Access to care following injury in Northern Malawi, a comparison of travel time estimates between Geographic Information System and community household reports

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Abstract

Introduction

Injuries disproportionately impact low- and middle-income countries like Malawi. The Lancet Commission on Global Surgery's indicators include the population proportion accessing laparotomy and open fracture care, key trauma interventions, within two hours. The "Golden Hour" for receiving facility-based resuscitation also guides injury care system strengthening. Firstly, we estimated the proportion of the local population able to reach primary, secondary and tertiary facility care within two and one hours using Geographic Information System (GIS) analysis. Secondly, we compared community household-reported with GIS-estimated travel time.

Methods

Using information from a Health and Demographic Surveillance Site (Karonga, Malawi) on road network, facility location, and local staff-estimated travel speeds, we used a GIS-generated friction surface to calculate the shortest travel time from all households to each facility serving the population. We surveyed community households who reported travel time to their preferred, closest, government secondary and tertiary facilities. For recently injured community members, time to reach facility care was recorded. To assess the relationship between community household-reported travel time and GIS-estimated travel time, we used linear regression to generate a proportionality constant. To assess associations and agreement between injured patient-reported and GIS-estimated travel time, we used Kendall rank and Cohen's kappa tests.

Results

Using GIS, we estimated 79.1% of households could reach any secondary facility, 20.5% the government secondary facility, and 0% the government tertiary facility, within two hours. Only 28.2% could reach any secondary facility within one hour, 0% for the government secondary facility. Community household-reported travel time exceeded GIS-estimated travel time. The proportionality constant was 1.25 (95%CI 1.21-1.30) for the closest facility, 1.28 (95%CI 1.23-1.34) for the preferred facility, 1.45 (95%CI 1.33-1.58) for the government secondary facility, and 2.12 (95%CI 1.84-2.41) for tertiary care. Comparing injured patient-reported with GIS-estimated travel time, the correlation coefficient was 0.25 (SE 0.047) and Cohen's kappa was 0.15 (95%CI 0.078–0.23), suggesting poor agreement.

Discussion

Most households couldn't reach government secondary care within recognised thresholds indicating poor temporal access. Since GIS-estimated travel time was shorter than community-reported travel time, the true proportion may be lower still. GIS derived estimates of population emergency care access in similar contexts should be interpreted accordingly.

Highlights

- Since the Lancet Commission on Global Surgery, analysis of population access to urgent surgical care, particularly using GIS, has expanded.
- Using GIS methodology in Northern Malawi, most of the studied population could not travel to a government secondary facility within two hours.
- Compared to community household-reports, GIS underestimated travel time, and correlated poorly with patient-reported travel time.
- This study is the first to validate GIS-estimated with community household-reported travel time, for injury care in any low-income country.
- GIS methods must be used with caution, accounting for potential error, when planning health system strengthening to improve injury care access.

Keywords

Wounds and Injuries, Healthcare Systems, Health Services Accessibility, Geographic Information Systems, Emergency Care.

Introduction

Trauma represents a major global health problem. According to Global Burden of Disease (GBD) estimates, injuries account for 7.6% of all deaths,[1] almost 90% of which occur in Low- and Middle-Income Countries (LMICs).[2] Globally, over 200 million years of life are lost to injuries, and one billion people sustain an injury sufficiently severe to require health care each year.[3]

Injury is a time-critical emergency condition where prompt medical care can be required for a life or limb saving intervention, and prolonged delays before hospital care have been associated with an increased risk of dying from severe injury.[4-10] A "Golden Hour" concept proposes that an injured patient should receive facility-based definitive resuscitation within one hour to avoid an increased risk of death or morbidity.[11, 12] This has been widely accepted internationally as a standard for quality health systems to aim for.[13] Although criticised as unrealistically long or short for some injuries, it has served as a valuable metric for supporting investments in the trauma system in high-income settings and remains a key benchmark to guide planning and investment in trauma care systems.[13] The Lancet Commission on Global Surgery (LCoGS) proposed a core indicator of access as the proportion of the population that can access specific surgical procedures, including laparotomy and open fracture management within two hours as proxies for the adequacy of trauma care.[14]

Estimating travel time to trauma care facilities has been advocated as a useful way to drive the production of solutions to reduce prehospital time and consequently improve trauma outcomes in LMICs.[15] Following advocacy from the LCoGS,[14] there has also been significant recent interest in estimating travel time to emergency care. Whilst not advocated for specifically by the LCoGS, there has been growth in researchers using geographic information systems (GIS) to study travel times to care.[15-20] GIS models estimate travel time between locations, taking into account differences in velocity across different terrains (for example, road, tracks, agricultural landscapes, forested areas).[21] They have been increasingly used to investigate injury epidemiology, often focusing on road traffic collisions, for example, by studying injuries' geographical locations to identify areas of high occurrence to help target prevention initiatives.[22, 23] However, GIS techniques have also been widely adopted in global health research to estimate the time to reach care facilities using variables of distance, terrain, and available road networks.[24-26]

Trauma is a substantial and growing burden within Malawi.[27, 28] A third of road traffic collisions end in fatality, exacerbated by the lack of a formal prehospital care system, particularly in rural areas.[29, 30] Longer GIS-estimated travel time to a referral facility is associated with a delayed presentation for fracture care, justifying further study into emergency facility access for rural Malawians.[31] However, despite interest in using GIS to study access to healthcare, little is known about how the GIS-estimated travel time relates to travel time reported by local community dwellers as potential injured patients, or those reported by actual injured patients.

Whilst access to care is more complex than travel time, including numerous dimensions such as finance, gender, culture, and service readiness,[32-34] the temporal dimension remains fundamental. [20, 35] Indeed, these other dimensions can affect the temporal dimension by causing delays from the recognition of the need to get to care to actually arriving at a place of care. However, expansion in available and affordable powerful computing, along with large scale and open-source data, has led to predicted growth in the use of GIS techniques – which assess optimal travel time - in health system research.[25] GIS lends itself well to integration with multiple data sources including health facility locations,[17, 36] population density,[15] road network data,[19, 21, 35, 37] and facility capacity.[15, 35] Given the potential for using remotely accessible data and low cost software, along with integration with other data sources, the method has many potential advantages for emergency health system research in low resource contexts. However to date there is little data on the accuracy of GIS models for emergency patient travel time in low-income settings.[21]

This study aimed to estimate the travel time to facility care for a rural population in Karonga, Northern Malawi, following injury. The objectives were: firstly, to use GIS analysis techniques to estimate the proportion of the local population able to reach primary, secondary and tertiary facilities within both the LCoGS two hour indicator and the "Golden Hour" hour timeframe, and; secondly, to compare potential patient estimated and recently injured patient-reported travel time to reach facilities, with GIS-estimated travel time.

Materials and Methods

Study setting

This study focused on the health system serving the Karonga Health and Demographic Surveillance Site (HDSS) population, Karonga District, Northern Malawi.[38] The HDSS has a population of over 40,000 who have been regularly surveyed since 2002.[38] At the time of study, there were 10,228 households within the HDSS. Households are within villages divided into smaller clusters that form the 21 reporting groups of the surveillance site.[38] The HDSS population is predominantly rural, although approximately 15% of inhabitants live in semi-urban settlements of a trading centre and the portside village of Chilumba, in the south of Karonga district. Karonga itself is a predominantly rural lakeshore district, typical of a Malawian subsistence economy community, dependent on farming and fishing.[38] Half of the population live within one kilometre of a paved road.[38] The main paved road runs through the district; most secondary roads are unpaved. The climate is cool and dry from June to August, hot and dry from September to December, with rains from January to May which can impair travel on unpaved roads.

The Karonga HDSS population is served by local government primary facilities, a military facility accessible by civilians, private facilities, and Christian Health Association of Malawi (CHAM) facilities. Secondary care facilities include a government facility 70km to the North of the HDSS and a CHAM facility 40km to the South of the HDSS over rugged hilly terrain. Tertiary care is provided in a government facility in the regional capital Mzuzu, 150km to the South of the HDSS. Surgical resuscitative care for severe injuries is available in secondary and tertiary facilities. These facilities were identified by experienced clinical HDSS staff and reconfirmed during the study by primary facility staff. Their locations are shown in Figure 1. Whilst secondary and tertiary facilities provide emergency surgical care required for serious injury, we included primary facilities since they are very commonly the first facility attended following injury in this population.

Data Collection

A previous study conducted with the Malawi Epidemiology and Intervention Research Unit (MEIRU) examined patient travel time for accessing facilities that provided chronic disease care.[39] Data on the location and estimated speeds achievable on the local road networks, including unpaved paths passable by two-wheeled motor vehicles, was therefore available and had been updated in 2008. Speed estimates were those previously obtained from embedded Karonga HDSS staff, based on experience travelling the routes conducting fieldwork. Road network locations were obtained from HDSS staff travelling the routes in vehicles or on foot, with a Global Positioning System (GPS) recording device. The route to one secondary and the tertiary facility had not been previously captured, so these were travelled, and the velocity of these road segments captured using a GPS recording device as part of this study. The position of each household within the HDSS is routinely captured using GPS. This information was used to define a friction surface, which quantifies how difficult a 100 x 100m grid-cell is to navigate, to allow calculation of travel time. On this surface, the value in each cell corresponds to the time needed to cross this cell. Each cell was classified into the one of three travel speeds: i) paved roads (speed = 35 Km/h), ii) unpaved tracks (speed = 5 Km/h), iii) any other walkable surface (speed = 3.5 Km/h). The quickest applicable speed was used for each cell. They incorporate stops for customs checks on main roads, the possible use of motorised car, bike or bicycle taxi, and preferences for major tracks over smaller paths. This GIS friction surface approach was conducted using the open-access statistical computing software R (cran.r-project.org/) and enables the calculation of the shortest possible travel time between points within the included geographic region. Travel time estimates derived from this method are referred to as GIS-estimated travel time.

Data on patient or potential patient travel time were collected during a household survey investigating the burden of injury. A random sample of 2200 households were selected from within the HDSS. Each household was visited by a trained research assistant fluent in the local language (Chitumbuka). An adult member of the household was asked the following:

- Which facility they would prefer to go to if they were to suffer an injury, with allowed categories of named local facilities within the HDSS or other specified (to capture facilities outside of the HDSS health system).
- Their estimate of how long it would take to get to their preferred facility in an emergency.
- Whether their preferred facility was the closest, and if not, which facility was closest (named facility or other specified).
- How long it would take to get to their closest facility in an emergency.
- How long it would take to get to the main government secondary and tertiary referral facilities in an emergency.
- Whether or not there had been either a fatal or non-fatal injury in the household in the preceding 12 months, and if so, how many.

These time estimates are referred to as community household-reported travel-time.

For those households with an injured person who had sought medical treatment, the respondents were asked which facility they first attended (named facility or other specified with free text) and how long it took to reach the first care facility (exclusive categories of <1 hour, 1-2 hours, 2-4 hours, 4-6 hours, 6-12 hours, 12-24 hours, >24 hours). This time is referred to as the injured patient-reported travel time.

Outcome variables

The primary study outcome was the proportion of the HDSS population able to travel to a referral (secondary or tertiary) facility within the LCoGS two hour target, according to GIS-estimated travel time. The secondary study outcomes were: first, the proportion of the HDSS population able to travel to any facility within the two hour LCoGS or "Golden Hour" targets according to GIS-estimated travel time, and; second, to compare the GIS-estimated travel time with the community household-reported travel time.

Using the friction surface, we estimated the travel time for a member from each household within the HDSS to the following locations: any primary, secondary or tertiary facility; the main government primary (Chilumba Rural Hospital) and secondary (Karonga District Hospital) facilities. We included primary facilities since they are commonly the first facility type attended following injury in Malawi.[40] The same friction surface approach was also used to produce GIS-estimated travel time for HDSS household survey participants to travel to their reported preferred facility and nearest facility, and for injured household survey participants who sought care, the facility they first attended. The quickest possible route was calculated for each healthcare facility. To enable comparison between the GIS-estimated travel time to facilities and injured patient-reported travel time, GIS-estimated time was further categorised into < 1 hour, 1-2 hours, 2-4 hours, 4-6 hours, 6-12 hours, 12-24 hours and >24 hours.

Analysis

Proportions describe GIS-estimated travel time to facilities within the categorical timeframes. We performed linear regression to assess the relationship between community household-reported and GIS-estimated travel time.[21, 41] To reflect the divergence from equivalence between community household-reported and GIS-estimated travel time we calculated the proportionality constant after excluding potential outliers calculated using

Cook's distance (and excluded if Cook's distance >1). The proportionality constant with a 95% confidence interval is reported. We display the results using kernel density and scatter plots.

To assess associations and agreement between categorical injured patient-reported and GIS-estimated travel time, we performed both the Kendall rank test for correlation and a linear weighted kappa test for agreement. The analyses were performed with the open-access statistical computing software R (cran.r-project.org/).

The study was approved by the Malawi National Health Sciences Research Committee and The UK MOD Research and Ethics Committee.

Results

According to GIS-estimated travel time, most (79.1%) of all HDSS households could travel to any secondary facility within the LCoGS two hour target. This figure fell to 20.5% when considering only the government secondary facility, and no HDSS member could reach tertiary care in this time (Table 1). According to GIS-estimated travel time, all HDSS households could travel to a primary facility within 2 hours. For the “Golden Hour” target, GIS-estimated travel time found 28.2% could travel to any secondary facility within this time frame, although none could reach the government secondary facility within one hour. According to GIS-estimated travel time, 94.0% of HDSS households could travel to a primary care facility within one hour; this fell to 64.9%, for the largest government primary facility. GIS-estimated travel time found two thirds (65.3%) of households would take four hours or more to reach the tertiary facility.

Of the 2200 households approached, participants were only available to complete the survey in 82.7% (1819/2200). A total of 611 non-fatally injured persons were reported, of whom 465 sought health care, almost all at a primary facility initially, 96.3% (448/465). The proportion of households for whom the reported closest facility was identical to the GIS calculated closest facility was 75.6%.

Community household-reported travel-time was consistently longer than that calculated using the GIS method (Table 2) for travel to the same facility. For the closest facility, the proportionality constant was 1.25 (95% CI 1.21-1.30); for the preferred facility, it was 1.28 (95% CI 1.23-1.34); for the main government secondary facility, Karonga District Hospital, it was 1.45 (95% CI 1.33-1.58); and for the tertiary facility Mzuzu Central Hospital it was 2.12 (95% CI 1.84-2.41). These regression models are illustrated in Figure 2. Community household-reported travel time tended to be distributed along discrete and often rounded values, representing approximations of time needed to reach health facilities (Figure 3).

The injured patient-reported and GIS-estimated travel time to facilities in which care was sought are shown according to survey categorical time intervals in Table 3. The relationship between the GIS-estimated and injured patient-reported travel time is shown in Figure 4 with the GIS-estimated travel time tending to be shorter, although there are some extreme outliers where this was not the case. Comparing the two methods using Kendall Tau correlation revealed a coefficient of 0.25 (SE 0.047, $p<0.05$), which represents a moderately positive linear relationship.[42] Comparing the methods using linear weighted Cohen's kappa gave a coefficient of 0.15 (95% CI 0.078 – 0.23, $p<0.05$) representing a statistically significant but only slight level of agreement.[43] Cohen's kappa statistics comparing categorical GIS-estimated with all participant-reported travel time are reported in Table 4.

Discussion

We used GIS methodology to estimate population direct travel time to primary, secondary, and tertiary facilities in Northern Malawi following injury. According to this method, travel time to government secondary and tertiary facilities, where definitive resuscitative care for severe injuries is available, was greater than two and four hours respectively for most of the population. Most of the HDSS population studied could, however, travel to a primary facility within one hour. The GIS-estimated travel time did not correlate well with injured patient-reported travel time following injury in the previous year. Community household-reported travel time tended to be longer than those estimated using the GIS method. The true proportion of the population able to reach emergency facility care within these timelines following injury might therefore be lower than we estimated using GIS.

Similar to our findings, other researchers using GIS methods to estimate travel time to care facilities following injury have found low levels of timely access. Stewart and colleagues used OpenStreetMap data combined with facility trauma capacity data to estimate the population's proportion with access to basic, intermediate and advanced orthopaedic trauma care in Ghana.[35] They reported only 58% and 35% of the population could access basic or advanced trauma care within one hour, and only 74% and 59% within two hours. Likewise, Tansley and colleagues used ArcMap road network data to map population road distance to facilities graded according to their capacity for emergency care.[15] They found only 49% and 28% of Haiti and Namibia's population, respectively, lived within 50km of a facility with a surgeon and resuscitative care.

GIS estimates of population access for surgery or emergency care more broadly have also been studied. Raykar and colleagues used Google Maps open-source software and ministry of health data to estimate the proportion of the population within a two hour drive of a surgeon in 9 LMICs.[16] They found this ranged from 17% in Somaliland to 84% in Pakistan.[16] When assessing access to essential surgery within two hours in the Pacific region, only 5 of 13 countries (38%) reached the LCoGS target of 80% of the population.[44] The low levels of population access to timely care that we found are therefore not unique. Interestingly, Ouma and colleagues used road data from Google Map maker and OpenStreetMap and estimated that only 29% of sub-Saharan Africa lived more than two hours from a public hospital with emergency services.[19] Their model suggested that this represented 90% of the population of Malawi, more than we estimated for a population in Northern Malawi.[19] The differences could be due to the model used by Ouma and colleagues, which included faster road speed estimates than those locally derived in our study. Given that others have found that travel time data obtained using local knowledge of the hospitals, terrain and local transport were more reliable than geospatial modelling techniques, it is likely that Ouma's estimates are more optimistic than experienced reality.[44] However, use of locally-derived travel time may not be practical for studying large populations,[44] such as those studied by Ouma and colleagues.[19]

There have been few attempts to validate the accuracy of GIS models for actual population travel time for surgical care in LMICs. Rudolfson and colleagues compared the reported travel time of 664 women who underwent C-Section at a referral facility in Rwanda with GIS-estimated travel time from their home village. Direct travel and travel via primary facilities models were used. The proportionality constants they calculated were similar to those in our study, finding GIS to underestimate patient-reported times by a factor of 1.49 in the direct travel model compared with 1.12 when assuming travel was via a primary facility.[21] Van Duinen and colleagues compared two GIS models with reported travel time from women treated with caesarean section in nine facilities within Sierra Leone.[41] They found their standard GIS model underestimated the patient-reported time by a factor of 2.85.[41] However, using a GIS model with more conservative travel time estimates, produced closer correspondence with patient-reported time.[41] They also found the LCoGS two hour target, whether measured through GIS-estimated or patient-reported travel time, to be clinically meaningful, and associated with better perinatal mortality outcomes.[41] Banke-Thomas and colleagues in urban Lagos compared estimated travel time derived from a GIS cost-friction approach, Open Source Routing Machine (OSRM), and Google Maps with professional driver replicated driving time.[45] They found all three methods underestimated travel time, with Google Maps closest to driver time. That study's urban Lagos context was described as having year-round bumper to bumper traffic, quite different from our study's rural setting.

It is important to consider why GIS may underestimate patient-reported travel time. The actual routes or modes of transport that patients take are only partially described by the existing road network. They may not have matched the assumptions of the road speed or the mathematically quickest route. Indeed, oxcarts may be the mode of transport for some injured patients in this community. Barriers to reaching care facilities may have been present and not represented in the GIS model, including the time to identify suitable transport or mobilise necessary funds to meet transport costs.[46, 47] Although less problematic in rural than urban areas, GIS models may ignore traffic variability and lead to significant underestimation of travel time to access facility care in LMICs.[45, 48] Similarly, seasonal variation, particularly with the rainy season, can adversely impact actual travel time, especially on unpaved roads.[46] The risk of some injury mechanisms, such as road traffic collisions, also usually increases during precipitation.[49] Current practice and policy within the local health system is for patients to move through the referral system from primary, secondary and tertiary care, rather than bypass to a referral facility directly. As across sub-Saharan Africa, primary facilities, whilst serving most of the population, have little capacity to manage emergency conditions.[34] This would mean the time between injury and reaching a better equipped secondary and tertiary facility may be further underestimated by GIS models evaluating direct travel to referral facilities.

Within Malawi, GIS methods have assessed equitable access to health services for people with disabilities,[50] access and use of contraceptives and contraceptive service[51] and HIV treatment.[39, 52, 53] However, this study is the first to our knowledge to attempt to validate GIS methods for injury care in any low-income country. It has demonstrated that GIS methods must be used with caution when planning health system strengthening to meet indicator targets of realised access to injury and other emergency care. Since our study and others have tended to underestimate travel time, health system development incorporating GIS could consider accounting for such potential error in assumptions about improving emergency care access.

Limitations:

As with any modelling study, our analysis comes with limitations. For injured household members, the specific location of injury GPS data was not available, and the household location was used instead. In Canada, 88% of injuries occur within 10 miles of home.[54] It is likely in rural Malawi that injuries may occur even closer to home as the main occupation of subsistence farming means that injuries are likely to occur close to home. In rural Bangladesh, 60% of fatal injuries occurred within or close to the home.[55] Most intentional injuries at a Tanzanian referral facility occurred in the home,[56] as did most burn injuries.[57] This limiting assumption is not unique to this study as others have assumed village centre points as a journey starting point, which can also introduce error.[21] This would not have affected the other comparator of household participant estimates that were from the theoretical starting point of the household.

Not all the 2200 households approached were available to complete the survey, nevertheless it is unlikely that the 17% of households not available to complete the survey would have provided substantially different travel time estimates to alter the message of the study. The comparator of household participant self-reported travel time used in our study may not be as accurate as alternatives such as asking patients on facility discharge to estimate travel time for a recent journey.[21, 41] Although reported closer in time to the actual journey, surveys on discharge are still subject to the limits of human recall and estimation. The accuracy of participant estimations of time could be influenced by low literacy levels[58] or cultural understandings of time,[59] or symptoms amongst the injured. However, person recall remains the standard comparator used to date.[21, 41] Similarly, we did not explore the thinking behind each household participants' estimate of travel time. The potential barriers delaying immediate access to transport, the route taken, or the mode of transport used were not specifically explored. Neither was the effect of season, which likely causes variation in achievable transport speeds.[60]

The road network survey was over ten years old. Whilst some smaller tracks may have changed, no major new paved roads were built since, and any effect is likely small relative to the main message of this paper. The road speeds used in our model may have been conservative for a major paved road compared to those used in other GIS models assessing geospatial access to injury and surgical care.[21, 35] The road speed assumptions were based on estimates from locally embedded HDSS staff. Participants living on the paved road with immediate access to a motor vehicle, able to achieve greater speeds than those assumed, could potentially reach the referral facilities more quickly than modelled. Despite this, relative to self-reported travel time, the GIS still underestimated the travel time to care.

Finally, access to care is a multifaceted concept including additional dimensions such as finance, gender, culture, and service readiness, which we did not study.[32-34] However, this temporal dimension remains a fundamental component of care access.[35] Assessing this together with all the other factors influencing emergency care access necessitates a complex study design. Recognising this complexity, the LCoGS have revised its indicators and now explicitly name the two hour access target “geospatial access” for reasons of clarity.[20]

Conclusion:

For this population in rural Karonga District, Northern Malawi, time to access to public facility surgical resuscitative care following injury exceeded both the “Golden Hour” and the LCoGS two hour indicator for most of the population. However, since we found GIS-estimated travel time was shorter than community-reported travel time the true proportion able to reach care within these timeframes may be lower still. Those wishing to adopt the benefits of increasingly available and affordable GIS modelling for emergency health system strengthening should recognise this, using the method with caution and adjust estimates of population access if experienced travel times are known.

Tables Legends

Table 1 Number and proportion of HDSS households travel time categories according to GIS methodology by facility type.

Table 2 Regression models comparing household participant reported estimates of travel time to facilities with the GIS-estimated travel time.

Table 3 Injured patient-reported and GIS-estimated travel time to the facility in which care was sought according to survey categorical time intervals.

Table 4 Weighted Cohen's kappa statistic for comparing categorical GIS-estimated with community household-reported travel time for each of injured patients, preferred facility, closest facility, Main government secondary facility (Karonga District Hospital) and the tertiary facility (Mzuzu Central Hospital).

Figure Legends

Figure 1 GIS-estimated travel time the HDSS population need to reach any primary facility, the main primary facility, any secondary facility, the main government secondary facility (Karonga District Hospital), and the tertiary facility (Mzuzu Central Hospital).

Figure 2 Kernel density plots illustrating the relationship between community household-reported and GIS-estimated travel time to reach the different facility types. The dotted line represents equivalence, and the blue line represents the regression model, with a 95% confidence interval. Karonga District Hospital is the main government secondary facility, Mzuzu Central Hospital is the tertiary facility.

Figure 3 Scatterplot illustrating the relationship between community household-reported and GIS-estimated travel time to reach the preferred facilities. The dotted line represents equivalence, and the blue line represents the regression model, with a 95% confidence interval (shaded area adjacent to line).

Figure 4 Boxplot for the relationship between categorised patient-reported and GIS-estimated travel time for patients with an injury (categories with >3 cases shown)

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Tables

Table 1 Number and proportion of HDSS households travel time categories according to GIS methodology by facility type

Intervals in hours	<1h	1-2h	2-4h	4-6h	6-12h	12-24h	>24h
Any primary facility	9674 (94.0%)	614 (6.0%)	0	0	0	0	0
The main primary facility (Chilumba Rural Hospital)	6679 (64.9%)	2359 (22.9%)	1250 (12.2%)	0	0	0	0
Any secondary facility	2898 (28.2%)	5232 (50.9%)	2144 (20.8%)	14 (0.16%)	0	0	0
The main government secondary facility (Karonga District Hospital)	0	2109 (20.5%)	7297 (70.9%)	882 (8.6%)	0	0	0
The tertiary facility (Mzuzu Central Hospital)	0	0	2836 (27.6%)	6620 (64.3%)	832 (8.1%)	0	0
N= 10,288							

Table 2 Regression models comparing household participant reported estimates of travel time to facilities with the GIS-estimated travel time

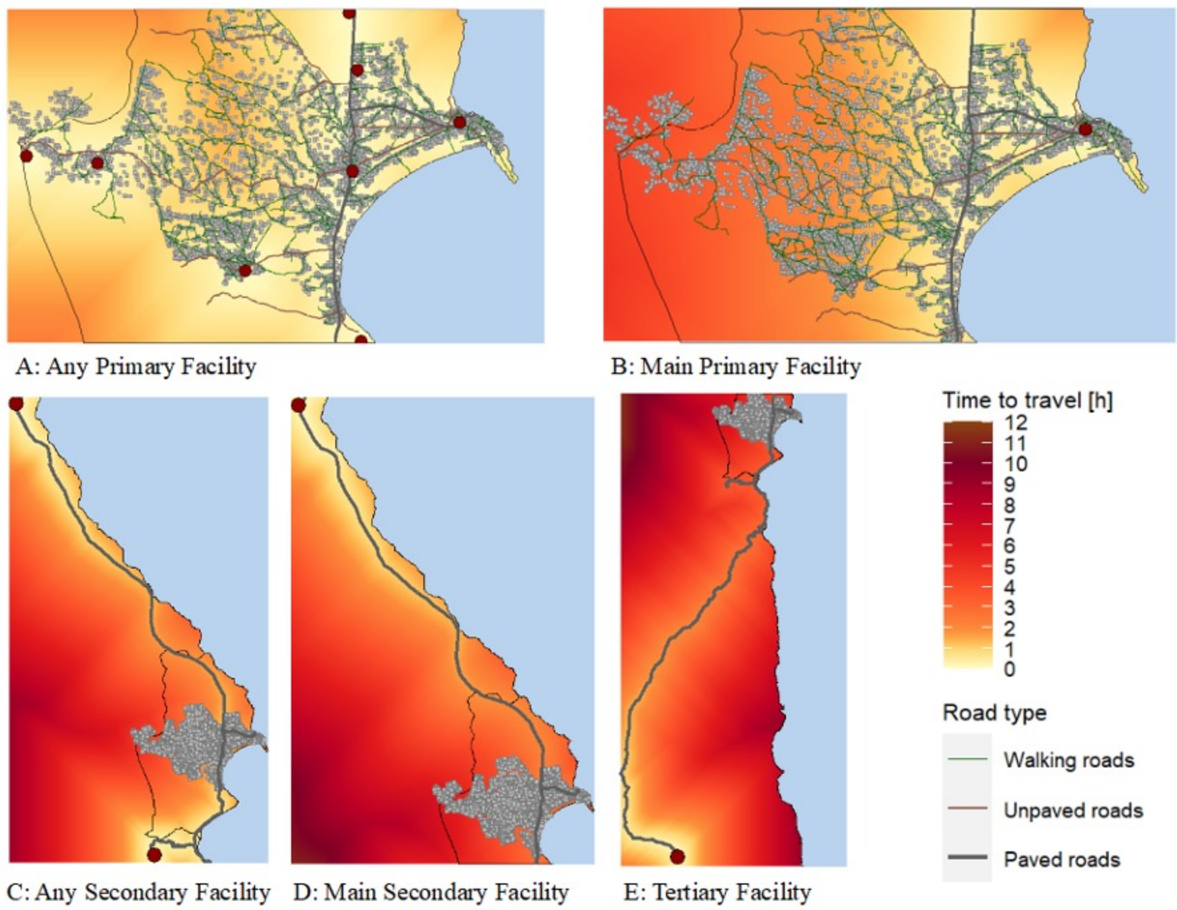
Facility	β	95% CI	Outliers excluded
Closest	1.25	1.21 - 1.30	2
Preferred	1.28	1.23 - 1.34	9
Main government secondary facility (Karonga District Hospital)	1.45	1.33 - 1.58	5
Tertiary facility (Mzuzu Central Hospital)	2.12	1.84 - 2.41	3

Table 3 Injured patient-reported and GIS-estimated travel time to the facility in which care was sought according to survey categorical time intervals.

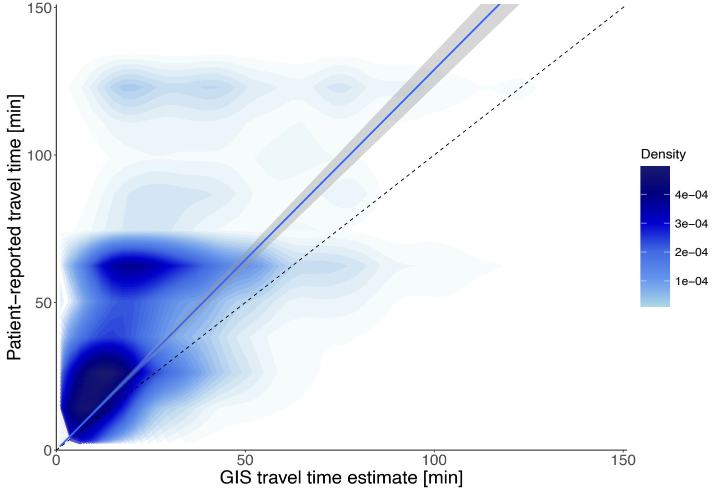
Interval in hours	<1	1-2	2-4	4-6	6-12	12-24	>24	NA
Injured patient-reported travel time	283 (60.9%)	130 (28.0%)	36 (7.7%)	0	1 (0.2%)	2 (0.4%)	3 (0.6%)	10 (2.2%)
GIS-estimated travel time	341 (73.3%)	56 (12.0%)	15 (3.2%)	1 (0.2%)	1 (0.2%)	0	0	51 (11.0%)

Table 4 Weighted Cohen's kappa statistic for comparing categorical GIS-estimated with community household-reported travel time for each of injured patients, preferred facility, closest facility, Main government secondary facility (Karonga District Hospital) and the tertiary facility (Mzuzu Central Hospital).

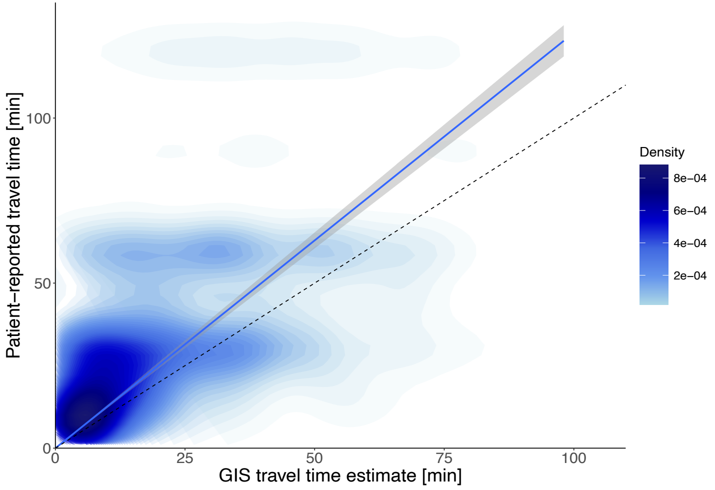
	Weighted Cohen's Kappa	95% CI
Injured patients	0.15	0.078 - 0.23
Household respondent's preferred facility	0.20	0.17 - 0.24
Household respondent's closest facility	0.15	0.11 - 0.19
Main government secondary facility (Karonga District Hospital)	0.096	0.068 - 0.12
Tertiary facility (Mzuzu Central Hospital)	0.088	0.064 - 0.11



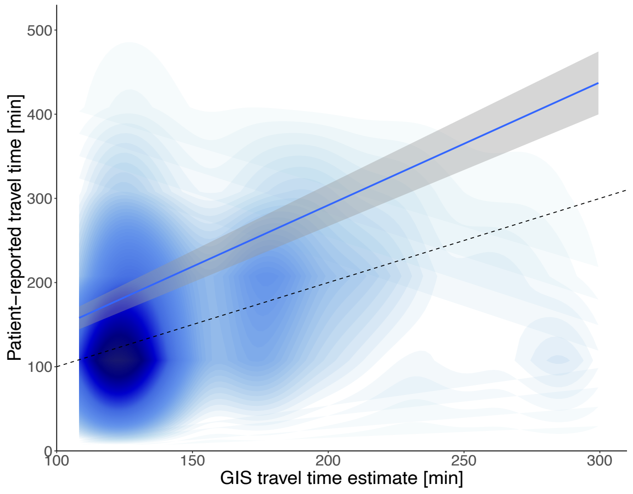
A: Any Primary Facility
B: Main Primary Facility
C: Any Secondary Facility
D: Main Secondary Facility
E: Tertiary Facility
Time to travel [h]
12
11
10
9
8
7
6
5
4
3
2
1
0
Road type
Walking roads
Unpaved roads
Paved roads



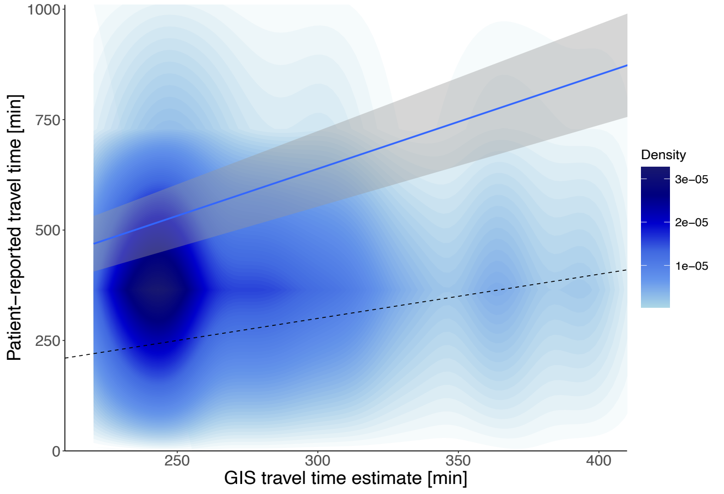
A. Preferred Facility



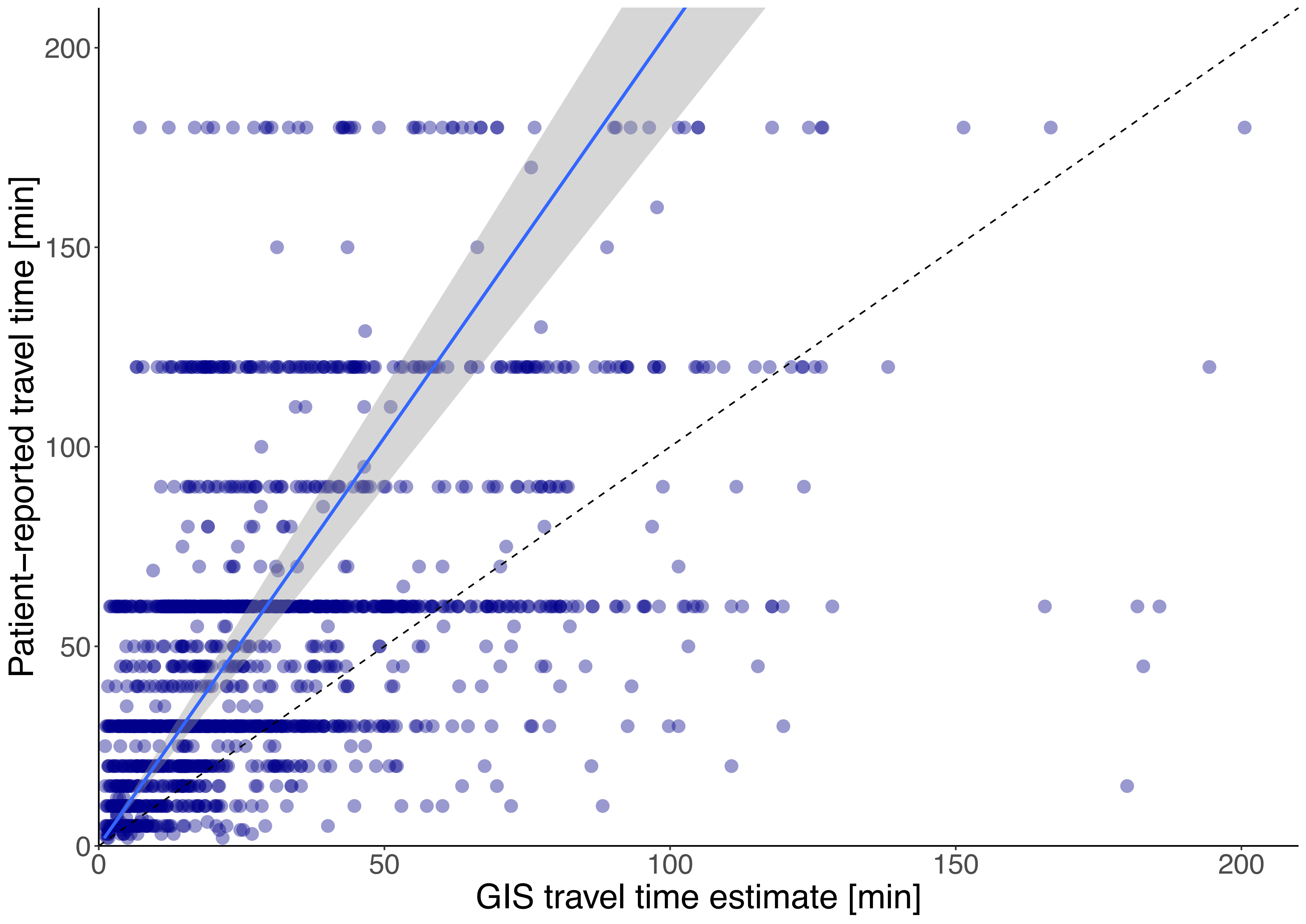
B. Closest Facility



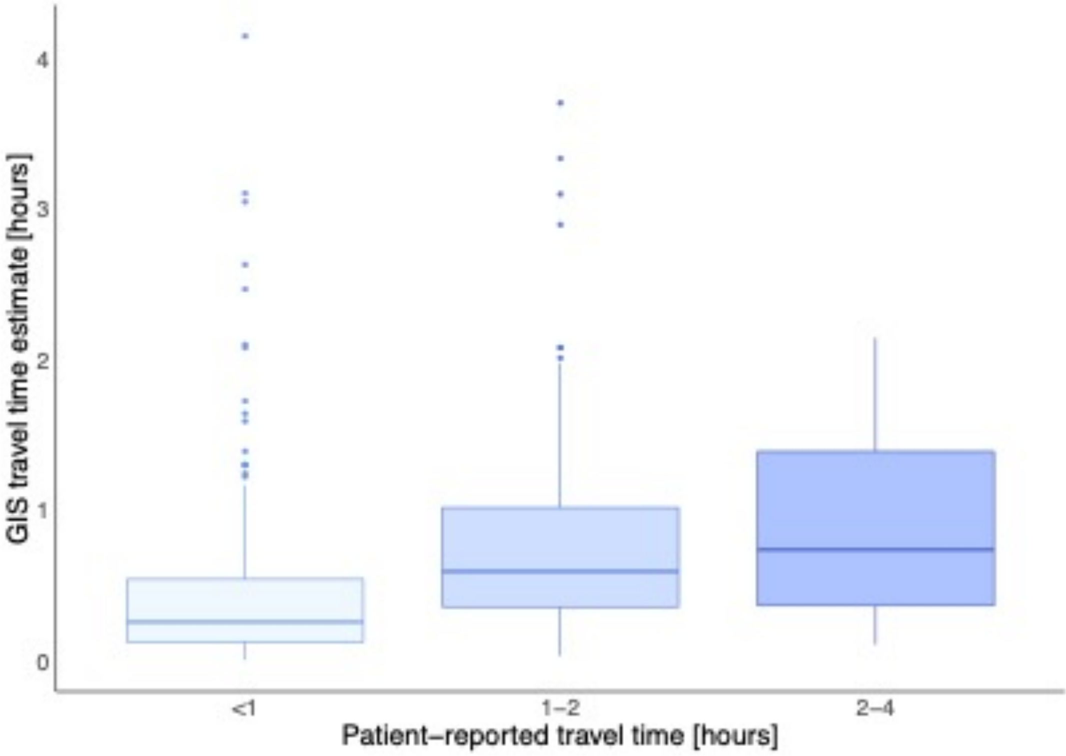
D. Karonga District Hospital



E. Mzuzu Central Hospital



Patient-reported travel time [min]
0
50
100
150
200
GIS travel time estimate [min]



GIS travel time estimate [hours]
0
1
2
3
4
<1
1–2
2–4
Patient–reported travel time [hours]