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Accessibility of TB diagnostic services at primary healthcare clinics in the eThekwini district, South Africa: a geospatial analysis

Thobeka Dlangalala ,[1] Alfred Musekiwa ,[1] David Mckelly,[2] Ethel Baloyi,[3] Tivani Phosa Mashamba-Thompson[1,4]

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[1]School of Health Systems and Public Health, Faculty of Health Sciences University of Pretoria Private Bag, Pretoria, South Africa
[2]CSIR, Cape Town, Inclusive Smart Settlements and Regions (ISSR) Central, South Africa
[3]Ekurhuleni Metropolitan Municipality, Germiston, Gauteng, South Africa
[4]Faculty of Health Sciences University of Pretoria, Pretoria, South Africa

Correspondence to
Dr Thobeka Dlangalala; u10225120@tuks.co.za

ABSTRACT

Background Improving geographic access can aid in managing tuberculosis (TB) by enabling early diagnosis and treatment initiation. Although geospatial techniques have been used to map the transmission patterns of drug-resistant TB in South Africa, fewer studies have investigated the accessibility of TB diagnostic services. This study evaluated the accessibility of TB diagnostic services and disease distribution in the eThekwini district of South Africa.

Methods In this cross-sectional study, population data for 2021 were disaggregated into smaller analysis units and then re-aggregated through the dasymetric mapping technique. Data on notified TB patients, including Global Positioning System coordinates of clinics, were obtained from the District of Health Information System, exported to ArcGIS 10.8.2 and used to calculate distances to the nearest clinics and hospitals.

Results 92% of the population (3 730 494 people) in eThekwini could access TB diagnostic services within 5 km. Patients travelled an average distance of 4.7 km (range: 0.1–26.9 km). TB diagnostic services were highly accessible in the Northern and Central regions and moderately accessible in the predominately rural Western and Southern regions. The smallest population of eThekwini resides in rural areas; however, 40.7% of its residents live >5 km from a diagnosing facility, with patients in the South having to travel up to 44.5 km. TB incidence was higher in the predominately rural West and South regions compared with the Central and North regions which are mainly comprised of urban and suburban areas. Our findings also showed that 98.4% of the clinics in eThekwini were located within 30 km of a hospital at an average distance of 9.6 km within the district. However, the distribution of these hospitals does not demonstrate equitable access as the majority are located within the Central region, and fewer are found in the other three regions of eThekwini.

Conclusions Addressing the disparities in access to TB diagnostic services is required in the eThekwini district. Leveraging the existing mobile health clinics can assist with this, particularly, in rural areas with inadequate access. Additionally, active-case finding should be intensified in these regions since they had a higher TB burden per population. Prioritising interventions in these areas is crucial for reducing the impact of the disease on affected communities.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ The study used dasymetric mapping to map accessibility which accounts for the spatial heterogeneity of the population and the geographic area allowing for realistic distance estimates.
⇒ The study employed numerous data sources including healthcare facility location, population and tuberculosis (TB) data to provide a holistic view of the accessibility of TB diagnostic services in light of the TB burden across the region.
⇒ The distance estimations in the study assume that patients will use facilities closest to them when in fact several other factors can influence patient-seeking behaviours.
⇒ The study assessed potential accessibility which accounts for distance and availability of healthcare services and did not consider revealed accessibility which assesses the utilisation of these services.
⇒ The study evaluated accessibility of TB diagnostic services based only on distance and did not consider travel time.

BACKGROUND

Tuberculosis (TB) is the leading cause of death by an infectious agent in low-income and middle-income countries (LMICs).[1] This is concerning given that TB is preventable and treatable, with an 85% treatment success rate following a 6-month drug regimen.[2] A major driver of the epidemic is the number of people who become infected but are never diagnosed.[3] Typically, 3 million are 'missed' annually by national TB programmes[1]; this number is largely from LMICs where underdiagnosis is partly due to financial and geographic barriers impeding access to healthcare.[4] These barriers became more pronounced during the COVID-19 period.[5–7] This has further widened the TB diagnostic gap and increased the number of TB deaths for the first time in over a decade.[2] These knock-on effects of COVID-19 will likely

continue in the years to come.[8 9] Strengthening TB services in a post-COVID-19 world should evaluate and address barriers to access.

Improving geographic access to healthcare can alleviate the TB burden through early diagnosis and treatment initiation.[4] Studies have linked geographic accessibility to TB outcomes,[10] showing that geographical barriers are associated with delays in seeking care, loss to follow-up and a lack of adherence during TB diagnostic and treatment processes.[11 12] These can prolong periods of infectiousness, leading to ongoing transmission within communities, an increased likelihood of poor clinical prognosis and the development of drug resistance among patients.[13] This is especially true for settings with a high HIV coinfection rate like South Africa.[13] Therefore, it is important to investigate access to TB services while also recognising the spatial heterogeneity of the disease to inform effective interventions where they are most needed.[14] This can be established using epidemiological data and geospatial technologies.

In South Africa, spatial analysis has been used to determine the risk factors associated with recurring drug-susceptible TB.[15] However, the bulk of the geospatial research as it relates to TB has been used to understand the occurrence and transmission patterns of extensively drug-resistant (XDR) TB.[13 16–18] Although this is important work, similar studies are also required for drug-susceptible TB which is still pervasive and has increased because of COVID-19-related disruptions to health services.[19] To our knowledge, no studies in South Africa have examined the access to TB services in relation to the population and disease distribution within a high-burden region. Therefore, we aimed to analyse the accessibility of TB diagnostic services at primary healthcare clinics (PHCs) in the eThekwini district of South Africa, in relation to the population and disease distribution. Specifically, we assessed the travel distances from residential areas to PHCs and from PHCs to district hospitals. Additionally, we mapped the spatial distribution of TB within the district. It is anticipated that the results of this study will reveal the level of accessibility of TB diagnostic services, which can guide governance and provision of equitable TB service delivery where they are most needed.

METHODS

Study setting

The study setting was in South Africa's Kwa-Zulu Natal (KZN) province. The province constitutes 11 districts and has the second-largest population in South Africa.[16] eThekwini is the largest district in terms of population and the only metropolitan municipality in KZN.[20] It has, however, the smallest area size of all the districts in the province at a total of 263 952 hectares.[21] The district comprises four municipal planning regions: the North, South, Central and Outer West.[20] The regions are further divided into wards, which amount to 111 in total. As of 2021, its population was estimated at 4 027 660, with the majority residing in the Northern region and the smallest group living in the Outer West region. There are 123 PHCs within the district, including community health centres offering primary healthcare services. The district has an additional 28 mobile clinics through the North, South and Western regions. These clinics are located in underserved areas where no fixed clinics are available; this includes rural areas and informal settlements.[22] Each mobile clinic serves multiple mobile points, which function as independent standalone clinics.[23] In 2015, the district recorded the highest incidence of TB in the country, at 24 588 cases.[24]

In South Africa, TB diagnostic services are primarily accessed through the public health sector at PHCs.[25] TB diagnosis usually occurs through passive case finding where patients who present to clinics with symptoms are screened and have their sputum tested using Xpert MTB/RIF (Cepheid, Sunnyvale, CA). Sputum collection occurs on-site but samples are sent for analysis at district hospitals, where Xpert MTB/RIF machines are located.[25] Once diagnosis is confirmed, treatment is initiated. Individuals requiring further investigation or exhibiting complications are referred to hospitals.[26] Referral to hospitals generally occurs among those with 'undetected' who often present to clinics with complex disease and other comorbidities.[27] However, if diagnosis and treatment initiation occur at a hospital, continuation and treatment completion are facilitated at PHCs. Since PHCs serve as the patient's first point of contact with formal healthcare, this study used distances to PHCs to measure the geographic accessibility of TB diagnostic services. Distances from PHCs to hospitals are also considered in the analysis because they act as entry points for referrals.

Study design

A descriptive cross-sectional study assessed the geographic accessibility of TB diagnostic services for 2021. The study helped reveal the size of the problem (access to TB diagnostic services) at a given time.

Data sources and manipulation

Global Positioning System coordinates for all the health facilities were provided by the KZN Department of Health, and any missing coordinates were obtained from Google Maps. Population data for the eThekwini district was provided by Stats SA using a community survey from 2021. The spatial road network and the municipal boundaries of the eThekwini district were obtained from the Council for Scientific and Industrial Research (CSIR). Additionally, to get more precise analysis outputs, the municipal boundaries were divided into smaller analysis units of 20-hectare hexagons, which give more precise analysis outputs and better distance estimates.[28] Each hexagon was populated with 2021 population data by calculating the population-weighted centroid based on the population distribution using dasymetric mapping. TB confirmation data for 2021 was obtained from the District of Health Information System. This data is

collected monthly from primary healthcare facilities by designated data capturers and reported to the district. These data were used to calculate the number of notified TB patients per ward (the smallest administrative unit).

Mapping and analysis techniques

The analysis was conducted using ArcGIS 10.8.2 software. The distances were measured using road network distance, which is more accurate than Euclidean distance. The distance is measured from the centroid of each hexagon to the closest health facility using the origin-destination matrix.[29] For distance measurements, the implicit mode of travel was assumed, which states that the shortest physical distance is a function of the mode of travel. It was also assumed that people would likely travel from their residence to the nearest health facility. To visualise the distribution of TB, the aggregated number of notified TB patients was linked to a base map in ArcGIS using the spatial join function. All distances computed were exported onto Excel to calculate means and SD.

Variables and study definitions

Outcome measures

The primary outcome was the travel distance to PHCs offering TB testing services in the eThekwini district. The secondary outcome was the travel distances from PHCs to the nearest hospital. The WHO and South Africa's CSIR have stipulated that populations should be within 5 km of a PHC.[28 30] Therefore, clinics that were <5 km from patients were deemed highly accessible; PHCs with distances between 5 and 10 km were moderately accessible, and >10 km were deemed poorly accessible. The CSIR guidelines further state that PHCs should ideally be situated within 30 km of district hospitals; therefore, distances greater than this were classified as inaccessible.

TB incidence estimation

To determine the TB incidence rate in each municipal planning region, the total number of notified patients was divided by the respective planning region's population and then multiplied by 100 000. This calculation allowed us to estimate the incidence rate per 100 000 people in each region.

Prime corridor

It is a strategically important area or route within a city or a region that plays a significant role in transportation, real estate or economic development.

Patient and public involvement

No patients/public were involved in any aspect of this study.

RESULTS

Travel distance analysis of PHCs in the eThekwini district

A total of 123 clinics were included in the analysis of geographic accessibility. The distances patients travelled to the closest diagnostic facility within the different regions of the eThekwini district are depicted in figure 1. The map shows that much of the population had good access to TB diagnostic services with only a few areas exhibiting poor accessibility. The mean distances travelled by patients to diagnostic facilities for each of the planning districts in eThekwini are found in online supplemental table 1. On average, patients visiting eThekwini PHCs travelled 4.7 km (range: 0.1–26.9 km). The Central and Northern regions were highly accessible, with average distances of 2.6 km (range: 0–13.9 km) and 4.5 km (range: 0.1–26.2 km), respectively. The Southern and Western regions were considered moderately accessible, with mean distances of 5.2 km (range: 0–44.5 km) and 6.2 km (range: 0–23.2 km), respectively. However, it is worth noting that patients from all four regions could travel maximum distances beyond the recommended 5 km to access diagnostic facilities. Patients from the South region residing furthest from PHCs could travel up to 44.5 km.

Table 1 describes the accessibility to TB diagnostic services per planning region and level of urbanisation, respectively, while the visual representation of these data is found in figure 2. Approximately 92.6% (3 730 494 people) of the population could access a TB diagnostic service within the required travel distance standard of 5 km and thus were considered well served. The remaining 7.4% (294 572 people) could access a TB diagnostic services facility beyond 5 km (table 1). The Central, Northern and Southern regions had ≥98% of the population residing within 5 km of a PHC (figure 2A; table 1A). These regions also constitute the district's built-up areas, including the prime corridor, and urban and suburban areas where most of the population resides. On the other hand, the West and Southern regions are primarily rural in their geographic make-up (figure 2B). This is also where most of the underserved population resides, constituting 4.4% of the total population and 59.5% of the underserved population (figure 2B; table 1B).

Distribution of notified TB patients in eThekwini District

The distribution of notified TB patients within the eThekwini district in the year 2021 is depicted in figure 3. An incidence rate of 250 notified patients per 100 000 people was calculated for 2021. The densely populated Central region had the lowest TB incidence, totaling 140 notified patients per 100 000 people. The Northern region followed closely with 253 notified patients per 100 000 people. The Southern region reported an incidence of 286 notified patients per 100 000 while the sparsely populated Western region had the highest incidence with 441 notified TB patients per 100 000 people. Most of the population in the Northern and Central regions had good access to TB diagnostic services. The Western region and Southern regions had moderate levels of accessibility but also had the highest number of notified TB patients within the district. However, these were concentrated in urban and suburban areas, and fewer patients were in rural areas. Furthermore, online supplemental table 1

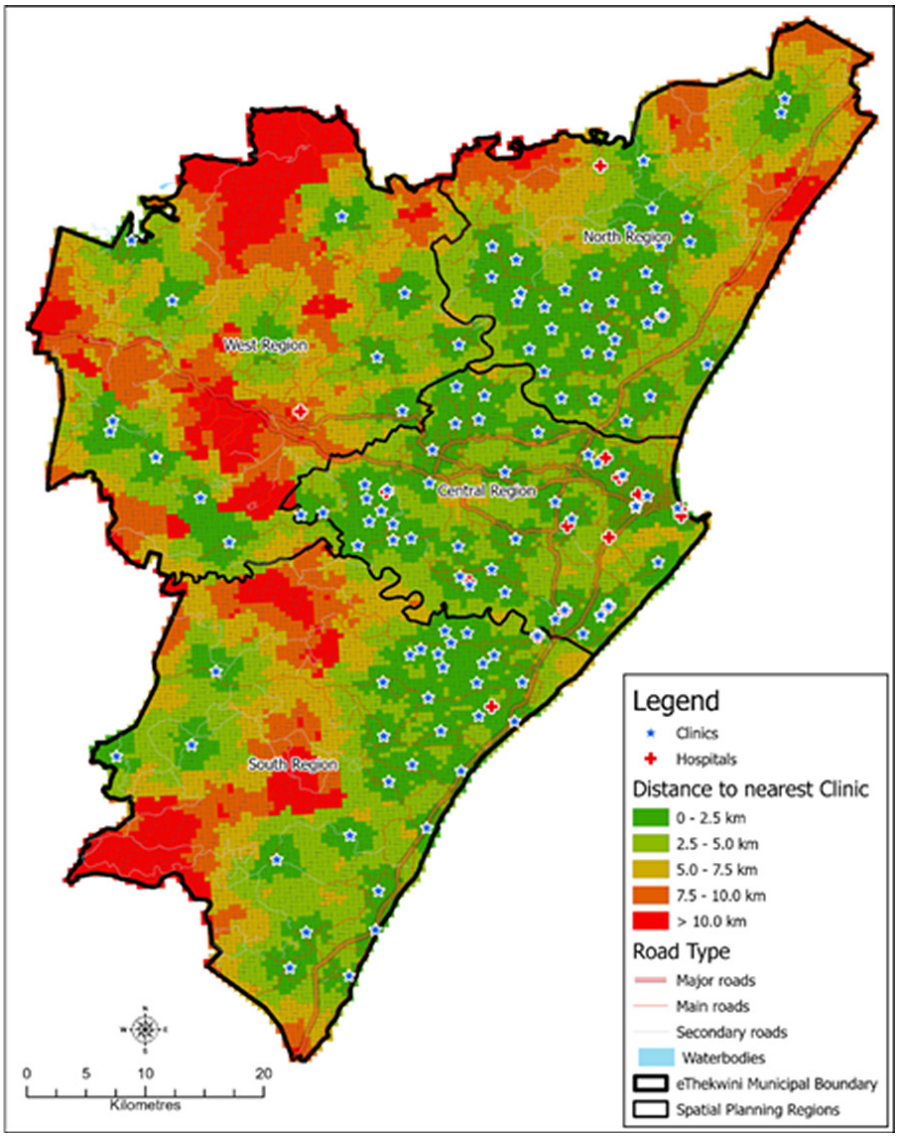

Figure 1 Travel distances to TB diagnostic service facilities in the eThekwini district. TB, tuberculosis.

shows that patients in the South could travel up to 44.5 km to reach a facility with diagnostic services.

Analysis of distances from PHCs to the nearest hospital

Travel distances from clinics to the nearest hospitals are depicted in figure 4. The average distance from PHCs to hospitals within eThekwini was 9.6 km (SD±7.6 km). A total of 121 clinics (98.4%) were within 30 km of a hospital. 80 clinics (65%) were situated within 10 km of hospitals, 28 (22.7%) were situated within 10.1–20 km, 12 (9.6%) were located between 20.1 and 30 km and only two (1.6%) were outside a 30 km radius from a local hospital. Most hospitals are concentrated in the Central region, and fewer are found in the three regions of eThekwini.

DISCUSSION

Our research evaluated the accessibility of TB diagnostic services at PHCs in the eThekwini district. The results showed that TB diagnostic services were accessible to most (92.6%) of the population. Of the 7.4% of the population that fell outside a 5 km radius of a clinic, 59.5% resided in rural areas. On average, the population in eThekwini had to travel 4.8 km to access TB diagnostic services. Moreover, the Central and Northern regions were highly accessible, while the Southern and Western regions experienced moderate accessibility, respectively. However, patients from all regions could travel distances longer than 5 km to reach a diagnostic facility, with distances in the Southern region reaching up to 44.5 km. TB incidence was higher in the rural areas compared with urban and suburban counterparts. Our analysis also revealed that 98.4% of clinics were <30 km from a hospital at an average distance of 9.6 km (SD±7.6 km). However, these hospitals are not spatially distributed, with many being in the Central region of the eThekwini district.

Geographic accessibility to healthcare services can significantly impact the health outcomes of a population. For TB, limited access to diagnostic facilities can worsen

Table 1 Accessibility of diagnostic services per region and density corridor within the eThekwini district

Accessibility and population data per planning region					
Planning regions	**Population per planning region (2021)**	**Population ≤5 km from clinic**	**%Population ≤5 km from a clinic**	**Population ≥5 km from a clinic**	**%Population ≥5 km from a clinic**
Central	1 246 322	1 214 392	30.2%	31 930	0.8%
North	1 340 765	1 269 623	31.5%	71 148	1.8%
South	992 601	935 849	23.2%	56 752	1.4%
West	447 973	310 631	7.6%	137 342	3.4%
Total	4 027 660	3 730 494	92.6%	294 572	7.4%
Accessibility and population data per level of urbanisation					
Level of urbanisation	**Population density (2021)**	**Population ≤5 km from clinic**	**%Population ≤5 km from a clinic**	**Population ≥5 km from a clinic**	**%Population ≥5 km from a clinic**
Prime corridor	902 728	889 913	22.10%	12 815	1.4%
Rural	431 689	255 701	6.3%	175 988	40.7%
Suburban	1 550 235	1 454 265	36.1%	95 970	6.1%
Urban	1 143 006	1 130 612	28.0%	12 394	1.1%
Total	4 027 660	3 730 494	92.6%	297 165	7.4%

disease progression and increase community transmission.[13] Our findings showed that 92.6% of the eThekwini population had good access to TB diagnostic services, enabling them to reach a facility within 5 km. Nevertheless, access remains a challenge in rural areas. Patients from the predominately rural Western and Southern regions had moderate access (5–10 km) to TB diagnostic services. These patients could travel up 23.2 and 44.5 km to reach a respective diagnosing facility. A Ghanaian study reported similar findings, showing that 81.4% of its population lived within 5 km of a PHC, travelling an average of 4.7 km to reach these facilities. However, access was

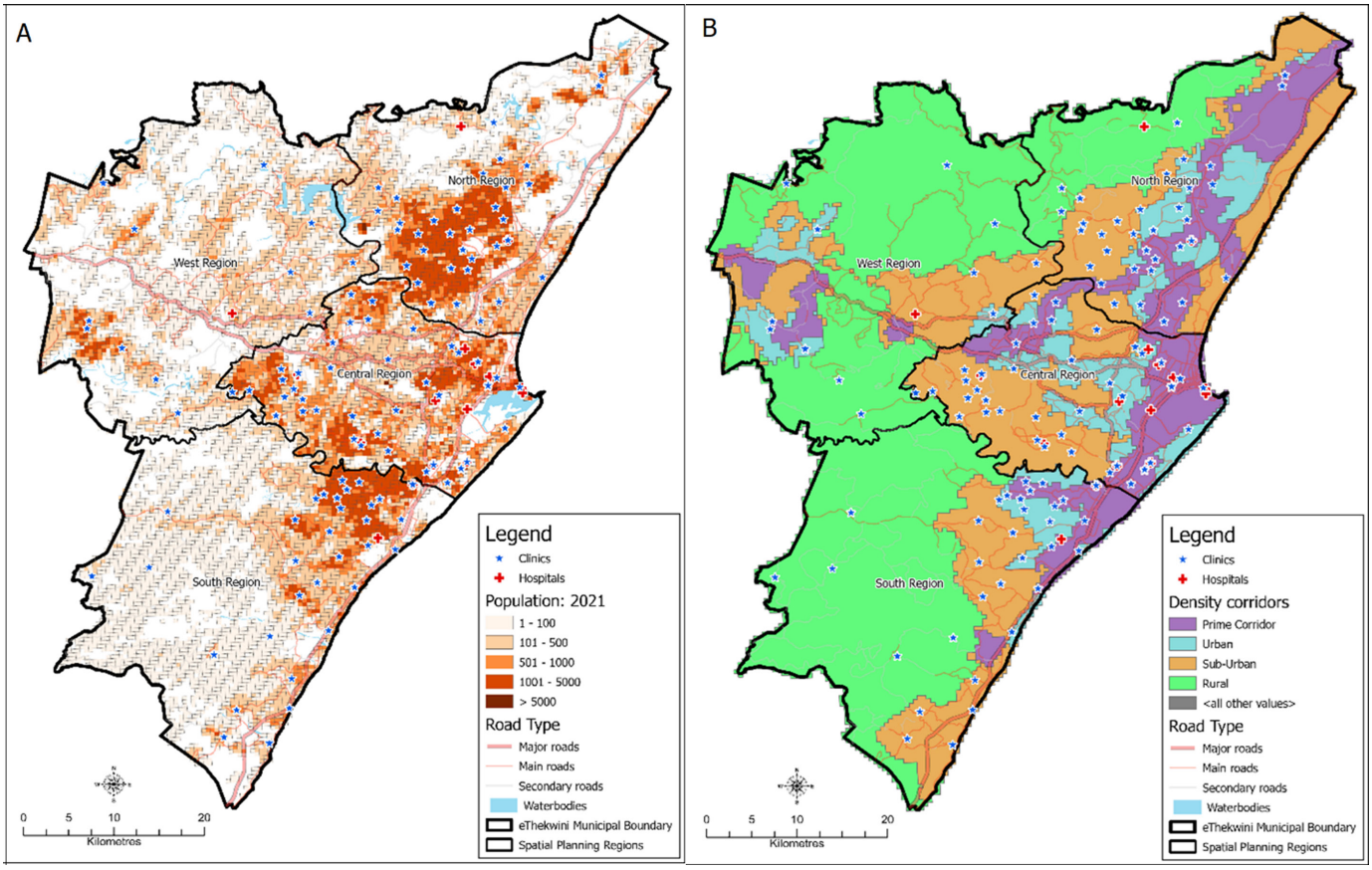

Figure 2 Population distribution and level of urbanisation within the eThekwini district in 2021.

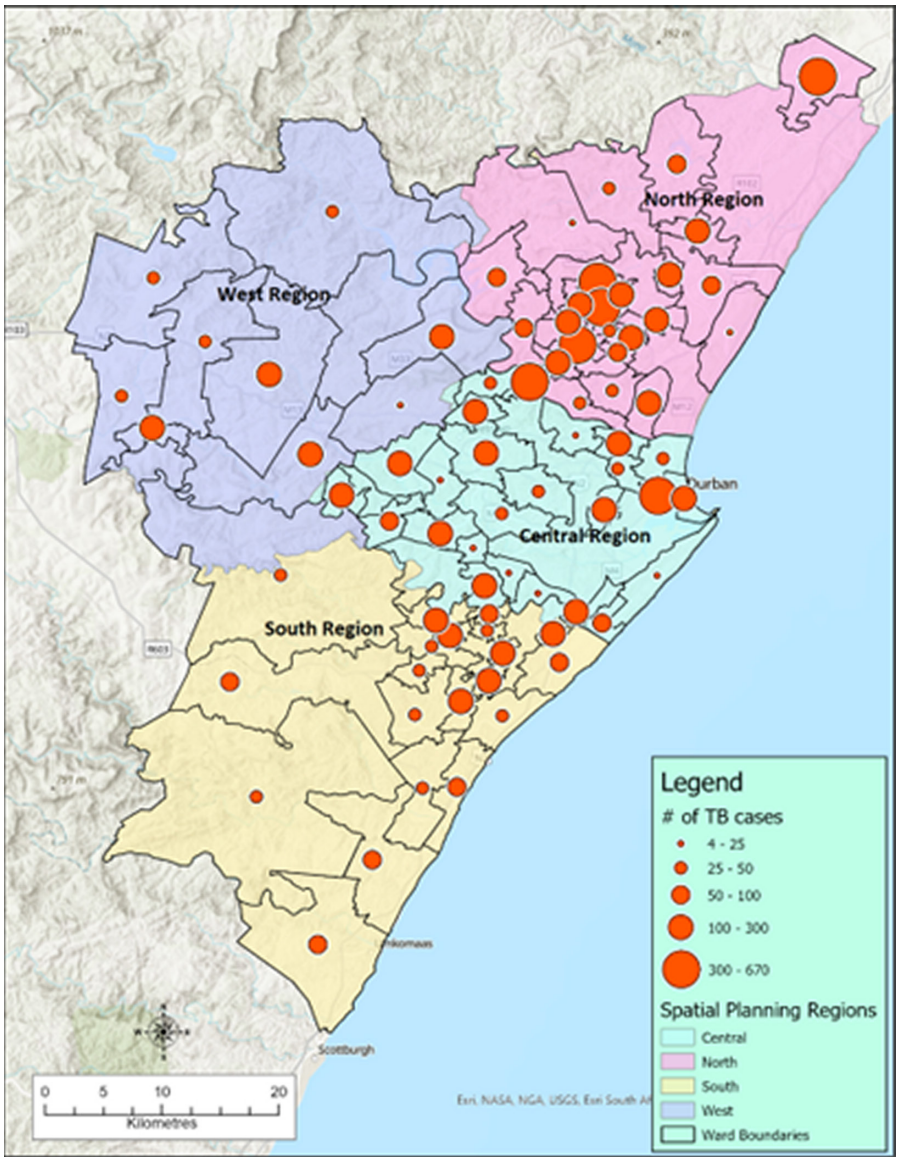

Figure 3 Notified TB patients within the eThekwini district per planning region in 2021. TB, tuberculosis.

still an issue in remote areas.[31] Limited healthcare accessibility for rural communities has been widely reported in LMICs.[32–34] A scoping review mapping the effect of geographic accessibility on infectious diseases found that lower levels of accessibility were associated with a higher disease burden and poorer health outcomes in remote regions.[34] Therefore, it is important to investigate access and the disease burden to ensure optimised healthcare services provision.

This study evaluated TB distribution in the eThekwini district and found a higher incidence in predominantly rural South and West regions. The moderate accessibility to diagnostic services in both regions and the fact that a majority (56.6%) of the underserved population resides in rural areas are particularly concerning. Rural communities are often susceptible to poverty and malnutrition, which, when combined with limited access to healthcare, can exacerbate the risk of contracting TB.[35 36] Although distance from health facilities likely influenced the higher incidence of TB in rural regions, other factors can also affect accessibility.[37] For instance, socioeconomics, job-related time constraints and the perceived quality of services can all hinder access to healthcare services.[10] Therefore, it is crucial to ascertain the significance distance plays in TB health outcomes, particularly, among underserved populations, to inform the provision of appropriate and adequate services.

Our findings also showed that 98.4% of clinics in eThekwini were within the recommended 30 km of a district hospital. However, many of the hospitals in the district are concentrated in the Central region. The post-apartheid South African government has worked hard to ensure equitable access to healthcare by providing healthcare free of charge and expanding PHCs.[38 39] The placement of district hospitals in eThekwini reveals the enduring effects of apartheid. Hospitals are mainly situated in areas where privileged individuals reside, while fewer are present in remote regions where people experiencing

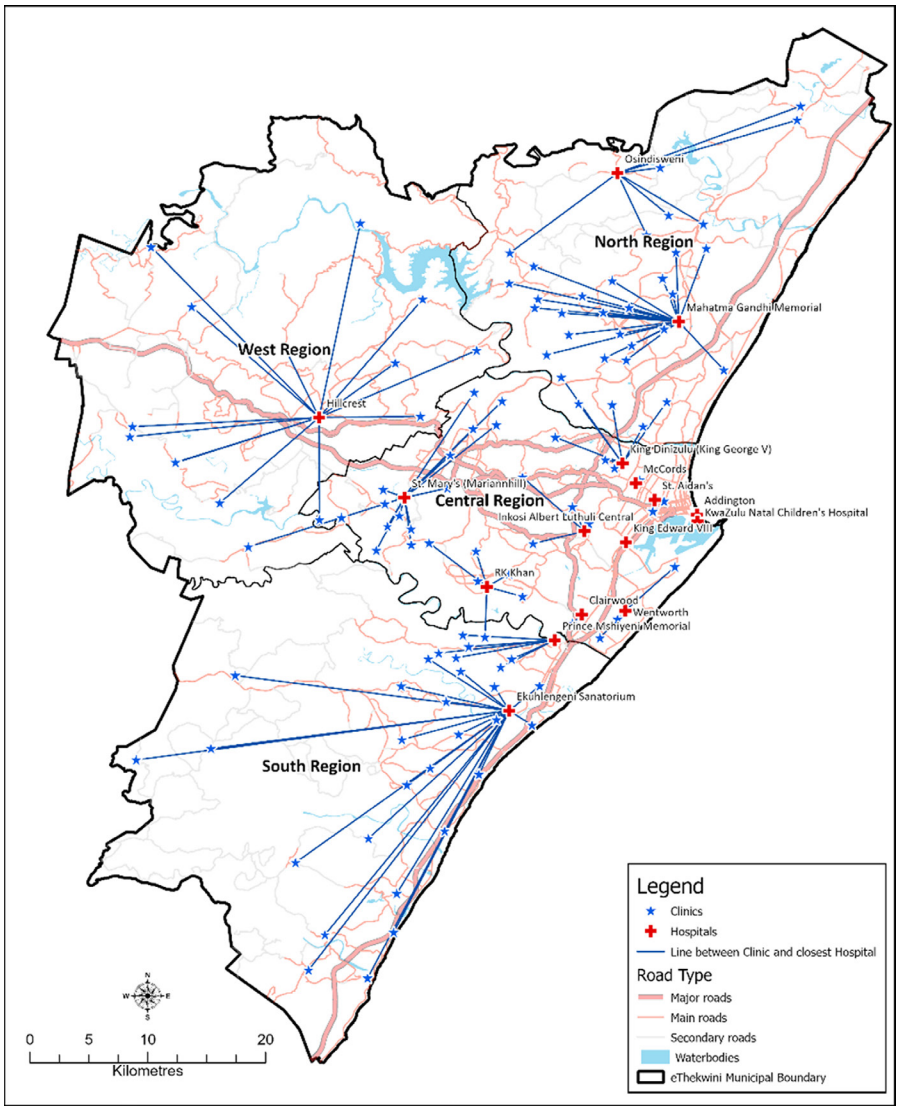

Figure 4 Travel distances between PHCs and hospitals in the eThekwini district. PHCs, primary healthcare clinics.

poverty still live. This distribution does not reflect the current population needs. Although PHCs offer initial contact for TB diagnosis, district hospitals act as referral points for patients requiring further investigation or exhibiting complications that require emergency care.[26] Moreover, patients with drug-resistant forms of TB receive treatment at district hospitals. As such, district hospitals like PHCs must be easily accessible to promote continuity of TB care. A study from India has linked distances longer than 7 km to delays in initiating treatment following diagnosis.[12] Other studies from Uganda and South Africa found that distance to treatment facilities was associated with unfavourable treatment outcomes.[10 40] It is imperative to conduct an assessment of the present hospital distribution and its impact on patient outcomes. Achieving equitable access to hospitals within the eThekwini district can contribute significantly to TB management by mitigating diagnostic delays, improving patient retention in care and reducing the financial burden of travelling to healthcare facilities.

The eThekwini district has mobile health clinics that provide TB services to remote communities. These mobile units offer comparable TB services to PHCs; however, they are only accessible to the communities on specific days. Based on our findings, we recommend that mobile clinics at rural locations be deployed according to the population distribution and the travel distance guidelines provided by the CSIR.[28] Furthermore, the quality of care of mobile health units and PHCs should be continuously assessed and improved. Improving geographic access and utilisation of services would be futile without ensuring high-quality care. eThekwini has started active case finding for asymptomatic high-risk groups. This is especially important in light of the COVID-19 pandemic which has not only increased the risk factors for developing TB but also the number of undiagnosed cases. Further studies are required to determine the relationship between distance to health facilities and the health outcomes of underserved populations. The exploration of these outcomes should not only be limited to TB

since PHCs assess and manage several other conditions including HIV services, perinatal care, child health and non-communicable diseases. Based on those findings, the government should consider upgrading existing PHCs to hospitals and introducing more clinics. This could assist with increasing emergency care in these regions for all health conditions treated at PHCs including TB.

While the study highlights the geographic accessibility of TB diagnostic services in PHCs in the eThekwini district, there were several limitations to the current research. First, geographic accessibility was measured using distance and did not consider travel time which accounts for road networks, traffic and geographic terrains. However, since travel times depend on different modes of transportation, distance allowed for a consistent measurement of accessibility. Moreover, using dasymetric mapping attempts to rectify some of the shortcomings associated with traditional distance measurements by using population distribution to measure distance thus excluding unhabitable areas. The study assumed that patients will use facilities closest to them; however, stigma, convenience due to work and perception of better quality of service elsewhere can influence seeking care further from home. Moreover, the study only reveals potential accessibility which assesses the availability and distance of the services but did not consider the revealed accessibility which considers the patients' utilisation patterns. Therefore, there may be discrepancies between the theoretical access and the actual utilisation of these services.

Conclusion

Geographic information system technology is a powerful tool that can reveal healthcare access and inform the development of equitable solutions. In our study, the eThekwini district had high accessibility to TB diagnostic services at PHCs. However, access remains a problem in some remote regions. This also was true for the location of hospitals within the region. The evidence shows a higher TB incidence in rural regions compared with urban and suburban regions, which is likely linked to the limitations in access. In order to continue making progress toward the elimination of TB, it is important to address the issues related to accessibility. While active case-finding and mobile clinics can be used in the short term, conducting studies on the impact of distance on TB outcomes in the district can help determine whether permanent solutions such as expanding clinics and district hospitals would be beneficial.

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Contributors TD and TPM-T conceptualised the study. DM conducted the mapping and analysis. TD under the guidance of EB wrote the first draft. AM and TPM-T critically reviewed the manuscript. All authors have read and approved the final manuscript. TD is responsible for the overall content (as guarantor).

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This research was reviewed and approved by the University of Pretoria's Faculty of Health Sciences Research Ethics Committee, reference number 652/2021, and the Health Research and Management unit of the KZN Department of Health (Ref No. KZ_202112_012).

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ORCID iDs
Thobeka Dlangalala http://orcid.org/0000-0003-1331-4247
Alfred Musekiwa http://orcid.org/0000-0001-5880-3680

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Supplementary file 1

Table 1 Travel Distance Statistics per Planning District of eThekwini District

Spatial Planning Region	Average distance (km) to Clinic	MIN distance (km) to Clinic	MAX distance (km) to Clinic
Central	2.6	0.0	13.9
North	4.5	0.1	26.2
South	5.3	0.0	44.5
West	6.7	0.0	23.2
eThekwini	4.8	0.1	26.9