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Participatory quantitative health impact assessment of urban transport planning: A case study from Eastern Africa

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ABSTRACT

Background: High rates of motorization in urban areas of Africa have adverse effects on public health. Transport-related mortality will increase as a result of inadequate transport infrastructure, air pollution and sedentary lifestyles. Health Impact Assessments (HIAs) have proven to be a successful tool to predict and mitigate negative health impact of urban transport planning policies, programmes or projects. Yet, there is a gap of evidence on transport and health in African countries. The aim of this study is assessing the health impacts of transport scenarios in Port Louis (city of 119,018 inhabitants in Mauritius) using a full chain participatory HIA model.

Methods: We estimated health and economic impacts associated to transport scenarios with qualitative data and quantitative comparative risk assessment methods. The health impact modeling was based on differences between the baseline and three transport scenarios (worse, good, ideal), estimating the averted deaths per year and economic outcomes by assessing health determinants of air pollution (AP), traffic deaths and physical activity (PA). Data on air pollution and traffic fatalities were obtained from public data sources. Data used to construct scenarios, establish baseline travel mode shares and physical activity were collected through (a) open-ended individual interviews (IDIs) with 14 stakeholders (b) closed-ended survey questions to 600 citizens and (c) 2 focus group discussions (FGDs) with the same 14 stakeholders from (a).

Results: In Port Louis, the worse-case transport scenario (doubling in car trips and a reduction in walking, motorcycle, and public transport), resulted in a total increment of 3.28 premature deaths per year. The good-case scenario (reducing car trips by half and increasing walking, motorcycle, and public transport trips) resulted in a total increment of 0.79 premature deaths per year. The ideal-case scenario (reduction in car and motorcycle trips and an increase in walking and public transport trips) resulted in a total reduction of 13.72 premature deaths per year. We estimated USD 23 millions of economic benefits related to mortality if the ideal-case was achieved.

Conclusion: Participatory HIA shows that implementing transport policies aiming for less than an ideal situation may not be adequate or sufficient to avoid negative transport-related mortality in Mauritius. Urban transport planning is an opportunity to encourage physical activity in rapidly urbanizing settings of Africa. Transport policies should aim to restrict all forms of private motorized vehicles and promote active and public transport to support public health. We highly recommend the use of participatory approaches in quantitative HIA to ensure context specificity and policy relevance.

1. Introduction

It is urgent to estimate and mitigate environmental health impacts of transport in cities of low- and middle-income countries (LMICs). Increased motorization and cumulative poor transport planning and infrastructure have irreversible health implications for urban populations. LMICs currently absorb 80% of global non-communicable disease (NCD) deaths, 92% of pollution-related deaths and 90% of traffic-

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related deaths (Alwan, 2011; UNEP, 2011; Landrigan et al., 2017; World Health Organization, 2016). And health risks will grow as more people move to cities. By 2050; 90% of 2.5 billion new urbanites will have migrated from rural to urban areas in LMICs of Africa and Asia. In sub-Saharan Africa, megacities rose from 10 in 1990 to 28 in 2014 (Nations U, 2014). This trend will continue as the number of African cities with more than half a million people will increase by 80% by 2030 (Nations U, 2014). Along with the surge of new cities, annual urban population growth rates in Africa will continue to be the highest in the world for at least until 2040 (Schwela, 2012). This rate is 3.09% for the 2011–2030 period, compared to 1.87% in Asia, 1.13% in Latin America, 0.98% in North America and 0.33% in Europe (Schwela, 2012).

Like elsewhere, African cities drive innovation, economic growth, increased access to health care and social advancement (Bettencourt et al., 2007; Cohen, 2006), yet claim high proportions of disease burden and deaths related to urban transport (World Health Organization, 2016). In sub Saharan Africa (SSA), air pollution (AP) is the fourth leading cause of DALYs (disability-adjusted life years) (Collaborators GBD 2015 RF, 2016), killing 176,000 people prematurely, inducing 626 000 DALYs (Amegah and Agyei-Mensah, 2017) and causing cardiovascular and cerebrovascular diseases and lung and respiratory infections (Cesaroni et al., 2014; Beelen et al., 2014; Stafoggia et al., 2014; Stewart-wilson, 2018). Besides adverse health effects, air pollution in African cities carry economic implications and costs 2.7% of GDP per year (Akumu). It is estimated that about 90% of urban air pollution in rapidly growing cities of LMICs (UNEP, 2011) and in SSA (Haq and Schwela, 2012) is attributable to motor vehicle emissions. In Africa only, CO2 emissions from transport have increased 53.7% between 1990 and 2010 (Haq and Schwela, 2012).

Increased motorization can lead to sedentary lifestyles and decrease in physical activity (PA) (Nieuwenhuijsen and Khreis, 2016). Globally, more than 2 million premature deaths per year are caused by insufficient PA (Collaborators GBD 2013 RF, 2015). The lack of data and the complexity involved in measuring PA levels has limited the study of physical activity in Africa (Assah et al., 2011). Across 22 African countries urbanization has led to decreasing physical activity (Guthold et al., 2008) inducing lifestyle related diseases such as diabetes (Mbanya et al., 2010; Christensen et al., 2009), high blood pressure (Luke et al., 2005) and obesity (Sobngwi et al., 2002).

In addition to adverse health effects due to less PA, commuting populations in Africa are exposed to unsafe roads (Adeloye et al., 2016). Road injuries have increased by 33% between 1990 and 2015 (Murray et al., 2015). Africa has the highest rate of fatalities from road traffic injuries worldwide at 26.6 per 100 000 population(Organization, 2015). Road traffic accidents are the major cause of mortality among people aged 15–29 years(Bonnet et al., 2017). While car ownership may rise to 2 billion motor vehicles worldwide by 2030 (Sperling and Gordon, 2008), it remains low in African settings (0.06–0.16 cars per household) (Rwebangira, 2001). In contrast, motorcycle ownership has increased drastically, with motorcyclists exposed to 16 times more risks of dying in a road accident than car occupants(Kudebong et al., 2011).

There is growing interest on the use of Health Impact Assessments (HIAs) to estimate the risks and benefits of traffic-related policies on health in high (De Nazelle et al., 2011; Mueller et al., 2015) and low income settings (Pereira et al., 2017; Winkler et al., 2013). HIAs combine mixed-methods to systematically assess the potential health effects of a proposed policy, programme, or project (European Centre for Health Policy WHO, 1999), also in terms of distributive effects within a population (social and equity effects). HIAs enable identification of the most healthy, feasible and acceptable transport policy measures in cities facing environmental and health hazards and high levels of social inequity (Nieuwenhuijsen, 2016). Transport-related HIAs in LMICs have assessed the impacts of air pollution only (Chang-Hong et al., 2009; He et al., 2016; Vu et al., 2013; Tashayo et al., 2017; Aggarwal and Jain, 2015; Mahendra and Rajagopalan, 2015; Dhondt et al., 2011; Ongel and Sezgin, 2016; Guo et al., 2010; Permadi et al., 2017); of air pollution, road traffic and physical activity combined (Mahendra and Rajagopalan, 2015; de Sá et al., 2017); air pollution and greenhouse gas emissions combined (Ren et al., 2016); and finally, noise, air pollution and greenhouse gas emissions combined (Ongel and Sezgin, 2016).

There is an urgent need to conduct and report on more HIAs in LMICs (Winkler et al., 2013; Erlanger et al., 2008). Particularly, there is little scholarship on HIAs of urban transport in Africa (Thondoo et al., 2019). Data scarcity and poor technical support impeded the completion of a transport-related HIA in Mozambique for this study (Rojas-Rueda et al., 2016). One paper collected primary data on air pollution in Kenya, but did not estimate the health outcomes of exposures (Kinney et al., 2011). Some studies have covered HIAs in mining and industry (Utzinger et al., 2005; Winkler et al., 2011; Winkler and Utzinger, 2014; Knoblauch et al., 2017); waste management (Gulis and Mochungong, 2013), and international development projects (O'Keefe and Scott-Samuel, 2010). To bridge scholarly and empirical gaps, we address the question: What are the major risk exposures and health impacts derived from urban transport planning policies in an African city? This study aims to conduct and present an HIA of urban transport planning in Port Louis, Mauritius, based on a full-chain participatory HIA model for quantitatively estimating health and economic outcomes. The model builds on previous work to account for 'the full-chain from source through pathways to health effects and impacts to substantiate and effectively target actions' (Nieuwenhuijsen et al., 2017). It aims to estimate the health impacts of urban transport on the basis of a transport mode shift using a combination of participatory approaches and quantitative modelling.

2. Material and methods

The participatory quantitative HIA includes (Alwan, 2011) baseline data collection (UNEP, 2011) co-validation of transport policy scenarios with stakeholders and (Landrigan et al., 2017) quantitative modelling of health impacts (see Fig. 1). The study was approved by the National Ethics Committee of the Ministry of Health and Quality of Life in Mauritius (project protocol MHC/CT/NETH/THONM) and by the Ethical Advisory Board of the Amsterdam Institute for Social Science Research (AISSR). Information and consent sheets were signed by all participants.

2.1. Study conceptual model

We conducted a full-chain participatory HIA to assess health impacts on the basis of a transport mode shift in Port Louis, Mauritius. By applying mixed-methods, we estimated averted deaths per year and economic outcomes by assessing the health determinants of air pollution, traffic deaths and physical activity (Fig. 1). As done elsewhere (Mueller et al., 2017), we follow the WHO's standard process of HIA (see left margin): screening, scoping, appraisal and reporting phases. We excluded the monitoring phase due to restricted duration of study.

In the screening and scoping phase, we applied a participatory process to examine the context of urban transport planning in Mauritius. It included (a) open-ended individual interviews (IDIs) with 14 stakeholders (b) closed-ended survey questions to 600 citizens and (c) 2 focus group discussions (FGDs) with the same 14 stakeholders from (a). The IDIs and FGDs were used to select health indicators and co-validate HIA scenarios. The survey was used to collect baseline data to establish current exposure levels to selected indicators.

The appraisal phase consisted of the quantitative assessment of health risks. Risk estimation was conducted by calculating the exposure difference between baseline and predicted exposure levels under the different scenarios studied. The scenarios represented the changes in status quo. We used the exposure Response Function (ERF) and Relative Risk (RR) to calculate the Population Attributable Fraction (PAF). We applied mortality rates to PAF to obtain scenario attributable deaths

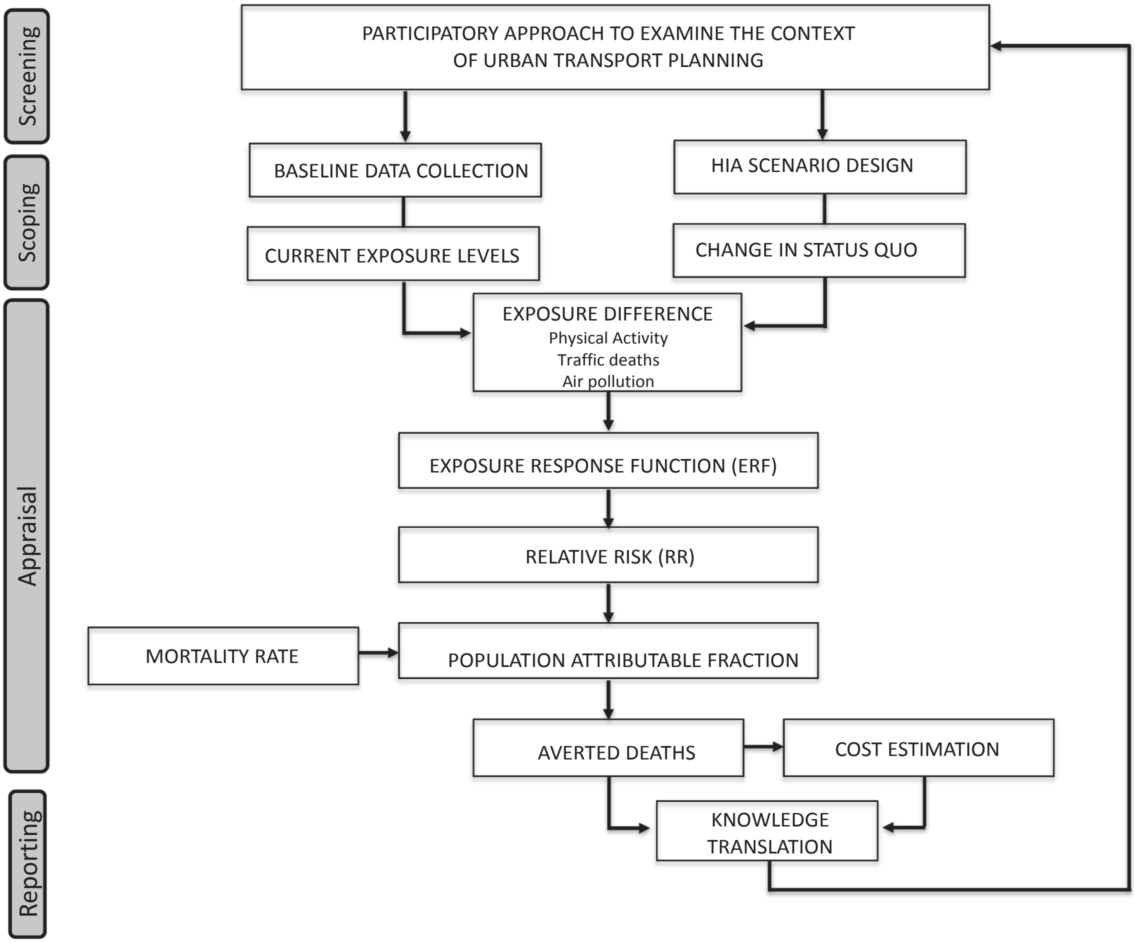

Fig. 1. Conceptual framework for participatory HIA.

and economic outcome estimation. The reporting phase consisted of a knowledge translation process on the HIA results and joint discussion on way forward with stakeholders.

2.2. Study setting

With 1.2 million people (Government of Mauritius, 2015), Mauritius (2040 km2) had the highest population density in Africa in 2013 (World Bank. Countries by Population Density, 2015). Mauritian urban population rates have doubled since 1980 with 60% living on 8% of the territory (one city and four main towns). Like elsewhere in Africa (Stewart-Wilson 2018), non-communicable diseases in Mauritius have been rising rapidly since 2010 with a current 15% prevalence of diabetes and 30% prevalence of hypertension in the adult population between 20 and 74 years old (Government of Mauritius, 2015). The national fleet increased by 625% between 1972 and 2000 (OECD, 2014) and road traffic accidents have increased by 4% annually (OECD, 2014). Traffic congestion costs Mauritius approximately USD 119.6 million per year (Ministry of Public Infrastructure and Land Transport, 2017).

The capital city Port Louis is comparable to many other African cities (Adeloye et al., 2016; Kudebong et al., 2011; Sietchiping et al., 2012). It is densely populated (2,563 persons per square km) with 119, 018 people residing on 46.7 km^2 (Mauritius and Digest of Demograpic, 2017). It is highly polluted, emitting 9 tons of carbon dioxide per capita, costing USD 0.1 billion every year (Fowdur and Rughooputh, 2012). During a 3-month stand-alone road-side test, the level of air pollution (PM 2.5) on the outskirts of Port Louis was about 68ug/m3 (Organization, 2016), six times higher than the WHO standards of 10 μg/m3 annual mean. Like other African cities (Sietchiping et al., 2012), Port Louis' transport planning fails to respond to population and spatial growth with heterogenous vehicles using limited and non-adapted road infrastructure. It is a car-oriented city with very little green space and pedestrian movement is limited to unsafe sidewalks. There is a poor integration of different modes of travel and limited possibility to introduce bus or cycle lanes. The city suffers from major traffic congestion caused by the daily influx of 201,567 people coming from 9 neighbouring districts, creating bottlenecks at the city entrance and exit. Traffic flow is further hampered by narrow roads, street vendors and side-street parking spaces.

2.3. Methods for the IDIs and FGDs

Sampling. We selected 14 individuals using purposive sampling methods across different communities of interest and following their role in current urban transport initiatives and policy-making processes (Table 1). The same informants were used for the IDIs and FGDs.

IDIs. We conducted face-to-face interviews using a semi-structured topic guide and open-ended questions in August 2019 (annex 1). We recorded, transcribed and anonymized IDIs using number identifiers. Interviewees were asked about (Alwan, 2011) the urban transport policies they are most familiar with, (UNEP, 2011) the linkages between urban transport planning and health, (Landrigan et al., 2017) the current challenges in the transport sector, and (World Health Organization, 2016) their idea of a healthy, feasible and sustainable urban transport planning system and what is needed to achieve that.

FGDs. From the IDIs, we isolated the factors stakeholders described as linking urban transport planning to health and the main challenges

Table 1
Stakeholder profiles.

Communities of interest	Expertise (information held)	Reason to for inclusion
Community-based organization	Expert (Ecosystems)	Active role in liaising between communities and developers of private urban project
Service provider/ industry	Consultant (Sustainable development)	Consults for public and multilateral organizations on the environmental impacts of land and sea infrastructure projects
Elected official	Adviser (Land Transport)	Provides expert advice and strategies to the high level politicians on transport related policies
Elected official	Permanent secretary (Medicine and health)	Reviews environmental impact assessment reports on national projects in order to identify health risks
Industry	Planner (Urban planning)	Leads on private and public transport urban planning projects such as main bus terminal
Public agency	Statistician (Land transport)	Updates and monitors data on land transport such as traffic incidents and deaths
International multilateral organization	Head of department (Sustainable development)	Reports on the advancement of sustainable development targets on the island including SDG 11
Public agency	Head of department (Traffic Planning)	In charge of deploying public transport strategies and involved in the new light-rail public transit system
Public agency at parastatal level	Technician (Sustainable economic development)	Works on establishing urban standard guidelines for economic development focusing on investments in transport, social housing and real estate projects
Public Agency at municipal level	Municipal agent (Town planning & services)	Works at municipal level on housing and transport initiatives and municipal policies
Industry	Executive and board director (Economic investments, Food services and Sustainable development)	Directs decisions for different companies focused on services and investments in the city of Port Louis
Resident	Journalist (urban development)	Critically analyses and reports on urban development projects across the island
Resident	Politician (Social & economic development)	Leads a stand-alone political party with expertise in sustainable economies
Resident	Social worker (Health and social justice)	Provides support and leads initiatives supporting the urban poor in the capital

faced by the sector. We presented these results at subsequent focus group discussions (FGDs), during which stakeholders contrasted their views, needs and priorities. They discussed different transport-related health indicators and shared their opinions on potential scenarios. They also debated if, where, and how their individual visions differ and clash with the proposed scenarios and discussed if they can reach similar endpoints (annex 2).

2.4. Methods for the survey

Sampling. We conducted randomized sampling of 600 individuals residing in Port Louis (n = 600). We considered an initial conservative sample of 384 participants to account for the key parameters surveyed and increased sample to 600 to account for statistical representation of population subgroups by gender, age group, and socio-economic status.

Survey. We used electronic mobile surveys to collect baseline data on demographics, PA and travel patterns (annex 3) from September to November 2019. PA data was collected using IPAQ (International Physical Activity Questionnaire) short questionnaire (Craig et al., 2003) that assesses the frequency (days) and duration (minutes/hours) of a person's activity over the preceding seven days, and group activity levels into vigorous-, moderate-, and low-intensity levels. Travel patterns were collected using one full week-day diary and all trips completed between wake-up and bed-time. Each trip was documented in terms of travel mode, duration and distance (annex 4).

2.5. Methods and data inputs for the quantitative HIA

We modelled all-cause mortality effects using (Alwan, 2011) three health indicators: AP, traffic deaths and PA, (UNEP, 2011) three future transport scenarios, (Landrigan et al., 2017) survey travel data, (World Health Organization, 2016) survey PA data, (Nations U, 2014) existing AP data, (Schwela, 2012) existing traffic death data, and (Bettencourt et al., 2007) natural all-cause mortality rate for the adult population (18–65 years old). Exposure–response functions were derived from existing studies and calibrated for current exposure and health conditions in Port Louis. We used RR functions and PAF for PA and AP and calculated the change in mortality (Fig. 1).

2.5.1. Selecting health indicators

Three health indicators were selected from different factors stakeholders identified as linking health to transport (see Section 2.3). The list of factors was drafted and assembled from the IDIs and discussed during the FGDs. Three final health indicators were selected by both consensus and elimination (Table 2): PA, traffic deaths and AP.

2.5.2. Three future transport scenarios

We co-designed the scenarios based on shifts in transport modes that created a change in the challenges reported in the IDIs (see Section 2.3). The challenges were coded and extracted as follows: overuse of cars, road congestion, bad road infrastructure, bad urban transport planning, government over spending, no smoke emission control, no regulation about private vehicle purchase, no entry regulations in the city, lack of green space, no walkable areas, lack of traffic safety, no bus lanes, no cycle infrastructure, high car social pressure, no legal framework for more sustainable and energy-sensitive mobility, lack of parking spaces, bad pavement and side-walk conditions, lack of hygiene and bad public transport conditions. During the FGDs, the challenges

Table 2
List of indicators and reasons for exclusion.

Included or not	List of indicators	Reason for inclusion / exclusion
Included	Physical activity	Ability to collect data within given timeframe
Included	Traffic deaths and air pollution	Availability of data
Not included	Congestion, stress, noise, mental distress, vibration, hygiene	Unavailability of data
	Consumption patterns, nutrition, nature exposure	Complexity to collect data within given timeframe
	Temperature, traffic injuries	Stakeholders found the indicator less relevant
	Violence, road rage, access to public transport	Selected but there is no current methodology to consider them in quantitative HIA

were discussed and placed within the context of a mode-shift possible scenario.

The process for generating and validating the scenarios included (1) discussing hypothetical baseline modes shares (2) proposing changes in car mode share and predicting how this change may impact other mode shares, (3) discussing which mode share splits would most benefit experts, citizens or public officials. Additional suggestions such as the inclusion of motorcycles as a standalone mode in the scenarios was proposed by several informants and were validated by consensus during the FGDs.

In the worse-case scenario, current challenges are exacerbated; car trips are doubled (10% to 20%) as people shift from walking, public transport and motorcycle trips. The overuse of motorized vehicles causes congestion, puts more pressure on road infrastructure, generates more emissions, encourages vehicle purchase, increases traffic accidents and deaths, decreases walking patterns and discourages use of public transport.

In the good case scenario, current challenges are reduced, car trips are halved (10% to 5%) and people use more public transport, motorcycle and walking trips. Less cars on the road applies less pressure on infrastructure, decreases congestion, while increasing walking patterns and use of public transport. This scenario has the highest proportion of motorcycle trips (18% mode share).

In the ideal-case scenario, current challenges are addressed, with car trips practically eliminated (10% to 1%), motorcycle trips reduced and walking and public transport trips are increased. The decrease of both forms of private motorization (cars and motorcycles) relieves pressure on traffic congestion and infrastructure, significantly decreases emissions, increases traffic safety, increases the possibility of regulating vehicle and motorcycle purchase, increases walking patterns and encourages use of public transport.

In order to calculate the health impacts of a shift in transport mode, several assumptions were applied. We assumed mode shifts scenarios by percentage and in proportion to the business as usual scenario (BAU) established from the survey results. Stakeholders took the lead in proposing different proportions for the car mode share (20%, 5%, and 1%) (Table 3). To maintain consistency in modelling, consensus was achieved that percentage switches from other modes of transports (bus, motorcycle, walking) would remain constant for each transport mode and across different scenarios (40% shift to/from public transport, 20% shift to/from walking, 40% shift to/from motorcycle trips) (see annex 4). The percentages for the switching trips were agreed upon given the current Mauritian context. For example, 40% switch from car to public transport trips was realistic given the new metro light rail project established by the government. We considered that cycling and informal transport modes remained constant to the BAU scenario due to data constraint issues and limited consensus on how peoples' choice in adopting these two modes could evolve. When cars were replaced by motorcycles or public transportation, we assumed the average length of car trips would remain constant. When cars were replaced by walking trips, we assumed the average length of walking trips would remain constant. During the modelling the following variables were assumed to remain constant: BAU mode share, trip length, per capita trip rate. We assumed a fixed value to the average speed of modes of transport as proposed elsewhere (Goel et al., 2015) (annex 4).

Table 3
Mode share shifts and scenarios.

Mode share (%)	Worse-case scenario 1	Good-case scenario 2	Ideal-case Scenario 3	BAU
Car	20%	5%	1%	10%
On foot	52%	55%	60%	54%
Public transport	10%	16%	23%	14%
Motorcycle	12%	18%	10%	16%
Cycle	1%	1%	1%	1%
Informal transport	5%	5%	5%	5%

Table 4
METs attributed to activity and transport mode.

Baseline PA[a]		Transport shift-related PA[b]	
Activity	METs*	Transport mode	METs
Walking	3.3	Walking	3.5
Cycling	6.8	Cycling	6.8
Moderate activity	4.0	Sitting in public transport	1.3
Vigorous activity	8.0	Car	1.3
		Motorcycle	2.8
		Sitting in public transport	1.3
		Walking 10 min to public transport	3.5

* METs: Metabolic Equivalent Task; Sources a (Committee, 2005); b (Ainsworth et al., 2011).

2.5.3. Travel data

We extracted baseline travel patterns from 600 individual surveys and 514 travel diaries (see Table 3). The data covered 1520 trips per day. Each person completed an average of 3 trips per day. Walking was the most popular transport mode in the city. The mode share was walking (54%), motorcycle (16%), public transport (14%), car (10%), informal transport (5%) and cycling (1%). The average distance and time of different modes were as follows: walking (1.04 km, 12.6 min), public transport (10.29 km, 29.4 min), car (10.11 km, 2 min) and motorcycle (7.12 km, 17 min) (annex 4).

2.5.4. Physical activity data

We translated the survey participants' IPAQ physical activity data into a metabolic equivalent of tasks per week (MET/hr/week) based on the type of activity practiced (baseline) and mode of transport used (Table 4). The survey participants' PA data was assumed to represent the overall PA behaviour of the Port Louis adult population (Assah et al., 2011; Guthold et al., 2008; Mbanya et al., 2010; Christensen et al., 2009; Luke et al., 2005; Sobngwi et al., 2002; Adeloye et al., 2016; Murray et al., 2015; Organization, 2015; Bonnet et al., 2017; Sperling and Gordon, 2008; Rwebangira, 2001; Kudebong et al., 2011; De Nazelle et al., 2011; Mueller et al., 2015, 2017; Pereira et al., 2017; Winkler et al., 2013, 2011; European Centre for Health Policy WHO, 1999; Nieuwenhuijsen, 2016; Chang-Hong et al., 2009; He et al., 2016; Vu et al., 2013; Tashayo et al., 2017; Aggarwal and Jain, 2015; Mahendra and Rajagopalan, 2015; Dhondt et al., 2011; Ongel and Sezgin, 2016; Guo et al., 2010; Permadi et al., 2017; de Sá et al., 2017; Ren et al., 2016; Erlanger et al., 2008; Thondoo et al., 2019; Rojas-Rueda et al., 2016; Kinney et al., 2011; Utzinger et al., 2005; Winkler and Utzinger, 2014; Knoblauch et al., 2017; Gulis and Mochungong, 2013; O'Keefe and Scott-Samuel, 2010; Nieuwenhuijsen et al., 2017; Government of Mauritius, 2015; World Bank. Countries by Population Density, 2015; OECD, 2014; Ministry of Public Infrastructure and Land Transport, 2017; Sietchiping et al., 2012). For baseline PA, MET score were assigned per activity (Committee, 2005). These values were summed up to calculate the individual overall baseline PA MET/hr for a week. For transport shift-related PA, MET score were assigned per mode (Ainsworth et al., 2011). After assigning MET scores, we calculated the difference between baseline PA and PA lost or gained due to modal shift scenarios studied. We estimated reduced mortality risk by using a curvilinear ERF, applying a 0.25 power transformation to PA, and using the relative risk of 0.81 for 660 MET minutes(Woodcock et al., 2013). The median baseline PA was 3.85 (MET/hr/week) with the following IQR values [0.508; 3.85; 3.85; 10.20; 36.13] (MET-hr/week) (see Table 5).

2.5.5. Air pollution data

We considered particulate matter with a diameter of ≤ 2.5 μm

Table 5
Health impact outcomes.

	Worse-case scenario		Good- case scenario		Ideal-case scenario	
Health determinants	Annual premature deaths*	(95% CI)	Annual premature deaths*	(95% CI)	Annual premature deaths*	(95% CI)
Air pollution (PM2.5)	−4.06	(−5.08, −2.63)	0.98	(1.26, −2.63)	−2.65	(−3.40, −1.52)
Road traffic fatalities	0.00		1.52		−0.66	
Physical activity	7.34	(5.54, 9.84)	−1.71	(0.29, −2.32)	−10.41	(−7.69, −22.98)
Total	**3.28**	**(−0.09, 5.98)**	**0.79**	**(3.76, 0.36)**	**−13.72**	**(−4, −21)**
Annual economic estimates (USD)	**6 million**		**1 million**		**−23 million**	

* Negative value: reduction in premature deaths.

(PM2.5) as an indicator of AP and proxy for exposure to all fossil fuel combustion sources. We only modelled the exposure to PM2.5 emissions; all other emissions were assumed to be constant. We used the background PM2.5 annual mean of 14.95 (microgram/m3) extracted from the WHO database for Port Louis for 2015 (Organization, 2016). Local data was available but not considered because the monitoring station for Port Louis is located on the top of a mountain surrounded by green space and does not provide valid measures for road-level exposure. The background level of PM 2.5 was calibrated to different microenvironments (background, sleep and rest in addition to microenvironments of each transport mode) using set ratios (De Nazelle et al., 2011) and was adapted for ventilation rates of each transport activity type (Buekers et al., 2015) (see annex 4). We used a linear ERF with a relative risk (RR) of 1.09 (1.04–1.09) per 10 µg/m3 increment of PM2.5 to quantify the association between PM2.5 and mortality (Organization, 2014; Kahlmeier et al., 2017).

2.5.6. *Traffic death data*

To estimate the reduction in fatalities, the fatality rate for alternative scenarios was assumed to be the average of traffic fatality values over six years (2013–2018) adjusted to the risk per billion km travelled for each mode of transport (National Transport Authority, 2017). The data was retrieved from official government reports and police stations with jurisdiction over the North and South of Port Louis. We calculated new risk ratios based on the shift between transport modes, using the average value and given difference in the kilometres travelled by mode for each scenario (Watkiss et al., 2000). We assumed that the proportion by age group remained constant. Traffic fatality impact was quantified on the basis of kilometres covered per mode and did not account for other risk reductions due to infrastructure improvement. No traffic fatalities were reported for public transport (annex 4).

2.5.7. *Mortality rate*

We estimated the health impacts for natural all-cause mortality for residents of Port Louis aged between 18 and 64 years old (n = 77′271) (Mauritius and Digest of Demograpic, , 2017). We assumed that this age group conducts most trips for work or study based on studies elsewhere (Rojas-Rueda et al., 2011) and also corresponded to the same age group as the survey respondents. The 2017 natural all-cause mortality rate after excluding external causes of death was 1031/100′000 persons.

2.6. *Data analysis and sensitivity*

Qualitative results from the interviews and focus groups were analysed using Atlas.ti 8. Quantitative modelling and results were analysed using Microsoft Excel 16.16.21 (2018) and R Studio 1.1.463. Confidence intervals for PA and AP were calculated by modifying the RR value (annex 4). We also conducted a sensitivity analysis on the input measures for PA and background AP (annex 4). Self-reported PA has been reported to underestimate the prevalence of PA because of the different interpretations of questions and recall difficulty. Therefore, we conducted sensitivity analysis by changing the average value of light PA in Mauritius (79%) by the average value of light PA in Malaysia (89.31%), a country with comparable urbanization rates, HDI and GDP (Poh et al., 2010). For background AP we used the average between the current measure (14 ug/m3) and the reported road-traffic level data officially reported on the outskirts of Port Louis during a 3-month monitoring exercise in 2011 (67 µg/m3) (Organization, 2016). We used the Value of Statistical Life (VSL) approach to estimate the economic value of deaths. Due to the lack reliable individual data, we used a population-average VSL for Mauritius using a base U.S. VSL calculated using U.S labour market estimates and adjusting VSL for differences in income elasticity from Mauritius (1.08) (Viscusi and Masterman, 2017).

3. Results

Results show health gains in the ideal-case scenario and health losses in both the worse- and good- case scenario (Table 3).

In the worse-case scenario, a doubling of car trips and a reduction in walking, motorcycle, and public transport trips resulted in a total increment of 3.28 premature deaths per year [95% confidence interval (CI) 0.09, 5.98]. We estimated an increment of 7.34 premature deaths per year [5.54, 9.84] due to decrease in physical activity. Air pollution exposure led to a reduction in 4.06 premature deaths [5.08, 2.63], with no additional changes in estimated premature deaths related to traffic fatalities.

In the good-case scenario, reducing car trips by half and increasing walking, motorcycle, and public transport trips resulted in a total increment of 0.79 additional premature deaths [3.76, 0.36]. We estimated a reduction of 1.71 premature deaths per year due to additional physical activity [0.29, −2.32]. Air pollution exposure led to an increment of 0.98 premature deaths [1.26, −2.63] and traffic fatality led to an increment of 1.52 premature deaths.

In the ideal case-scenario, a reduction in car and motorcycle trips and an increase in walking and public transport trips resulted in a total reduction of 13.72 premature deaths [−4, −21] In this scenario, increase in physical activity led to a reduction of 10.41 premature deaths [−7.69, –22.98], decreased exposure to AP to a reduction of 2.65 premature deaths [−3.40, −1.52], and traffic fatality led to a reduction of 0.66 premature deaths.

The economic value associated to premature deaths was estimated to a societal economic impact of USD 6 million annually in the worst-case scenario and USD 1 million for the good-case scenario. In the ideal-case scenario, the economic value estimated due to the reduction of premature deaths resulted in USD 23 million reductions in terms of economic impact.

4. Discussion

This study supports current evidence that the flexibility and scientific validity afforded in quantitative HIAs are crucial to estimate health risks that can inform policy-making in LMICs (Benaissa et al., 2016; Chilaka and Ndioho, 2015; Burke and Ambasa-Shisanya, 2014). The lack of data in Africa hampers the generation of long-term robust environmental and epidemiological measurements for transport-related risk assessments. Yet, HIAs provide methodological flexibility with a risk assessment approach that can be contextually adapted and applied in places like Mauritius where there are weaker epidemiological surveillance systems. Particularly, our study reflects well the value of participatory approaches in quantitative modelling. Three crucial components of the proposed model were brought forth by local stakeholders: (Alwan, 2011) the integration of motorcycles in the scenarios (UNEP, 2011) the creation of scenarios based on context-sensitive realities and (Landrigan et al., 2017) the type of policies needed to address current challenges.

Our results show that in order to obtain health benefits, strong action and policies are needed to decrease at least these two forms of motorization: an extreme reduction of car trips from 10% to 1% and motorcycle trips from 16% to 10%. This ideal case scenario would lead to a combination of (Alwan, 2011) increase in physical activity (UNEP, 2011) decrease in traffic fatality and (Landrigan et al., 2017) decrease in air pollution exposure. A similar combination of exposures leading to health benefits were reported in HIAs of transport mode shifts in São Paolo (Brazil) and Barcelona (Spain) (de Sá et al., 2017; Mueller et al., 2017). While it is hard to imagine a city without cars (or with 1% car mode share), the advent of Covid-19 has shown us that extreme motorization can become a reality (even if policies may apply only temporarily depending on settings). Several cities including Ghent, Hamburg, Helsinki, Madrid, Bogota, Brussels, Chengdu, Copenhagen, Dublin, Hyderabad, and Milan are however, showing that partially or drastically reducing motorization is possible on a long-term basis by implementing car free days, investing in cycling infrastructure and pedestrianization, restricting parking spaces and considerable increases in public transport provision (Nieuwenhuijsen and Khreis, 2016).

The application of such measures may be facilitated given the smaller size of Port Louis (42 km2), yet may be hindered by the complexities of a developing African city. For instance, the health risks caused by increased motorcycle use and ownership in developing countries like Mauritius are worth discussing (Adeloye et al., 2016; Jones et al., 2016). Scarce evidence indicates that motorcycle accidents in northern Ghana account for 4% of all crashes per year but related mortality is not provided (Kudebong et al., 2011). In Mauritius, motorcycles account for 38.5% of road accidents, ten-fold the northern Ghanaian value. In Port Louis, motorcycles account for 43% of traffic-related deaths versus 20% for car users (see annex 4). This may be the reason why more cars (worse-case scenario) did not increase the risk for traffic fatality. Both motorcycles and cars are passive modes of travel, therefore not the best choices for maintaining healthy physical activity levels. This explains why fewer cars coupled with more motorcycles (good-case scenario) did not result in reducing overall premature mortality even if physical activity benefits are achieved. Therefore, ‘weaker’ forms of policies aiming for the reduction of cars only may not be adequate or sufficient for contexts similar to Port Louis. It is highly probable that car users will shift to motorcycles which is a scenario that should be avoided at all cost (this will significantly increase their exposure to air pollution and they will face higher risk of traffic fatality). It is also crucial to avoid motorcycle users to shift to cars which are an increasing trend in developing countries due to large investments in road infrastructure such as highways.

HIAs from high income countries (HICs) show that replacing car trips by walking, public transport and cycling trips (i.e. active travel modes) can increase health benefits (De Nazelle et al., 2011; Mueller et al., 2015; Rojas-Rueda et al., 2016b; Lindsay et al., 2011; Götschi et al., 2015). Like in other African cities (Rwebangira, 2001), safe cycling is not a current option in Port Louis. However, 36% of motorcyclists and 20% of car users cover 5 kms or less per trip, which are distances that could be covered on foot. Motorcyclists would maintain physical activity while being less exposed to air pollution (lower ventilation rates as pedestrians). Car users would increase physical activity. Yet, walking mode share is already high (54%), with increased traffic fatality rate (331 fatalities/billion kms). Walking distances are short (12:45 min compared to 33 min in Switzerland for instance (Götschi et al., 2015), therefore the levels of PA achievable on foot is limited. Therefore, a strong policy aiming at reducing both cars and motorcycles may be effective by targeting the 64% of motorcyclists and 80% of car users covering more than 5kms to use public transport or electric bicycles if safe cycling infrastructure is provided.

4.1. The importance of scaling up

Our study shows that even on a small sample (n = 77′271), urban transport planning affects mortality. The bulk of urban population growth in the near future will not occur in big cities (Nations U, 2014). In LMICs particularly, more than half of urban populations live in settlements with fewer than 500′000 residents (Rojas-Rueda et al., 2011). However, scaling up studies similar to ours is important because many cities do not yet exist. Two-thirds of the investments in urban infrastructure to 2050 have yet to be made in African cities and towns (Migration IO for. World migration report, 2015). In African cities with over 15 million people such as Cairo, Lagos, and Kinshasa, the levels of air pollution, physical activity and road traffic accidents are likely to be very different, causing higher mortality and morbidity.

In line with previous studies (Rojas-Rueda et al., 2011, 2016b), we found that physical activity in Port Louis is the most important driver of health impacts (Table 1) and is the most efficient way to increasing transport-related health benefits. The reverse correlation between urbanization and physical activity (Guthold et al., 2008) is bound to be a challenge given the annual urban population growth rate in Africa is and will continue to be, the highest in the world for at least the next two decades (Schwela, 2012). In HICs, more physical activity in urban settings can be achieved by active travel (walking and cycling) (De Nazelle et al., 2011; Woodcock et al., 2013; Rojas-Rueda et al., 2011; Macmillan et al., 2014; Xia et al., 2015). Much of current Africa’s urbanization has been rapid and unplanned, making it difficult to change the way infrastructure has already been laid out (ex: integrating cycle lanes). In India, the introduction of a Bus Rapid Transit (BRT) increased walkers and cyclists in urban corridors, saving up to 14 lives per year (Mahendra and Rajagopalan, 2015). This suggests that in developing settings, large public transport projects rather than stand-alone infrastructural changes, may be more efficient for increasing active travel and benefitting LMIC urbanites who are often the most socio-economically deprived (walkers and cyclists).

The health impacts of air pollution in our study were modeled using ambient emission data because no data exists at road-traffic level. This may have caused underestimation of mortality outcomes related to transport in Port Louis. Scaling quantitative HIA may be challenging given the lack of viable data on air pollution in many African countries (Laid et al., 2006). So far, existing air quality information shows that if and when data is available, it exists in an unsystematic form and at different degrees of quality, depth and completeness(Schwela, 2012). Currently Mauritius and no other African country restrict the use of cars based on emission standards. Twenty-five African countries including Mauritius, however, impose age restriction on imported vehicles. These policies encourage the purchase of vehicles emitting lower emissions, but do not decrease motor-vehicle use as a general rule. Such policies disregard scientific findings that increasing active travel and decreasing general motor-vehicle use has higher health benefits than increasing the use of motor-vehicles with lower emissions (Woodcock et al., 2009).

Our study estimates the economic value of averted deaths in the ideal scenario (60% increase in public transport trips and extreme decrease in private motorization) to 23 million USD. This corresponds to 20% of the total amount (119.6 million USD) spent by the Mauritian government every year on road accidents and traffic congestion (Ministry of Public Infrastructure and Land Transport, 2017). It is estimated that road traffic crashes in LMICs cost between 65 and 100 billion USD per year, more than the total annual amount received in development aid (Kudebong et al., 2011). In SSA countries, the economic burden of road traffic deaths and injuries can account for 1–3%

of the Gross National Product (GNP). Our study highlights that in economic terms, health impacts provide an opportunity for savings in LMICs where a motor vehicle is over a hundred times more likely to be involved in a fatal crash than in HICs (Haq and Schwela, 2012).

4.2. Strengths and limitations

This is the first participatory quantitative HIA of urban transport planning in Africa. It contributes to the few participatory quantitative HIAs in the world (Chang-Hong et al., 2009; Benaissa et al., 2016; Nieuwenhuijsen et al., 2016) and confirms that even conservative measures of health impacts can reduce transport-related mortality in LMICs (Conti and Mahendra, 2014). Quantitative HIAs of transport have previously assessed modal shift impacts through physical activity, air pollution and traffic deaths (de Sá et al., 2017; Mueller et al., 2017; Woodcock et al., 2009), but none employed participatory approaches. Indeed, despite consensus on the need for participation in HIA (European Centre for Health Policy WHO, 1999; Jones et al., 2014; Tamburrini et al., 2011), participatory approaches in HIA remains an exception rather than rule (Iroz-Elardo and McSharry, 2016) particularly in quantitative models (Nieuwenhuijsen et al., 2017; Veerman et al., 2005).

We estimated health impacts on a small scale (n = 77,271), but the scientific approach is robust and supported by high quality data collected in the local context. The validity of the input data for quantitative modelling is based on data triangulation from a survey (n = 600), national government emission reports (Mauritius and Digest of Demograpic, 2017) and police records. We used traffic fatality data from 6 different years to avoid single year trends. By conducting primary data collection, we have limited exposure-outcome misclassification by using exposure, health and population data from the same time span (2017–2018). Although the scenarios were hypothetical, they were built based on direct feedback from local stakeholders to provide more realistic projections. We conducted a sensitivity analysis to address uncertainties related to PA and background AP data (see Section 3.5). We did not identify significant variations in sensitivity analysis results (see annex 4).

HIA estimates must be interpreted with care given the multiple assumptions and uncertainties entailed in quantitative modelling. There is systematic evidence on causal inferences relating the three exposure factors (PA, AP, traffic fatality) to all-natural cause mortality (Watkiss et al., 2000; Prabhu and Pai, 2012; Organization, 2006; Kahlmeier et al., 2011). However, none of them were based on studies conducted in LMICs or tropical zones. The application of risk assessment methodology adds uncertainties due to the extrapolation of risk estimates to other settings. It also disregards the challenge that actual ERF may vary across populations. Although we used risk estimates established on valid epidemiological evidence, it should be noted that such estimates were not estimated based on Mauritian populations.

Similarly, PAF values indicating the proportion of disease preventable due the variation in a specific factor must be interpreted cautiously. The main assumptions in estimating PAF imply that the risk factors should be independent from other factors that influence disease and death- meaning that there should be a causal relationship between factor and outcome (death or disease). In this study, we examine motorized traffic as one common source of exposure for the three risk factors. This makes it difficult to ensure that the effects of the risk factors are independent and that we have not double-counted the deaths estimated by each environmental exposure.

5. Conclusions and recommendations

This study reported a full-chain participatory quantitative HIA model estimating the health and economic value of transport mode shift an Africa capital, Port Louis (Mauritius). Participatory approaches were crucial to involve stakeholders and design a context-specific HIA model adapted to local needs. This study estimated that 13.72 premature deaths, representing an economic benefit of 23 million USD, would be averted if the ideal-case scenario is implemented in the city. This scenario involved a mode shift reduction for cars (10% to 1%) and motorcycles (16% to 12%) *and* a mode shift increase for walking (54% to 60%) and public transport (14% to 23%).

Building on our findings and previous LMIC-based studies (40,96,104), we propose the following policy recommendation for urban transport planning policies for Port Louis and cities with similar features. Urban transport must be tackled as an opportunity to encourage physical activity in rapidly urbanizing settings of Africa. Transport policies should aim to restrict all forms of private motorized vehicles and promote active and public transport to support public health. This can be done with policies including specific restrictions for motorcycle traffic. Policies promoting the benefits of physical activity should be accompanied by interventions to increase pedestrian and cyclists' safety. Policies to increase public transport use should provide incentive for users of private motorized modes.

More environmental health studies are needed to encourage the estimation and mitigation of health risks rapidly urbanizing developing countries (Nieuwenhuijsen, 2020). We recommend that morbidity impacts be considered especially in terms of cardiovascular diseases which are on the rise in Africa. And if data availability permits, further analysis should be stratified by population groups, particularly for vulnerable populations suffering from transport-related inequities and urban poverty. We highly recommend the use of participatory approaches in quantitative HIA to ensure context specificity. Further research is needed to assess to what extent stakeholder engagement in HIA models lead to evidence-based policy and protection of human and environmental health.

Author contributions

The individual contributions of each authors are as follows: conceptualization, M.T., N.M., D.R.-R., J.G., D.H.d.V., and M.J.N.; methodology, M.T., N.M. and D.R.-R.; software, M.T.; validation, M.T., N.M., D.R.-R., J.G., D.H.d.V., and M.J.N.; formal analysis, M.T.; investigation, M.T.; resources, M.T.; data curation, M.T., N.M., and D.R.R.; writing—original draft preparation, M.T.; writing—review and editing, M.T., N.M., D.R.-R., J.G., D.H.d.V., and M.J.N.; visualization, M.T., N.M., D.R.-R., J.G., D.H.d.V., and M.J.N.; supervision, D.R.-R., J.G., D.H.d.V., and M.J.N.; project administration, N.A.; funding acquisition, N.A.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Annex 1: Individual interviews topic guide; Annex 2: Protocols for FGDs; Annex 3: Survey Questionnaire; Annex 4: HIA Input Data. Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2020.106027.

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