of health promotion activities.

"Urbanization of our cities has resulted in the importation and adoption of certain risk behaviours to cardiovascular disease, the lack of suitable services (development of recreational areas for sports, development health promotion programmes) in our councils. All this will, in years ahead, be one of the causes of the worsening of the current epidemiological situation (NIMSPC-CNCD Cameroon 2011-2016 - Health)" [279].

"Health promotion activities are poorly implemented in the country... However, the cost-effectiveness of health promotion interventions on the behaviour change of individuals justifies the effective implementation of the strategic activities of promotion and prevention of CNCDs (NIMSPC-CNCD Cameroon 2011-2016 - Health)" [279].

The link between the increasing NCD prevalence and different risk factors was also acknowledged, and the 2016–2027 Health Sector Strategy (HSS) emphasised the rising prevalence of some NCDs and their related behavioural risk factors in the two largest cities in Cameroon, Yaoundé and Douala. Obesity and overweight, unhealthy diets and insufficient PA were identified as the principal risk factors that needed tackling. The NCD policy document contains clear recommendations for other sectors, including improving public transport for physical activity.

"Roles of related ministries and stakeholders: Ministry of transport: Implementing policies that limit traffic circulation of private vehicles in urban centres to promote the use of public transport hence encourage physical activities (NIMSPC-CNCD Cameroon 2011-2016 - Health)" [279].

The contextual perception and framing of the NCD problem and the role of PA in its prevention were found to influence the attention accorded to these diseases. NCDs were framed as a problem in different ways, including as a share of disease burden, disease epidemiological risk factors, and economic consequences associated with the condition. NCDs were also perceived to receive less attention within the health system than infectious diseases, such as malaria and HIV, tuberculosis, and maternal and child health. The underfunding of the health systems was perceived to have had a knock-on effect on the failure to prioritise NCD prevention.

> *"In the same year, they [NCDs] were responsible for 882 and 862 deaths per 100 000 inhabitants in men and women, respectively […]. Among the most frequent NCDs are cardiovascular diseases, cancers, and road accidents (National Health Development Plan 2016-2020.Cameroon -Health)"* [293].

> *"The current health situation is characterized by the predominance of communicable diseases (HIV/AIDS, malaria, tuberculosis, etc.) and a significant increase of non-communicable diseases, including cardiovascular conditions, cancers, mental diseases, and trauma due to road accidents (National Health Development Plan 2016-2020. Cameroon – Health)* [293]*".*

5.4.2. Actors

Documents from the President's office and Parliament about the conduct of PA and sports in the country tended to cut across multiple sectors. Similarly, the Office of the Prime Minister (head of Government) played a coordinating role in intersectoral actions through executive orders.

The main sectors involved in policies that influence PA included the Ministries of Sport and Physical Education, Health, Decentralisation (Local Governance and Development), Education, Urban Planning, and Youth Affairs. Figure 5.2 shows the main sectors involved and with whom they collaborated in developing policies. The transport sector did not have policies that mentioned PA. The health sector involved multiple sectors in developing its strategic plans, although the participating sectors did not have corresponding plans reflecting their engagement with the Ministry of Health.

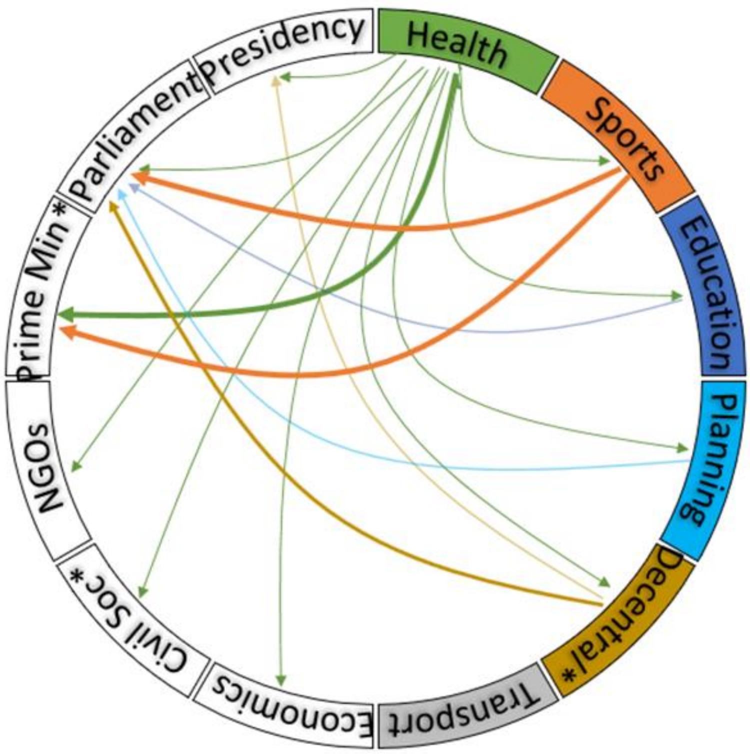


Figure 5.2 Main actors involved in physical activity-related policies in Cameroon. Boxes represent the sectors that owned the policies; the arrows point to the sector that collaborated on a policy; the thickness of the line represents the number of policy documents

5.4.3. Processes

As expected, most policy documents did not explicitly outline the processes involved in policy development. Laws would have been deliberated in parliament before being signed by the President. Still, the information that could enable tracing the sectors involved in the working groups was not available in the documents. Similarly, executive orders issued by the Prime Minister's Office were mainly informed by existing policies. While their development may have been instigated by the ministries concerned, this was not documented. Where documents described the process in detail, policies were developed within national and global strategic plans and frameworks. For example, the National Integrated and Multi-sector Strategic Plan for the Control of Chronic NCDs (NIMSPC-CNCD) of 2011–2015 [287] was derived directly from the Health Sector Strategy 2001–2015 [292]. Core working groups gathered information and evidence through national surveys, existing studies, and global and regional plans and drafted the initial documents. The initial drafts were finalised in workshops with multi-sectoral teams, including representatives from different ministries and non-governmental organisations in the country, and were adopted by the heads of the different sectors or their representatives.

> *"The process of developing the NIMSPC-CNCD [The National Integrated and Multi-sector Strategic Plan for the Control of Chronic NCD] was structured around the following major steps: ● Preparation of draft 0 of the NIMSPC-CNCD 2011-2016 by the main actors involved in the fight against NCDs; ● Update of the NIMSPC-CNCD linked to the 2013-2020 global action plan to combat NCDs; ● Conducting a national survey on the prevalence of the main risk factors common to NCDs in Cameroon, STEPS survey, etc.; ● Taking into account the results of the STEPS survey in the finalization of the draft of the strategic plan; ● The budgetary framework; ● The organization of a finalization workshop with a small team; ● The organization of a validation workshop by a multisectoral team; ● Adoption of the strategy document in the Council of Ministers.(NIMSPC-CNCD Cameroon 2011-2016—Health)"* [279].

Global and Regional Policy Reference

Most policy documents drew from global rather than African regional policies. In elaborating the 2016–2027 Health Sector Strategy, for example, the objectives were aligned with the sustainable development goals. However, more recent global (NCD and PA) [240] and regional (PA) [278] plans have not yet found expression in any national policy documents.

> *"Following the expiration of the MDGs, the UN General Assembly in November 2015 validated new objectives that will guide the development programme of member countries from 2016-2030. The 2016-2027 HSS [Health Sector Strategy] complies with health-related SDGs (SDGs No.3, No.6 and No.13) (Health Sector Strategy, 2016-2027—Health)"* [292].

The new national policies referred to existing national policies for two reasons. Firstly, to contextualise and describe work being done in a sector as seen in the *Growth and Employment Strategy Paper*, which described state-led sports promotion interventions.

> *"Government… will encourage, within the framework of law n ° 74/22 of December 5, 1970 on sports and socio-educational equipment, of law n ° 96/09 of August 5, 1996 fixing the charter of the physical and sports activities, as well as their texts of application, the creation of sports grounds for mass sport (Growth and Employment Strategy Paper, 2010—all Government policy)"* [287].

The second reason was to contextualise the policy that was being proposed. For example, in the 2016–2027 Health Sector Strategy, Vision 2035 of the President of the Republic and the *Growth and*

Employment Paper were referenced as the overarching direction under which the health sector strategy is being developed.

> *"The 2016-2027 HSS [Health Sector Strategy] vision which derived from the 2035 vision of the President of the Republic is formulated as follows: "Cameroon, a country where global access to quality health services is insured for all the social strata by 2035, with the full involvement of communities". To this end, the health sector will work towards contributing to the achievement of the development objectives of the Cameroon Vision by 2035 and the Growth and Employment Strategy Paper (Health Sector Strategy, 2016-2027—health)"* [292].

5.4.4. Content

Based on our analysis of the policy proposals, two broad categories were addressed across the 17 policy documents: proposals on changes in infrastructure for PA and proposals on communication for behaviour change. The proposals on communication for behaviour change encouraged behaviour change to promote PA through different channels such as advocacy, information, and campaigns without changes in infrastructure or equipment. Proposals on PA infrastructure suggested providing sports, exercise, physical education and other physical infrastructure or equipment to facilitate PA. All the proposals on infrastructure focused on the development of infrastructure that was specific to the promotion of PA without alternative uses. None of the proposals targeted integrated changes in the built environment that align with placemaking principles, i.e., collective reimagining and use of public spaces such as roads and public parks.

Table 5.2 summarises PA policy proposals identified from different sectors: sport (n = 5), health (n =4), urban planning (n =1), local governance (n = 3), education (1), youth affairs (n = 1), cross-government (1) and Office of the Prime Minister (1). Thirteen policies (13/17) targeted infrastructure improvement for enhancing physical education, exercise, sports, and thus leisure domain PA. However, no policies were identified that addressed other PA domains, such as occupational, domestic, and transport-related PA. Four policies (4/17) also targeted communication for behaviour change to enhance leisure domain PA. Policies that explicitly acknowledged the role of PA in preventing NCDs were mainly from the health sector.

Table 5.2 Proposals of physical activity-related policies in Cameroon

Year	Policy document (Sector)	Communication for Behaviour Change	Physical Activity Infrastructure
1974	Law on Sport and Socio-educational Equipment (Sport) [280]		*"Construction of sports and socio-educational facilities on school, building and societies (industries)"*
1996	Law on Charter of Physical and Sporting Activities (Sport) [281]	Information about "*organization of physical and sport activities, and practice of physical and sport activities (leisure and competition)"*	

1998	Law on the Orientation of Education (Education) [282]		*"The State defines the standards of construction and equipment of public and private educational establishments and ensures their control"*
2001	Health Sector Strategy 2001-2015 (Health) [283]	*"Establishing specific programmes to control obesity and encourage regular physical activity in schools"*	
2004	Law on City Planning in Cameroon (Urban Planning) [284]		*"To construct sports facilities"*
2008	Order on Supervision Development of Sports Infrastructures (Prime Minister) [286]		*"Article 2: The mission of the Committee is to help improve infrastructure and provide sports equipment".*
2010	Growth and Employment Strategy Paper (GESP) (Cross Government) [287]	Supervision of the sports movement: - *"Provide training in quantity and quality of supervisors* - *Strengthen sports research and excellence centres, promote the organization of competitions in all its dimensions* - *Improve the social protection of athletes and sports professionals* - *Facilitate the functioning of federations, etc."*	The strengthening of sports governance - *"Sanitation of the sports environment, the introduction of good management rules* - *Establishment of a real maintenance policy for existing and future infrastructures* - *Implementation of various incentives for the private sector to invest sustainably and in a multifaceted way in sports* - *The development of sports infrastructures for elite and mass sports.* - *Elite sport: construction of quality sports stadiums will be judiciously constructed and distributed over the national territory, making it possible to deal with the organization of competitions if necessary* - *School sport and the promotion of the practice of sport by the greatest number, the Government will*

			encourage the creation of sports arenas for mass sport".
2011	NIMSPC-CNCD 2011–2015 (Health) [279].	*"Key activities: Reinforcement of existing messages and creating new ones for health promotion in order to include major CNCDs risk factors such as unhealthy diet and physical inactivity."*	
2011	Law on the Organization and Promotion of Physical and Sporting Activities (Sport) [288]		*"Schools, vocational training, higher education and any urban development project must include sports infrastructure and equipment suitable for the practice of physical and sporting activities. The development and management of sports facilities should be organized by the State and local governments"*
2012	Decree on Powers Devolved to Councils in Matters of Sports and Physical Education (Local Governance) [289]		*The State through municipalities is responsible for the creation and the management of sports infrastructures*
2012	Order on Organization and Functioning of Parcours Vita (Sport) [290]		*"Ameliorate the grooming of extra scholar youths by creating socio educative and sporting infrastructure in compliance with urbanization rules; development of proximity infrastructure for the practice of physical education and sports"*
2015	National Youth Policy (Youth Affair) [291]		*"Ameliorate the grooming of extra scholar youths by creating socio educative and sporting infrastructure in compliance with urbanization rules; development of proximity infrastructure for the practice of physical education and sports"*

2016	Health Sector Strategy 2016-2027 (Health) [292]	*"Establishing specific programmes to control obesity and encourage regular physical activity in schools"*
2016	National Health Development Plan 2016-2020 (Health) [293]	*"Strengthening sport and physical activities. Construction/rehabilitation of proximity sport infrastructure for the practice of physical exercise, increase the number of sports instructors in divisions/subdivisions"*
2018	Law on the Promotion of Physical Activity and Sport (Sport) [294]	*"Article 12 (5): the plan for the construction of schools, vocational training and higher education must include sports equipment suitable for the practice of physical and sports activities."*
2019	Law on the General Code of Decentralized Territorial Authorities (Local Governance) [295]	*"Between the powers transferred to the municipalities, we have the creation and management of municipal stadiums, sports centres and courses, swimming pools, playgrounds and arenas."*

5.5. Discussion

We explored if and how relevant sectors expressed PA in their policies and the level of intersectoral action in Cameroon's PA and NCD policy spaces. We found that multiple sectors (n = 7) expressed PA in their policies, namely sport, health, local governance, urban planning, education, youth affairs, and the Office of the Prime Minister, although crucial sectors such as transport and culture made no mention of PA in their policies. A total of 17 policy documents explicitly expressing PA were identified; 4/17 proposals targeted the promotion of communication for behaviour change. 13/17 proposals targeted infrastructure development for promoting PA, mainly leisure domain PA. Notably, none of the proposals targeting infrastructure considered integrated urban development to promote PA domains such as transport (walking, cycling and public transport). The promotion of PA to prevent NCDs and improve health and well-being has progressively been acknowledged, although only the health sector has taken an interest in the health benefits of PA. Concerning intersectoral action, many vital sectors involved others when undertaking activities relevant to PA, but most of the invited sectors did not mention PA in their policies.

The involvement of multiple sectors in the PA policy space in Cameroon speaks to the intrinsic trans-sectoral nature of PA actions, on the one hand, and to the perceived importance of PA, on the other hand. Actions such as improving sports and recreational facilities, road traffic conditions, cultural and social activities, and educational facilities to increase PA are often the direct responsibility of different sectors. PA policies are poorly developed and researched in many LMICs [296]. Filho et al. (2016) [297] reported that only a few studies in the literature had explored PA interventions in LMICs, mainly noting the importance of school-based, multicomponent interventions. More studies have explored multisectoral approaches in promoting PA-related outcomes such as NCDs and general health in LMICs [296, 298–300]. The multisectoral nature of PA is exemplified in the 2018–2023 Kenyan National Physical Activity Plan, led by the Kenyan Ministry of Health. The plan identifies multiple PA-relevant sectors and their responsibilities. In South Africa, just as in Cameroon, multisectoral actions for PA are addressed in the NCD prevention plan and not in a separate national plan for PA. Kang (2013) [301] detailed the multisectoral nature of PA in South Korean cities, where he examined 393 PA programmes and showed that 85% of them had some form of multisectoral collaboration.

We found that PA expressions were primarily confined to sports, organised exercise, and physical education, which is geared towards improving leisure PA, with policy proposals failing to address other domains of PA such as work and transport-related PA (walking, cycling and public transport) that might not only contribute significantly to daily PA levels but also create room for stronger intersectoral actions. Walking, for example, is the dominant mode of transport in Cameroon and other LMICs (mode shares of walking for transport can be as high as 70% in some settings [302]) and an essential source of PA. Ignoring the presence and quality of walking environments downplays their importance and encourages people who can afford them to switch to other transport modes [303]. Similarly, cycling has both transport and PA benefits, and the lack of cycling infrastructure, such as cycling paths, does not encourage improving the cycling culture in the population [304]. Generally, public transport in urban areas contributes to PA mainly through associated walking and cycling. Public transport in Cameroon is unreliable and unsuitable, with formal buses contributing to only 1% of all trips. At the same time, commercial motorcycles, likely to reduce walking, account for over 60% of motorized urban travel [48]. However, information on travel behaviour in Cameroon is scanty, as is the case with many African countries [305].

Health is a fundamental human right, and the PA's ability to improve overall health and prevent NCDs makes a relatable case for most sectors. The fact that most policies do not explicitly acknowledge the health benefits of PA, except those from the health sector, is a problem, given that policies are partly informed and motivated by perceived benefits or averted harms. The failure to see how PA contributes to health in most sectors limits the sectors' opportunities to improve PA. It is unclear whether the failure to acknowledge the full spectrum of PA health benefits broadly results from a lack of knowledge or reflects the sector's area of priority. Still, an intersectoral approach to policymaking could help in both cases, especially the former, which leads to an increased understanding of potential policy benefits. Kahan (2013) argues that a condition is recognised as a social issue when people present information about it in a way that leads society to believe it is essential and worthy of attention [306]. It follows that framing appropriate actions for PA requires the basic step of acknowledging its benefits to health. The World Health Organisation recognises that the health ministries, rather than other ministers or heads of Government, will often need to lead intersectoral initiatives for health. The sector needs to suggest practical steps, such as illustrating the health impact of other ministries' policies and the health benefits of a collaborative approach to policy development [307].

Our findings showed key strategies concerning intersectoral actions for promoting PA. The creation of intersectoral committees has been recognised as a successful approach [308]. Collaborations among sister sectors directly align with intersectoral action principles as expressed by the WHO from its inception in the 1978 Alma Ata declaration [309] and in subsequent statements, including that of the commission on social determinants of health in 2008 [310]. The cross-government sectors, such as the Office of the Prime Minister, organise interministerial committees to tackle PA-related interventions [286], and ministries identify and collaborate with relevant sister sectors [292].

Although there are no rules on how intersectoral actions should proceed in any context, two potentially helpful strategies are partially incorporated in the Cameroonian context. Firstly, the parliament/presidency has promulgated multiple pieces of legislation with overlapping and shared common goals administered differently across ministries but lacked the intersectoral structures [56] to follow through on this laudable intention. For example, laws on decentralisation and sport could specify the required intersectoral committees or identify a coordinating ministry. Secondly, the failure to express PA and NCD actions in policies of relevant sectors indicated a lack of consideration of the 'health in all policies' approach promulgated by the SDGs and emphasised in the Adelaide Statement on Health in All Policies [311]. Actions of sectors invited to collaborate on PA interventions seemed to be limited to collaboration, as mention of PA could not be traced in most sectors. In addition, more structured tools such as the Urban Health Equity Assessment and Response Tool (Urban HEART) [312], which was jointly developed by the World Health Organisation, academia, and city officials in 2010, have been used in over 100 cities and 53 countries to address health inequities through actions on social, economic and physical environmental determinants of health. Both small towns such as Matsapha, Swaziland, with a population of 35,000 and large ones such as Tehran, the Islamic Republic of Iran, with eight million people, have used this tool, which in the context of intersectoral action, has directions on how to identify and gather relevant stakeholders [313].

The findings of this study highlight the need for Cameroonian NCD and PA-related policies to adopt a more robust approach for developing whole-of-society policies, health in all policies, and intersectoral policies. As whole-of-society policies provide overarching directions for key societal goals and serve as a reference for many sectors, including PA objectives in such high-level documents can facilitate their consideration and elaboration downstream. For example, urban health concepts will need to be embedded within national urban development mandates to shift the political will of urban planning-relevant sectors, such as transport or human settlements, towards intersectoral action to improve health. Relevant PA sectors should also explicitly articulate the link between PA, NCDs and well-being in their policies. This approach aligns with the health in all policies principle, highlighting PA's contribution to reducing NCDs as the leading global cause of mortality and ultimately preserving fundamental human health rights. Encouraging different sectors to sit around the table and develop policies on shared problems, including sharing approaches, experiences, and expectations, will enhance the intersectoral development of policies. In the case of PA policy, this would mean bringing together the urban planning, health, and transport sectors, among others, to discuss needed changes in the urban transport environment. Finally, actors involved in PA policies should consider the full breadth of the PA domains, which will promote a holistic approach to improving PA.

This study has two main strengths. First, it was conducted in tandem with GDAR global and regional analyses of policies on NCDs and risk factors, which allowed for the cross-pollination of ideas. As such, the study benefited from an overarching rigorous methodology, iterative feedback from an international steering committee, and real-time comparison of national, regional, and global outcomes to clarify the analysis. Second, the Cameroon context is socio-culturally and politically similar to many LMICs, with Cameroon often referred to as Africa in miniature [314]. Our findings would, therefore, be relevant to a broader context of LMICs undergoing rapid urbanisation and epidemiological transition. Despite filling an essential literature gap, our study has limitations. Our study's main limitations are those typically associated with case study designs, which include limited bases for generalising findings and subjectivity in interpreting findings. Cameroon's specificities could limit our results' generalisability; however, the country shares many similar geographical, cultural and political features with other LMICs that allow for the extension of findings to those settings. We reduced the subjectivity in our work by regularly reviewing the research process in team meetings and receiving feedback from the more extensive GDAR network and external members. A document-based policy analysis also has to contend with the many information gaps in policy documents. Still, as this is part of a broader research agenda, the complimentary information on the lived experiences of citizens of PA and other NCD determinants is addressed in other parts of the overarching project.

5.6. Conclusions

We identified multiple sectors involved in the PA policy space in Cameroon, although crucial sectors such as transport are notably absent. Policies primarily focused on physical education, exercise, and sport, targeting only leisure PA rather than including work and transport-related PA, which are significant PA sources for many people. In addition, the health benefits of PA were not broadly acknowledged, downplaying its importance. The findings highlight the need for intersectoral action to integrate physical activity into policies in all relevant sectors. These actions will need to encompass the breadth of PA domains, including transport PA while emphasising the health benefits of PA for the population. From a modelling point of view, evidence of transport health impacts from simplified scenarios would be a logical entry point for engaging with stakeholders at this stage.

6. A systematic review of studies modelling transport health impacts

This chapter presents a systematic review of studies modelling the health impacts of urban transport scenarios. It summarises model use cases on the health impacts of urban transportation, including the description of the differential effects of transport health impacts. The chapter discusses themes relevant to urban transport health impact models and their suitability for the African context; thus, it provides a basis for conducting urban transport modelling and adapting existing models for use in African settings. I co-lead the conception, analysis, and manuscript write-up. Other team members provided feedback on the case study, shaping the output presented in this chapter.

6.1. Abstract

The literature on urban transport health impacts has grown recently, with studies using various models and producing different health impacts. This systematic review aimed to synthesise modelling approaches on urban health impact modelling studies. The review followed the PRISMA guidelines and was registered on PROPERO (CRD42019136720). Databases searched were Ovid Medline, Ovid Embase, Scopus, the Web of Science Core Collection, the Cochrane Central Register of Controlled Trials and the Transportation Research International Documentation. We combined search terms about different transport modes, health outcomes, and health impact assessment methodologies. We included studies that focused on scenarios/interventions that led to mode shifts to/from active travel, used a health impact assessment methodology, and reported quantitative outcomes in at least the physical activity pathway. Many impact modelling studies (87) of varying transport scenarios exist, mainly in high-income settings. Researchers largely developed the assessed scenarios, which focused on switching car trips with defined characteristics to more active modes and infrastructure changes (e.g. implementation of bike lanes). The main assessed pathways were air pollution, road traffic injuries, and physical activity, but studies show the potential for including more pathways. Less than a third of these studies explored health impacts in different population groups. The review highlights advances in urban transport health impact modelling in terms of tools, scenarios, pathways, and subgroup analyses, as well as cues to help close the gap in lower-income settings.

6.2. Background

Urban transport, as an essential determinant of health, affects health through multiple quantifiable pathways via changes in population exposure to health risk factors such as air pollution (AP), road traffic injuries (RTI), and physical activity (PA) [15]. These pathways often interact, so changes in one pathway may improve or worsen other exposures. For example, improving physical activity through active transport (i.e. walking and cycling for transport, including when accessing public transport) may increase active travellers' exposure to RTI and AP, especially if they travel in proximity to other vehicles. The risk of RTI per active traveller somewhat reduces as their numbers increase (safety-in-numbers), and the population exposure to AP reduces as more people switch from driving to active travel (section 2.4). The complex interactions among transport-to-health pathways complicate the evaluation of the health impacts of urban transport policies, and many researchers have embraced modelling studies to understand transport health impacts.

Compiling studies modelling transport health impacts provides an opportunity to examine the models, settings and scenarios in which modelling has been applied, identify patterns in transport's health impacts across different dimensions, and evaluate methodological influences on estimates. Earlier reviews have found that active transport can provide substantial net health benefits irrespective of geographical context [315] and that increases in physical activity are the most critical contributor to the health impacts of active transport [316]. In addition, the authors noted differences in benefits across different population groups, but the health equity impacts of active transport were uncertain [315].

This systematic review addresses the following questions: (1) what scenarios and models are adopted for transport health impact assessments in different settings? (2) How are transport health impact estimates affected by the choice of modelling methodologies?

6.3. Methods

The systematic review of studies modelling transport health impacts followed the 2020 PRISMA guidelines [317], and the protocol was registered on PROPERO (CRD42019136720). The guideline items are detailed in the following subsections.

6.3.1. Eligibility criteria

Modelling studies that evaluated the health impact of transport were eligible for inclusion in our review if they met the following criteria: (i) focused on prospective or retrospective interventions or scenarios in transportation, built environment, land use, economy, or energy that directly or indirectly produced a mode shift to/from motorised transportation to/from active transport or public transport, or mode change in active or public transport. (ii) comprised quantitative HIA methodology of comparative risk assessment, cost-benefit analysis, risk assessment, benefit assessment, or simulation modelling. (iii) reported a quantitative change in the exposure distribution of at least one health pathway (physical activity). (iv) reported a quantitative change in at least one health endpoint. These eligibility criteria were similar to those used by Mueller et al. (2015) [315], with additions to the original eligibility criteria, such as including walking, cycling, and micro-mobility (e.g. e-scooters) as active transport modes. Studies were ineligible for inclusion if they were: (i) non-English language studies, abstracts/conference proceedings, and studies for which no full texts were available and (ii) studies that quantified the disease burden from transport without mode shifts.

6.3.2. Information sources

We searched studies from the following databases: Ovid Medline, Ovid Embase, Scopus, the Web of Science Core Collection, the Cochrane Central Register of Controlled Trials and the Transportation

Research International Documentation. We selected these databases to cover relevant academic disciplines (i.e. health, transport and the social sciences). We tracked additional studies through forward (citation screening using Scopus and Web of Science) and backward (reference list) screening and through senior team members.

6.3.3. Search strategy

Following a pilot in May 2019, we conducted the last database searches in February 2021 in consultation with a medical librarian (Appendix 10.2.1). We adapted the search strategy from Mueller et al. (2015) [315] to include equity-related terms (e.g. inequality*) (informed by Smith et al. (2017) [318]) and a more comprehensive range of HIA methodologies (e.g. through including DALY as a search term as this is a standard outcome measure). The search strategy combined search terms spanning different transport modes, health outcomes, and HIA methodologies. The search strategy was tested and refined using a list of known relevant studies, including studies included from the earlier review. The complete list of search terms for each database is included in Appendix 10.2.1.

6.3.4. Selection process

We imported citations into the Ryyan software and removed duplicates. Two team members double-screened all titles, abstracts, and full texts against the eligibility criteria. A third team member resolved discrepancies and singly screened articles resulting from forward and backward reference screening. Full texts of eligible articles were downloaded as pdf for data extraction.

6.3.5. Data collection process

Two investigators independently extracted data from each selected study into Microsoft excel sheets, and a third investigator combined the data while resolving discrepancies. Discussions within this group resolved other differences. We did not contact the study authors to confirm the accuracy of the extracted data.

6.3.6. Data items

We extracted data using the extraction template included in the appendix (Appendix 10.2.2). Briefly, we extracted the following outcome information: scenarios/interventions assessed, the modelling approach used (as described by the authors), the health pathways considered, the health outcomes reported, and whether the study examined differential impacts. Additionally, we extracted information about the study settings, authors' information and funding details.

6.3.7. Study risk bias assessment

We used several steps to minimise the risk of bias in our review. We used an extensive list of search terms to search all relevant databases; used the Ryyan software to flag discrepancies between reviewers; double screened titles, abstracts, and full texts; and double extracted selected studies and used group discussions to agree on other differences.

6.3.8. Effect measures and evidence synthesis

Studies had varied endpoints, so we included all the reported outcomes in their units. Syntheses included inductive and deductive summarising qualitative elements and harmonising and aggregating quantitative elements. When possible, we further grouped studies based on setting (high- vs low-income) and population subgroups (age and sex) to examine differential transport health impacts.

6.3.9. Reporting bias and certainty description

Our appraisal of the certainty of the evidence was bespoke, as it was impossible to apply existing frameworks such as GRADE [319]. Instead, we used vote counting combined with elements of Bradford Hill's principles of causation [320] to guide us towards more certain findings. In particular, we considered the Bradford Hill domains of consistency (similar results across multiple studies and countries), plausibility (plausible mechanism of cause and effect informed by qualitative synthesis), coherence (similar findings across different disciplines and methods) and analogy (similarities between related results).

6.4. Results

6.4.1. Search outcome

We gathered 24,494 records from all databases and retained 7802 records for screening after removing duplicates and records published before 2014. We identified 188 records after the title and abstract screening and 88 after full-text screening (6 of which overlap with Mueller et al. (2015) [315]). Figure 6.1 details the PRISMA flow diagram for this study.

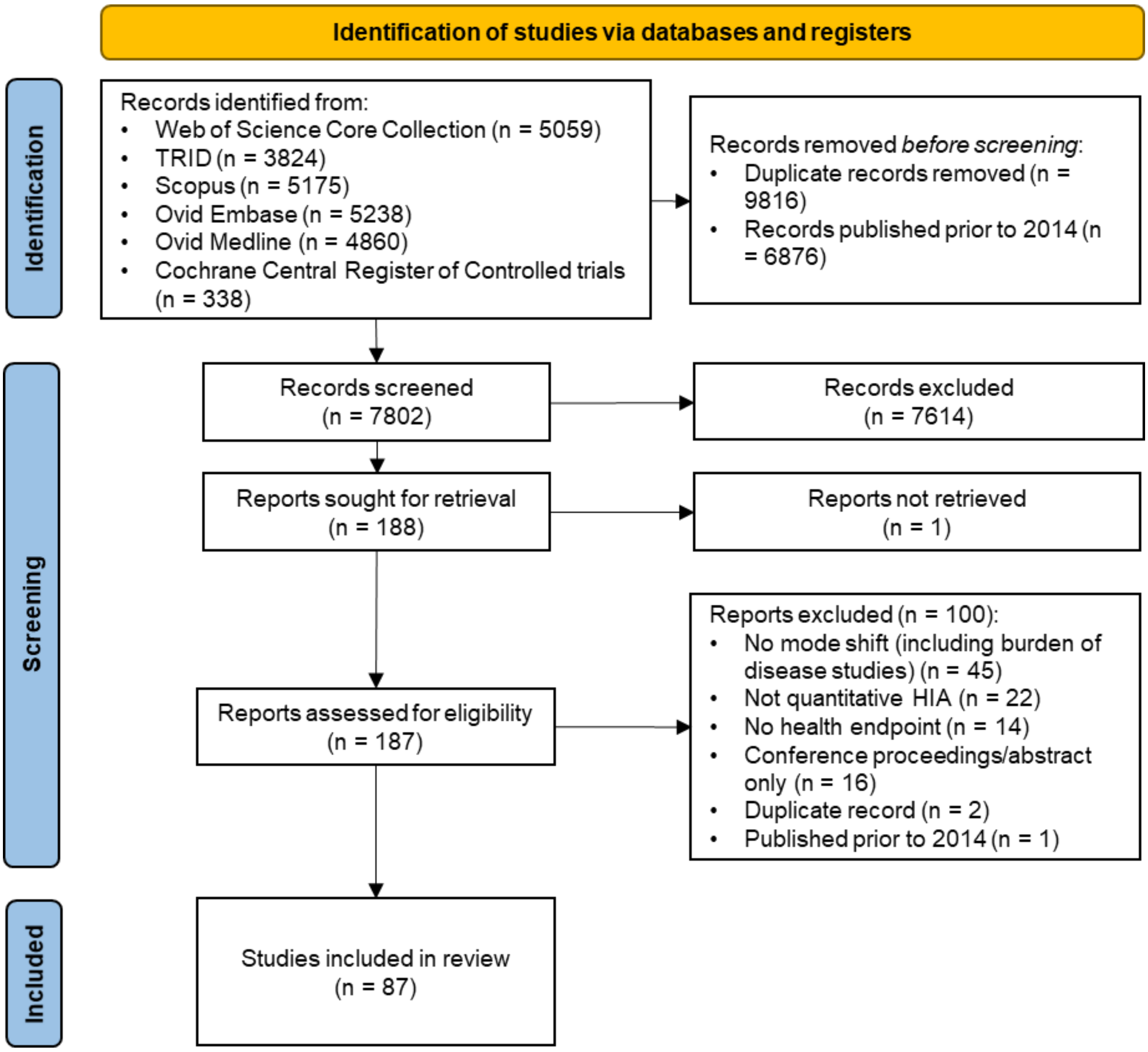


Figure 6.1 PRISMA flow diagram for health impact urban transport

6.4.2. Study Characteristics

Table 6.1 shows the key details of the included studies. The majority of studies (n = 75) focused on a single setting, typically a single city or other jurisdiction within a country (n = 64) or a single country (n = 11), with one study using the European Union as the setting. Eleven studies had multiple settings; four covered multiple jurisdictions within a country, and seven covered multiple jurisdictions across multiple countries. Evaluations spanned 28 countries (six of which were only represented in studies spanning multiple settings). Countries that had more than five studies that exclusively focused on a particular setting were the USA (n = 22), Australia (n = 10), the UK (n = 6), Ireland (n = 5) and New Zealand (n = 5). Thirty-nine studies were conducted in Europe or included European countries or cities in HICs. And only five studies included LMIC cities: São Paulo and New Delhi.

Table 6.1 Key details of included studies on urban transport health impact modelling.

Author (Year)	Study setting	Scenarios	HIA approach	Health pathway(s)	Health outcomes	Differential impacts
Arsenio (2015)[321]	Portugal, Viana do Castelo	The potential of new walking infrastructure: 1) Conservative change: the number of regular walkers increases from 440 to 644 per day 2) Optimistic: 50% of 25-64-year-olds in one borough (n=2,708) change behaviour, increasing the total number of regular walkers to 914	CRA - WHO HEAT	Physical activity	Economic	No
Babagoli (2019)[322]	USA, New York, New York City	Evaluation of bike share scheme (Citi Bike)	CRA - WHO HEAT	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Economic	Yes - Deprivation
Bassett (2020)[323]	New Zealand	Per kilometre impacts of walking and cycling	CRA	Physical activity	Composite health metric, Economic	Yes - Age and ethnicity
Beavis (2014)[324]	Australia, Melbourne	1) Mode of transport: 10% of vehicle users changed to either public transport or cycling 2) Residential sub-region: outer suburban population developed incidental PA levels seen in other sub-regions	CRA	Physical activity	Mortality-related, Morbidity-related, Composite health metric, Economic	Yes - Geographic
Brey (2017)[325]	Spain, Seville	Construction of a city-wide 140km long bicycle lane network in Seville	Economic analysis - cost-benefit analysis	Physical activity, Road injury	Morbidity-related, Economic	No

Brinks (2015)[326]	Germany	1) Business-as-usual (current population patterns) 2) Increased active travel	Life table - cohort Markov model	Physical activity	Mortality-related, Morbidity-related	Yes - Gender
Brown (2017)[327]	Australia	1) Doubling of current rates of cycling commuting 2) Doubling of current rates of walking commute 3) Achieving 30% commuting modal share in capital cities by cycling 4) Achieving 30% commuting modal share in capital cities by walking	Life table - Multi-state life table	Physical activity, Road injury, BMI	Mortality-related, Morbidity-related, Composite health metric, Economic	No
Brown (2017)[328]	Australia	Increase in fuel excise taxation of AUD0.10 per litre	Life table - Multi-state life table	Physical activity, Road injury, BMI	Composite health metric, Economic	No
Brown (2017)[329]	Australia, Melbourne	5% increase in active commuting of the working-age population	Life table - cohort Markov model	BMI	Composite health metric, Economic	No
Brown (2019)[330]	Australia, Melbourne	1) Trend for public transport accessibility under current policy settings (including the completion of projects that already have funding and implementation commitments) and the patterns of population growth identified under current trajectories of urban intensification and outer expansion 2) Aspirational, 'best case' approach, assuming the development of an outer orbital rail link and a range of inner orbital tram and bus connections to create a more multi-directional, high-frequency network	Life table - Multi-state life table	Physical activity, Road injury, BMI	Mortality-related, Morbidity-related, Composite health metric, Economic	No

Buekers (2015)[331]	Belgium, Flanders	25km long bicycle highway from Antwerp-Mechelen and the 30km long bicycle highway from Leuven to Brussels	Economic analysis - cost-benefit analysis	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Composite health metric, Economic	No
Bullock (2017)[332]	Ireland, Dublin	Bike share scheme	Economic analysis - cost-benefit analysis	Air pollution ($PM_{2.5}$, PM10), Road injury	Economic	No
Chapman (2018)[333]	New Zealand, New Plymouth and Hastings	Real-world extension of walking and cycling networks and other support for active transport (e.g. 'Share the Road' marketing campaign)	CRA - ITHIM	Physical activity, Air pollution (other), Road injury	Mortality-related, Composite health metric, Economic	No
de Sa (2017)[334]	Brazil, São Paulo	A counterfactual scenario in which the whole city adopts travel patterns: 1) from those living in the centre of the city 2) from London in 2021 (high PT and walking levels) 3) highly motorised - similar walking, car and PT to California combined with São Paulo levels of walking and cycling 4) vision with much higher walking and cycling based on official documents, including the municipality's long-term plan	CRA - ITHIM	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Morbidity-related, Composite health metric	Yes - Gender
Deenihan (2014)[335]	Ireland, Dublin, a buffer around proposed	60km cycle route along a disused towpath	CRA - WHO HEAT	Physical activity	Mortality-related, Economic	No

	cycleway (141,777 people)					
Doorley (2015)[316]	Ireland, Dublin	All work commuter trips under 5km taken by car or van taken by walking or cycling instead	CRA - Adapted from WHO HEAT	Physical activity, Air pollution ($PM_{2.5}$, NOx, other), Road injury	Mortality-related, Morbidity-related, Economic	Yes - Geographic, age, and gender
Doorley (2017)[336]	Ireland, Dublin	1) Current Mode Share 2) Smarter Travel Mode Share: increased cycling, reduced car use in line with National Cycle Policy Framework goal 3) Intermediate Mode Share: mode share halfway between Current and Smarter Travel Scenarios	CRA	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Morbidity-related, Composite health metric	Yes - Age and gender
Doorley (2018)[337]	Ireland, Dublin	All commuter trips currently undertaken by car under 5km are cycled	CRA	Physical activity, Air pollution ($PM_{2.5}$, NOx, other), Road injury	Mortality-related, Morbidity-related, Composite health metric, Economic	Yes - Age and gender
Edwards (2014)[338]	USA	Substitution of a 6-mile (10 km) daily round-trip bicycle commute for five days each week over 50 work weeks for an equivalent set of commutes by car, starting at age 20 and ending at age 65	Life table	Physical activity, Road injury	Mortality-related	Yes - Age

Elvik (2017)[339]	Norway, Oslo	Differing amounts of cycling with and without substitution from driving	Injury risk model	Road injury	Morbidity-related, Economic	No
Elvik (2019)[340]	Norway, Oslo	Four scenarios reducing person km performed by car by 10%: 1) displaced car trips allocated proportionally to other modes - walking, cycling, and PT all increase by 28.6% 2) displaced car trips are replaced by a 20% increase in walking and cycling and a 31.6% increase in public transport 3) displaced car trips replaced by a 10% increase in walking and cycling and a 35.1% increase in PT 4) displaced car trips are replaced by a 35% increase in walking and cycling and a 26.3% increase in PT	Injury risk model	Road injury	Morbidity-related	No
Farzaneh (2019)[341]	Iran, Tehran	Implementation of the Tehran Transportation Master Plan. It includes increasing the length of subway lines, developing bus rapid transit, increasing natural gas buses, improving the restricted traffic zone enforcement, increasing bike routes, improving fuel economy	CRA	Air pollution (PM_{10}, NOx, other)	Mortality-related, Economic	No
Friedrich (2016)[342]	European Union	Traffic management, public transport, rural speed limits, freight, maritime ships, shore-based electricity, low emission zones, Euro 7, tyre and braking technology, increased bicycling	Economic analysis - cost-benefit analysis	Air pollution ($PM_{2.5}$, NOx)	Composite health metric, Economic	No

Giallouros (2020)[343]	Multiple: Six cities (Helsinki, London, São Paulo, Warsaw, Beijing, New Delhi)	Restricted mobility on high air pollution days: 1) Days where PM2.5 concentration exceeds set thresholds (35μg/m3, 53μg/m3, 70μg/m3, 100μg/m3 or 150μg/m3) 2) 'High air pollution days' classified as the ten most polluted days in each year	CRA - Adapted from WHO HEAT	Physical activity, Air pollution ($PM_{2.5}$)	Mortality-related	No
Gibson (2015)[344]	USA, North Carolina, Raleigh	Potential effects of the new small area plan	CRA - Adapted from WHO HEAT	Physical activity	Mortality-related, Morbidity-related, Economic	No
Goryakin (2019)[345]	Italy	Multiple physical activity interventions. The active Transport scenario entailed the expansion of mass transit options to an additional 1% of the Italian population in 2019.	Life table - microsimulation - OECD SPHeP-NCD (Strategic Public Health Planning for NCDs) model	Physical activity	Mortality-related, Morbidity-related, Composite health metric, Economic	No
Gotschi (2015)[346]	UK, England and Wales	Shifts to travel patterns of Switzerland, the Netherlands, and California	CRA - ITHIM	Physical activity	Mortality-related, Composite health metric	No
Gu (2016)[347]	USA, New York, New York City	Bike lane construction	Injury risk model (with secondary values used for	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Composite health metric, Economic	No

			other outcomes)			
Guariso (2017)[348]	Italy, Milan	1) Current scenario - the current situation in Milan 2) 2024 scenario – a higher number of cyclists, based on the modal split estimated for 2024 by the Plan of Urban Sustainable Mobility 3) Improved air quality scenario - scenario 2024 with an additional decrease in PM10 level of 5g/m3 4) Amsterdam scenario - scenario assumes that Milan achieves Amsterdam's cycling situation	CRA - Adapted from WHO HEAT	Physical activity, Air pollution (PM_{10})	Mortality-related, Economic	No
He (2017)[349]	China	Changes in the price of gasoline and diesel (by +30%, +5%, -40%, and -3%)	Economic analysis	Air pollution ($PM_{2.5}$, NOx, other)	Mortality-related, Economic	No
Hou (2020)[350]	USA, New York, New York City	1) With bike share (Citi Bike) 2) Without bike share (hypothetical): bike share trips allocated to other modes to presume the Citi Bike program did not exist	CRA - ITHIM	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Composite health metric	Yes - Age and gender
Iroz-Elardo (2020)[351]	USA, California, San Joaquin County	Three scenarios based on the San Joaquin Council of Government's 2018 Regional Transportation Plan	Other - land use regression model	Physical activity, BMI	Morbidity-related	Yes - Geographic
Jaller (2019)[352]	USA, California, San Francisco Bay Area	Focused on first-mile transit access using ridesharing. Scenarios included reductions in access time and cost per mile.	CRA- ITHIM	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Composite health metric, Economic	No

Jaller (2020)[353]	USA, California, San Francisco Bay Area	1) Connected autonomous vehicle (CAV) scenario 2) CAV+50% active transport 3) CAV+10% active transport	CRA- ITHIM	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Composite health metric, Economic	No
James (2014)[354]	USA, Massachusetts	Speed Limit Bill: legislation to reduce speed limits from 30mph to 25mph on local roads.	CRA (with Elkik power model for injuries)	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Morbidity-related, Economic	No
James (2014)[355]	USA, Massachusetts, Boston	1) PT fares increase by 43%, service reductions affecting 34-48million trips per year 2) PT fares increase by 35%, with service reductions affecting 53-64 million trips per year	CRA	Air pollution ($PM_{2.5}$, NOx, other), Road injury, Noise, Access to healthcare	Mortality-related, Morbidity-related, Economic, Environmental	No
Johansson (2017)[356]	Sweden, Stockholm county	Switching commutes from car to cycling if commute can be cycled in 30mins	Life table	Air pollution (NOx, other)	Mortality-related	Yes - Geographic
Kriit (2019)[357]	Sweden, Stockholm	The proposed investment in urban bicycle infrastructure in Stockholm, Sweden	Economic analysis - cost-effectiveness	Physical activity, Air pollution (other), Road injury	Composite health metric, Economic	No
Kwan (2016)[358]	Malaysia, Kuala Lumpur	Klang Valley Mass Rapid Transit	Life table	Physical activity, Air pollution ($PM_{2.5}$, NOx, other), Road injury	Mortality-related, Environmental	No

Kwan (2017)[359]	Malaysia, Kuala Lumpur	Modal shift resulting from two upcoming mass rapid transit lines	CRA - ITHIM	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Composite health metric, Environmental	Yes - Users/non-users
Lamu (2020)[360]	Norway, Oslo	Expansion of cycle network in Oslo	CRA - ITHIM	Physical activity	Composite health metric, Economic	No
Macmillan (2014)[361]	New Zealand, Auckland	Investment in cycling proposed in 30-year strategic transport plan. Policy scenarios examined were a regional cycle network, arterial segregated bike lanes, self-explaining roads, and bike lanes combined with self-explaining roads	Economic analysis - cost-effectiveness	Physical activity, Air pollution (PM_{10}), Road injury	Economic	No
Mahendra (2015)[362]	India, Madhya Pradesh, Indore	Implementation of bus rapid transit	Complexity science - system dynamics	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related	No
Maizlish (2017)[363]	USA, California	Four alternatives to a 2010 baseline maintaining total miles travelled: 1) Walk: increased transport-related walking to the population mean of 283min/person 2) Cycle: cycling increased to 283min/person, other modes constant 3) Transit: ambitious expansion of transit 4) Blend: increased walking, cycling and transit to equal time	CRA - ITHIM	Physical activity, Road injury	Mortality-related, Composite health metric, Environmental	Yes - Geographic

Mansfield (2015)[364]	USA, North Carolina, three target communities	Proposed changes to the built environment aiming to increase walkability	CRA - HEAT and DYNAMO-HIA	Physical activity	Mortality-related, Morbidity-related, Economic	No
Mansfield (2016)[365]	USA, North Carolina, Raleigh-Durham-Chapel Hill region	1) increased land use diversity, transit stop coverage, and intersection density increase by 10%, resulting in a 7.9% increase in walking 2) as above, 7.9% of current drivers switch to walking instead of driving to work 3) transit coverage increases by 50%, resulting in 14.5% of drivers switching to public transit for their work commutes	CRA	Physical activity	Mortality-related	Yes - Geographic
McAuley (2016)[366]	UK, Scotland	Multiple non-transport scenarios. Changes in the extent of active (walking and cycling) commuting to and from work	Life table	Physical activity	Mortality-related, Morbidity-related, Economic	Yes - Deprivation
McClure (2015)[367]	Multiple: Six cities (New York, London, Delhi, Beijing, Copenhagen, Melbourne)	1) Reduce travel mode risk: reduced risk of crash per kilometre (primary prevention) and the risk of serious injury per crash (secondary prevention) 2a) Mode shift: change the transport mode distribution from individual motorized transport to mass transport and active transport 2b) Mode shift plus mode separation: mode shift with adequate purpose-specific infrastructure so that users of one mode do not increase the crash risk of users of other modes. 3) Combined: combined implementation of 1 and 2.	Complexity science - system dynamics	Road injury	Mortality-related, Composite health metric	No

Meehan (2017)[368]	USA, Tennessee, Nashville	Shifting vehicle miles travelled to walking and cycling while holding total miles constant: 1) Conservative: +1.7miles/week/capita for walking, +1.0miles/week/capita for cycling 2) Moderate: +3.7miles/week/capita for walking, +1.5miles/week/capita for cycling 3) Aggressive: active transport to meet physical activity guidelines (5.7miles/week per capita walking and 3.0miles/week per capita cycling)	CRA - ITHIM	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Economic	No
Mizdrak (2019)[369]	New Zealand	1) Switching car trips under 1km to walking 2) Switching car trips under 5km to a mix of walking and cycling	Life table - Multi-state life table	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Composite health metric, Economic, Environmental	Yes - Age, gender, and ethnicity
Mueller (2018)[370]	Multiple: Europe, seven cities (Antwerp, Barcelona, London, Orebro, Rome, Vienna, Zurich)	Expansion of the cycling network: 1) 10% expansion 2) 50% expansion 3) 100% expansion 4) Network expansion to all streets	Economic analysis - cost-benefit analysis	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Economic	No
Mueller (2020) [371]	Spain, Barcelona	Barcelona Superblocks - 503 superblocks	CRA	Physical activity, Air pollution (NO2), Noise, Heat, Green space	Mortality-related, Economic	No

Muennig (2014)[372]	USA, New York, New York City	Safe routes to School - roadway improvement to build new sidewalks and bicycle lanes and improve safety at crossings	Economic analysis - cost-effectiveness	Road injury	Composite health metric, Economic	Yes - Age
Nicholas (2019)[373]	USA, California, Los Angeles	Three alternative scenarios of Mobility Plan implementation compared to a 2035 BAU scenario: 1) conservative - more AT and transit than BAU 2) aspirational - low active transportation (conservative + more transit) 3) aspirational - high active transport (conservative + more AT)	CRA - ITHIM	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Composite health metric, Economic	No
Nilsson (2017)[374]	Sweden, Stockholm	Car occupants in Stockholm change mode of transport to a bicycle if the workplace can be reached within 30 minutes by bike	Injury risk model	Road injury	Mortality-related, Morbidity-related, Composite health metric	No
Otero (2018)[375]	Multiple: Europe, cities with bike share schemes with >2000 bikes (Barcelona, Brussels, Hamburg, Lille, Lyon, Madrid, Milan, Paris, Seville, Toulouse, Valencia, Warsaw)	1) Observed level of car substitution by bike share scheme (BSS) bike trips 2) Minimum level of car substitution by BSS bike trips (4.7%) 3) Maximum level of car substitution by BSS bike trips (12%) 4) 50% of all BSS trips come from car trips 5) 100% of all BSS trips come from car trips	CRA - TAPAS tool	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Economic	No

Perez (2015)[376]	Switzerland, Basel	1) Decided Policies: implementation of all transport-related measures decided by local government to 2020 2) Z9: additional transport measures to further reduce traffic by 4% on inner roads, with a local shift of car trips to active transport 3) p10: Z9 but with a 10% reduction of traffic on inner roads 4) p50: expansion of p10 with the assumption that 50% of the private car fleet would be electric	CRA and Life table	Physical activity, Air pollution ($PM_{2.5}$, other), Noise	Mortality-related, Morbidity-related, Composite health metric, Environmental	Yes - Gender
Perez (2017)[377]	Spain, Barcelona	Pre/post evaluation of changes in walking and cycling trips between 2009 and 2013	CRA - WHO HEAT	Physical activity, Road injury	Mortality-related, Morbidity-related, Economic	No
Rodrigues (2020)[378]	Portugal, Porto	1) conservative scenario: a change of 5% from driving to cycling and 10% from driving to walking 2) moderate scenario: a shift of 10% from driving to cycling and 15% from driving to walking 3) optimistic scenario: a shift of 15% from driving to cycling and 20% from driving to walking	Economic analysis	Physical activity, Air pollution (PM_{10}), Road injury	Mortality-related, Morbidity-related, Composite health metric, Economic, Environmental	No
Rojas-Rueda (2016)[379]	Multiple: six cities from Europe (Barcelona, Basel, Copenhagen, Paris, Prague, Warsaw)	Two active transport targets based on active transport levels were achieved in similar settings (35% cycling and 50% walking)	CRA	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Environmental	No

Rowangould (2019)[380]	USA, California, Sacramento	Different variations of the Metropolitan Transportation Plan/Sustainable Communities Strategy	CRA	Physical activity, Road injury	Mortality-related, Composite health metric	Yes - Geographic
Sabel (2016)[381]	Multiple: five cities from Europe (Kuopio, Finland; Rotterdam, Netherlands; Stuttgart, Germany; Basel, Switzerland and Thessaloniki, Greece) and two from China (Xi'an and Suzhou)	Different policies for each of the cities. Transport policies included: electric cars, fewer vehicles, congestion charges, parking restrictions, biofuels, active transport, new metro	CRA	Physical activity, Air pollution ($PM_{2.5}$), Noise	Mortality-related, Morbidity-related, Composite health metric, Economic, Environmental	No
Schepers (2015)[382]	Netherlands, a hypothetical city	3.3 km of new bicycle lanes and 3 km of bicycle paths in a hypothetical city of 100,000 inhabitants	Life table	Physical activity, Air pollution (NOx, other), Road injury	Mortality-related, Economic	Yes - Age
Shaw (2018)[383]	New Zealand, five cities (Auckland, Hamilton, Tauranga, Christchurch, Dunedin)	Mode share of Wellington City applied to the other five most prominent cities in New Zealand (Auckland, Tauranga, Hamilton, Christchurch and Dunedin)	CRA - ITHIM	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Morbidity-related, Composite health metric, Environmental	No

Smargiassi (2020)[384]	Canada, Greater Montreal	Three urban core densification scenarios for 2061: 1) BAU 2) Optimal scenario with teleworking/schooling 3) Optimal scenario without teleworking/schooling	CRA	Physical activity, Air pollution (NOx), Road injury	Composite health metric, Environmental	Yes - Geographic
Smith (2016)[124]	UK	The Committee on Climate Change proposed measures in Medium Abatement Scenario, the UK statutory advisor on carbon budgets. For transport, measures include a switch to EVs and a 5% reduction in VKT	Economic analysis - cost-benefit analysis	Physical activity, Air pollution ($PM_{2.5}$, PM10, NOx, other), Road injury, Noise	Composite health metric, Economic, Environmental	No
Stevenson (2016)[385]	Multiple: Six cities (Melbourne, Boston, London, Copenhagen, São Paulo, Delhi)	Compact cities - a combination of higher residential density, mixed land use, proximate and enhanced public transport, and an urban form that encourages walking and cycling	CRA	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Morbidity-related, Composite health metric	No
Taddei (2015)[386]	Italy, Florence	Car, moped, motorcycle, and scooter trips switched to cycling with different probabilities: 1) 25% chance of switching trips in less than 15mins and a 15% chance of switching trips between 16 and 30mins 2) 50% chance of switching to trips less than 15mins and a 15% chance of changing to trips between 15 and 30mins	CRA - WHO HEAT	Physical activity, Road injury	Mortality-related, Morbidity-related, Economic	No

Tainio (2017)[387]	UK, England	Different shares of existing trips done by car replaced by cycling	CRA	Physical activity	Mortality-related, Economic, Environmental	Yes - Socioeconomic status, gender
Tetreault (2018)[388]	Canada, Montreal	1) Transport infrastructure for 2031 identical to that of 2008 2) Public transport scenario in which the 2008 transport infrastructure is supplemented by new public transit infrastructures planned for 2031	CRA - ITHIM	Physical activity, Air pollution (NOx), Road injury	Composite health metric	Yes - Geographic
Thondoo (2020)[179]	Mauritius, Port Louis	1) Worst-case scenario: car trips are doubled (10% to 20%), and people shift from walking, public transport and motorcycle trips 2) Good case scenario: car trips are halved (10% to 5%), and people use more public transport, motorcycle and walking trips 3) Ideal-case scenario: car trips are practically eliminated (10% to 1%), motorcycle trips reduced and walking and public transport trips are increased	CRA - participatory quantitative health impact assessment	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Economic	No
Ulmer (2015)[389]	Canada, Toronto	West Don Lands Precinct Plan: redevelopment of underutilized, waterfront industrial land	Regression model	Physical activity, BMI	Morbidity-related, Environmental	No
Veerman (2016)[390]	Australia, Perth, typical neighbourhood	Spending to increase the length of sidewalks by 10km in each 1.6km road network buffer surrounding a participant's home and maintaining this for 30 years.	Life table - Multi-state life table	Physical activity	Composite health metric, Economic	No
Vert (2019)[391]	Spain, Barcelona	Evaluation of completed new urban riverside park	CRA - Blue Active Tool	Physical activity	Mortality-related, Morbidity-related,	No

					Composite health metric, Economic	
Villegas (2019)[392]	USA, Washington, Seattle	Based on transportation policy scenarios on the Washington Transportation Plan 2035 (WTP-2035)(38)and the Drive Clean Seattle Strategy. Three different urban transport scenarios: 1) BAU 2) Same VMT and AT as BAU but 35% of gasoline cars replaced by EVs 3) scenario 2 + 50% of car trips less than 1.5 miles replaced by walking and 50% of car trips between 1.5 and 5 miles replaced by cycling.	CRA	Physical activity, Air pollution ($PM_{2.5}$, NOx)	Mortality-related, Environmental	No
Whitfield (2017)[393]	USA, Tennessee, Nashville	Increased walking and cycling participation while holding total miles travelled by all modes constant 1) Conservative (+1mile/week walk, +0.7mile/week cycle) 2) Moderate (+3miles/week walk, +1.2miles bike) 3) Aggressive (meeting recommendations by +5mile walk, +2.7miles bike) 4) Injury neutral (reduction in car travel necessary to offset any additional injuries incurred by increasing per capita walking and biking by 1mile each)	CRA - ITHIM	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Composite health metric, Economic	No
Wolkinger (2018)[394]	Austria, three cities (Graz, Linz, Vienna)	Three scenarios based on the transport action plans of the local governments: 1) 'Green Mobility' (GM): politically-determined	CRA	Physical activity, Air pollution	Mortality-related, Morbidity-related, Composite health	No

		targets for mode share are almost achieved. Policy strategies include the improvement of pedestrian and bicycle infrastructure and service (environmental/pedestrian zones, restricted access for cars in the inner city), improvement of public transport and service, and parking regulations 2) 'Green Exercise' (GE): change in mode share beyond the policy targets. It can be achieved by additional measures to promote active mobility (pedestrian and bike) and expanding access restrictions for cars in city centres and public transport supply. In this scenario, domestic transport by cars is drastically reduced, and commuter transport requires the introduction of further incentives, such as price reductions for public transport. 3) 'Zero Emissions' (ZE): contribution towards achieving the IPCC 2C with the same modal shares as in the Green Exercise scenario and remaining vehicle-or passenger-kilometres, driven by conventional combustion engines, with electric cars and electric public transport		($PM_{2.5}$, PM_{10}, NOx)	metric, Economic, Environmental	
Woodcock (2014)[395]	UK, London	London cycle hire scheme evaluation	CRA - ITHIM	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Morbidity-related, Composite health metric	Yes - Gender

Wu (2019)[396]	USA, California, Sacramento	Different variations of the Metropolitan Transportation Plan/Sustainable Communities Strategy	CRA - ITHIM	Physical activity, Road injury	Mortality-related	Yes - Geographic and ethnicity
Xia (2015)[397]	Australia, Adelaide	1) BAU 2030 2) Increased cycling: a shift from passenger vehicles to cycling, resulting in a 5%and 10% reduction in passenger VKT 3) Increased PT: increased public transport use scenarios assumed that 20% and 30% of passenger VKT would shift to public transport 4) The 'Towards Alternative Transport' scenario (TAT) assumed that a total of 40% of the kilometres travelled by passenger vehicles would be replaced by alternative transport options (including public transport and cycling)	CRA	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Composite health metric, Environmental	No
Xue (2015)[398]	China, Xiamen	Series of policies and measures for mitigating traffic-related GHGs and air pollution, including motor vehicle controls, fuel economy regulations, promotion of new energy vehicles, fuel tax, and promotion of biofuels	CRA	Air pollution (PM_{10}, NOx, other)	Economic, Environmental	No
Yang (2020)[399]	UK, England	Free public transit policy assessed in the context of the varying spatial distribution of high- and low-income households	Complexity science - an agent-based model	Depression	Morbidity-related	No

Yu (2018)[400]	USA, New York	Expansion of bike share scheme (Citi Bike) to low-income neighbourhoods	Life table - cohort Markov model	Physical activity, Air pollution (other), Road injury	Composite health metric, Economic	Yes - Age
Yu (2019)[401]	USA, New York, New York City	Two potential congestion pricing plans considered by the municipal and state governments: 1) Fix NYC (a higher-cost but geographically focused proposal) 2) Move NY (a lower-cost city-wide proposal focused on equality)	Life table - cohort Markov model	Physical activity, Air pollution ($PM_{2.5}$), Road injury, Noise	Composite health metric, Economic	No
Zapata-Diomedi (2016)[402]	Australia	28 scenarios representing changes in the built environment, including density, land use, connectivity, bike lanes, street lights, destination increase, bus stops, walkability	CRA	Physical activity	Economic, Environmental	No
Zapata-Diomedi (2017)[403]	Australia, Brisbane	A shift from car travel to active transport was based on the transport targets for South East Queensland and Brisbane.	Life table - Multi-state life table	Physical activity, Air pollution ($PM_{2.5}$), Road injury	Mortality-related, Morbidity-related, Composite health metric, Economic	Yes - Gender
Zapata-Diomedi (2019)[404]	Australia, Melbourne	Two different urban developments: a planned brownfield redevelopment at Altona North and a new urban development in a suburb called Truganina	Life table - Multi-state life table	Physical activity	Mortality-related, Morbidity-related, Composite health metric, Economic	No

The main health impact pathways included physical activity, air pollution, and road injury; noise pollution was considered in only a few studies (Table 6.1). Most physical activity assessments used linear (log-linear) and the HEAT approaches. Air pollution assessment considered active travel and the general population in many cases. Most studies relied on linear DRF and distance/time travel, while a few used non-linear relationships and safety in numbers in estimating RTI. Most health outcomes were mortality (including road traffic injuries), DALYs and monetised outcomes (including medical costs).

6.4.3. Scenarios

The included studies covered a wide range of scenarios from retrospective evaluation of real-world changes in transport (e.g. riverside regeneration [391], walking and cycling infrastructure [333], pre/post evaluation of walking/cycling levels [377]) to hypothesised mode shifts examining the sensitivity of outcomes to changes in behaviour (e.g. limiting active transport on high air pollution days [343]). In many studies, the scenario was a specified mode shift (e.g. increment increase in walking/cycling [321, 329, 339, 340, 363, 368, 393]), whereas, in others, the scenario was a policy or intervention that in turn led to a mode shift (e.g. bike share [322, 332, 350], congestion pricing [400], change in fuel price [329, 349], and improved walkability [364]). Scenarios included ones where the modelled population adopted travel patterns of other populations (e.g. mode distribution of other locations in the same country [328, 383] or of well-known case studies [323, 346, 348]). Other studies evaluated the health impacts of switching specific trips to different modes (e.g. trips under specified distance or duration [316, 337, 369, 390, 391], commute trips that could be cycled in under 30 minutes [356, 374], the share of total trips or distance [387, 397]). In most cases, the degree of mode shift was explicitly specified as the scenario. However, there were a small number of studies where additional modelling was used to estimate the magnitude of the mode shifts. This covered studies that directly linked transport demand models to the health impact model [352, 353] and studies where mode shift impacts of specific scenarios had been estimated separately. The included study used these as the starting point for modelling the health impacts [348].

Evaluated scenarios also included assessments of the health impacts of transport plans [341, 344, 351, 373, 376, 380, 392, 396] or targets [379, 394, 405] and HIAs of broader societal interventions that impacted transport (e.g. land use changes [371, 385, 389, 404], climate change policies [406], teleworking [384], mitigation of air pollution [398], urban redevelopment [404]). Some scenarios examined innovations (e.g. ridesharing [352], connected autonomous vehicles [353]), and some examined implementation or expansion of existing interventions (e.g. mass transit [345, 358, 359, 362, 388]). A mixture of studies focused on single interventions (e.g. bike share [322, 332, 375, 395, 400], reduction of speed limits [354], congestion charging [401], sidewalks [390], accessible public transit [399]) and those focused on a package of interventions [330, 333, 367, 381, 402]. Some studies focused on specific trip types or purposes (e.g. travel to school [372], commuting [316, 327, 329, 337, 338, 356, 374]).

Bike lanes were evaluated multiple times across various settings as a standalone intervention [325, 331, 335, 347, 357, 370, 382] and as part of intervention packages [333, 361, 372, 394]. Two studies were not focused on transport but included mode shift interventions: an Italian study assessing the health impacts of a range of interventions aimed at increasing physical activity [345] and a UK study examining investments to reduce inequalities [366].

The choice of scenarios appeared to be researcher-led in the majority of studies. However, there were some examples where health impact modelling was conducted in response to specific policy needs [354, 355, 400]. One study combined health impact modelling with a participatory process to define scenarios [179].

6.4.4. Health pathways and outcomes

Most studies included more than one health pathway in the HIA (n = 63) (Table 6.1). The most commonly considered pathway was physical activity (n = 73), followed by road injury (n = 54) and air pollution (n = 51). Other health pathways that were less commonly considered were noise (n = 6), body mass index (BMI) (n = 6), social isolation leading to depression (n = 1), heat (n = 1), green space (n = 1) and access to healthcare (n = 1). The most common combination of pathways examined in an HIA matched the most common individual pathways, with 36 studies quantifying the impact of the combination of physical activity, road injury, and air pollution.

There were differences in how different studies quantified health impacts within specific health pathways. For example, there were studies within the air pollution pathway that examined the impact at the population level and others that examined risks to the active traveller. Different exposure proxies were used for air pollution: 31 studies used particulate matter, three used nitrous oxides, three combined impacts of particulate matter and nitrous oxides, and 14 used other combinations of pollutants to quantify health impacts.

Health outcomes included those that were related to mortality (n = 60) and morbidity (n = 33), composite health metrics (such as disability-adjusted life years) (n = 47), economic outcomes (n = 57) and environmental outcomes (n = 18). Most studies (n = 74) examined more than one type of outcome.

6.4.5. Approaches to health impact assessments

A wide range of methodological approaches was used to quantify the health impacts of scenarios. Comparative risk assessment was the most used methodological approach (n = 51) – likely due to the popularity of the Integrated Transport and Health Impact Model (ITHIM) (n=17) and the WHO Health Economic Assessment Tool (n = 11, including studies that adapted or used components of the tool). Nineteen studies used life table approaches, of which eight used multi-state life table methods. Less common approaches were economic analysis (n = 11), injury-risk models (n = 4), approaches from complexity science (n = 3, two studies that used systems dynamics modelling and one using agent-based modelling), and regression methods (n = 2). A small number of studies used combined approaches. For example, comparative risk assessment was combined with cost-benefit analyses in one study [370] and a life table approach in another [376].

6.4.6. Differential impacts

The majority of studies focused on quantifying the total population impacts of modelled scenarios (n = 79). Those that did not quantify impacts at the population level focused on either a hypothetical population (a hypothetical city [382], synthetic population [399, 400]) or a defined group of people exposed to the intervention (benefits to those who take up cycling [336], cyclists [339, 343], park users [391]). One study also quantified impacts for a birth cohort [326]. In studies that focused on quantifying total population impacts, we found evidence of differences in how health impacts were quantified across different health pathways. For example, in the Barcelona superblocks study [371], physical activity impacts were accrued to those who shifted to active transport, but the benefits from air pollution, noise, heat, and green space were accrued across the entire population.

Less than one-third of studies included estimates of the impact of modelled scenarios on different population sub-groups (n = 28). In these studies, impacts were disaggregated by gender (n = 11), age (n = 10), geographic area (n = 10), ethnicity (n = 3), level of deprivation (n = 2), and socioeconomic status (n = 1). Eight studies disaggregated impacts by multiple characteristics (e.g. gender and socioeconomic status [387]). Finally, one study disaggregated impacts based on whether people were users of rapid mass transit or not (n = 1). There were differences in whether scenarios appeared to lessen or widen existing inequalities across different studies. For example, McAuley et al. (2016) found that increasing active commuting to work could widen existing health inequalities by neighbourhood deprivation [366]. In contrast, Wu et al. (2019) [396] found greater overall health benefits for people of colour compared to non-Hispanic whites.

6.5. Discussion

6.5.1. Main findings

There are many health impact modelling studies of various transport scenarios. The breadth of included studies demonstrates the flexibility of health impact modelling to evaluate different scenarios across various settings. The studies also showcase various methodological approaches to quantify impacts through different pathways linking transport and health.

The earlier review of quantitative HIAs of active transportation interventions conducted by Mueller et al. (2015) [315] included 30 studies published between September 2001 and January 2015 [315]. There was a small degree of overlap in the studies captured with six overlapping studies [335, 338, 355, 361, 395] owing to our inclusion of studies published in 2014 to ensure there was no gap in the periods covered by the two reviews. Overall, we found a much larger number of eligible studies, despite having only minor differences in search strategies and eligibility criteria. Therefore, the difference in the number of studies likely reflects growth in published health impact modelling studies of mode changes in transport.

6.5.2. Scenarios

Our review demonstrates that health impact modelling continues to be a flexible method of assessing transport interventions. A key strength of health impact modelling is its ability to be applied across various scenarios. The breadth of scenarios captured evaluations of real-world change observed in transport patterns [333, 377] and aspirational scenarios [337, 348]. Commonly assessed scenarios in this review include studies assessing scenarios where trips with defined characteristics were switched from being taken by car to more active modes and studies evaluating infrastructure changes (e.g. implementation of bike lanes)—these represent a continuation of scenarios that were identified by Mueller et al. [315]. However, quantitative HIA methods have also been adapted to evaluate innovative transport interventions, including technological innovations such as connected autonomous vehicles [353] and social innovations such as bike share schemes [332, 400].

Most scenarios assessed appeared to have been developed by researchers. However, some studies evaluated the health impact of local transport plans [341, 351, 380, 395] or explicitly articulated that the engagement of local stakeholders was influential [179, 354, 355]. While scenarios were usually well-articulated, information on the scenario development process or target audience was often not clearly described. Quantitative HIAs with solid stakeholder engagement provide an opportunity to inform local decision-making in transport. In contrast, researcher-led assessments may fulfil other essential functions, including a better understanding of the relative health impacts of different health pathways or refining methodologies [343]. Different approaches to scenario development and stakeholder engagement are likely to be appropriate for different types of assessment; we recommend that these details are described alongside evaluated scenarios to enable readers to understand the rationale and context of the quantitative HIA. Given increasing calls to further engage stakeholders in health impact assessment [407, 408], we expect details about the level and nature of stakeholder engagement to feature more prominently in health impact modelling.

6.5.3. Settings

There has been an increase in the number of multi-setting and multi-country assessments since 2015, and twice the number of countries were captured across the included studies in this review compared to the Mueller et al. review [315]. Included countries captured a range of settings—studies assessing cities or other within-country jurisdictions were dominant. Studies continue to be predominantly in high-income settings, and there continues to be a high proportion of studies capturing European contexts. Expanding the range of settings covered by quantitative HIA will help fill gaps in our understanding of the health impacts of changes in transport across diverse backgrounds, including low- and middle-income countries.

Studies that cover multiple settings show differences in the patterns of health impacts across diverse settings. Giallourous et al. (2020) [343] demonstrate that increased walking and cycling results in reduced mortality across cities with very different levels of air pollution. However, deaths averted are estimated to be twofold higher in cities with low air pollution compared to cities with high air pollution.

McClure et al. (2015) [367] also find differences in the patterns of health impacts across six cities in diverse contexts. McClure et al. (2015) [367] examined two scenarios: a mode shift scenario and a reduced mode risk scenario (where the risk associated with travelling by a given mode was reduced). In all six cities, the mode risk scenario led to greater health gains when deaths measured health impacts. However, different patterns emerged across different cities when health impacts were measured in disability-adjusted life years. In London and Copenhagen, the mode shift scenario led to greater health gains, whereas in the other four cities (Beijing, Delhi, New York, and Melbourne), more health would be gained in the reduced mode risk scenario. Studies evaluating health impacts across multiple settings provide an opportunity to understand the variability in health impacts due to differences in context.

6.5.4. Health pathways and outcomes

There has been little change in how quantitative HIA captures health—physical activity, air pollution, and road injury remain dominant. These represent a selected subgroup of the pathways that link transportation and health [15]. Studies examining the disease burden from transport have captured additional pathways, including green spaces and urban heat islands [409, 410]. These studies demonstrate that additional pathways are feasible in health impact modelling studies. Details of the main pathways are shown in Appendix 10.2.3.

The selective inclusion of health pathways in quantitative models may bias estimates of the health impact of specific scenarios. In many cases, restricting the analysis to a limited range of health pathways could over- or under-estimate the net health impact of particular interventions. For example, included studies that estimate increases in fuel prices have a net positive health impact due to reducing air pollution [349] or reducing obesity and increasing physical activity [328]. However, it is also plausible that fuel price increases negatively impact health by inhibiting access to healthcare and other vital services – particularly for households vulnerable to cost increases [411] or already experiencing transport poverty [412]. A complete assessment of all health impacts may never be possible - due to conceptual and measurement challenges, resource constraints or insufficient data. However, any limitations associated with the selective inclusion of health pathways in models can be ameliorated. These include explicit commentary highlighting the reasons for including or excluding specific health pathways from the analysis, scenario descriptions illustrating anticipated changes in unmodelled health pathways, and discussion of the likely magnitude and direction of impacts not captured in the quantitative synthesis.

Whilst many studies captured greenhouse gas emissions as an outcome [333, 337, 359, 363, 387], this was not part of a health pathway. Transport systems are significant contributors to greenhouse gas emissions directly and indirectly, with the adverse and inequitable health effects caused by these emissions [413]. The current carbon-intensive transport system directly contributes to around a fifth of global GHG emissions [414]. The transport system configuration critically influences emissions in other sectors, including healthcare. Healthcare is responsible for around 5% of national emissions in OECD countries, and one of the critical components of reducing health system emissions is preventing the need for healthcare [415]. Further consideration of interactions between transport systems, greenhouse gas emissions, and the health system is an area ripe for future model extension and development.

6.5.5. Differential impacts

Less than one-third of the studies included examined the impacts of scenarios across different population groups (e.g., age or ethnic groups), and only eight examined impacts across multiple population groupings. It is similar to the proportion of studies reported by Mueller et al. (2015) [315] that examined differential impacts. The importance of why studies need to investigate the effects for different groups can be seen in the studies that did; these studies show diverse and avoidable inequities from interventions. For example, James et al. (2014) [355] showed that modest changes within a planned intervention could have far-reaching equity consequences. They found a fourfold difference in the number of public transportation-dependent households isolated from basic healthcare resources across two scenarios with similar cuts in public transport budgets but differing relative contributions of fare increases and service reductions. Their assessment contributed to decisions about the fare and service changes [355] and provided a clear example of how health impact modelling can contribute to implementing a more equitable transport policy.

Health impact modelling provides an opportunity to understand the equity impacts of proposed changes to transport. Our review suggests that this ability is underutilised, in line with Cole et al.'s (2019) [407] assessment of health equity across a broader range of HIAs [407]. Understanding distributive impacts is a core component of the WHO definition of health impact assessment and should be incorporated in quantitative health impact modelling studies. We note that different modelling methodologies may differ in their ability to assess differential impacts of scenarios. The transport sector is experiencing a rapid transition with new technology [416], challenges to the current model of car dependency [411] and imperatives to decarbonise rapidly [414]. The policy changes required to achieve this transition may adversely impact equity. Failing to consider equity in transforming the transport system risks embedding current injustices in our future transport systems.

6.5.6. Strengths and limitations.

This review provides a timely update of studies that quantify transport scenarios' health impacts, focusing on scenarios examining mode changes. Our search strategy covered many databases to ensure relevant studies were identified. We created a pool of studies known to the authors, including those included by Mueller et al. (2015) [315]. We used this to test whether the search strategy was adequate to identify eligible studies. Despite the broad search strategy, relevant assessments in the grey literature may not have been determined, and therefore, our findings predominantly capture peer-reviewed literature. Given the large number and heterogeneity of included studies, we did not attempt to extract their results or make formal assessments of study quality. An accompanying review aims to examine methodological aspects of health impact modelling studies focused on transport and how these influence the results of quantitative evaluations.

We have attempted to simplify details from included studies into broad categories – such as grouping studies by general methodological approaches (e.g. WHO HEAT, ITHIM) and health pathway levels (i.e. physical activity, injury). By doing so, we acknowledge that heterogeneity within each category is missed. For example, ITHIM exists in multiple versions, starting with two very similar versions for Britain and California [184, 417] but then branching, with sequential versions developed in Cambridge, UK [180, 395] and other versions in the USA [417]. We may have missed other similarities between different methodological approaches due to differences in how authors reported them.

6.6. Conclusion

Health impact modelling provides an opportunity to evaluate transport interventions. It has been applied to a wide and growing range of transport interventions across various settings. This review provides an overview of literature published since 2014 and highlights the diversity of ways in which health impact modelling has been applied and dominated by the ITHIM and HEAT models. Significant gaps remain in using health impact modelling to capture differential impacts of transport scenarios across different population groups. Quantifying differential impacts as part of health impact modelling studies should be considered a high priority, given the widespread prevalence of inequities in both health and transport. Future health impact modelling studies should also endeavour to capture the full range of transport-related health pathways. Where there is insufficient data on exposures or dose-response relationships, we encourage alternate forms of synthesis.

7. **Modelling the health impacts of urban transport changes in five African cities: Accra, Cape Town, Kisumu, Nairobi, and Port Louis**

This chapter combines information from the preceding chapters to model the health impacts of urban transport changes in selected African cities. It, therefore, uses data identified and processed during explorations in chapters 3 and 4, plausible policy scenarios informed by the policy analysis in chapter 5, and modelling information based on the review of use cases presented in chapter 6. The chapter also presents the results of uncertainty analyses to highlight variations in outcomes due to the randomness of input parameters. The current version of ITHIM (ITHIM Global) applied in the study presented in this chapter is developed by my research group. I contributed to the model development by curating and quality-checking travel surveys and physical activity data from various settings, testing written codes, suggesting assumptions, and interpreting model behaviour. I applied the model and interpreted the results in African cities with minimal support from team members.

7.1. Abstract

The lack of urban transport health impact assessments in Africa limits our understanding of which policies increase health benefits and reduce harm. This study aimed to model the health impacts of likely changes in urban transport policies through travel behaviour changes in five selected African cities: Accra (Ghana), Nairobi and Kisumu (Kenya), Port Louis (Mauritius), and Cape Town (South Africa). I used the Integrated Transport Health Impact Modelling (ITHIM) approach to calculate changes in exposure to air pollution ($PM_{2.5}$), physical activity, road traffic deaths, and their corresponding health impacts for four scenarios: bus, bicycle, car and motorcycle. Each scenario represented a 5% point increase in the named mode share from the baseline. Results showed reduced deaths from shifts towards cycling and public transport (bus), mainly from gains in physical activity and reduced air pollution across cities. However, road traffic fatalities were high in some cities' cycling scenarios. Comparatively, car and motorcycle scenarios showed increased deaths from air pollution and physical inactivity, with additional road injuries observed in the motorcycle scenario across cities. Uncertainty analysis showed consistent outcomes for random input parameters. This study showed a useful urban health impact assessment model that allowed policy comparisons across African cities. The model could be further refined and tested in new cities for consistency.

7.2. Background

As noted earlier, the potential health impacts of urban transport changes in low- and middle-income countries (LMICs) could be substantial since the exposure to health risks, such as road traffic injuries and transport-related air pollution, are higher and worsening in these countries. LMICs are also undergoing rapid urban, epidemiological, and mobility transitions [5, 11, 418] that increase peoples' exposure to urban transport health hazards and escalate the health impacts of urban transport. Addressing these health impacts needs quantitative assessments of different urban transport policies to unveil the policy options that increase health benefits and reduce harm. Studies from high-income settings have demonstrated net health benefits from policies that encourage active transport. Active transport, primarily walking, is generally high in LMICs (and is now rapidly declining as motorisation increases). Still, it is unclear if small changes to active transport lead to net health benefits in these contexts. Studies quantitatively assessing health impacts in LMICs are simply scarce.

Until recently, mother and child health problems and infectious diseases such as malaria and HIV/AIDS and those related to hygiene and sanitation have dominated the chart of health burdens in LMICs [419]. Consequently, research in these countries has been focused on those problems and has only timidly acknowledged and explored the influence of transport, urban planning, and other non-health sectors on health [40]. The neglect of urban transport as a critical health determinant has persisted despite rising road traffic injuries and fatalities and the strong evidence from high-income countries on the impacts of urban transportation on air pollution, physical inactivity, and health. The inattention of policymakers to these health impacts partly contributes to the lack of urban transport impact assessment initiatives. Other significant barriers are the lack of routine data and ready-to-use models. The multitudes of pathways through which transport affects health need multiple input data. Regular primary data collection to feed this need also requires resources that city managers understandably want to direct toward basic living, aggravating data scarcity. The lack of data can be a substantial barrier when attempting to comprehensively evaluate urban health impacts from multiple pathways. Limited technical capacity in these settings often limits the exploration of crowd-sourced data and other heavy tech-based data sources and the development of contextually valuable models.

Initial efforts have shown that modelling studies can yield relevant results in LMICs. Findings from São Paulo, Delhi, and Accra show that shifting travel patterns towards more sustainable transport options can provide significant health benefits and decrease health burdens [180, 334]. Thondoo et al. (2019) have further demonstrated a cost-effective, participatory framework for a transport health impact assessment in Port Louis [40]. These studies have mainly concentrated on individual cities; they focus on proving that transport health impact assessments and modelling are possible in LMICs. They do not provide generalisable solutions to modelling issues nor a comprehensive picture of urban transport health impacts from multiple cities.

This study aimed to model the health impacts of likely changes in urban transport policies and, consequently, urban travel behaviours in five selected African cities: Accra (Ghana), Nairobi and Kisumu (Kenya), Port Louis (Mauritius), and Cape Town (South Africa). The first objective was to estimate changes in the health burdens associated with reasonable urban travel behaviour changes through changes in physical activity, road traffic injury, and air pollution. The second objective was to estimate health outcome uncertainty resulting from the variability in input parameters to gauge the need for input data precision.

7.3. Methods

7.3.1. Study design and settings

I used the Integrated Transport Health Impact Modelling (ITHIM) approach to calculate changes in health outcomes due to potential changes in urban travel behaviours [184]. This model's latest version (ITHIM-Global) has been piloted in Accra [180]. Essentially, it uses a comparative risk assessment approach introduced by the WHO to estimate changes in health outcomes based on changes in relative risk exposure. Thus for a chosen transport scenario, it estimates changes in exposure to air pollution (PM2.5), physical activity, road traffic deaths, and the corresponding health impacts. Compared to the previous version of ITHIM, this new implementation uses microsimulations to estimate the changes in individual exposures by creating a synthetic population for each city. The synthetic population is demographically representative of the city's population and has travel characteristics for a selected transport scenario. This crucial dataset allows health impact estimates for more realistic scenarios by altering individual trips according to different criteria such as distance band and travel mode. The new model uses updated dose-response functions for physical activity [186].

Table 7.1 and Figure 7.1 compare the essential characteristics of the five study cities. The city boundaries resulted from an overlap of official administrative boundaries, target boundaries of travel surveys and Global Human Settlement's functional urban boundaries [420]. The main selection criteria of cities were the availability of input data, especially travel behaviour data required for generating synthetic populations and road injury data, which contributes significantly to the urban transport health burden in this context. I selected cities of different sizes and geographical representations (east, west and south). I also focused on cities where contacts had contextual knowledge to assess data availability and the plausibility of the scenarios. Therefore, while I initially considered many cities, I selected those with sufficient contact information to request more details for the study.

Table 7.1 Characteristics of case study cities

Country	City	Population (2014)	Population density	GDP/capita ($)	Car Ownership/1000
Ghana	Accra	2,052,341	10261	4000	46
Kenya	Kisumu	490,079	297	3356	69
Kenya	Nairobi	3,138,369	4515	6344	69
Mauritius	Port Louis	119,018	2800	11200	..
South Africa	Cape Town	4,178,700	3675	14086	232

Values were obtained from disparate national sources.

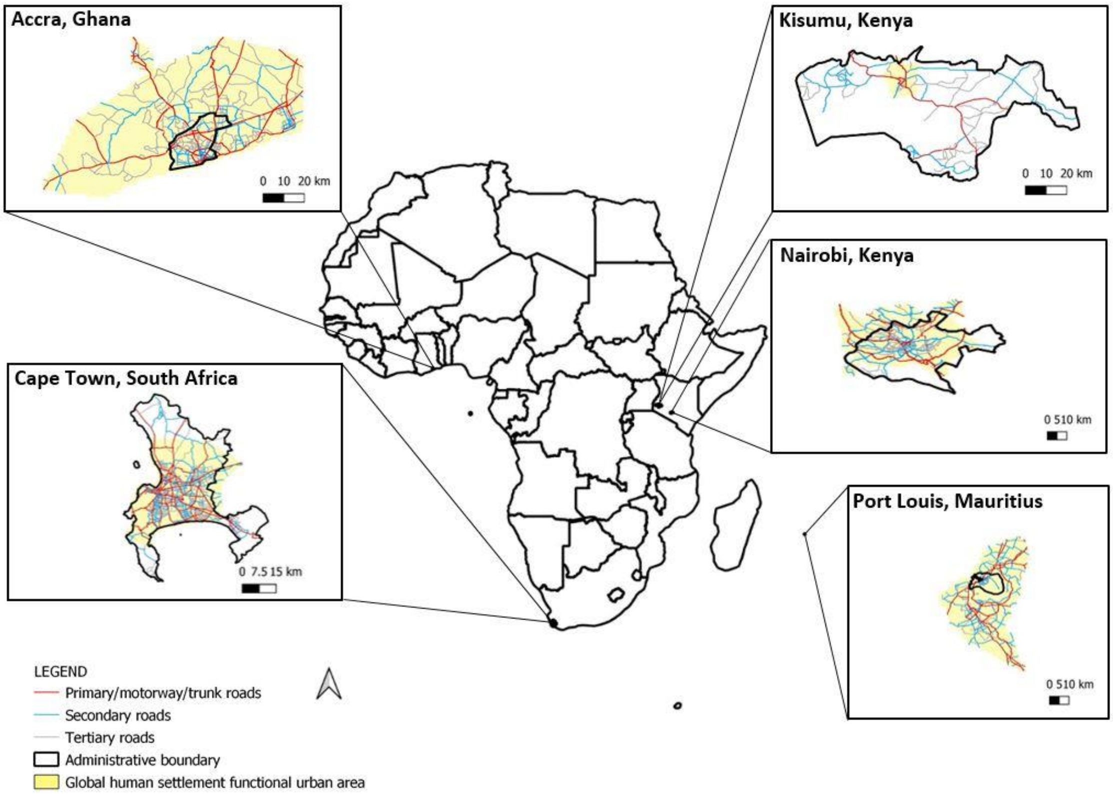


Figure 7.1 Study cities' road networks showing city administrative boundaries (Open Street Map) and functional urban boundaries from Global Human Settlement

7.3.2. Data

The six essential input data for each city were (1) Travel behaviour, (2) Road traffic fatalities, (3) Background air pollution concentration, transport contribution to air pollution and mode share of transport-related air pollution, (4) Physical activity, (5) Burden of disease, and (6) Population by age and sex. For ITHIM, the two most crucial data are travel behaviour data used for creating synthetic populations and travel scenarios for road traffic injuries, which contribute significantly to health impact calculations.

1. Travel behaviour

Travel behaviour data came from travel and time-use surveys and was accessed through collaboration with local researchers and practitioners. These data reported individuals' trip details, including duration, distance, and mode. To allow comparison of travel behaviour across cities using different data sources, I harmonised the travel surveys using a pre-established data harmonisation protocol included in the ITHIM package. The harmonisation process catered for different trip definitions and vehicle types in cities. Briefly, after reviewing the meta-data of each travel behaviour dataset (household, person, trip, stage, and vehicle), I mapped the local vehicles to predefined transport modes, created new variables, and generated a dataset with the highest trip resolution (stage level). I compared travel data across cities while noting trip definitions, collection time windows, geographical coverage and the captured modes. If stage-level walking was unavailable or poorly captured walking to public transport, I added a short walking stage for all public transport trips. The added walking duration to/from public transport was 10 minutes for buses and 12 minutes for trains, based on the median values of travel surveys adequately detailing trip stages. Table 7.2 describes the travel data used.

Table 7.2 Travel behaviour datasets used for modelling transport health impact in African cities.

City	Year of survey	Number of households	Number of individuals	Resolution	Source
Accra	2021	602	1159	Stage	New collection
Nairobi	2013	10000	15954	Stage	JICA
Kisumu	2016	2760	5790	Stage	ITDP
Cape Town	2013	2502	7562	Trip	Website
Port Louis	2017	NA	512	Stage	Collaboration

2. Road traffic fatalities

Road traffic fatality data mainly included the different road traffic accidents, the number of victims, victims' demographics, and the vehicles involved. The focus was on fatalities and not all road traffic injuries because fatalities are more consistently reported across settings, albeit reporting rates are generally low. On the other hand, reporting non-fatal road traffic injuries highly depends on the setting's regulations, health-seeking behaviour and ability to pay for healthcare. I obtained these data from country agencies and research collaborators. Data processing included identifying the victim and striking modes for each victim. I included the sociodemographic characteristics of victims, but these variables were missing in many cities and thus were used only for simulations when available. When multiple years of data were available, I used all the available years to obtain an average yearly injury rate with an improved mode representation.

3. Air pollution

Background $PM_{2.5}$ concentrations and their transport share were extracted from WHO databases [421]. I used the EDGAR database to estimate the mode share of transport $PM_{2.5}$ emissions. EDGAR provides average annual $PM_{2.5}$ measurements from different modes on points on a global grid. City boundaries enclose multiple points. I used averages of point locations within the selected cities to calculate the transport mode share of $PM_{2.5}$.

4. Physical activity data

I obtained cities' latest physical activity data from research collaborators and public websites. These data resulted from the GPAQ, which captures PA in three domains: leisure, travel, and occupational PA. Data processing and harmonisation included separating individuals' PA into different domains. All non-occupational, non-travel PA from the PA surveys were complemented by travel PA from the travel behaviour datasets to produce an individual's non-occupational PA for which the dose-response exists.

5. Disease burden

Disease burden (mortality and years of life lost for different diseases) were obtained from the Global Burden of Disease database. These data were only available at the country level, so I scaled them down to city levels based on city-country population ratios. I used the most recent GBD data (2017).

6. Population

Cities' populations and demographics (age and sex distribution) were obtained from population censuses and projections. I used the 2014 population estimates or forecasts to allow for comparison across cities.

Travel behaviour data often contain detailed information on transport-related physical activity (walking and cycling) but no information on other domains contributing to background physical activity levels. I, therefore, used the non-occupational, non-transport domains from physical activity surveys to complete individual physical activity information in the travel surveys. Individuals from both surveys were matched probabilistically using age and sex, leading to a synthetic population with complete travel and physical activity information.

The model provides default input parameters and prompts for updating when running the model. Additional parameters that need specifying are detailed in the ITHIM-Global methodology paper in preparation to which I am contributing. These parameters include scaling factors and distribution parameters that complement the input data. Distribution parameters allow for sampling input parameters from their assumed distributions for uncertainty and value of information analysis.

7.3.3. Health impact calculations

Scenarios

The baseline travel behaviours were those of the synthetic population. I defined four scenarios to represent desired likely mobility changes across cities while contrasting them with undesired ones. To allow comparison across study cities, I set each scenario to an overall 5% point growth in the scenario mode. I proportionately spread the increase across three distance bands: 0 to 1 Km, 2 to 5 Km and 6+ Km. For example, supposing a city's baseline cycling share in the different distance bands were in the ratio of 4:5:1, a cycling scenario with a 5% increase in cycling would allocate 40, 50, and 10% of the trips in the short, medium and long-distance bands, respectively. Therefore, each scenario would update the travel behaviour of the same individuals in the synthetic population. Table 7.3 shows the average change in each distance band across study cities.

Table 7.3 Average ratio of trips sampled from each distance band to constitute a five per cent mode increase.

Scenario	0-1km	2-5km	6+km
Cycle	3.9	7.3	3.5
Bus	0.2	4.9	19.9
Car	0.9	6.7	13.9
Motorcycle	1.1	5.4	16.2

Outcome calculations

I calculated two health outcomes for each pathway: deaths and years of life lost (YLL). For AP and PA, outcomes are available on three levels since different epidemiological studies report outcomes for specific diseases (e.g., strokes), groups of diseases (e.g., cardiovascular diseases), and all diseases (e.g., all-cause mortality). I focused on all-cause mortality and years of life lost. Overall health outcomes for each scenario were the sum of the three pathway outcomes. Detailed calculation steps used in the ITHIM-Global are presented in a method paper by Khreis et al. I provide only a brief description here:

- Physical activity

Individuals' physical activity volumes were the sum of their transport (which varies by scenario) and other non-occupational (non-variable) PA. PA volume was expressed as the marginal Metabolic Equivalent of Task (mMET). The Metabolic Equivalent of Task (MET), the ratio of the energy spent on a task compared to energy spent when sitting quietly, is the standard unit for PA volume. The marginal MET is the MET above the resting MET, which discounts the energy that one would spend doing nothing. I used the non-linear dose-response functions from a recent meta-analysis [186] to estimate individuals' mortality and years of life lost relative risks when their physical activity changed from baseline to scenario levels. The relative risks for scenarios are compared to the baseline to obtain potential impact fraction and are combined with disease burden to obtain PA impact. The non-linear dose-response functions implied that risk reductions were not proportional to PA changes, with the highest changes observed in the least active population.

- Air pollution

I calculated the health impacts of air pollution by estimating changes in individual $PM_{2.5}$ exposure. Personal $PM_{2.5}$ exposure depends on the overall background $PM_{2.5}$ concentration and individual respiratory rate. I calculated scenario background $PM_{2.5}$ concentrations using the city's baseline background $PM_{2.5}$ concentration, the transport share of $PM_{2.5}$, the mode contribution from the emission inventory, and the distance travelled by vehicles under the scenario. Changes in $PM_{2.5}$ concentration, therefore, resulted from changes in distance travelled by vehicles in different scenarios. Individuals' respiratory rate was minimal during sleep (fixed at 8 hours for everyone), low during resting (everyone not travelling actively) and high during active travel. I linked changes in individual $PM_{2.5}$ exposure to health outcomes using a linear exposure-response function [422]. Unlike PA, risk changes were proportional to $PM_{2.5}$ changes.

- Road traffic injury

I modelled road traffic fatalities using Poisson regression, with age, sex, and vehicle mode distances as predictor variables. I used mode distance changes to predict road fatalities in a given scenario. I also accounted for the safety provided by increasing a particular mode share (safety-in-numbers) using predefined factors in the model.

Uncertainty calculations

The numerous model inputs are estimated from sources with varying uncertainties; these uncertainties are propagated into the model outcomes through the outcome variance. Uncertainties exist for dose-response functions, individual exposure data and other parameter estimates. The ITHIM model handles uncertainty by repeatedly sampling input parameters from their supplied plausible distributions. I drew 2000 random samples from default and specific parameter distributions in the model to examine uncertainties around health outcomes. Relative contributions of different inputs to the overall outcome uncertainty are obtainable through the value of information calculations, which are out of the scope of this thesis.

Sensitivity analysis

We conducted a sensitivity analysis to test the robustness of our results by altering one underlying assumption, representing a plausible change in the city's future wider context. All scenarios were executed considering the new background condition for each scenario, following the same procedures detailed in the previous sections. Since the primary focus was PA, we dropped non-occupational PA by 20%.

7.4. Results

7.4.1. Baseline travel behaviour and exposure characteristics

Table 7.4 summarises the baseline travel characteristics of people ≥15 years in the study cities. The mobility rate ranges from 69 to 95%, and mode usage varies widely. Car use is distinctly high in Cape Town, while motorcycle use is high in East African cities, especially Kisumu and Port Louis. Walking is nearly dominant in all cities except Cape Town and Nairobi, while cycling is relatively higher in Kisumu and almost nonexistent in Cape Town.

Daily travel duration per capita is high in larger cities, nearing two hours but barely reaching an hour in smaller cities. The distribution of daily trip duration per capita by mode mirrors the mode shares, with substantial time per capita spent walking and cycling being lower across the board.

Table 7.4 Baseline travel behaviour in study cities

	Accra	Cape Town	Kisumu	Nairobi	Port Louis

People with trips (%)	4779 (86)	3878 (69)	2702 (72)	13970 (95)	515 (84)
Stage mode share					
Car	9.7	37.3	7.8	13.4	14
Motorcycle	1	1.4	20.4	4.5	18.9
Bus	28.4	25.5	15.3	44.5	18.2
Pedestrian	53.5	26.8	46.1	33.6	40.3
Truck	0.6	0.9	1.5	0.6	5.6
Cycle	1.1	0.3	5	1.6	1.1
Total	94.3	92.2	96.1	98.2	98.1
Trip duration per capita (minutes)	104.2	103.9	44.6	139.3	54.4
Stage mode share					
Car	19.2	53.6	5.4	31.6	10.7
Motorcycle	2	0.5	9.1	7.8	9.2
Bus	34.2	18.1	7.4	46.5	11.9
Pedestrian	43.9	20.8	19.6	44.8	19.5
Truck	4	10.7	1	6.9	2.6
Cycle	0.9	0.2	2.1	1.7	0.5

Table 7.5 shows baseline exposure characteristics for study cities. Baseline physical activity is higher in Accra and Nairobi and lower in the rest of the study cities. Background air pollution is distinctly high in Accra, albeit levels in all study cities exceed the WHO-recommended 5 µg. Cars and trucks contribute the highest to air pollution, except in Cape Town, where buses contribute as much as cars. Road traffic fatalities are highest in Port Louis, and the main victim modes are pedestrians and motorcycles, except in Cape Town, where cars contribute four times more than motorcycles.

Table 7.5 Baseline physical activity, air pollution and road traffic fatalities in study cities

	Accra	Cape Town	Kisumu	Nairobi	Port Louis
Mean baseline PA (MMET)	24.4	8.8	13	21.2	11.6
Baseline PM2.5 Concentration	55	14.86	10.79	5.91	14
Transport share	22	31	22	22	22
Mode share					
Big truck	19.2	39.6	29	12.5	26.3
bus	5	21.6	6.7	4.2	7.2
car	59	20.5	41.8	69	42.7
motorcycle	0.2	0.7	0.1	0.2	0.2
truck	16.5	17.6	22.3	14	23.7
Baseline predicted road traffic fatality per 100000	15.86	22.56	25.89	22.6	35.9
bus	0.9	0.76	3.28	1.03	0.89
car	1.95	7.03	0.86	2.12	0
cycle	0.72	0.29	0.69	0.3	2.37
motorcycle	2.02	1.78	13.12	4.88	18.1
other	0	0.08	1.21	0.27	0
pedestrian	9.84	12.39	6.56	13.85	13.06

rail	0	0	0	0	0
truck	0.43	0.23	0.17	0.15	1.48

7.4.2. Health impacts of scenarios compared to the baseline scenario

Figure 7.2 shows the pathway and overall deaths per 100,000 city population for the different study scenarios. Negative values indicate increased deaths, and positive values indicate averted deaths. Across cities, bus and cycling scenarios show substantial health benefits compared to car and motorcycle scenarios. The bus scenario leads to maximum health gains by increasing physical activity and reducing road traffic injuries and air pollution. Cycling leads to similar significant health gains, except that road traffic injuries are higher in cities with low baseline cycling. Conversely, car and motorcycle scenarios lead to high negative health impacts by increasing air pollution and reducing road traffic injuries. Air pollution-related deaths from the motorcycle scenario are not as high as for cars, but road traffic injuries are more elevated. The PA pathway contributes the highest overall mortality changes for all scenarios.

Figure 7.3 shows detailed changes in the bus scenario. A 5% increase in bus travel in Nairobi could avert 338 deaths per 100,000 inhabitants per year, with 89% averted deaths due to gains in physical activity. Fewer deaths are prevented in the other cities, and physical activity still contributes the most. The injury pathway is the next most important contributor to death aversion in the bus scenario, except in Accra, where air pollution contributes more than injury.

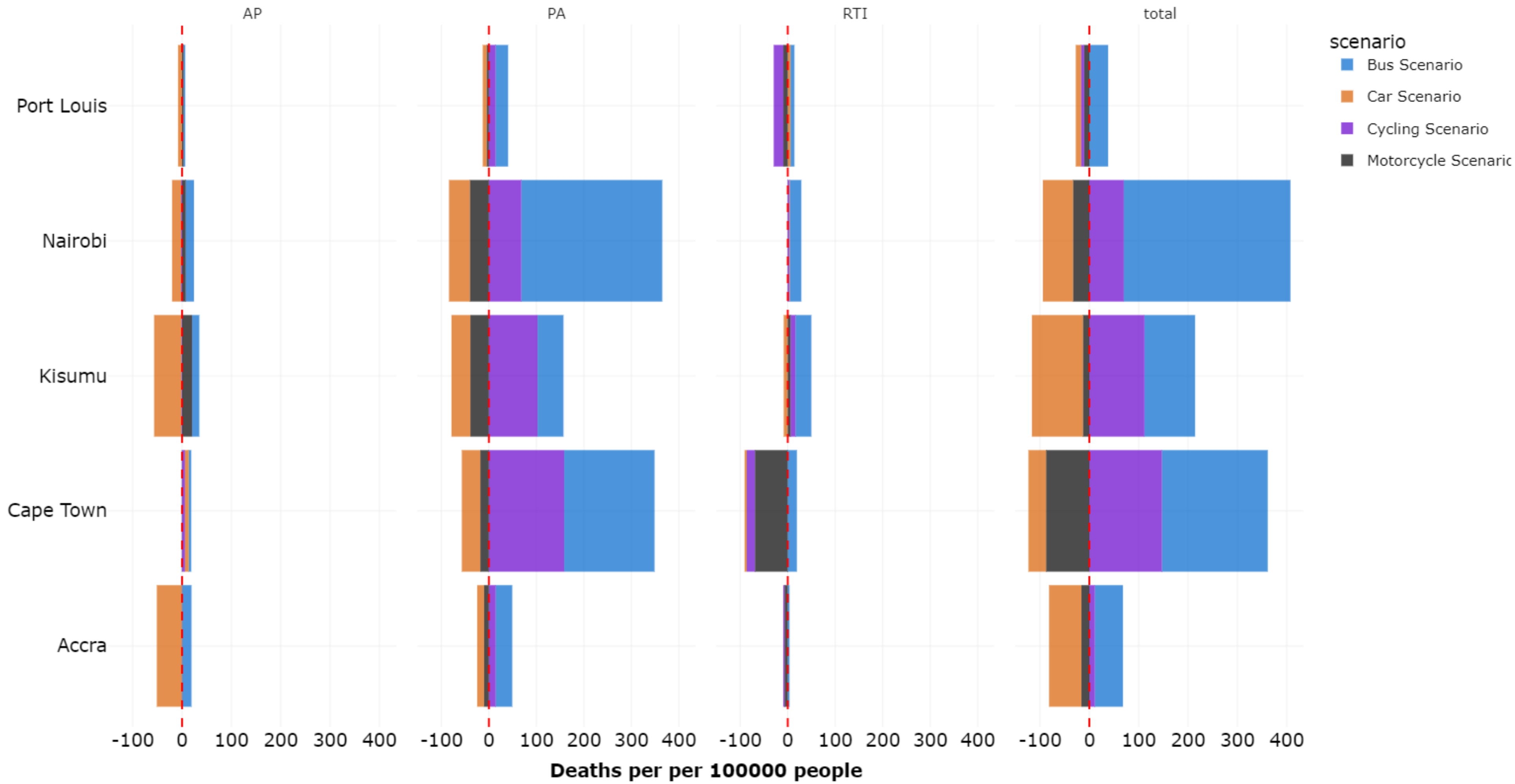


Figure 7.2 Health impact of transport for four scenarios in five African cities

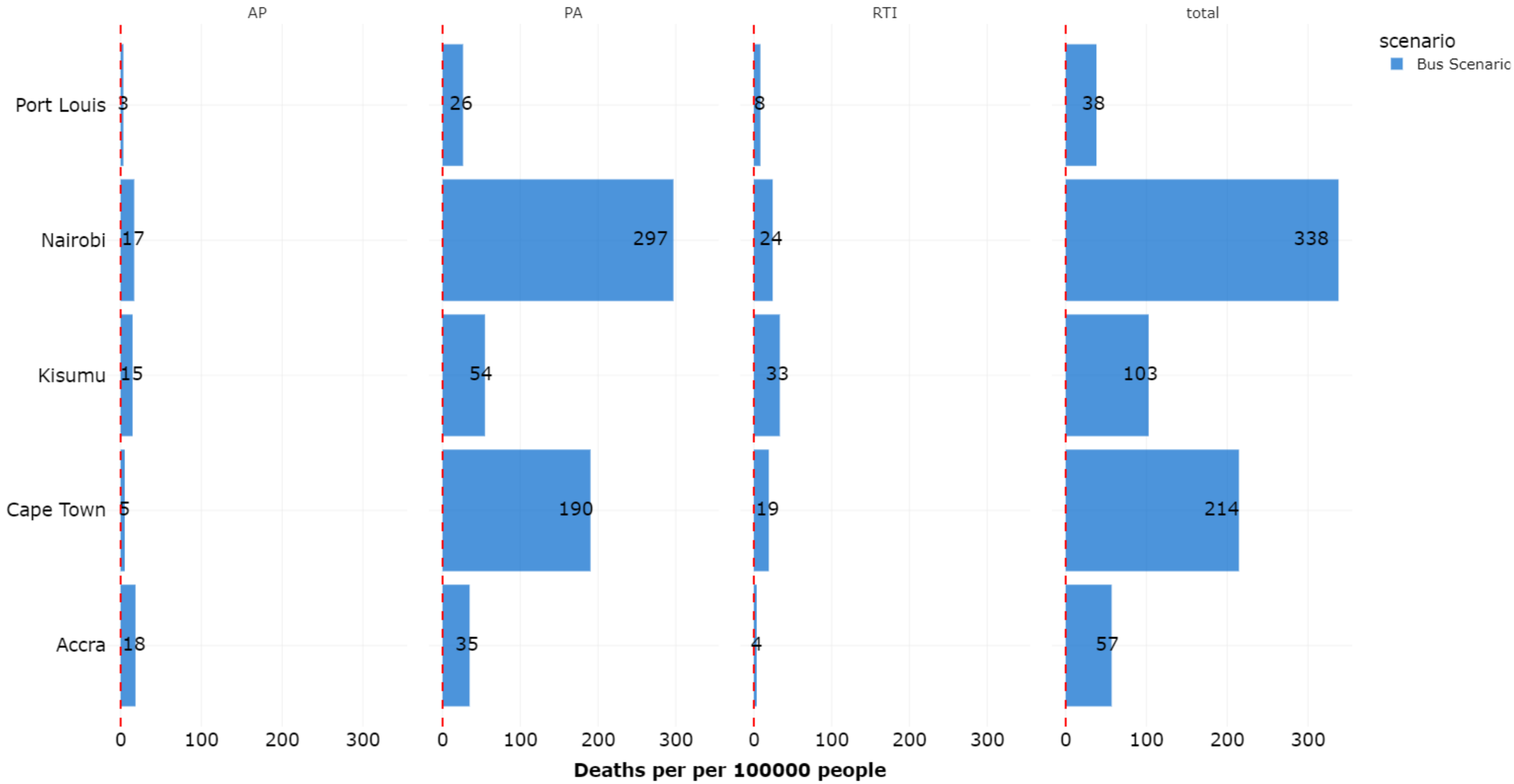


Figure 7.3 Deaths averted in the bus scenario in five case study cities.

7.4.3. Uncertainty of estimates

Figure 7.4 shows scenario distributions of all-cause years of life lost for combined AP, PA and injury pathways by case study city. The x-axis indicates the years of life lost, and the y-axis shows the frequencies. The red dotted lines indicate the 95% confidence limits, which suggest that health changes significantly differed from zero if the interval excluded zero. Changes in all-cause years of life lost were significant in almost all scenarios in all cities except the cycling scenario in Accra, motorcycle scenario in Kisumu, and cycling and car scenarios in Port Louis, where outcomes were more random. These uncertainty results indicate that supplying input parameters from the current distributions will likely produce valid results for all scenarios except motorcycle scenarios.

7.4.4. Sensitivity analysis

Overall, the direction (i.e., benefit or harm) of the total health impacts across scenarios was not significantly affected after considering changes in the city's broader background context. When non-occupational PA was reduced by 20% in all cities, there were no relevant changes in averted total and pathway-specific deaths and YLL (Figure 7.5).

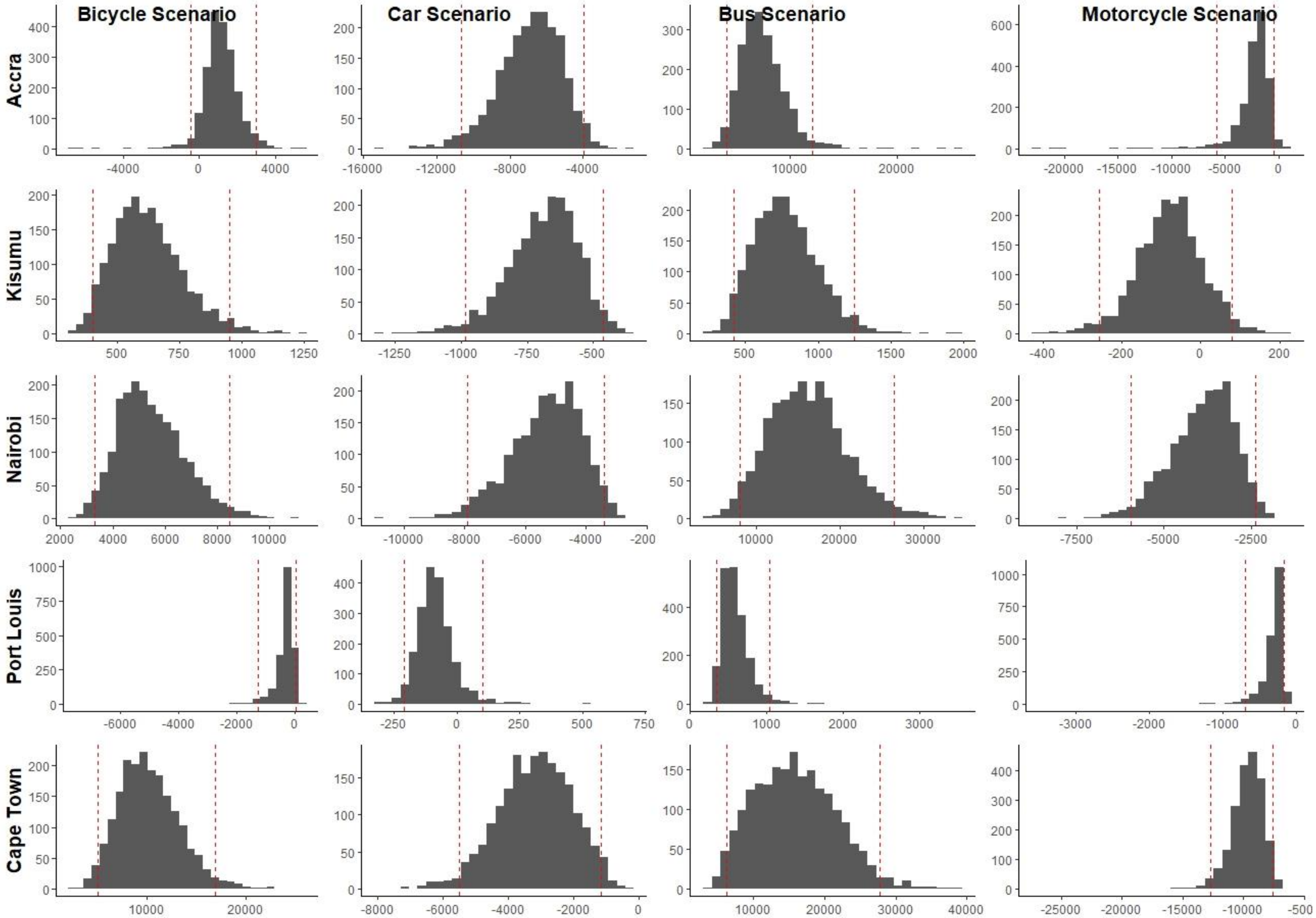


Figure 7.4 All-cause years of life lost for combined air pollution and physical activity pathways show 95% confidence intervals (bounded by red vertical lines)

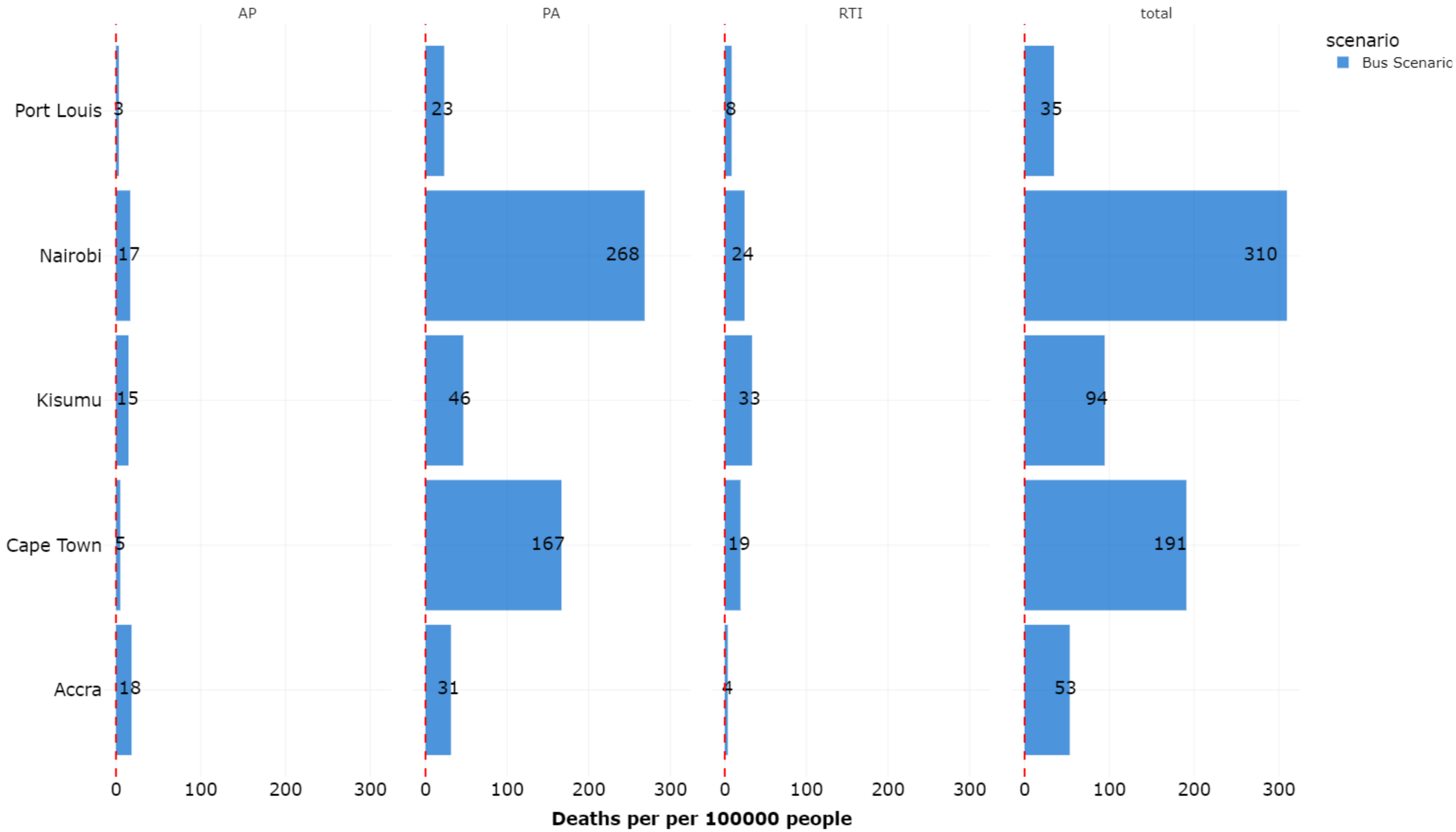


Figure 7.5 Sensitivity analysis showing deaths averted in the bus scenario in five case study cities following 20% drop in non-occupational physical activity

7.5. Discussion

7.5.1. Main findings

This study is the first to estimate urban transport health impacts across several African cities comparatively. I used the best available data and modelling approaches and availed the support of contextual knowledge from research collaborators. The results showed that increasing bus transportation yields substantial health gains through increased physical activity and reduced air pollution and injury. Cycling similarly produces health gains through physical activity and reduced air pollution, but it is associated with substantial road traffic injuries in some cities. Cars and motorcycles reduce health through loss of physical activity, increased air pollution, and road traffic injury. Air pollution health impacts are higher for cars, while road traffic injuries are higher for motorcycles. Random samples of input data and parameters from reasonable distributions produced consistent results.

7.5.2. Strengths and Limitations

The main strength of this study is the successful application of the ITHIM-Global model in several African cities. The study exploited the model’s flexible data requirements to transform and harmonise data from disparate sources such as time-use and travel diaries. Thus, it showcases the potential application of the model in data-poor settings. The results are comprehensive as the model combines outputs from several pathways and robustly employs a microsimulation approach of individuals from a more representative synthetic population. Including multiple cities shows how health impacts and model performance vary across cities.

The study, however, has limitations worth considering. Although I used the best available data for cities to build the scenarios, some data were outdated, e.g., available travel surveys for Nairobi and Cape Town were a decade old. The surveys also suffer from the usual limitations of self-reported data. The number of participants available to inform the synthetic population of many cities was too small to divide into multiple age bands. In most cases, I restricted the sample to those living in urban settings, which overlaps with cities, though not perfectly. Physical activity behaviour is socially patterned. Even though surveys collected socioeconomic factors, the variables were incompatible and could not be used to merge the travel behaviour and non-travel physical activity datasets more accurately. The travel surveys recorded activities only on the preceding day, which does not accurately represent the differences in individuals’ travel patterns across the week (e.g., work and non-work days). Many surveys also did not ask about short walks to/from bus trips (rail trips were asked in only a few surveys but excluded from the analysis because they accounted for only a few trips in the dataset). By scaling down the background number of country deaths and YLL for a metropolitan area population's age- and sex-specific demographic profile, I may have misestimated the share of non-communicable diseases and road injuries in the target population. It highlights the need for further improvements in the background death burden in the area.

The scenarios assume people's trips remain the same even if the mode changes. However, access to more motor vehicles might increase travel distances. If this happens, higher motor vehicle scenarios will likely lead to more significant increases in air pollution and traffic injuries.

The model considers only a few health impacts. Although I tried to include the causes responsible for the most significant health burdens, the potential total effects may be greater than the current estimates. Other health pathways, such as noise pollution [409] and other forms of interpersonal violence related to travel behaviour (e.g., street harassment), were also not included. Also, I did not include the lagged impacts on older age groups.

7.5.3. Interpretation

While buses are just one form of mass public transport, literature shows health gains from mass public transport [1]. The considerable health gains noted in the bus scenario were expected because, compared to cars, buses in most study cities were cleaner, involved in fewer accidents and almost always needed a walking segment. This finding is important because it supports the recent trend of Bus Rapid Systems observed in several African cities, such as Lagos, Cape Town, and Dar es Salam. Infrastructure-wise, compared to trains and metro, public bus transport investments are more straightforward.

Similarly, cycling has known health benefits [113, 125], and their observation in this study was no surprise. The primary health gains result from increased physical activity and reduced air pollution from the low use of cars. Cyclists, however, have a higher risk of road injuries when the infrastructure is inadequate and other road users are reckless. Injuries to cyclists reduce as cyclist numbers increase due to the safety-in-number phenomenon [164]. It means that despite the apparent rise in cyclist injuries, as their number increases, the increasing numbers offer more protection. The focus will remain on making infrastructure that facilitates cycling.

The gaps in public transport and active transport systems have contributed to the rise of cars and motorcycles in African cities. These modes do not encourage physical activity; instead, they add significantly to air pollution in the case of cars and road injuries in the case of motorcycles. This study shows that it would be dangerous to encourage such shifts.

7.5.4. Implications of findings

This work has important implications for policy and practice in LMICs. Other cities in the same countries can replicate this model since the datasets used here are mostly subsets of national data. Most of the local stakeholders involved in this study either have direct responsibilities or are linked with those who have responsibilities over multiple cities in different countries. The case cities are strategic players in several networks of cities and initiatives targeting sustainable development (e.g., Urban Health Initiative, 100 Resilient Cities, C40 Cities, and Partnership for Healthy Cities); thus, they can lead and share experiences with other cities on this practical framework. The methodological advances made for these cities have already helped inform the model's adaptation and application in other LMIC towns in Latin America (e.g. São Paulo, Bogotá) and India (e.g. New Delhi, Bengaluru). Through this study, the successful experience of applying the ITHIM Global model process to foster the best use of local assets (e.g. data, knowledge and expertise) will also contribute to advancing work in other LMICs to improve the evidence around the population health impacts of decisions in transport.

The findings of this study not only demonstrate the feasibility of applying transport health impact models in African cities but also underscore their potential as vital tools for informing urban transport policy. This proof of concept paves the way for more extensive and in-depth applications of such models in various African urban settings. To further this endeavour, several steps can be taken to enhance the utility and impact of these models.

Firstly, active engagement with stakeholders is crucial. Policymakers, urban planners, public health officials, and transport authorities should be involved in the modelling process from the outset. By doing so, the model can be tailored to address specific policy questions and trade-offs that are most relevant to each city's context. For instance, models can be used to simulate the health impacts of proposed transport infrastructure projects, urban development plans, or changes in public transport policies. This collaborative approach ensures that the model outputs are directly applicable to decision-making processes and that stakeholders have a vested interest in the results.

Secondly, refining the model to accommodate local nuances and specificities of African cities is essential. Future research should focus on incorporating more localized data, such as detailed demographic profiles, city-specific travel patterns, and locally relevant health impact measures. As more comprehensive and high-quality data become available, these should be integrated into the model to enhance its accuracy and relevance.

Additionally, the model could be expanded to include additional health impact pathways that are particularly pertinent to African urban settings, such as the effects of noise pollution, heat islands, and other environmental factors on health. Integrating these additional dimensions would provide a more holistic view of the health impacts of transport policies.

Moreover, to facilitate wider adoption, efforts should be made to simplify the model without compromising its robustness. Simplification could involve developing user-friendly interfaces, clear guidelines, and training materials for stakeholders who may not have specialized expertise in health impact modelling.

Finally, documenting and disseminating successful applications of the model in African cities is essential. By sharing case studies and best practices, other cities can learn from these experiences and apply the model to their unique contexts. Establishing a network of cities and experts working on transport health impact models in Africa would foster collaboration, knowledge exchange, and continuous improvement of modelling practices.

7.6. Conclusions

ITHIM provides a practical approach for modelling and comparing African urban transport health impacts. The model outputs support policies that promote public transport and cycling and oppose those that promote cars and motorcycles. Pathway contributions to health outcomes depend on the scenario: changes in physical activity and road injuries contribute most to bus and cycling scenarios, air pollution to car scenarios, and injury to motorcycles scenarios. Although the model requires numerous data inputs and further research to adapt the dose-response functions, it fits the purpose of evaluating transport health impacts in LMICs.

8. **General discussion**

To understand the health impacts of changes in urban transport in African cities, I pursued five specific objectives in this thesis. (1) To describe travel behaviours and their data sources in selected African cities. (2) To describe physical activity behaviour and data sources in a selected African city. (3) To identify policy opportunities and constraints for integrating health into transport policies. (4) To systematically explore use cases of transport health impact models and synthesise approaches on the health impacts of urban transport from modelling studies. (5) To model and compare the health impacts of urban transport in selected African cities. I addressed these objectives through analyses of existing and newly collected surveys, a policy document review, a systematic literature review of modelling studies, and quantitative modelling of urban transport health impacts in selected case study cities. In this concluding chapter, I summarise, integrate, and interpret the main thesis findings, focusing on the three running themes: bridging the data, policy, and tool gaps in modelling urban transport health impacts in Africa. I highlight the thesis's strengths and limitations. I also discuss the research implications and future research on transport health impact modelling in African cities. I end the chapter with some personal reflections and a conclusion.

8.1. Summary and interpretation of main findings

8.1.1. Travel behaviours and data in African cities

Three case studies on four African cities (Accra, Nairobi, Kisumu, Yaoundé) provided valuable insights into travel behaviours and their data sources in Africa (chapter 3), contributing a central piece of information needed for understanding the health impacts of changes in urban transport. The results show a wide variability in immobility rates across cities: 5% in Nairobi, 33% in Yaoundé and Accra and 36% in Kisumu. Daily travel duration ranges from 51 (0-70) minutes (Accra travel diaries) to 101 (30-130) minutes (Accra time-use) with a median value of 77 (0–120) minutes (Yaoundé). Public transport is the second most popular mode, with shares ranging from 13% to 46%, and almost exclusively provided by low-capacity privately owned minibuses and shared taxis. Motorcycle taxi shares vary from 1% (Accra) to 19% (Kisumu). Larger-capacity public transport vehicles (buses and trains) are nearly nonexistent in these cities. Walking is the dominant transport mode in most cities, with mode shares ranging from 27% to 65%. Apart from Kenyan cities where cycling shares range from 2% to 5%, this mode is far lower in other cities. Put together, pedestrian-dominated urban travel in Africa can evolve in any direction: cycling-dominated, where affordable bicycles replace most walking trips; public transport-dominated, with the introduction of efficient, large-capacity vehicles, such as the BRTs; car-dominated, as socioeconomic status increases and more people can afford private cars; motorcycle-dominated as economic growth continues to be slow and motorcycles provide cheaper motorised options to navigate the poor transport infrastructure. The direction can be oriented purposefully through policies, which is where the work presented in this thesis comes in.

Surveys using travel and time-use diaries are valuable data sources. Estimates from the two diary types are comparable for trip modes, durations and purposes but diverge for trip-making rates, number of trips and daily travel durations. The data are obtainable through collaborations with development and research organisations; they are generally scarce and not collected routinely; thus, most datasets are likely outdated and of limited use, especially for fast-changing settings. Nonetheless, they provide indicative estimates. It is challenging to strongly recommend new empirical surveys in these settings since the problem of systematic data collection is long-standing. At the same time, novel data sources can improve travel survey quality issues. Alternative data sources, such as mobile devices, satellites, street views and crowd-sourced social media data, have all been underexplored. While continuing to explore these sources would increase knowledge of urban travel, one more straightforward approach would be to use transport models that need fewer travel behaviour variables to simulate/predict population travel behaviour.

8.1.2. Physical activity behaviour and data in Accra, Ghana

When modelling urban transport health impacts, it is essential to understand the data issues associated with each transport-to-health pathway. I focused on physical activity since it was this thesis's primary pathway of interest. The case study in chapter 4 analysed physical activity behaviour and data sources in Accra, Ghana, comparing estimates from the GPAQ and travel diary surveys as essential and complementary physical activity data sources. Overall, physical activity was high in Accra, with 86% of participants reporting physical activity in at least one domain. The median physical activity level was 18 (IQR: 5–75) metabolic equivalent of task (MET) hours per week, with 50% of females and 37% of males classed as having low physical activity levels based on WHO recommendations. Transport was the second most popular source of physical activity after the work domain; the main contributor to transport physical activity was walking, and cycling was almost insignificant.

The two data sources showed similar estimates of walking rates. Eighty per cent (80%) and 56% of participants reported walking in the GPAQ and travel diary surveys, respectively; still, the proportion of participants expected to report daily walking in the GPAQ was 54% (95% CI: 51–58), similar to the travel diary. Other parameters were significantly different between the two instruments. The mean (standard deviation) daily walking duration was 31 (65) minutes in the travel diary and 51 (82) minutes in the GPAQ. The mean bias error in daily walking duration (GPAQ minus diary) was 20 minutes (95% limits of agreement: –151 to 192). This bias was more pronounced in males and participants with lower than secondary education. The correlation of walking time between the instruments was low ($r = 0.31$; 95% CI: 0.25–0.37). Therefore, there was a substantial disagreement between the tools, with daily walking time estimates in the GPAQ corresponding to 0.1 to 9 times the measures from the travel diary.

Because physical activity and health exhibit a non-linear relationship, health gains depend on the starting physical activity levels. Thus, for a given change in physical activity, health gains are higher in those with lower compared to higher baseline physical activity. Transport physical activity in the travel data must be complemented with data from other sources to obtain the needed baseline physical activity levels. The results of this case study show that complementary data from the GPAQ could lead to higher baseline physical activity levels and affect the health estimates of transport physical activity changes. On the other hand, physical activity questionnaires do not capture different transport modes apart from walking and cycling to serve as a complete input dataset for transport health impact modelling. In addition, the walking and cycling variables in the GPAQ are often aggregated without origin/destination information; thus, these are usually sufficient for reproducing the trips needed for modelling.

8.1.3. Integrating PA into transport and other PA-relevant policies in Cameroon

The role of health goals in setting transport and other associated policies provides an understanding of a system's readiness to embrace health impact assessment methods and outcomes. Using physical activity and NCDs as health indicators, I explored how the transport and other PA-relevant sectors expressed PA in their policies and the level of intersectoral actions in Cameroon's physical activity and NCD policy spaces.

Seven sectors expressed PA in their policies in some form. These sectors were sport, health, local governance, urban planning, education, youth affairs, and the Office of the Prime Minister. Transport and other crucial sectors, such as culture, did not mention PA in their policies. Seventeen (17) policy documents explicitly expressed PA; 4/17 proposed improved communication for behaviour change. Most records (13/17) proposed infrastructure development for promoting PA, mainly in the leisure domain. Notably, none of the proposals targeting infrastructure considered integrated urban development to promote transport PA (walking, cycling and public transport). The promotion of PA to prevent NCDs and improve health and wellbeing was progressively acknowledged, although only the health sector took an interest in such benefits of PA. Many vital sectors involved others when undertaking activities relevant to PA, but most of the invited sectors did not subsequently mention PA in their policies. Therefore, quantifying physical activity and NCD gains from transport could interest policies in multiple sectors. However, the transport sector would need more nudging to recognise these essential indicators. Under such circumstances, simplistic, generic scenarios, rather than complicated ones, would lead to outcomes that are easy to explain during dissemination and engagements with urban transport stakeholders.

8.1.4. Use cases of transport health impact models and outcomes from modelling studies.

To gain insights into existing models and inform model adaptation in Africa, I undertook a systematic review of the use cases of transport health impact models. The review identified a range of modelling approaches and scenarios applied in different settings. There are a large number and range of health impact modelling studies. The breadth of included studies demonstrates the flexibility of health impact modelling to evaluate different scenarios across various settings. The studies also showcase various methodological approaches to quantify impacts through pathways linking transport and health, dominated by the ITHIM and HEAT models.

The scenarios range from retrospective evaluation of real-world changes in transport (e.g. riverside regeneration [391], walking and cycling infrastructure [333], pre/post evaluation of walking/cycling levels [377]) to hypothesised mode shifts examining the sensitivity of outcomes to changes in behaviour (e.g. limiting active transport on high air pollution days [343]). In many studies, the scenarios specified mode shifts (e.g. incremental increases in walking/cycling [321, 329, 339, 340, 363, 368, 393]), whereas, in others, the scenarios were policies or interventions that, in turn, led to a mode shift (e.g. bike share [322, 332, 350], congestion pricing [400], change in fuel price [329, 349], and improved walkability [364]). Scenarios included cases where the modelled population adopted travel patterns of other populations (e.g. mode distribution of other locations in the same country [328, 383] or well-known case studies [323, 346, 348]). Other studies evaluated the health impacts of switching specific trips to different modes (e.g. trips under specified distance or duration [316, 337, 369, 390, 391], commute trips that could be cycled in under 30 minutes [356, 374], the share of total trips or distance [387, 397]). Studies are predominantly in high-income settings, and many studies report on European cities. Physical activity, air pollution, and road injury are the principally captured health pathways. These represent a selected subgroup of the pathways that link transportation and health [15]. Studies examining the disease burden from transport have captured additional pathways, including green spaces and urban heat islands [409, 410]. Therefore, where possible and appropriate, additional pathways could be included in health impact modelling studies. Less than one-third of included studies examined the impacts of scenarios across different population groups (e.g. age or ethnic groups), and only eight examined impacts across multiple different population groupings.

8.1.5. Transport health impact modelling in Accra, Cape Town, Nairobi, Kisumu and Port Louis

This study combined results from preceding studies about data, policies, and modelling approaches to model urban transport health impacts in selected African cities. Results showed that increasing bus transportation yields substantial health gains through increased physical activity and reduced air pollution and road traffic injuries/fatalities. Cycling similarly produces health gains through physical activity and reduced air pollution, but associated road traffic injuries are substantial in some cities. Cars and motorcycles reduce health through physical inactivity, increased air pollution, and road traffic injuries. Increasing the number of motorcycles is associated with more road traffic injuries than any other mode. When accounting for uncertainties associated with the input data and parameters, the model outcomes for the different scenarios were generally stable. Changes in years of life lost were random for the cycling scenario in Accra, the motorcycle scenario in Kisumu, and the cycling and car scenarios in Port Louis. Outputs of the uncertainty and sensitivity analyses showcase the model's robustness.

8.1.6. Overall thesis findings

Modelling the health impacts of changes in urban transport is a complex task from a data standpoint due to the multiple pathways through which transport can affect health, which all require data. Many unique pieces of information are required to model this impact accurately. One of the key challenges in this process is the collection of data on travel behaviour and physical activity, which is often obtained through real-world individual-level surveys. These surveys can be expensive, particularly in

LMIC cities. Their results may not represent the population as a whole due to issues such as recall bias, small sample sizes and outdated datasets.

Results of different survey types often diverge, even when they are collected for the sole purpose of health impact modelling—for example, the estimates of transport-related physical activity from the GPAQ and travel diary in chapter 4 showed substantial differences when they were both collected for modelling. The divergence suggests that model input varies with the data source, and the uncertainties around these data must be considered when modelling transport health impacts. The yet unexplored data sources could produce their own divergent results.

One possible solution to this problem is using data from modelling studies that produce more plausible estimates using fewer indicator variables. For example, a combination of transport models, such as trip generation, trip distribution, mode choice, route choice, and traffic assignment models, can predict travel behaviours with fewer input parameters. This approach could also help to reduce the cost and complexity of data collection, making it more feasible for cities in the developing world.

Evidence from the health impact of urban transport can potentially influence policy decisions. According to the "rational decision theory", decision-makers can directly use this evidence to weigh the costs and benefits of different options and choose the ones that maximise benefits. On the other hand, Kingdon's multiple stream approach suggests that evidence on the health impact of urban transport can contribute to the recognition and definition of the issue that needs to be addressed in the problem stream. It subsequently couples with the other streams to lead to policy decisions. Regardless of the theory, it is clear that as evidence on the health impact of urban transport is used by policymakers, there will be an increased demand for transport health impact assessments.

To this end, several factors have hindered the development of transport health assessments in Africa. One factor is the general low use of evidence in policymaking. Additionally, health has not traditionally been considered a priority in African urban transport policies, contributing to the general lack of progress in this area. To improve the development of transport health assessments, it is crucial to prioritise the use of evidence in policymaking and make health a priority in urban transport policy. One way of achieving this is by showing stakeholders easy-to-digest evidence about the health impacts.

There is a need for robust and standardised tools for modelling the health impact of transport in Africa, considering the specific context, data availability, and dominant pathways of transport health impact in this setting. Additionally, developing models that consider non-motorized transport in the African-specific context will be beneficial. The successful application of the ITHIM-Global model is part of the solution to the problem whereby existing tools for modelling the health impacts of transport are developed for HICs, which may not be directly applicable to the African context.

8.2. Research strengths and limitations

The strengths of this thesis are manifold. I used the most up-to-date data and modelling approach to estimate the health impacts of changes in urban transport in African cities. The selected modelling approach is supported by evidence from a systematic review. The assessed scenarios are simplistic enough for nudging stakeholders in settings where urban transport policies do not explicitly consider health. The integrated modelling of multiple health pathways allows analysts to judge the overall effect of policy changes, not just those limited to a single path: combining results tells a complete story, especially as these can often be in different directions. Exploring multiple cities allowed for understanding model behaviour in various cities and how cities would react to the same changes—this is critical as cities now tend to work collaboratively and learn from one another. The thesis has also explored ways of obtaining modelling data, including collecting new travel data for Yaoundé and Accra to improve on old data.

The research also has several limitations. The thesis heavily relies on the rational approach to decision-making, attempting to balance urban transport policy health gains against harms as the requisite for policymaking. This approach is somewhat limited since actual policymaking sometimes requires much more than the evidence of a problem.

Many proxy parameters were used during the modelling process for many cities despite attempts to obtain the most updated complete data. Proxy parameters came from cities based on similarities in location, population, and socio-economic characteristics. That means that estimates could slightly differ if the actual parameters were available. For example, I used car occupancy from Cape Town for the rest of the cities. The model requires many data inputs and technical knowledge, making it challenging to apply in settings with scarce data or by less technical persons. Most surveys did not define city boundaries and could lead to wrong inferences about city characteristics and behaviours. Policy scenarios were very simplistic because of the need to compare across multiple cities but not detailing their application feasibility. Finally, the dose-response functions of the chosen model still relied on studies from HICs, increasing bias in our results. However, developing setting-specific dose-response functions was out of the scope of this thesis and recommended as the next urgent step for advancing health impact modelling in Africa.

8.3. Implications of research

African cities should pursue the effective implementation and monitoring of initiatives that aim to facilitate active travel and slow the growth of cars and motorcycles. Policies tackling age and gender disparities in urban transport, especially cycling, are relevant for achieving substantial positive health impacts from changes in urban transport. Walking and cycling should be the safest, cheapest, most pleasant and most convenient options for everyday trips. That means shifting priorities and investments from roads for motorists towards improvements that favour active travel and mass transit. A strong commitment towards sustainable transport would potentially significantly reduce CO_2 emissions from road transport, the sector with the single most significant contribution and growing trend of CO_2 emissions in most cities.

The high road injury rates indicate that, together with improving infrastructure and traffic conditions, it would be indispensable to enact policies that focus on reducing the risk of road traffic injuries in higher-risk groups, particularly pedestrians, cyclists, and motorcyclists [422]. Ongoing policies that shift cities in this direction should be encouraged, with proper evaluation to ensure that the hoped-for transport and health benefits are realised. Examples of such policies include the construction of dedicated cycling infrastructure, improvements in sidewalks, more significant investments in mass transit, and strategies for traffic-calming and traffic law reinforcement. Other promising initiatives for which net health effects have not been established in low- and middle-income settings include the planned expansion of the cycle hire system for cities and vehicle inspection programmes. Buses could be much cleaner: strategies to reduce the contribution and mitigate the negative impact of public transport on air pollution, such as fleet renewal, adequate fleet maintenance and changes in the energy matrix, could increase the benefits observed. Proper planning for cleaner public transport is essential so that new programmes do not lead to unintended consequences, such as reducing public transport availability and use, as seen in other low- and middle-income cities [421].

A better-designed and more compact, decentralised and diverse city would support active travel uptake and increase access to other social determinants of health, such as education, work, leisure, green space, services, and health facilities. It would also generate considerable travel time savings [423] in cities with high traffic congestion. In other words, contrary to traditional transport goals and policies, planners should aim for travel time savings not by moving people faster but by reducing necessary distances. Cities would have to overcome the long history of segregation and dispossession against the poor population and the privileges traditionally given to the middle class and the elite [424]. African cities still have remarkable social inequities in eradicating hunger and improving housing, employment and health, particularly among poorer groups; addressing those from the urban transport perspective is a sensible entry point for tackling inequities.

8.3.1. Lessons to support policymaking from the COVID-19 pandemic

The *COVID-19* pandemic prompts further reflections on the future of urban mobility in Africa. Work-from-home and hybrid remote working models have grown in many sectors following the COVID-19 stay-at-home strategy adopted by many governments worldwide [425–427]. However, in most African countries, COVID-19 lockdowns and travel restriction measures were relatively brief, as countries were under pressure to reopen their dominant informal sectors [426, 428]. That underscores the importance of adapting transport response strategies to similar epidemics where most of the working population is engaged in the informal sector. Emphasis should, therefore, be on developing the transport infrastructure that will allow the disadvantaged [429] to meet their mobility needs without exposing them to higher risks of infectious diseases, violence, and injury. Cycling is a logical option for trips up to around 8 to 10 Km. Cities may have unsuitable climates or hilly terrain for cycling, making electric-assisted bikes a more useful alternative. Long-distance travel in expanding cities still requires shared modes of transportation, including informal public buses, where physical distance protocols are not realisable with low-capacity vehicles [430]. There is an opportunity to reshape housing and land-use designs in these growing cities towards compact cities that allow for active travel and reduce the need for long-distance travel for daily activities.

Beyond building resilient transport infrastructures for epidemics, future transport management and control policies must address the mobility inequity that makes travelling difficult for some population groups, especially females. In addition, further considerations should be made about introducing large-capacity public transport vehicles to curb growing problems of road traffic congestion, albeit there are apparent drawbacks of forcing a formal public transport system in systems that are dominated by the informal sector.

The COVID-19 pandemic brought mathematical modelling into the spotlight as scientists rushed to use data to understand transmission patterns and disease severity and to anticipate future epidemic outcomes. Because of a few particularly erroneous projections at the start of the pandemic, the use of COVID-19 modelling has been criticised, mirroring long-existing concerns over the validity of modelling studies [431]. Modelling helped predict the pandemic progress, e.g. there are major uncertainties around disease dynamics and policy outcomes, as well as ample opportunity for models to "get it wrong" [432]. We should expect that the evidence base and epidemiological context will continue to shift, sometimes making earlier modelled results obsolete. Modelling is likely to remain prominent as new policy questions arise, yet the uncritical acceptance of modelling results will not serve public health or the field of modelling. Careful evaluation and comparison of results—and benchmarking against empirical findings where possible—will be important for revealing assumptions and potential biases and spurring progressive improvement in modelling approaches.

8.3.2. Research transferability

This research sought to understand the health impacts of urban transport in Africa, emphasising Sub-Saharan African cities. Because of resource and time constraints, I focused the analysis only on five case study cities (Accra, Nairobi, Kisumu, Port Louis and Cape Town). The research findings are potentially beneficial for other LMIC cities, which, because of limited resources and lack of political commitment, are likelier to look elsewhere for decision-making evidence [433]. The chosen case studies fulfil many criteria for the transferability of results. Given (2008) [434] notes that researchers should focus on two key considerations to increase transferability: (a) how closely the populations are linked to the context being studied and (b) the contextual boundaries of the findings. To this end, I have teased out some similarity parameters of the case study contexts to other sub-Saharan African cities, increasing the ability to transfer some research findings to those contexts.

In many ways, the five case study cities compare favourably to several Sub-Saharan African cities. The research indicates that there is virtually no car assembly and production in the study countries; hence, the countries rely heavily on imported cars; for instance, more than 96% of cars imported into Nairobi are second-hand cars [435]. In addition, in Addis Ababa and Lagos, second-hand imports account for more than 80% of vehicles owned [435]. Another similar characteristic among Sub-Saharan African cities is the dominance of informal public transport. In this research, minibuses are the most frequently used motorised mode, with up to 70% of mode shares. In Lagos, the informal public transport minibuses known as "danfos" had a mode share of over 70% in 2017 [436]. Another similar characteristic among Sub-Saharan African countries is the use of old cars. The average age of cars used in Lagos and Nairobi was 15 years in 2015 [437]. These similarities provide a foundation for using these findings in other Sub-Saharan African cities.

Although similarities exist, the data-gathering approach adopted in this research must be critiqued when considering the findings for other Sub-Saharan African cities. Firstly, some of the travel surveys reported in the thesis were conducted around the COVID-19 pandemic, which limited human movements and social interactions in many cities worldwide. Hence, the findings cannot represent routine city data. However, the approach used in this research provides a foundation for gathering modelling data in LMIC cities with limited resources and a lack of time series data to undertake trend analysis. The essential travel, injury and air pollution patterns resonate with descriptive literature on transport in other Sub-Saharan African cities.

8.4. Further research

Data presented in this thesis and previous literature about urban transport still provide an insufficient characterisation for a broad area like Africa. There is a need to expand the description of urban transport parameters, such as travel behaviours, road traffic injuries, and air pollution, to other cities to improve the picture of urban transport in Africa. Artificial intelligence (AI) and advanced machine-learning techniques could quickly fix this problem since reliance on surveys and traditional analytic methods has not yielded much in these settings.

The policy scenarios evaluated in this thesis were simple per cent point additions of selected mode shares to allow for easy cross-city comparisons. Like many other studies, these simplistic scenarios do not thoroughly explore the pathways to achieving them. Future studies should focus on decomposing policy targets into meaningful modelling scenarios. Modelling specific policies and empirical research, in close coordination with policymakers, would also allow a more refined analysis of how to achieve context-specific changes in population travel patterns.

The model itself still requires further refining. Some parameters resulted from high-income settings, including the relation between daily and weekly travel behaviour, the average years of life lost for lifelong and temporal road injuries, the mode-specific ventilation rates, and dose-response functions. Future research should aim to understand the relationship between travel patterns and other risk factors, such as noise, food behaviour, independent mobility and social isolation, as well as other health-relevant issues, such as quality of life, happiness, violence, and mental health well-being. Moreover, more studies on low- and middle-income settings would be welcome to clarify exposure-response relationships for air pollution.

Considering the advancements and findings presented in this thesis, several key steps can be taken to further refine the modelling approaches specific to African urban environments. While the application of the ITHIM-Global model in various African cities has yielded valuable insights, continuous refinement of this model is essential to enhance its accuracy and relevance to the unique transport, health, and environmental dynamics of these regions.

Firstly, refining the model must involve a concerted effort to compile more comprehensive, up-to-date, and locally-specific data. This includes detailed travel behaviour data, demographic profiles, and health statistics pertinent to African urban contexts. Partnerships with local authorities, universities, and international research bodies can facilitate the collection of this crucial data. Additionally, leveraging technological advancements such as big data analytics, machine learning, and geospatial analysis can play a significant role in enriching the data sets used for modelling.

Further, there is a need to pose nuanced and contextually relevant questions that the model can interrogate. These questions should not only focus on traditional metrics of transport efficiency and health impacts but also explore broader socio-economic, cultural, and environmental considerations unique to African cities. For example, questions could revolve around the impacts of non-motorized transport infrastructure development on urban sprawl, the socioeconomic disparities in access to public transport, or the environmental consequences of various transport policies.

Additionally, future research should focus on developing models that incorporate the informal transport sector, which plays a significant role in many African cities. This sector's inclusion will provide a more accurate representation of the transport landscape and its health implications.

Another critical aspect is the integration of qualitative research methods into the modelling process. This integration will help in understanding the perceptions, attitudes, and preferences of African city dwellers regarding transport and health. Such insights are vital for formulating transport policies that are not only effective in theory but also acceptable and practical in the lived realities of urban residents.

8.5. Personal reflections

When I started my PhD journey, I held a relatively positivist perspective. This view came from a background in the pragmatic fields of Medicine, Public Health and Disasters in low- and middle-income countries (LMICs), where understanding ways to provide practical solutions was crucial to improving health provision. I wanted to focus on identifying practical solutions to support more and better policy health impact assessments in LMICs. This pragmatic research is reflected in the specific research objectives of the studies I undertook during my PhD.

This PhD encouraged me to appreciate the value of developing conceptual frameworks to shed light on complex issues. The shift in perspective arose from gaining a greater understanding of qualitative research and learning from my supervisors and team members, who provided invaluable support and insights about exploring environmental health exposures across my PhD projects. The qualitative approach led me to appreciate better the potential value of taking a more reflexive, interpretive approach to thematic analysis rather than being limited by a more restrictive, positivist stance. I believe my thesis findings can provide insights into other public health issues, particularly around the issues of creating and analysing scenarios of the world we want and demonstrating contextually relevant examples to inspire decision-makers.

My previous work in LMICs, which includes understanding ways to support population health in stable and humanitarian contexts, encouraged me to pursue research. Having conducted my research while based in a high-income setting, I am pleased that it was possible to demonstrate that research in

LMICs can be considered an independent strand without necessarily imposing leaning on concepts from high-income backgrounds.

8.6. Conclusion

This thesis has addressed critical data gaps in transport health impact modelling by presenting case studies of travel and physical activity behaviours in selected African cities, highlighting high walking rates, use of low-capacity vehicles for public transport, and varied cycling and motorcycling. It has addressed a policy gap by showing that the transport sector in developing cities must explicitly incorporate physical activity and non-communicable disease goals and work with other relevant sectors in an intersectoral manner. This incorporation is necessary for policymakers to appreciate health impact modelling fully. The gap in modelling tools has been addressed by systematically selecting and applying a suitable modelling tool for the setting. Results from the modelling study support policies that promote public transport and cycling but not motorcycles or cars. The diverse range of cities successfully modelled in this thesis implies that the approach can be applied to many other cities. Critical areas for further research to consolidate findings presented in this thesis are improving the picture of travel behaviour in Africa, operationalising transport scenarios and improving contextual fitness of dose/exposure-response functions of the models.

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10. **Appendices**

10.1. Other contributions during my PhD

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10.2. Chapter 6 supplementary materials

10.2.1. Full search terms for each database

Medline finalised search (13/11/20):

1	exercise/ or running/ or jogging/ or walking/ or pedestrians/ or bicycling/ or motor vehicles/ or motorcycles/ or automobiles/
2	("public transport*" or walking or walkability or running or bicycling or biking or bikeability or ebiking or jogging or pedestrian* or bike or bikes or ebike* or scooter* or escooter* or car or cars or motorcycle* or motorbike* or "motor* vehicle*" or "electric vehicle*" or "passenger vehicle*" or "private vehicle*" or bicyclist* or "physical activity" or "physical exercise" or rideshar* or "ride shar*" or carpool* or bikeshar*).tw,kw,kf.
3	((active or green) adj (transport* or commut* or travel or travelling or transit or mobility)).tw,kw,kf.
4	or/1-3
5	city planning/ or environment design/ or urban renewal/ or urban population/ or suburban population/
6	(transport* or travel or travelling or commut* or traffic or transit or ((city or cities or urban* or suburban or environment) adj3 (design* or infrastructure or plan* or redesign* or renewal or regenerat* or greening or intervention* or population* or policy or policies))).tw,kw,kf.
7	5 or 6

8	4 and 7
9	transportation/
10	8 or 9
11	Health Impact Assessment/ or health status/ or socioeconomic factors/ or health status disparities/
12	(((health or socioeconomic* or illness or disease* or mortality or morbidit*) adj2 (impact* or benefit* or outcome* or consequence* or assessment* or estimat* or status or severity or model* or factors or factor or inequalit* or equalit* or disparit* or equit* or inequit*)) or "impact assessment*").tw,kw,kf.
13	((life adj1 year*) or QALY* or DALY* or HALY* or CBA or HIA).tw.
14	or/11-13
15	10 and 14
16	limit 15 to english language

Embase

1	cycling/ or jogging/ or running/ or walking/ or bikeability/ or walkability/ or pedestrian/ or motor vehicle/ or car/ or motorcycle/ or physical activity/ or exercise/
2	("public transport*" or walking or walkability or running or bicycling or biking or bikeability or ebiking or jogging or pedestrian* or bike or bikes or ebike* or scooter* or escooter* or car or cars or motorcycle* or motorbike* or "motor* vehicle*" or "electric vehicle*" or "passenger vehicle*" or "private vehicle*" or bicyclist* or "physical activity" or "physical exercise" or rideshar* or "ride shar*" or carpool* or bikeshar*).tw,kw.
3	((active or green) adj (transport* or commut* or travel or travelling or transit or mobility)).tw,kw.
4	or/1-3
5	city planning/ or environmental planning/ or built environment/ or universal design/ or urban population/ or suburban population/ or "traffic and transport"/
6	(transport* or travel or travelling or commut* or traffic or transit or ((city or cities or urban* or suburban or environment) adj3 (design* or infrastructure or plan* or redesign* or renewal or regenerat* or greening or intervention* or population* or policy or policies))).tw,kw.
7	5 or 6
8	health impact assessment/ or health status/ or health disparity/ or health hazard/ or exp socioeconomics/
9	(((health or socioeconomic* or illness or disease* or mortality or morbidit*) adj2 (impact* or benefit* or outcome* or consequence* or assessment* or estimat* or status or severity or model* or factors or factor or inequalit* or equalit* or disparit* or equit* or inequit*)) or "impact assessment*").tw,kw.
10	((life adj1 year*) or QALY* or DALY* or HALY* or CBA or HIA).tw.
11	or/8-10
12	4 and 7 and 11
13	limit 12 to english language
14	limit 13 to conference abstracts
15	13 not 14

Cochrane Central

1	exercise/ or running/ or jogging/ or walking/ or pedestrians/ or bicycling/ or motor vehicles/ or motorcycles/ or automobiles/
2	("public transport*" or walking or running or bicycling or biking or ebiking or jogging or pedestrian* or bike or bikes or ebike* or scooter* or escooter* or car or cars or motorcycle* or motorbike* or "motor* vehicle*" or "electric vehicle*" or "passenger vehicle*" or "private vehicle*" or bicyclist* or "physical activity" or "physical exercise").mp.
3	((active or green) adj (transport* or commut* or travel or travelling or transit or mobility)).mp.
4	or/1-3
5	city planning/ or environment design/ or urban renewal/ or urban population/ or suburban population/
6	(transport* or travel or travelling or commut* or traffic or transit or ((city or cities or urban* or suburban or environment) adj3 (design* or infrastructure or plan* or redesign* or renewal or regenerat* or greening or intervention* or population* or policy or policies))).mp.
7	5 or 6
8	4 and 7
9	transportation/
10	8 or 9
11	Health Impact Assessment/ or health status/ or socioeconomic factors/ or health status disparities/
12	(((health or socioeconomic* or illness or disease* or mortality or morbidit*) adj2 (impact* or benefit* or outcome* or consequence* or assessment* or estimat* or status or severity or model* or factors or factor or inequalit* or equalit* or disparit* or equit* or inequit*)) or "impact assessment*").mp.
13	((life adj1 year*) or QALY* or DALY* or HALY* or CBA or HIA).mp.
14	or/11-13
15	10 and 14
16	limit 15 to english language

Scopus
5137
TITLE-ABS (("public transport*" OR walking OR running OR bicycling OR biking OR ebiking OR jogging OR pedestrian* OR bike OR bikes OR ebike* OR scooter* OR escooter* OR car OR cars OR motorcycle* OR motorbike* OR "motor* vehicle*" OR "electric vehicle*" OR "passenger vehicle*" OR "private vehicle*" OR bicyclist* OR "physical activity" OR "physical exercise") OR ((active OR green) W/0 (transport* OR commut* OR travel OR travelling OR transit OR mobility))) AND TITLE-ABS-KEY (transport* OR travel OR travelling OR commut* OR traffic OR transit OR ((city OR cities OR urban* OR suburban OR environment) W/3 (design* OR infrastructure OR plan* OR redesign* OR renewal OR regenerat* OR greening OR intervention* OR population* OR policy OR policies))) AND TITLE-ABS ((((health OR socioeconomic* OR illness OR disease* OR mortality OR morbidit*) W/2 (impact* OR benefit* OR outcome* OR consequence* OR assessment* OR estimat* OR status OR severity OR model* OR factors OR factor OR inequalit* OR equalit* OR disparit* OR equit* OR inequit*)) OR "impact assessment*")) AND (LIMIT-TO (LANGUAGE , "English"))

Web of Science
5026

(TS=("public transport*" OR walking OR running OR bicycling OR biking OR ebiking OR jogging OR pedestrian* OR bike OR bikes OR ebike* OR scooter* OR escooter* OR car OR cars OR motorcycle* OR motorbike* OR "motor* vehicle*" OR "electric vehicle*" OR "passenger vehicle*" OR "private vehicle*" OR bicyclist* OR "physical activity" OR "physical exercise" OR ((active OR green) NEAR/0 (transport* OR commut* OR travel OR travelling OR transit OR mobility)))) AND (TS=(transport* OR travel OR travelling OR commut* OR traffic OR transit OR ((city OR cities OR urban* OR suburban OR environment) NEAR/3 (design* OR infrastructure OR plan* OR redesign* OR renewal OR regenerat* OR greening OR intervention* OR population* OR policy OR policies))) OR WC=Transportation) AND (TS=(((health OR socioeconomic* OR illness OR disease* OR mortality OR morbidit*) NEAR/2 (impact* OR benefit* OR outcome* OR consequence* OR assessment* OR estimat* OR status OR severity OR model* OR factors OR factor OR inequalit* OR equalit* OR disparit* OR equit* OR inequit*)) OR "impact assessment*"))

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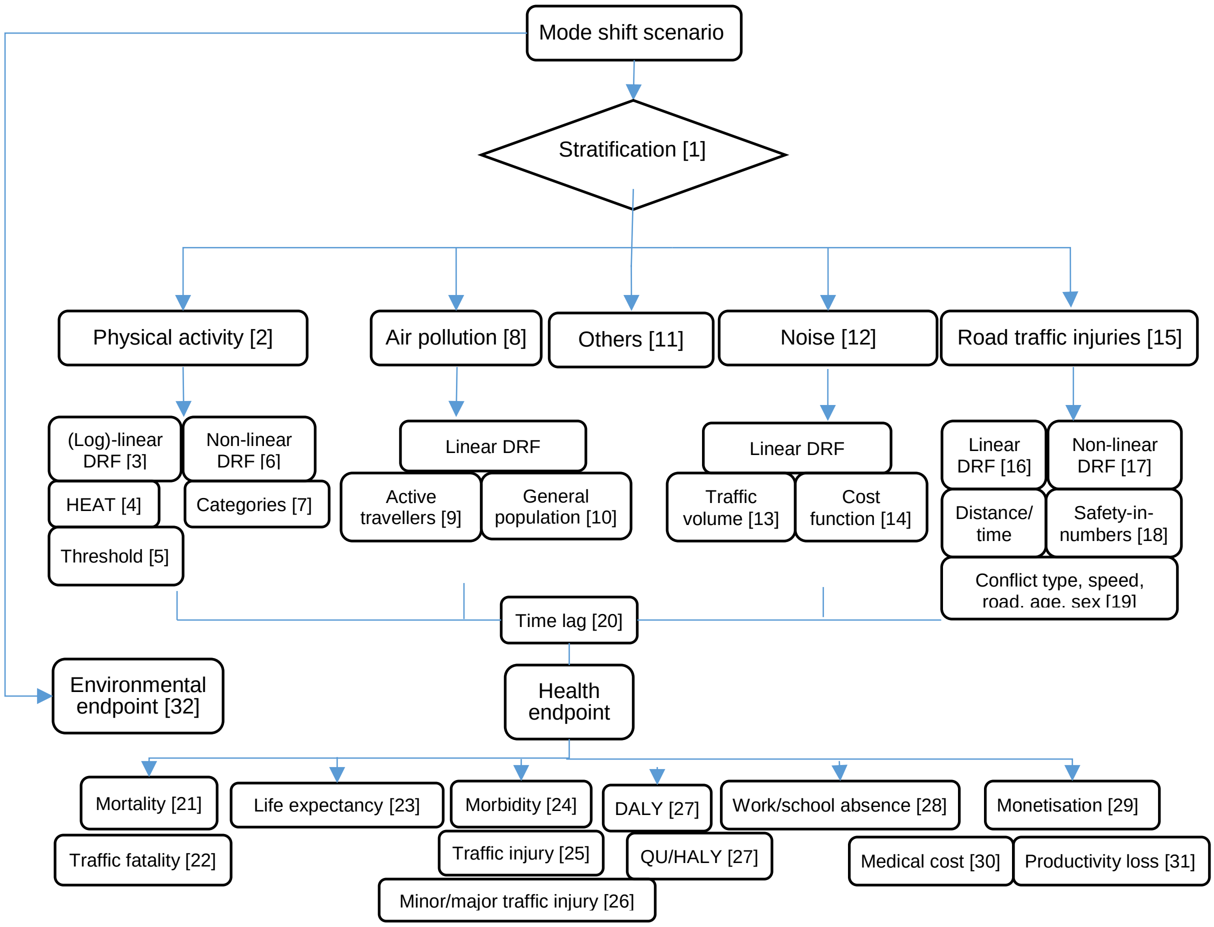
("public transport*" OR walking OR running OR bicycling OR biking OR ebiking OR jogging OR pedestrian* OR bike OR bikes OR ebike* OR scooter* OR escooter* OR "car" OR "cars" OR motorcycle* OR motorbike* OR "motor vehicle*" OR "electric vehicle*" OR "passenger vehicle*" OR "private vehicle*" OR bicyclist* OR "physical activity" OR "physical exercise" OR "active transport*" OR "active travel*" OR "green transport*" OR "green travel*") AND (commut* OR traffic OR transit OR city OR cities OR urban* OR suburban OR environment OR infrastructure OR plan* OR redesign* OR renewal OR regenerat* OR greening OR intervention* OR policy OR policies) AND (health impact OR socioeconomic* OR illness OR disease* OR mortality OR morbidit* OR "impact assessment*") AND model*

10.2.2. Data extraction form

Field	Standard / Custom	Format	Note
Identification			
Study details			
Sponsorship Source	standard	Free Text	Check whether a funding source is reported. Often this can be found in a section titled 'Acknowledgements' or 'Funding' or reported on the first page of the manuscript near the author information. Enter the funding source If more than one, list separated by a comma Otherwise enter 'no source reported' *Example* Medical Research Council, Heart Foundation
Country	Standard	Free Text	Enter the country being studied If more than one, list separated by a comma *Example* Ghana
Setting	Standard	Free Text	Enter the city where the data were collected If more than one, list separated by a comma If information given at different levels of geographical aggregation (e.g. region, city, district), list all this information and where possible give information on the level of aggregation in brackets *Example* Accra, Kumasi, Tamale, Sekondi–Takoradi (metropolitan areas)
Comments	Standard		Leave the field blank
Authors contact details			
Authors name	Standard	Free Text	Enter the name of the first author Use the format [surname, initials] *Example* Abane, AB
Institution	Standard	Free Text	Enter the institution or affiliation of the first author with the country of this affiliation in brackets If more than one, list separated by a comma
Email	Standard	Free Text	Enter the email address of the first author If none provided enter' email not provided' *Example* am_abane@yahoo.com
Address	Standard		Leave the field blank
Additional identification data			
Country of first author	Custom	Text	Enter the country where the first author's institution or affiliation is located If more than one, list the country of the first affiliation
Country of last author	Custom	Text	Enter the country where the last author's institution or affiliation is located If more than one, list the country of the first affiliation If the study has only one author, enter 'no last author' *Example* United States of America
Date of publication			Enter the year that the study was published *Example* 2014
Methods			
HIA approach	Custom	Text	Enter the approach of HIA used Example: Comparative risk assessment, risk-benefit analysis
Policy Focus	Custom	Text	Enter the policy focus of study

			Example: Reduction of Co_2
Mode Shift	Custom	Text	Enter the mode shifts considered; If more than one scenario is considered enter mode shift for each scenario Example car to bus, car to motorcycle
Scenario	Custom	Text	Enter the scenario considered. If more than one scenario is being considered, enter all the scenarios and number them so that the numbers can be used to reference the scenario Example: 1. S1: BAU 2013 2. S2: Low carbon driving
Health Endpoint	Custom	Text	Example: 1. DAILY, 2. YLL etc
Population			
Inclusion criteria	Standard		Leave the field blank
Exclusion criteria	Standard		Leave the field blank
Group differences	Standard		Enter age groups and gender considered separated by comas
Baseline characteristics	Standard		Leave the field blank – will be completed later
Intervention			
Table with each pathway eg PA as column and rows as below			
Population			General population? An age group? etc
Data type			Primary data e.g. Travel survey; review
Data source			Xxx survey? Yyyy et al?
Parameter			METs, mMETs, Kcal/….
Method / Tool			Review, HEAT, ITHIM
Dose response function			Linear, categorical
Health outcomes measured			Cardiovascular diseases, Death …
Estimated Health Impact			RR for each health outcome
Source of Risk Estimate			Xxxx et all for each outcome
Outcome			
Table with outcomes. Scenarios as columns and pathways as rows			
Baseline 1			Baseline Health endpoint for each pathway Example for PA: 100(being the median DAILY), 20 (LQ), 190 (UQ)
Baseline 2			Baseline Health endpoint 2 for each pathway Example for PA: 100(being the median YLL), 20 (LQ), 190 (UQ)
Scenario 1 -1			IDEM
Scenario 1 – 2			IDEM

10.2.3. Health impact pathways



Frequently modelled pathways of transport mode shift to health and environmental outcomes (modified from Natalie et al. 2015). Stratifications were age, sex, ethnicity, population density, or socioeconomic status; HEAT applies a threshold for PA at RR 0.5, after which no additional health benefit can be obtained. Woodcock et al. 2009, Jarrett et al. 2012, and Maizlish et al. 2013 applied a threshold or a square-root function for higher PA exposure levels; Safety-in-numbers describes a disproportional increase in traffic incidents with increasing modal share; Time-lags describe potential delays until health benefit or risk occurs in the lifespan.

			PA						AP			Oth	NP			RTI																	
Study	**Pathways**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Mooy 2001	1	●	●					●														●											
de Hartog 2010	3	●	●	●					●	●	●					●	●						●	●									●
Lindsay 2011	3	●	●	●	●	●			●		●					●		●	●			●	●			●			●	●	●		●
Olabarria 2012	1	●	●	●	●	●																●								●	●		
Stipdonk 2012	1	●														●	●			●		●	●		●	●							
Dhondt 2013	3	●	●				●		●		●					●	●			●		●	●	●		●		●					
Schepers 2013	1	●														●		●	●	●		●	●		●	●							
Woodcock 2014	3	●	●				●		●	●						●	●				●					●	●	●					●
Edwards 2014	2	●	●													●	●				●		●	●									
Muennig 2014	2	●														●		●					●					●		●	●		
Gotschi 2015	1	●	●				●															●						●					
Hou 2020	3	●	●	●					●	●						●	●					●						●					
Smargiassi 2020	3	●	●	●					●	●						●	●											●					●
Yang 2020	2	●										●													●								
Bassett 2020	1	●	●					●																				●		●	●		
Saelensminde '04	1		●					●																						●	●	●	●
Boarnet 2008	1		●					●																						●	●		
Cobiac 2009	1		●					●																						●	●		
Woodcock 2009	3		●	●		●			●		●					●	●						●			●	●	●		●	●		●
Guo 2010	1		●	●																										●	●		●
Gotschi 2011	2		●	●	●	●										●		●				●								●	●		●
Rabl 2012	3		●				●		●	●	●		●		●	●	●													●	●		●
Meschlik 2012	1		●																														
Jarrett 2012	2		●	●		●										●	●									●				●	●		
Holme 2012	3		●					●	●	●						●	●						●			●		●					
Hankey 2012	1		●																														
Grabaw 2012	2		●	●	●	●			●		●											●			●				●	●	●	●	●
Rojas-Rueda 2011	3		●	●					●	●						●	●					●	●										●
Rojas-Rueda 2012	3		●	●					●	●	●					●	●					●	●	●									●
Foltynova 2012	1		●																														
Crutzig 2012	3		●	●	●	●			●		●		●		●	●	●						●			●				●	●		●
Woodcock 2013	1		●																														
Rojas-Rueda 2013	3		●	●					●	●						●	●								●		●	●					
Maizlish 2013	3		●	●		●			●		●					●		●	●	●						●		●					●
Woodcock 2013	3		●				●		●		●					●		●	●	●			●			●		●					●
Mulley 2013	1		●	●																										●	●		
James 2014	3		●	●	●	●			●		●		●	●		●	●					●	●		●					●	●		
James 2014	1		●																														
Deenihan 2014	1		●	●	●	●																●								●	●		
Smith 2014	1		●																														
Beavis 2014	1		●																														
			PA						AP			Oth	NP			RTI																	
Study	**Pathways**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Macmillan 2014	3		●						●		●					●		●	●	●			●		●					●	●		●
Ulmer 2015																																	
Tainio 2015	3		●						●				●			●												●					
Taddei 2015	2		●		●											●	●					●			●						●		
Mahendra 2015	3		●		●				●		●					●	●					●	●										
Buekers 2015	3		●		●			●	●	●	●		●		●	●	●			●								●		●			●
Mansfield 2015	1		●		●																	●			●								
Xue 2015	1								●																					●			●
Gibson 2015	1		●		●																	●								●			
Brinks 2015	1	●	●																						●								
Doorley 2015																																	
Briggs 2015	3		●					●	●		●		●	●		●						●	●					●					
McClure 2015																							●			●		●					
Arsenio 2015	1		●		●																									●			
Schepers 2015	3	●	●	●	●				●	●	●					●						●								●			
Xia 2015	3		●						●							●						●						●					●
Perez 2015	3		●						●				●												●			●					●
Veerman 2016	1		●																									●		●			
Mansfield 2016																																	
Kwan 2016	3	●	●						●							●						●											●
McAuley 2016	1		●																			●						●			●		
Friedrich 2016	1								●																					●			
Stevenson 2016	3		●						●							●									●			●					
Sabel 2016	3		●						●				●															●					●
Gu 2016	3		●						●							●												●		●			
Zapata-Diomedi 16	1		●																									●			●		
Zapata-Diomedi 17	3		●						●							●						●						●		●	●		
Brown 2017	1		●																									●		●			
Guariso 2017	2		●		●				●													●											
Maizlish 2017	1		●													●						●						●					
Doorley 2017	3	●	●		●			●	●	●	●					●	●			●								●					
de Sa 2017	3	●	●						●							●						●	●		●			●					
Mueller 2017																																	
Brey 2017																																	
Johansson 2017	1								●		●											●		●									
Meehan 2017	3		●						●							●						●								●			
Nilsson 2017	1															●	●					●	●					●					
Tainio 2017	1	●	●	●																		●								●			
Brown 2017	1		●																			●			●			●		●			
Brown 2017	2		●													●						●			●			●					

			PA						AP			Oth	NP			RTI																	
Study	**Pathways**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
He 2017	1								●		●											●								●			
Kwan 2017	3		●						●		●					●						●						●		●			●
Bullock 2017																																	
Perez 2017	2		●		●											●						●								●			
Whitfield 2017	3		●						●							●						●						●		●			
Chapman 2018	1		●																			●						●		●			
Tetreault 2018	3		●						●							●												●					
Wolkinger 2018	2		●						●		●											●						●		●	●	●	●
Shaw 2018	3		●						●							●						●			●								●
Mueller 2018	3		●						●		●					●	●					●								●			
Otero 2018	3		●				●		●		●					●	●					●											
Doorley 2018	3	●	●		●			●	●	●	●					●										●		●		●			●
Mueller 2018	3		●				●		●	●	●					●	●					●								●			
Yu 2018	3		●		●				●							●												●		●			
Elvik 2019	1															●	●		●							●							
Brown 2019	2		●													●									●						●		
Rowangould 2019	2		●													●	●			●		●						●					
Jaller 2019	2		●										●			●						●			●					●			
Babagoli 2019	3		●		●				●	●						●	●					●								●			
Vert 2019	1	●	●				●															●			●			●			●		
Krit 2019	3		●						●							●												●			●		
Ilie 2019	1		●		●																	●											●
Elvik 2019	1															●	●		●	●										●			
Wu 2019	2	●	●													●	●			●		●											
Zapata-Diomedi 19	1		●																														
Mizdrak 2019	3		●						●							●						●			●			●		●	●		
Goryakin 2019	1		●																									●		●	●		
Nicholas 2019	3		●						●		●					●												●			●		
Yu 2019	3		●						●				●			●												●		●			
Villegas 2019	2		●		●				●													●											●
Farzaneh 2019	1	●							●		●											●											●
Jaller 2020	3		●						●							●						●			●			●					●
Iroz-Elardo 2020	1		●																						●								
Mueller 2020	3		●						●			●	●			●						●			●								
Rodrigues 2020	3		●	●		●			●	●						●	●					●						●	●	●	●	●	●
Pourrahmani 2020	3		●	●					●	●						●	●			●		●			●			●					●
Lamu 2020	1		●					●																				●		●	●		
Thondoo 2020	3		●	●					●	●						●	●					●											
Giallouros 2020	2		●	●					●	●												●											