NETWORK ACCESSIBILITY STUDY TO EVALUATE THE EXTENT OF PUBLIC TRANSPORT COVERAGE IN THE HARARE METROPOLITAN AREA

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ABSTRACT

Understanding the extent of informal public transport networks is especially important for cities that rely on these modes to access facilities and amenities which enable them to fulfil their needs. The advent of mobile technology, and proliferation of location-based services enables basic computational capabilities to be implemented to analyse such type of networks. This study presents an accessibility modelling approach to examine the response of public transport services to changes in land use. Location based point-of-interest data is used to develop adaptive accessibility metrics. An integrated pedestrian and transit network are modelled to evaluate the accessibility metrics to points-of-interest on the network spatially and temporally. This approach is demonstrated for the Harare metropolitan area to evaluate the performance of the partially regularised public transport service and its response to changes in land use. Understanding public transport network performance particularly in emerging cities is useful for the development of strategies that can potentially help fulfil the mobility needs of city inhabitants.

1. INTRODUCTION

The living experience of an urban environment is dependent upon the availability and accessibility of facilities and amenities, such as schools, clinics, police stations and sporting facilities. The relationship between the spatial structure, the quality of the transportation network, the spatial distribution and attributes of land use can have important implications to quality of life, social equity, and the environment Blanchard and Waddell (2017).

Metropolitans and regions around the world are investigating alternative ways to evaluate the effectiveness of their transportation systems Cervero (2013); Garcia et al (2018); Miller (2018); Corazza and Favaretto (2019). However, the complex nature of spatial processes presents challenges in delivering impactful land use and transport policies. Firstly, the presence of multiple modelling and planning tools makes the integration of planning and system functions between multiple stakeholders difficult if not impossible. Relevant data on urban transport systems and its interaction with land use patterns is rarely available and reliable. In cases where it exists for specific urban systems variation in the metadata make it difficult for integration with multiple planning functions.

While the influence of spatial structure on transport demand is very well documented in traditional transport master plans as highlighted by May and Marsden (2010) and Dhingra (2011). There is relatively minimal research about coordinated transportation and land use planning and the rebound effects of transport and spatial development in emerging cities.

This study presents an approach to measure the extent of public transport services using accessibility metrics that account for both spatial and temporal characteristics of an urban transport system. The approach presented in the study exploits mobile, computational, and location-based technologies to develop a framework to evaluate performance of urban transport systems. The framework is applied to the Harare metropolitan area to examine the interaction between land use planning and public transport service supply.

2. LITERATURE REVIEW

2.1 Defining Accessibility

Accessibility is a concept that has taken on a variety of meanings. Accessibility can be defined in terms of potential (opportunities that could be reached) or in terms of activity (opportunities that are reached) Litman (2016). These opportunities can be defined as facilities and amenities that encourage interaction and exchange. For example, hospitals provide access to health, libraries provide access to information and food markets give access to food.

In this study, accessibility is defined as the extent to which the land use transport system enables (groups of) individuals or goods to reach activities (facilities) or destinations (amenities) by means of a combination of transport modes.

2.2 Characteristics of Accessibility Measures

Although there is no best definition for accessibility because of different situations and purposes, several criteria can be derived to evaluate the usefulness and limitations of accessibility measures for different study purposes. An accessibility measure should firstly be sensitive to changes in the transport system, i.e., the ease for an individual to cover the distance between an origin and a destination with a specific transport mode including amount of time, cost, and effort. Secondly, an accessibility measure should be sensitive to changes in the land use system i.e., the amount, quality and spatial distribution of supplied opportunities and the spatial distribution of the demand for these opportunities. Thirdly a measure should be sensitive and take temporal constraints of opportunities into account and should take individual needs, abilities, and opportunities into account Hull et al (2012).

Accessibility frameworks demonstrating these characteristics have been presented by Logan et al (2019) and Biazzo et al (2019) in measuring proximity using network distance and population at a building level. Holl and Mariotti (2018) georeferenced data with detailed information on transport infrastructure to investigate the geographical accessibility of logistics firms in Spain. In transport and land use planning, accessibility frameworks have been demonstrated in Munich Büttner et al (2018), Buenos Aires Quirós and Mehndiratta (2015) and Lisbon Garcia et al (2018) as planning tools to solve specific urban problems.

With the advent of big data sets there has been empirical advances in calculating accessibility metrics. These ideas are good examples of methodological advances in the field of accessibility analysis. Theory and methods are still important as emphasised in Stępniak and Rosik (2018) and Östh et al (2018).

2.3 Accessibility Data Sources

Nowadays a large amount of data is available enabled by the widespread use of sensors and devices such as GPS, smartphones, credit cards, and transport smart cards. All these technologies generate massive geo-location data which is characterized by its high temporal and spatial resolution. These sources of data can be used to monitor the movement of populations across space and time, estimate speeds and travel times on a network, measure social networks' intensity or analyse cities' daily dynamics Condeço-Melhorado et al (2018).

Ziemke et al (2018) demonstrated the applicability of open-source data for accessibility analysis in Nelson Mandela Bay. Using open data Dingil et al (2018) demonstrated an accurate analysis and comparison of transport indicators from 151 urban areas. Moya-Gómez et al (2018) analysed urban accessibility by consigning dynamic data from TomTom and social media platforms like Twitter. Haklay (2010) demonstrated the accuracy of OpenStreetMap data using a comparative ordinance survey dataset and Perkins et al (2008) on the assessment of the potential of user data generated platforms. In addition, research has demonstrated the application of mobile technologies to map transit-based access and develop standardised transit schedules such as the widely adopted Global Transit Feed Specification (GTFS).

2.4 Accessibility Modelling Tools

Models of transport accessibility, and its interaction with sustainability have been developed over many years. The common theme in these models is the objective to achieve a holistic understanding of development patterns and the interaction of these with land use and transport policies. Mccahill and Ebeling (2015) extended the concept as a land use transport model where the ease of travel between population and employment is a key determinant of land use. Hull et al (2012) investigated accessibility instruments for planning practice common in European cities and categorised them into three buckets. i) instruments analysing walk times to public transport services and or local facilities. ii) instruments analysing travel times using public transport systems and motorised vehicles through a road network. iii) instruments or models that are not specifically developed to measure accessibility but however involve the process of accessibility modelling. Several tools exist for accessibility analysis. These tools are comprised of both open source, developed in GIS environments and out of the box tools that require licenses such as ArcGIS and Conveyal.

For this study all software and data acquisition and processing and analysis are implemented in python together with the UrbanAccess Blanchard and Waddell (2017) and Pandana Foti et al (2012) analysis tools. Python is a widely used and accessible programming language. UrbanAccess is a tool for creating multi-modal graph networks for use in multiscale transit accessibility analysis. Pandana is a python package that uses contraction hierarchies to perform rapid network calculations including shortest path and accessibility buffers. Two components are required to calculate transit accessibility. a) a set of origin and destination representing any geographic unit between which accessibility will be calculated and an associated variable such as socio economic or employment characteristics and b) a transportation network weighted by an impedance that quantifies the ease of travel connecting origins and destinations Blanchard and Waddell (2017).

2.5 Accessibility Measure Framework

Land use policy and geographical studies often use maximum transit travel time or distance to a location or to transport infrastructure as the standard for accessibility measures. The main advantage of these measures is the ability to present an easily explainable accessibility measure without implicit assumptions about a person's perception of transport, land use and the interaction of these two. Alshalalfah and Shalaby (2007); Oliver et al (2007); and Iacono et al (2010) demonstrated the application of distance measures in determining the population with walking access to bus stop locations and examined the influence of land use type (residential, commercial, recreation and park land) on 'walking for leisure' and walking for errands using circular and line-based road network buffers. Jiang et al (2012) and Mavoa et al (2012) evaluated walkability access and transit travel time by measuring potential access to destinations via public transit and walking modes.

To visualise the outputs from accessibility Yigitcanlar et al (2007) suggested the use of isochrones (lines of equal travel time) as a way to combine transport system and land use. They incorporate the transport component (travel time, costs, distance) and the land use component (location of facilities). Isochrone measures used in this study aim to describe the transport and land-use system from the user's point of view. Distance and transit travel time measures will be used as accessibility metrics in this study. The metrics are presented to indicate the number of opportunities (facilities/amenities) reachable within a given travel time and walkable distance.

3. HARARE METROPOLITAN AREA

3.1 Background

The spatial structure of the Harare metropolitan area is characterized by a radial road network with the central business district (CBD) at its core and the industrial areas to the east and south Kamusoko et al (2013). Urban development is guided by development plans prepared by local authorities. The conventional land-uses provided for in such plans are housing, industrial, commerce, open spaces, and servitudes (roads, electricity, telephone etc). The metropolitan area has witnessed extensive urban sprawl, unlike in other cities in the world it has not been driven by industrialisation, instead, it has largely been driven by rural-urban migration and rapid population growth. Increased unrestrained built-up area expansion and spread in the south and east of the metropolitan province reveal urban sprawl.

Public transportation in the metropolitan area is considered as either bus, minibuses known as commuter omnibuses – Kombi - or shared taxis. Kombis act as the main motorized public transport for most city inhabitants even though they are privately run and operated. Cycling plays a limited role accounting for only less than 3% of total trips in Harare and minibuses (commuter omnibuses) serve 90% of the market currently UN-Habitat (2013).

A route network discovery was performed for the Harare metropolitan area using the GoMetro Pro mobile data collection application and methodologies for network discovery as outlined by Ndibatya et al (2016) and Coetzee et al (2018).

Data collection for the network discovery occurred between August 2018 and January 2019. The first step in the data collection process involved identifying existing routes on common corridors. Interviews were conducted at the major transfer terminals to establish the destinations (routes) from these terminals. Onboard vehicle surveys were performed on all origin destinations identified to develop a geospatial route network from all terminals. Services on these routes do not always have fixed schedules and fares, often drivers take detours to avoid traffic or police and sometimes take the liberty of improvising stops. The data collection study focused on performing a network discovery from official terminals. Informal street ranks are not part of the study. On-street ranks are largely a result of low capacity in the official terminals and suggest overcrowding. The extent of route coverage network is summarised in Figure 1.

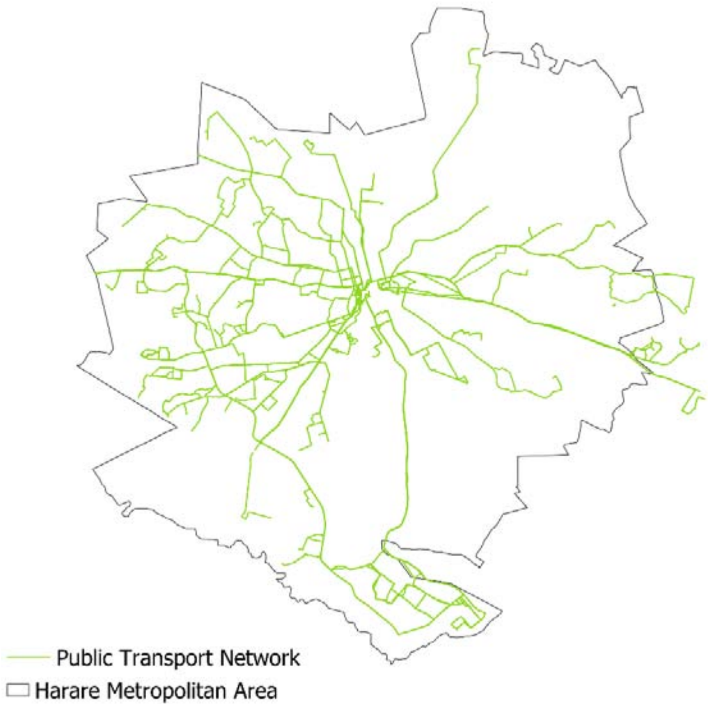

Figure 1: Extent of public transport coverage in the City of Harare

3.2 Application of Accessibility Measures

For analysis performed in this study facility and amenity Points of Interest - (POI) data gathering placed emphasis on 1) health(time cost to travel to health facilities), 2) education(time cost to travel to education facilities) and 3) economic (time cost travel to shops, markets, banks and any other contextual location of economic activity). Garau and Pavan (2018) and Lawal and Anyiam (2019) presented the service needs and priorities and why they are essential to urban inhabitants. These POIs were extracted from location service platforms such as Google Places and OpenStreetMap (OSM) Points of Interest. Point of interest data distribution for the Harare metropolitan area is summarised Table 1. POIs categorised as government were included in the analysis. Government facilities provide amenities such as identify document, birth, or company registration. These services are key to ensuring in access to education, health, and economic opportunities.

Table 1: The number of points of interests used for the accessibility analysis

Point of interest category	Total
economic	873
educational	387
government	79
health	217
Grand Total	1556

One could build a weighted index of facilities and amenities depending on how crucial they are for daily life in that instance. This study treated all key amenities equally and did not apply any weighted index. Land use patterns and the geospatial distribution of the Points of Interest used for the accessibility analysis is summarised in Figure 2.

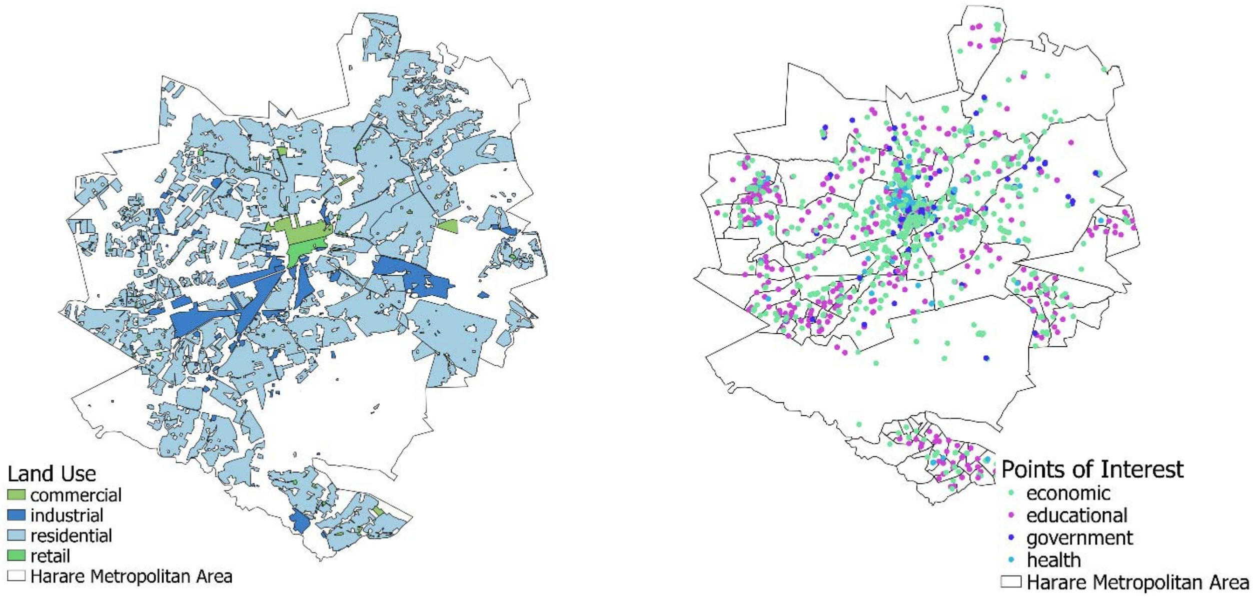

Figure 2: Distribution of land use patterns - source: OSM b) Points of Interest for accessibility analysis

The street network for the study area was created using the OSMNet python library. From the street network the pedestrian travel time weight network graph is generated using a travel impedance of 1.4m/s. All transportation features in the OSM network including pedestrian paths, stairways, and plazas and roads that are accessible to pedestrians are included, and non-pedestrian-accessible features such as limited access highways are excluded Blanchard and Waddell (2017). The transit network was created by reshaping the data collected during the network discovery exercise into GTFS. The GTFS contains trip, stop, stop time and frequency. The GTFS (transit) and OSM (pedestrian) networks are merged to create an integrated transportation network with weighted impedance for walking and public transit travel speeds. UrbanAccess Blanchard and Waddell (2017) GTFS and OSM capabilities were used to develop the integrated pedestrian and transit network and Pandana is used to perform the accessibility calculations. Maximum walking distance to transit stop and facility/amenity was set to 800m and 1500m respectively El-Geneidy et al (2013). The transit network data used in this study represents the best-case scenario transit travel time and service coverage and may not represent the real transit system passenger's experience.

4. RESULTS OF ACCESSIBILITY ANALYSIS

Figure 3 shows the walking distance in meters from each pedestrian network node to the nearest public transport facility. Social housing and informal settlements in the southwest and southeast are highly dependent on public transport and are in areas that offer limited transit accessibility relative to residents with auto accessibility.

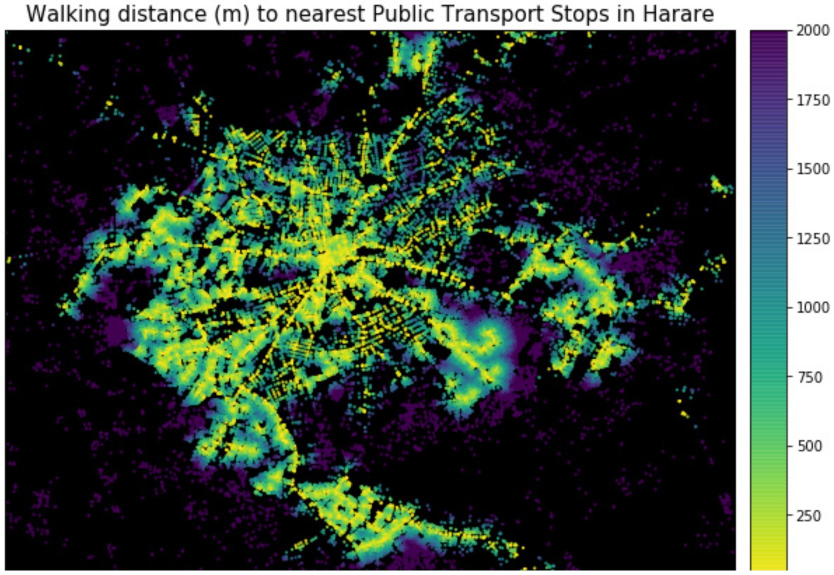

Figure 3: Accessibility to public transport stops within a walking distance of 800m

The maps in Figure 4 further reveal high-amenity hot spots within walking distance are more prevalent in the city centre than in relatively new developments in the southwest and southeast urban settlements. The sprawl demonstrates that most residents are unable to accomplish most of their daily tasks on foot. Figure 4 show a) the level of accessibility for all points of interest within a walking distance. Focusing on educational facilities as a key measure in b) the level of accessibility within walking distance to educational facilities is illustrated. It shows that most residents live in locations in which an educational facility in not reachable within a walking distance.

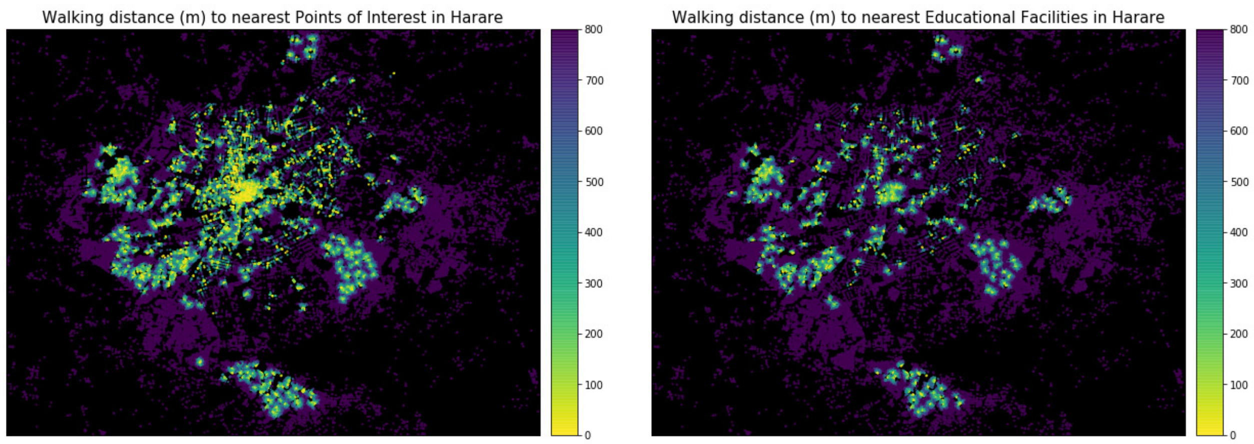

Figure 4: Walking distance to a) All POI b) Educational facilities

Using the facilities and amenities identified, the travel time using public transit from each pedestrian node to points of interest is illustrated in Figure 5. From the spatial representations of the metropolitan area, we can observe it has been densifying in the periphery with the southwest and southeast representing much of the urban sprawl. Low density areas in the north-western and north-eastern side of the metropolitan area do not promote active transport and instead have increased the dependence on motorized transport despite its negative impacts on travel times, travel cost and general quality of an urban system. Many residents will spend more than 45 minutes to reach a facility or amenity to meet their social needs. We can infer from Figure 5 that the new urban settlements in the south of the city still require more than 45 minutes of travel time or more for low mobility groups to access primary healthcare. It also indicates the degree to which the supply of health facilities is being outpaced by urban growth. Developments in high-density areas seen in the southwest and south-eastern edges of the metropolitan area are massively unstructured and lack basic regulatory oversight in terms of adherence to building standards and planning frameworks. This form of uncoordinated development has failed to create urban cohesion and impacts the provision of utility infrastructure such as roads.

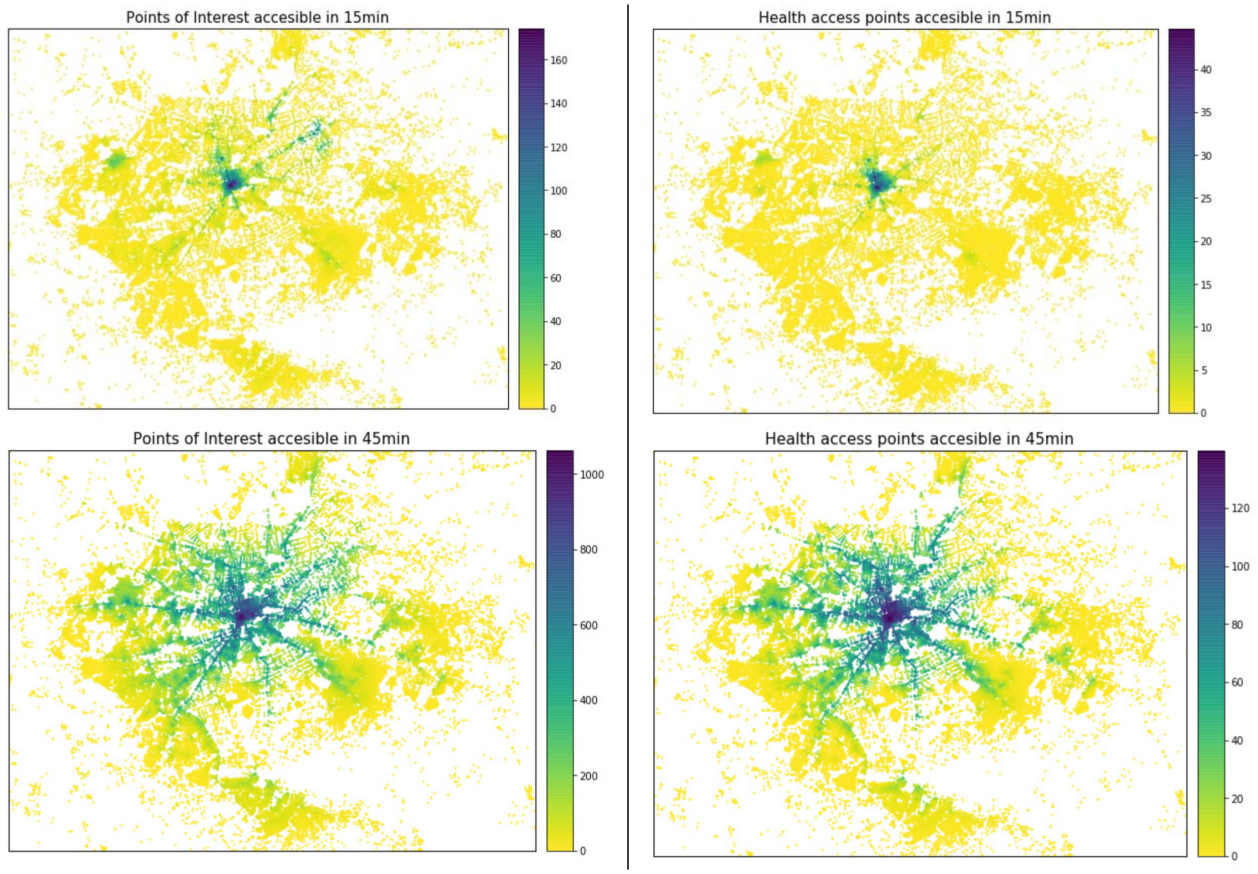

Figure 5: Left -Travel time accessibility for all facilities and amenities. Right - Travel time for all health facilities

5. DISCUSSION AND KEY FINDINGS

A casual examination of the population data suggests Harare metropolitan area has experienced rapid urban sprawl. Housing policies have set ambitious targets for affordable housing units without necessarily paying attention to their location and have driven urban sprawl causing large-scale peripheral expansion with limited service provision. Development typologies include some gated communities and, large high-density informal settlements and government driven housing projects. This form of urban sprawl characterised by unplanned, uncoordinated, separated, or single-use developments does not provide for functional mixed use of land.

With an understanding of accessibility in different parts of the metropolitan area, we note that the city has been growing in places with little public transport accessibility. The outcome of the accessibility measures emphasizes that the city has been growing inefficiently from a transit accessibility point of view. The growing suburbs around Harare do not have well-defined activity centres which make it really challenging for communities to access social and economic opportunities. Many residents in Harare, are required to travel using motorised modes to access facilities and amenities to meet their social needs. The centralisation of facilities and amenities especially to the central business district of the city forces long travel times for most residents in the metropolitan's periphery. The analysis presented suggests that high density development areas require land and transport planning interventions to improve accessibility. This will require an incremental approach which is multi-stakeholder and multi-disciplinary enabling the re-agglomeration of urban functions and spaces that have been subject to urban sprawl. Lastly, the metropolitan area should ensure that land-use regulations increase access to public transport services and promote affordable densities using flexible planning standards.

6. CONCLUSION

This paper provides some important evidence, previously missing, on the understanding of land use and transport planning for the Harare metropolitan area. Using the lens of accessibility, we can provide more insight on spatial development and transport service development trends. This is largely due to the ability to now create data on mobility networks and operation using low-cost technology including mobile phone application at a scale and detail that allows for detailed accessibility analysis. Overall, the approach presented in this analysis enriches our understanding of the transit system with easily accessible data gathering and analysis tools-particularly open-source accessibility tools. For developing cities this helps to frame questions for a deeper analysis of land use and spatial development that inform strategies and policy reactions to support a more accessible pattern of spatial development. It further provides an approach to formulate answers to the question, does an urban mobility initiative increase accessibility?

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