Associating socioeconomic factors with access to public healthcare facilities using geographically weighted regression in the city of Tshwane, South Africa

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Abstract

Access to healthcare is influenced by various socioeconomic factors such as income, population group, educational attainment and health insurance. This study used Geographically Weighted Regression (GWR) to investigate spatial variations in the association between socioeconomic factors and access to public healthcare facilities in the City of Tshwane, South Africa based on data from the Gauteng City-Region Observatory Quality of Life Survey (2020/2021). Socioeconomic predictors included population group, income, health insurance status and health satisfaction. The GWR model revealed that all socioeconomic factors combined explained the variation in access to healthcare facilities (R^2=0.77). Deviance residuals, ranging from -2.67 to 1.83, demonstrated a good model fit, indicating the robustness of the GWR model in predicting access to healthcare facilities. Black African, low-income and uninsured populations had each a relatively strong association with access to healthcare facilities (R^2=0.65). Additionally, spatial patterns revealed that socioeconomic relationships with access to health care facilities are not homogeneous, with significance of the relationships varying with space. This study highlights the need for a spatially nuanced approach to improving healthcare facilities access and emphasizes the need for targeted policy interventions that address local socio-environmental conditions.

Introduction

Primary healthcare, according the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), aims to address people's health needs and preferences across the continuum from prevention to palliative care, emphasizing a whole of society approach for optimal wellbeing and equitable distribution (https://iris.who.int/handle/10665/328065). In South Africa, where disparities in healthcare access persist, understanding how socioeconomic and geographic factors influence access is critical. Healthcare access is a multi-dimensional concept, encompassing factors like availability, acceptability, accommodation, affordability and timeliness. Among these, geographic accessibility remains a significant challenge for achieving universal health coverage, as the dynamic needs of the population often contrast with the fixed locations of healthcare providers (Groenewegen *et al.*, 2021; Moturi *et al.*, 2022). Spatial factors, such as the distance to healthcare facilities and the capacity of healthcare centres, pose barriers to access, while non-spatial factors, including affordability, acceptability and patient demographics, address the financial, cultural, and individual characteristics of healthcare delivery (Kiani

et al., 2021; Raeesi *et al.*, 2023). Social determinants like education, income and economic status influence individuals' and communities' access to and use of healthcare services. Additionally, cultural norms and perceptions of healthcare shape healthcare-seeking behaviours. Those with lower socioeconomic status and limited education often receive lower-quality care compared to individuals with higher incomes and better education, leading to disparities in treatment (Tuczyńska *et al.*, 2022; Shobichah *et al.*, 2023). International standards recommend that healthcare facilities be located five km or less from the location of demand in order to prevent healthcare disparities (Usman *et al.*, 2022). This, however, may not be realised as access to healthcare can be influenced by various socioeconomic characteristics, such as income level, race/ethnicity, educational attainment and age. For example, Panezai *et al.* (2017) examined gender-based analysis to investigate access to primary healthcare services and associated factors in Pakistan. They found that, due to their greater healthcare demands than men, women accessed primary healthcare services more frequently. Similarly, a study by Bushelle-Edghill *et al.* (2015) in Barbados found an increase of hospitalization by 30.6% for older males and 33.6% for older women. The results point to the need to increase access to primary healthcare, especially for older women.

Cultural affiliation has also been shown to affect primary healthcare accessibility. Bell *et al.* (2013) examined geographical access to primary healthcare in the city of Mississauga, Canada and reported that accessibility was significantly lower for linguistic minorities than the general population. A somewhat similar study conducted in Norway found that undocumented migrant women had limited access to healthcare (Kvammea & Ytrehus, 2015). This was attributed to fear of being reported, financial hardships and limited language proficiency. This problem can also be observed in countries with diverse ethnic composition. For example, Paek and Lim (2012) examined ethnic disparities in healthcare access and health outcomes between Whites and Asian Americans as well as between Asian American subgroups. The study also examined the effects of cultural factors and looked into the moderating effects of health risk behaviours between cultural characteristics and healthcare access and outcome. The findings revealed that Asian Americans and Whites, as well as various Asian American subgroups, experienced significant racial inequalities with regard to healthcare access and health perception. Relationships between cultural characteristics and healthcare access and outcome were modified by health risk behaviours. Findings show that an individual's ethnicity influences access to healthcare, general impression of the health situation and health practices, which consequently constitute significant components that may enhance or worsen the outcome.

Factors such as health insurance are important determinants of healthcare accessibility. Holmes *et al.* (2022) investigated the relationship between adult residents of a vulnerable neighbourhood in central Florida and their access to care and health outcomes. Participants reported insurance to be a barrier to receiving healthcare. That study found that the individual's feature of financing healthcare, such as health insurance coverage and income for out-of-pocket payments, co-occurred frequently and had an impact on the use of health services and health outcomes. Lin *et al.* (2016) studied the methods used by African migrants in Guangzhou to overcome obstacles to receiving health care as well as their perspectives on how to best meet their requirements. African migrants have used a variety of subpar and unsustainable methods to acquire healthcare due to the numerous restrictions they must overcome, including self-medication; leveraging personal ties to doctors; travelling to home countries or to nations that offer English-speaking doctors for medical care; and employing their Chinese friends or partners as interpreters.

It is vital to evaluate how easily accessible healthcare facilities are geographically and to offer suggestions for how to make that accessibility better in line with international best practices (Usman *et al.*, 2022). Geographic Information Systems (GIS), which is used for a spatial analysis of geographical phenomena, has become a popular tool in healthcare settings (Bagheri *et al.*, 2009; Davenhall & Kinabrew, 2012; Fradelos *et al.*, 2014; Shaw & McGuire, 2017; Kitutu *et al.*, 2018; Ramzi & El-Bedawi, 2019). Geographically Weighted Regression (GWR) is a spatial regression model that allows for building local linear models relating predictor and response variables (Brunsdon *et al.*, 1998). The method differs from the standard global regression approach as it recognizes the spatial dependence of social/natural variables and their interrelationship (Fotheringham *et al.*, 2002; Brunsdon *et al.*, 1996). The method enables the estimation of parameters for each point in space as opposed to the fitting of a generic trend parameter. Thus, GWR examines whether and how geographical differences affect relationships between response and predictor factors (Brunsdon *et al.*, 1996; Comber *et al.*, 2023) and generates variable regression coefficients, together with the statistical inference that goes along with them, to offer measures of spatial variation in data relationships (Comber *et al.*, 2023).

GWR has found a wide-ranging application in healthcare service characterization. For example, Wang and Wu (2020) used GWR to look into how infant mortality rates varied geographically in connection to economic and healthcare parameters. The GWR showed geographical variation in the relationships between infant mortality rates and factors related to the economy and healthcare. Shen and Tao (2022) used GWR to identify enabling factors in the associations of spatial accessibility to medical facilities and socio-institutional factors with individuals' health-seeking behaviour in Shanghai, China. The findings indicated that participants could readily access hospitals of various grades and metro stations if they lived in the central city area. While the effect of access to a general hospital was minimal, easy access to a community hospital was significantly connected with getting professional care at a medical facility (Shen and Tao, 2022). Shen *et al.* (2023) investigated the use of medical services in remote areas of western China and found spatial disparities in the service capacity of township healthcare centres through GWR analysis. Similarly, Marwal and Silva (2024) explored inequities in service accessibility in Delhi using GWR, revealing that accessibility at the neighbourhood level is primarily influenced by spatial location rather than income or the percentage of scheduled caste populations.

In the context of South Africa, the socioeconomic status of the population and other related factors and their influence on access to healthcare have not received enough attention at local level. This paper aimed to determine how socioeconomic factors, such as income, education, and population group, and other related factors are associated with access to public healthcare facilities at the local level in the City of Tshwane, South Africa. Published studies often focus on global or regional contexts resulting in a lack of emphasis on local-level disparities within South Africa. This study addresses these gaps by examining the relationship between selected socioeconomic factors and access to public healthcare facilities using GWR and local bivariate relationship to quantify the association between socioeconomic factors and access to public healthcare

facilities and thus capture the spatial variations in these relationships across different regions.

Materials and Methods

Data

The present paper builds upon the previous work by Moeti *et al.* (2023) which utilized data from the Gauteng City-Region Observatory's 6th quality of life survey covering the years 2020-2021 (https://gcro.ac.za/research/project/detail/quality-life-survey-vi-202021/) to investigate factors associated with access to public healthcare facilities in the City of Tshwane, South Africa. This survey, which is carried out every two years among randomly chosen people in the Gauteng region of South Africa, is representative at the municipality subdivision (ward) level (Hamann & de Kadt, 2021). Using data from the province-level database, benchmarking was used to modify design weights to the most recent GeoTerra Image (https://geoterraimage.com/) 2021 population predictions for the City of Tshwane (Neethling, 2021).

The explanatory variables included the number of people in different socioeconomic and related categories these were sex, population group (Black African or other), age (youth (18–34) or adult (35–65+), monthly income A for lower (Rand 1–3,200) or B for higher (Rand ≥3,201), health status (poor or good), health service satisfaction (satisfied or dissatisfied) and length of stay in the same neighbourhood (<10 years or >10 years). Only the groups female sex, Black African population group, young age, low income, high income, poor health, and health service satisfaction had sufficient variations to produce a successful GWR model.

Although, the National Youth Policies of 2009, 2015 and 2030 define young people as those aged 14–35 years (South African Government, 2021), the age variable the category 'Youth' was defined as 18–34. Additionally, 35 was placed in the 'Adult' category as it was originally grouped with the older age range (35–39) in the original dataset used in this study. The threshold of Rand 3,200 was selected based on the distribution of income categories in the original data, where this range is commonly associated with lower-income individuals, reflecting economic vulnerability or poverty in South Africa. This recoding allowed for a clear distinction between economically disadvantaged groups and those with higher income levels, which is crucial for analysing socioeconomic disparities in healthcare access. Variation was assessed using the GWR model outputs, including coefficients, deviance residuals, and significance levels as well as local bivariate relationships. Variables that demonstrated meaningful spatial variation and significant local relationships were retained to ensure that the GWR model effectively captured spatial differences in access to healthcare. The explanatory variables are summarized in Table 1.

Spatial analysis

Autocorrelation

Global Moran's *I* was applied to examine whether access to public healthcare facilities was dispersed, clustered or random. This technique works by concurrently considering the positions and values of features in the study area (Kianfar & Mesgari, 2022).

GWR

The GWR was used to model the relationship between access to public healthcare facilities and socioeconomic variables and related factors. Access to healthcare facilities, derived from the survey question: 'Are there healthcare facilities you usually use in the area where you live?', with Yes=1, No=0, was the response variable, while the socioeconomic variables mentioned above served as explanatory variables. The people belonging to "Yes" responses were tallied for each ward and therefore represent counts per ward. The boundaries of the wards (polygons) served as the spatial unit when assessing the relationship between socioeconomic factors and access to healthcare facilities.

Given that the response variable is expressed as counts of people with access to healthcare facilities in each ward, it is important to use a model suitable for such data. The mean value of the counts of people with access to healthcare across wards (11.1) was less than the variance (36.7) indicating overdispersion (Poisson distribution) in the data distribution. As a result, the Poisson regression was applied to build the GWR models. The number of neighbours was chosen as the basis of neighbourhood type in the GWR process, since this specification ensures sufficient number of individuals to develop a model within each neighbourhood. The golden search, which finds the ideal neighbourhood automatically, was chosen as selection approach. The GWR modelling was implemented in ArcGIS Pro version 2.9 (ESRI, 2021).

Local bivariate relationship

Local bivariate or multivariate analysis can explore spatially diverse connections among two or more variables. Most local spatial analyses, including GWR, typically presuppose a predetermined relationship pattern, commonly a linear relationship (e.g., High-High and Low-Low associations) or a regression model (Guo, 2010). Local bivariate relationship, which is a non-parametric method, does not assume a prior relationship form, hence it can determine different relationships regardless of their forms (Gou, 2010). In building the local bivariate relationships, access to public healthcare facilities was used as the response variable with the socioeconomic factors as explanatory variables. Depending on how accurately the explanatory variable parameter can predict the response variable, the final result classifies the correlation into one of six relationship types (Yaakub *et al.*, 2022). These types include non-significant relationships indicating that the connection between the variables lacks statistical significance; positive linear relationships indicating that the response variable increases proportionately to the increase in the value of the explanatory variable; negative linear relationships showing the opposite trend in the explanatory and response variables; concave relationships that show a curved pattern in which the trend between the variables is opposite up to a certain value becoming direct after that value; convex relationships showing a direct relationship between the variables up to a certain value and becoming opposite after that value; undefined relationships that indicate a complex link between the variables making it difficult to classify them into any well-defined pattern. All the above analyses were implemented using ArcGIS Pro version 2.9 (ESRI, 2021).

Results

Spatial autocorrelation and GWR

Global Moran's *I* was quantified to determine if there was a spatial pattern in access to public healthcare. The results showed a Moran's $I = 0.31$; Z-score = 9.062 and *p*-value <0.001 (Figure 1) illustrating that access to public healthcare facilities was spatially clustered. GWR modelling resulted in a relatively strong relationship between the observed and predicted number of people who had access to healthcare facilities with an overall R^2 value of 0.77. A look at the relationship between each explanatory variable and the outcome variable is illustrated in Figure 2. The number of Black Africans, low-income earners (Rand 1 – 3,200), and people with no insurance was each related with the number of people having access to healthcare facilities at an R^2 value of 0.65. The relationships were slightly lower when the number of people with access to healthcare was compared with the adult population and with the number of females. The lowest relationship was observed with high-income earners (Rand ≥3,201), number of people with poor health status and with the number of people who were satisfied with the health services.

The GWR model produced deviance residuals that ranged between -2.67 and 1.83 (Figure 3). This shows the goodness of the model in predicting the number of people who had access to healthcare using the socioeconomic explanatory variables considered in the study. Certain locations surrounding Soshanguve, Centurion, Bronkhorstspruit and Pretoria CBD showed high negative residuals, ranging from -2.67 to -1.28. Conversely, high positive deviance residuals (0.74 - 1.83) were noted in Pretoria CBD, Atteridgeville, Bronkhorstspruit and certain areas of Soshanguve and Mamelodi.

Figure 4 shows the spatial distributions of the correlation coefficients of individual explanatory variables in predicting access to healthcare facilities. The results indicate that female contribution to healthcare access was greatest in Mamelodi and some areas in Pretoria CBD, somewhat lower in other parts of Pretoria CBD, certain areas in Hammanskraal and Centurion and regions following

Table 1. Socioeconomic and related variables used as inputs to determine access to healthcare facilities.

Factor	Original categories	Used/Recoded categories
Sex	Male Female	Male Female
Population group	Black African Coloured Indian/Asian White Other	Black African Other
Age	18–19 20–24 25–29 30–34 35–39 40–44 45–49 50–54 55–59 60–64 65+	Youth (18–34) Adult (35–65+)
Income	Rand 1–800 Rand 801–3,200 Rand 3,201–12, 800 Rand 12,801–25,600 Rand 25,601–51,200 >Rand 51,200	Income A or lower income (Rand 1–3,200) Income B or higher income (Rand 3,201 or more)
Health status perception	Excellent Good Poor Very poor	Good Poor
Health service satisfaction	Very Satisfied Satisfied Neither satisfied or dissatisfied Dissatisfied Very dissatisfied	Satisfied Dissatisfied
Length of stay in the same neighbourhood	I have always lived here >10 years 5–10 years 2–4 years 1–2 years <1 year	<10 years ≥10 years

Mamelodi. Black Africans' contribution to access was significant in Mamelodi, parts of Pretoria CBD, Soshanguve and Hammanskraal. Soshanguve, Pretoria CBD and the area towards Bronkhorstspruit had average contributions to access to public healthcare facilities, whereas Atteridgeville, Centurion, Soshanguve and Bronkhorstspruit hadthe least.

Both Youth (18–34 years old) and adults (35–65+ years old) made good contributions to access to public healthcare facilities with both having high contributions in Pretoria CBD, Atteridgeville, Centurion and some areas of Mamelodi, while less contribution by youth was observed in Hammanskraal and Bronkhorstspruit and by adults in Mamelodi and Bronkhorstspruit. Similarily, lower (A) and higher (B) income made equally a favourable overall contribution to access to public healthcare facilities, with the contribution high in Atteridgeville, Centurion, Pretoria CBD, Mamelodi, and Bronkhorstspruit for Income A, however only in Bronkhorstspruit, Cullinan and Mamelodi for Income B. Lack of insurance had a generally detrimental impact on access to public healthcare facilities, but seems to be more prominent in Centurion, Bronkhorstspruit, Pretoria City and Atteridgeville. In Soshanguve, Hammanskraal and Mamelodi, it made a low or moderate contribution. Poor health status had had a high contribution to healthcare access in most of the City of Tshwane, while its contribution was less in Mamelodi and some portion of Bronkhorstspruit. Satisfaction of existing healthcare service has a high contribution to access to healthcare facilities only in a small portion of the City of Tshwane (Figure 5). Some factors, including females, Black Africans, and the groups termed poor health status and health service satisfaction, were significant across all areas in the City of Tshwane. Figure 5 shows the factors that were significant in certain places, while being not significant in others. The number of youths was a significant predictor in areas adjacent to Hammanskraal and

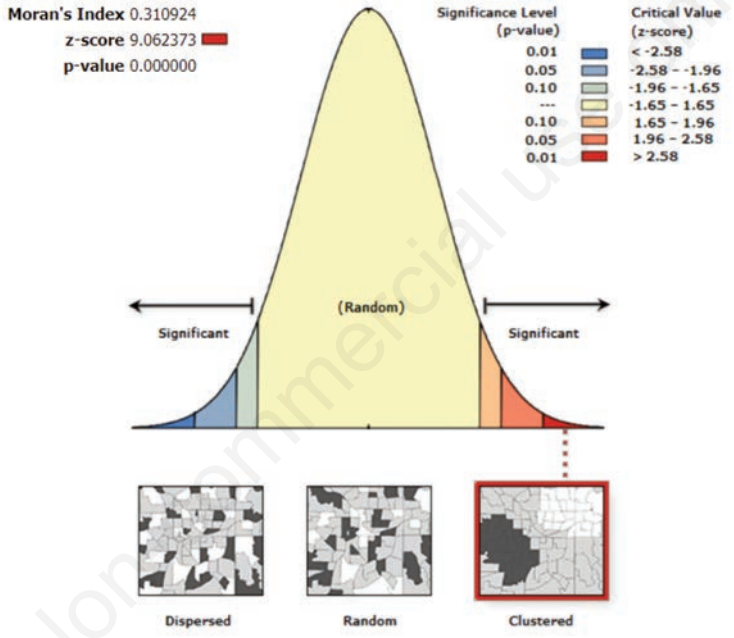

Figure 1. Global Moran's *I* analysis for access to public healthcare facilities.

Table 2. Number of wards belonging to local bivariate relationship categories between access to healthcare facilities and explanatory variables.

Variablea	Positive linear	Negative linear	Concave	Convex	Without significance	Total	Entropy	p
Female	48	0	28	0	31	107	1.3655	0.0387*
Black African	59	0	20	0	28	107	1.3625	0.0274*
Youth[b]	62	0	4	0	41	107	1.5029	0.2321
Adultc	99	0	5	3	0	107	1.4006	0.0100*
Income A[d]	17	0	56	0	34	107	1.3135	0.1181
Income B[d]	0	0	0	0	107	107	1.5326	0.2195
No Insurance	59	0	20	0	28	107	1.3024	0.0620
Poor	0	0	0	0	107	107	1.5121	0.2831
Satisfied	70	0	3	0	34	107	1.3492	0.0968

**p<0.05; [a]that relates with access to healthcare facilities; [b]18–34 years old; [c]35–65+ years old; [d]lower income; dlower income.*

in Bronkhorstspruit, while the number of adults was only significant in Bronkhorstspruit. Lower income (A) was significant in Mamelodi, Soshanguve, Hammanskraal, Centurion and other regions of Pretoria CBD, but higher income (B) was significant everywhere else with the exception of Bronkhorstspruit. In almost all areas of the City of Tshwane, lack of insurance was not significant. Poor health status and health services satisfaction were also significant across all areas in the City of Tshwane.

Local bivariate relationship

The results of the local bivariate relationships between access to public healthcare and explanatory variables are shown in Table 2. The relationship between access to public healthcare facilities and most explanatory variables exhibited a positive, linear relationship in most wards except those with higher income (B) and with poor health status that had a non-significant relationship in all the wards. Also lower income (A) had a positive, linear relation-

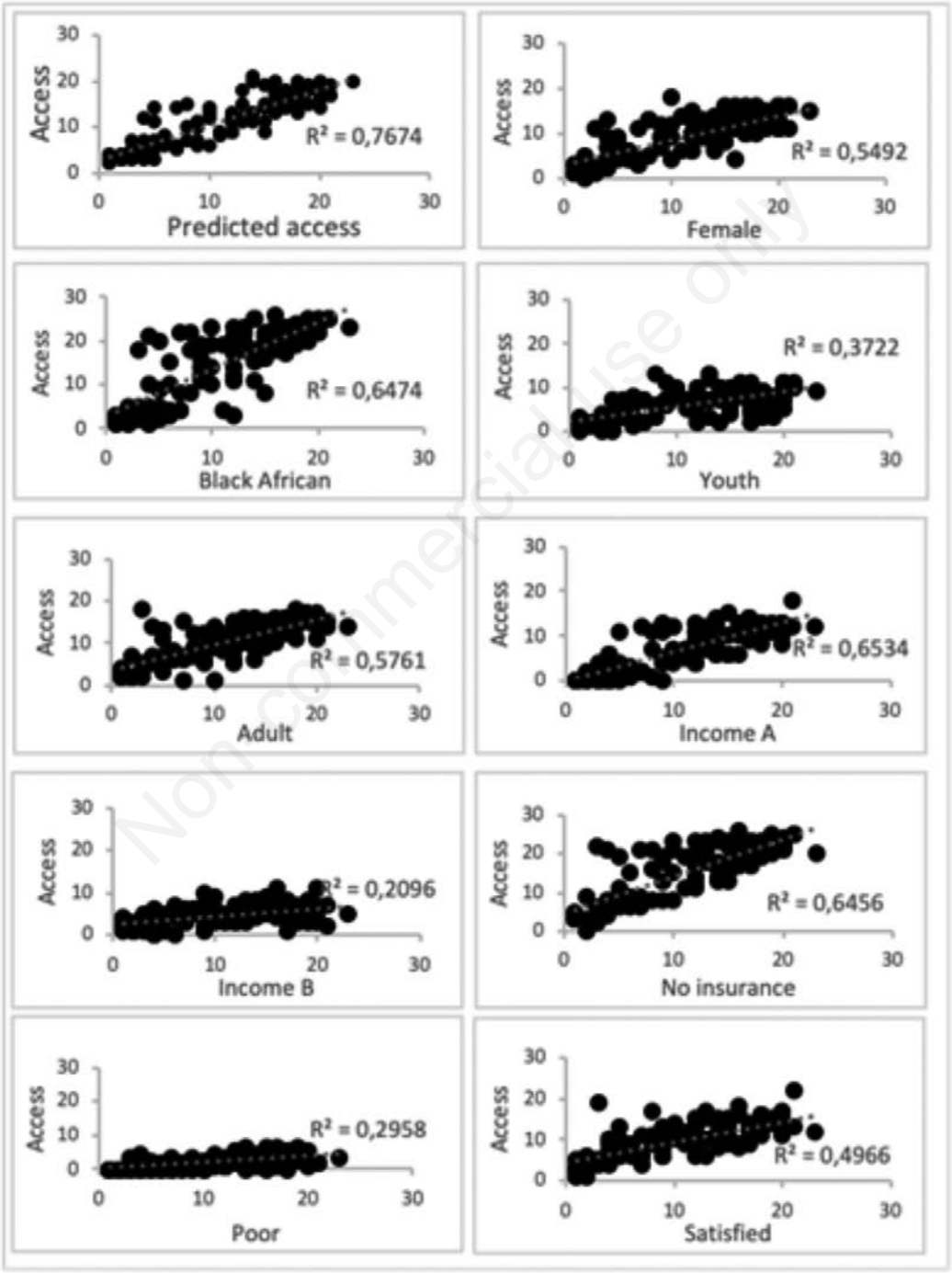

Figure 2. Global Moran's *I* analysis for access to public healthcare facilities.

ship with access to public healthcare facilities in 17 wards, while it had a concave relationship in 56 wards and a non-significant relationship in 34 wards. Adults (35–65+ years old) exhibited a positive relationship in 99 wards, a concave relationship in five wards and a convex one in three wards.

The number of females was positively correlated with the number of people with access to healthcare facilities for 48 of 107 wards of the City of Tshwane (Figure 6a). On the other hand, the relationship of females with healthcare access showed a concave trend in 28 wards, while the relationship was not statistically significant in the rest of the wards. The relationship between the number of Black African and healthcare access was positive, linear in 59 of the 107 wards, 20 showed a concave relationship and the remaining ones were not statistically significant (Figure 6b). The number of youths was positively correlated with the number of people with access to healthcare facilities in 62 of 107 wards of the city (Figure 6c). The relationship between youth and access to healthcare facilities also showed a concave trend in four wards, while the rest were not significant. Looking at the number of adults and the number of people with access healthcare facilities, 99 of

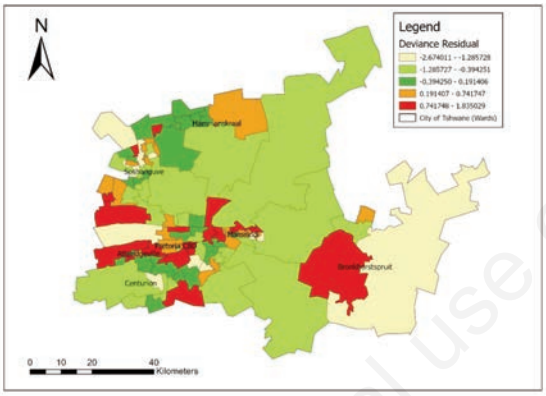

Figure 3. GWR deviance residual for access to public healthcare in the City of Tshwane.

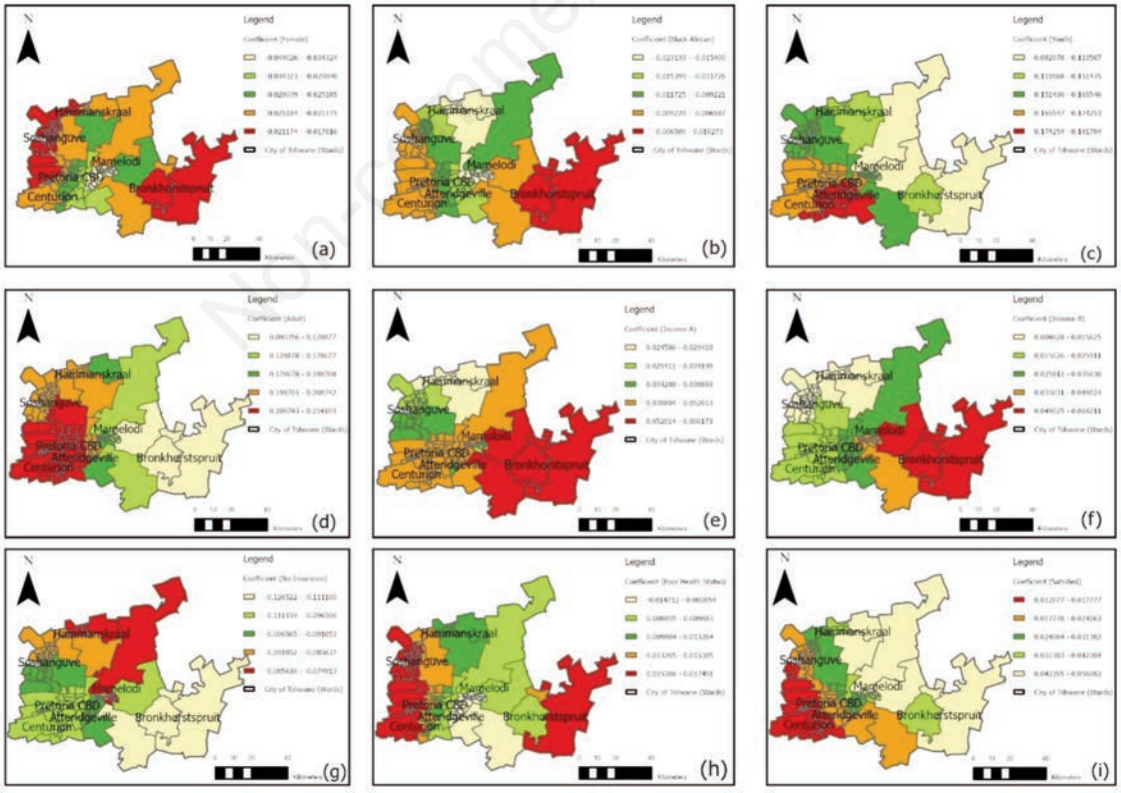

Figure 4. GWR coefficient maps of socioeconomic variables. **a**) females; **b**) Black africans; **c**) youth; **d**) adults; **e**) low income; **f**) high income; **g**) without insurance; **h**) poor health status; **i**) satisfied with the health services.

107 wards had a positive, linear relationship, five wards exhibit a concave relationship and three wards showed a convex trend (Figure 6d). The number of people with lower income (A) correlated positively with the number of people with access to healthcare facilities for 17 of 107 wards of the city (Figure 6e). There was a positive correlation between the number of those without insurance and the number of people having access to public healthcare facilities in 59 wards, 20 wards showing a concave relationship and the remaining wards were not significant (Figure 6f). The number of people who was satisfied with health services showed a positive, linear relationship with access in 70 wards, while three wards showed a concave relationship and the remaining ones were not significant (Figure 6g). The relationship between number of people with poor health status and high income earners (Rand ≥3,201) and access was not statistically significant in all the wards. The spatial analysis of socioeconomic variables and healthcare access in the City of Tshwane revealed diverse patterns across different wards. Positive correlations between socioeconomic indicators such as income level, insurance status, satisfaction with healthcare services and access to healthcare facilities were evident in numerous wards suggesting better access in areas with socioeconomic advantages. However, variations in strength and significance of these relationships across wards highlight the complex spatial distribution of healthcare access disparities within the city.

The spatial distributions of relationships between individual explanatory variables and access to healthcare facilities in the City of Tshwane are shown in Figure 6. A positive relationship between the number of females and access to healthcare facilities was seen to be mainly concentrated in the south-western and south-eastern parts of the city, while concave relationships were clustered in between the positive relationships (Figure 6a). The northern part showed a significant relationship between females and access to healthcare facilities. The positive relationships between Black African populations and access to healthcare facilities were predominantly seen in the south-western, north-western and south-eastern areas. Concurrently, concave relationships were observed to be clustered between the positive relationships (Figure 6b). Notably, the northern part exhibited a significant relationship between Black African populations and access to healthcare facilities, with additional pockets observed in the north-western region. Examining youth and access to healthcare facilities (Figure 6c), a notable relationship was observed in the northern and eastern regions. Additionally, positive relationships are evident in the southern parts, with concave relationships appearing between the significant relationships. With regard to adults and access to public healthcare facilities (Figure 6d), it was evident that the majority of relationships were positive and concave, encompassing most areas within the city. Only a small portion displayed a convex relationship, observed between the positive and concave relationships. For lower income groups (A) and access to public healthcare facilities (Figure 6e), the predominant relationship observed was convex, followed by a non-significant positive relationship in the northern and north-western parts. When considering the relationship between people without insurance and access to public healthcare facilities (Figure 6f), the predominant observation was a positive relationship. However, also smaller areas exhibited non-significant

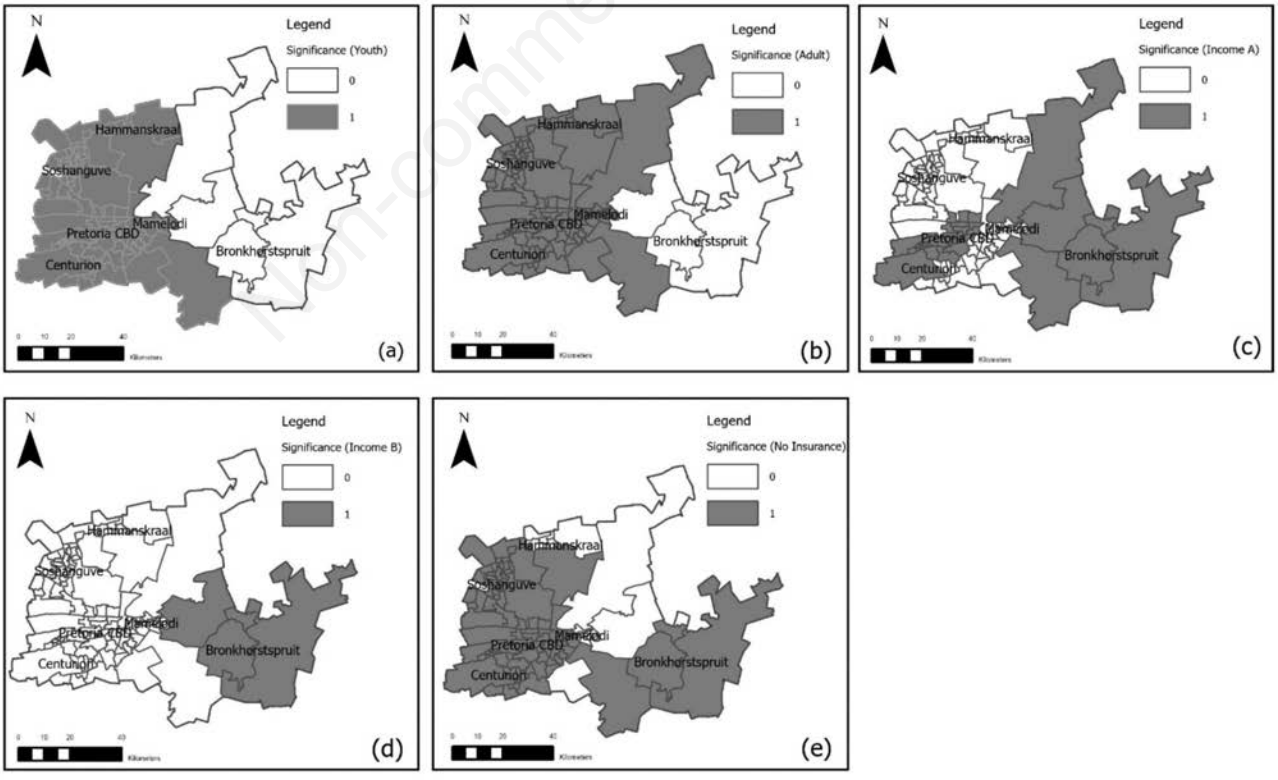

Figure 5. Significance map per variable. **a**) youth; **b**) adults; **c**) low income; **d**) high income; **e**) without insurance; Shaded regions show significant contributions.

and concave relationships. In relation to health services satisfaction and access to public healthcare facilities (Figure 6g), the predominant trend was a positive relationship. Additionally, a concave relationship was observed in the eastern parts, with areas in the western parts showing non-significant relationships.

Discussion

This study evaluated accessibility to public healthcare facility in relation to socioeconomic factors and other related factors in the City of Tshwane. Regarding spatial autocorrelation, the findings from the Global Moran's *I* demonstrated that access to public healthcare facilities exhibited spatial clustering, indicating that areas with similar levels of healthcare accessibility tend to cluster together geographically. The results suggest the importance of socioeconomic factors in determining access to public healthcare facilities within the City of Tshwane. Additionally, the spatial clustering of healthcare accessibility implies that certain areas may experience similar patterns of healthcare access, highlighting the importance of targeted interventions and resource allocation to address disparities and improve healthcare access across different geographic regions.

The findings presented here indicate a positive association between access to healthcare facilities and Black Africans, lower income and lack of insurance and also to a degree, though lower, with poor health status as well as health service satisfaction (Figure 2). The study by Christian (2014), reporting that Black people had more affordable and widespread access to public healthcare, supports this finding. Similar conclusions can be drawn from a study carried out by Wijaya and Widaningrum (2021), where GWR was employed to identify the link between the socioeconomic and demographic makeup of the community and the spatial distribution of health facilities. Here, gender ratio and the proportion of working-age people had the strongest correlation with the distribution of all healthcare facilities. Another GWR study, like ours based on variables such as gender, income and insurance (Shen & Tao, 2022), explored the relationships between socio-institutional characteristics and spatial accessibility to medical services. They found that residents' health-seeking behaviours to be influenced by a combination of spatial accessibility and socio-institutional factors. While there are similarities between the two studies in terms of the socioeconomic variables examined, our study diverged in its findings regarding the relationship between insurance status and access to healthcare. In contrast to our finding that lack of insurance was positively correlated with access to public healthcare facilities, their study indicated that local medical insurance was not associated with actively seeking medical treatment. The present study identified areas with significant positive relationships between each explanatory variable and access to pub-

Figure 6. Local bivariate relationship between number of people with access to healthcare facilities and socioeconomic variables. **a**) females; **b**) Black Africans; **c**) youth; **d**) adults; **e**) low income; **f**) without insurance; **g**) satisfied with the health services.

lic healthcare facilities, with notable variance in the strength of GWR coefficients (Figure 4). This study and the study by Bascuñán and Quezada (2016) are comparable in that they both used GWR and socioeconomic data and examined spatial disparities related to public health in populous areas. However, Unlike the latter study, we did not include transport as an explanatory variable. The findings in Bascuñán and Quezada (2016) indicate that areas close to the hospital had high levels of accessibility, surrounding areas had intermediate levels, and majority of remote rural areas had limited access to healthcare facilities. Thus, both studies support the notion that populations located far from public healthcare facilities have insufficient access to these resources.

Youth was only significant in the areas adjacent to Hammanskraal and in Bronkhorstspruit (Figure 5), possibly because there is little to no built-up area in these locations, whereas youth is not prominent in the other areas. Further, Black African, female, poor health status and being satisfied with the quality of the healthcare services were significant factors to healthcare access in the City of Tshwane, which underline the likelihood that access and these variables are related. Black African individuals and females may face socioeconomic disadvantages, such as lower income or education levels, which can impact their access to healthcare (Christian, 2014; Shartzer *et al.*, 2015). Addressing healthcare disparities for these groups may be crucial in improving overall access to healthcare facilities. Individuals with poor health status may have greater healthcare needs and are therefore more likely to seek access to healthcare facilities. Those who are satisfied with the quality of healthcare services may be more inclined to utilize available healthcare resources, contributing to their significant association with healthcare access. Access to healthcare facilities and socioeconomic opportunities may vary spatially within the City of Tshwane due to better infrastructure, higher income levels and more employment opportunities in certain areas resulting in a stronger association between socioeconomic factors and healthcare access. In contrast, underserved areas may exhibit weaker associations due to limited resources and socioeconomic disparities. Comber *et al.* (2011) investigated the many aspects of health facility accessibility, and reported that the difficulty of accessing those facilities had a significant association with health status. In contrast, the present study found no significant correlation between poor health status and access to public healthcare facilities as illustrated in Figures 2 and 6.

The varied spatial patterns observed in the relationships between explanatory variables and access to healthcare facilities in the City of Tshwane given by the local bivariate relationship results (Figure 6) can be attributed to multiple factors. Firstly, the geographic distribution of healthcare facilities and population demographics across different regions plays a pivotal role. Areas with a higher concentration of healthcare facilities or specific demographic compositions may exhibit more positive relationships, while those with fewer facilities or different demographics may show concave, convex or non-significant relationships. Another crucial determinant is that regions of higher socioeconomic status generally experience better access resulting in positive relationships, while lower-income areas may face barriers to access, leading to concave or convex relationships. Additionally, health insurance coverage and healthcare utilization patterns among different demographic groups influence the observed relationships, with higher coverage and utilization rates generally associated with positive relationships. These findings have direct policy implication as in areas where there was concave or convex relationship, which mean that intervention levels have to change with time based on the change in relationship between access to public healthcare facilities and the explanatory variable at a given ward. This study offers new insights into the specific socioeconomic factors that can be related to healthcare access in the City of Tshwane. In contrast to prior research focusing on larger geographical areas, our findings pinpoint specific locations where variables, such as population group, income and satisfaction with health services, have a significant impact on access to public healthcare facilities. While studies like those by Wijaya and Widaningrum (2021) looked at the spatial distribution of healthcare facilities, our research goes a step further by exploring the distinct spatial disparities in an African urban setting. This is important because healthcare infrastructure in this context faces unique challenges compared to other regions. The differences between our results and those of Shen and Tao (2022) regarding the influence of insurance status on healthcare access could stem from variations in healthcare policies and insurance coverage systems between South Africa and China. Contrary to the results by Comber *et al.* (2011), our finding that poor health status did not significantly impact access, may indicate that structural barriers in the City of Tshwane, *i.e.* physical distance to healthcare facilities, have a greater influence than individual health conditions.

Limitations

One of the limitations of this study is that we used self-reported survey data that are vulnerable to social desirability bias. The findings of this paper should therefore be interpreted with this caution in mind. In addition, the choice of explanatory variables was limited to the availability of variables that might be related to access to public healthcare facilities in the current data. Therefore, future spatial research should be explored with other variables that are related to access to public healthcare facilities based on literature but were not available in this data. Although the use of GWR enabled us to uncover local, spatial variations in access to healthcare that would have been hidden in a traditional global regression approach, GWR's dependence on geographical data may have limited the broader applicability of these findings to regions with different spatial characteristics. Another limitation of this study is that the available healthcare facility data may not capture informal or unreported healthcare providers. Additionally, the analysis did not account for factors like transportation infrastructure or cultural barriers to healthcare access, which was due to data constraints.

The spatial disparities in healthcare access underscore the need for focused policy interventions. In regions where there were negative or disproportionate relationships between income and healthcare access, efforts to increase the availability of public healthcare facilities or enhance transportation infrastructure could help reduce these inequities. Policymakers should also prioritize expanding outreach initiatives in underserved areas, where the distribution of healthcare facilities and socioeconomic challenges intersect. Future research could address these limitations by incorporating a broader range of spatial and non-spatial variables that better reflect the complex factors influencing healthcare facilities access. Attention should also be paid to the possibility of using of a broader range of variables and in different contexts as that would enhance the accessibility of public healthcare in urban settings.

Conclusions

This study highlights the effectiveness of spatially explicit models like GWR in revealing the intricate socioeconomic and other related factors that are associated with access to healthcare. The findings emphasize the need for localized policy interventions that take into account the spatial distribution of healthcare facilities and the socioeconomic conditions of the population.

The Geographically Weighted Regression (GWR) analysis revealed a strong overall relationship between the observed and predicted number of individuals with access to healthcare facilities. Notably, the access to healthcare had the lowest relationship with high-income earners, individuals with poor health status, and those satisfied with health services. The findings underscore the value of using data-driven approaches to inform healthcare policy and practice. By analysing spatial patterns and relationships, policymakers and healthcare providers can better understand local healthcare needs and prioritize resource allocation accordingly.

The local bivariate analysis revealed positive, linear relationships between the number of Black Africans, individuals without insurance, females, youths, adults, individuals satisfied with health services associated with access to healthcare facilities in a majority of wards. Importantly, the presence of convex relationships in a small portion of areas indicates regions where access accelerates disproportionately as adult population increases, highlighting potential opportunities for targeted interventions to optimize access in specific locations.

Given the dynamic nature of healthcare access and socioeconomic conditions, ongoing monitoring and evaluation are essential. Regular assessments of access patterns, disparities, and the effectiveness of interventions can guide evidence-based decision-making and ensure that healthcare systems remain responsive to the evolving needs of the population. This information can guide geo-targeted strategies for improving access to healthcare facilities within specific subgroups of the population at different local areas.

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