GIS in healthcare planning and provision: A case study of Homa-Bay district, Kenya

Moses M. Ngigi[a], Nathan O. Agutu[a], David Kuria[b]

[a]Jomo Kenyatta University of Agriculture and Technology, Department of Geomatic Engineering and Geospatial Information Systems (GEGIS)
P.O. Box 62000-00200 Nairobi, Kenya
murimi99@gmail.com, chasseagutu@yahoo.co.uk

[b]Kimathi University College of Technology, dn.kuria@gmail.com

KEY WORDS:
Healthcare planning and provision, inventory mapping, enhanced two step floating catchment area method, spatial accessibility, GIS

ABSTRACT:

The healthcare system in Kenya faces numerous problems such as lack of coordination in infrastructural and human resource investments, mismatch between demand and supply of available resources, poor accessibility, underfunding, political interference and high number of home deliveries among others. The purpose of this research work was to illustrate how healthcare planning and provision problems, which characterise the health sector in developing countries, can be addressed with the aid of geographical information systems. Through a case study of health facilities in Homa-Bay District in Kenya, an inventory mapping of the health facilities was undertaken, and the enhanced two step floating catchment area method was applied to analyse their spatial accessibility. The spatial accessibility map was integrated with poverty map through overlay to provide a healthcare accessibility index map. The problems of lack of coordination and mismatch of demand and supply were found to be easily solvable through inventory mapping of health facilities, while low or poor accessibility could be addressed by the analysis of spatial accessibility through enhanced two step floating catchment area method. The integration of non-spatial factors was utilised to improve the analyses of accessibility. Almost all the facilities within the study area were found to be ill equipped and understaffed. Both the eastern and western parts of the district were found to have relatively lower levels of accessibility in comparison with the northern and southern parts. A high correlation between poverty and spatial accessibility patterns was also elucidated in the area.

1 Introduction

Healthcare planning and provision is a very critical issue to the well-being of the population. Population subgroups differ in terms of healthcare needs and accessibility according to their age, sex, social class, ethnicity, and other non-spatial characteristics. Healthcare planning involves mostly accessibility to, and location of health facilities; it is in most cases measured by level of accessibility, which is in turn ensured by optimum distribution of health facilities. The levels of accessibility also take into account the necessary human resource and equipment. Healthcare provision on the other hand deals with optimal utilization of the available medical facilities and services; it involves attempts to strike a balance between available medical facilities, resources, personnel and the population demand for the respective facilities.

Access to healthcare varies across space because of uneven distribution of healthcare providers and consumers (spatial factors); it also varies among population groups because of their different socioeconomic and demographic characteristics (non-spatial factors). Accordingly, spatial access emphasizes the importance of geographic barriers such as distance or time between consumer and provider, whereas non-spatial access stresses non-geographic barriers or facilitators such as social class, income, ethnicity, age, sex, etc. (Joseph and Phillips, 1984).

The Government of Kenya, together with various donors, spend a lot of money in building hospitals and provision of medical services when addressing its mandate to provide health care to its citizens. The health care system consists of facilities categorized into five major levels of institutions each having distinct functions and characteristics. The categories include: dispensaries, health centres, district hospitals, provincial hospitals and teaching and referral hospitals. The level of service and demand expected of these facilities are dictated by norms and standards for service delivery which is a policy document by the Ministry of Health. It also details the level of investment expected over a given period of time.

The health care system faces myriad of problems which among them are related to the location of these facilities in relation to the population they are expected to serve. Lack of coordination in investments, especially in infrastructural and human resource allocation, result in inequitable and imbalanced distribution within and across facilities. Other problems in the health sector include high infant mortality rates, delay in procurement and delivery of drugs, lack of funding and political interference.

The main objective of the research was to demonstrate how geographical information systems GIS) could be utilised in analysing healthcare planning and provision problems, especially the locational and coordination related ones. Specifically it sought to undertake an inventory mapping of health facilities based on serviceable areas, and then analyze accessibility to the health facilities as influenced by their capacity, the level of demand, and impedance to its accessibility; the enhanced two step floating catchment area method was applied to achieve this.

Homa-Bay, an administrative district in the Nyanza Province, lying in the western part of Kenya and located along the shores of Lake Victoria was the case study. The district falls between 0° 21' 27.9" S, 34° 11' 30.3" E and 0° 52' 46.4" S, 34° 39' 14.6" E. It is characterised by high levels of disease incidences, with the common diseases being malaria, pneumonia, diarrhoea diseases and respiratory infections. The district has also had high HIV/AIDS levels, with a reported prevalence of 13.9% in 1998--99 against the national prevalence of 7.1% (KDHS, 2009). According to the 2009 population and housing census, the district had 963,794 people. The area is served by a single district hospital, several sub-district hospitals, health centres and dispensaries. The population mainly engages in subsistence farming and fishing.

2 GIS in healthcare planning and provision

Birkin et al.(1996) looks at the spatial change of health status as elucidated through the comparison of actual number of mortalities in an area with the national average; Nicol (1991), Brown et al (1991) and Wrigley (1991) delve into spatial epidemiology where the spatial incidences of diseases and environmental relationship are tackled. Healthcare facilities accessibility and utilization researches, strengthen the usefulness of GIS in addressing answering critical questions like optimal location of facilities such as the location of healthcare facilities, especially in the evaluation of accessibility and optimal demand of a given facility (Gatrell and Senior,1999: Jones and Bentham, 1995, and Forbers and Todd, 1995).

In Kenya, the application of GIS in healthcare system is still in its infancy compared to other fields and other countries like United Kingdom and United States which have made tremendous progress in this area. Notable contributions include Noor et al. (2004), who created a health service provider database and analyzed their relationships; others studies have looked at GIS applications to analyzing specific diseases. A comprehensive literature review related to GIS in health applications can be found in Rushton and Armstrong (1997).

2.1 Spatial accessibility

Most issues of healthcare planning and provision revolve around spatial accessibility to the health facilities. Spatial accessibility comprises two components, namely availability and proximity; both of which need to be measured together to define spatial accessibility (Joseph and Phillips, 1984; Luo & Wang, 2003). The high availability of services does not guarantee high accessibility because it depends on the proximity of the population to those services. Similarly, close proximity does not also guarantee high accessibility as it depends on the size of the population competing for the available services. Historically, three approaches namely distance/time to nearest service, gravity models, and population-to-provider ratios, dominated measures of spatial accessibility.

The ***distance/time to nearest service*** method, which uses travel impedance (distance or time) to the nearest service, is a simple and the most commonly used measure of spatial accessibility (Fortney et al., 2000; Hewko et. al, 2002; Rosero-Bixby, 2004). However, nearest service impedance only captures proximity between population and service locations with no account taken of availability (either the capacity of the service provider or the size of the population). Additionally, bypassing the nearest service is frequently observed where populations commonly have more than one health service to choose from (Fryer, et al., 1999; Goodman et al., 2003; Hyndman et al. 2003). Thus, the nearest service is an ineffective measure of spatial accessibility where overlapping catchments exist such as for primary care services.

The ***gravity model*** provides a measure that accounts for both proximity and availability (Joseph & Phillips, 1984; Weibull, 1976). This model assumes that the attractiveness of a service diminishes with distance and associated increasing travel impedance. Unlike nearest service, the gravity model does capture bypassing whereby the closest service is most likely to be chosen. Additionally, both supply and demand are captured within the gravity model. Most criticism of the gravity model has concentrated on the difficulty in selecting or empirically determining the distance-decay function (Guagliardo, 2004; Joseph & Phillips, 1984; Luo& Wang, 2003).

An extension of the population-to-provider ratios is ***floating catchment areas*** (FCAs) (McGrail, 2008; Luo, 2004; Talen, 2003, and Peng, 1997). The key difference between population-to-provider ratios and the FCA method is the use of floating catchment areas or 'windows' rather than set boundaries. In general, this method better meets the assumption that populations will only use services within their catchment area. The size of the window is determined by a choice of maximum travel impedance, where all services contained within that window are considered accessible to the population, and all other services are not accessible. This process creates as many catchments as there are defined populations, the boundaries for which 'float' and overlap. The significant problem with the FCA was that it was only the supply but not demand that was accounted for (Luo & Wang, 2003). Radke and Mu (2000) were able to address the supply demand issue with the development of a spatial decomposition method, which Luo and Wang (2003) then incorporated and referred to as *a two-step floating catchment area (2SFCA) method.*

2.2 The two-step floating catchment area (2SFCA) method

The first step of the 2SFCA is to determine what population falls within the catchment of each service provider (that is, potential population size being 'served'). The second step of the 2SFCA is to allocate available services to populations, by determining what services fall within the catchment of each population. Calculation of both steps gives a familiar population-to-provider ratio. In the studies it has been used, the 2SFCA method is found to have two major limitations: (1) it does not differentiate distance impedance within the catchment (i.e., all population locations within the catchment are assumed to have equal access to physicians) and (2) it is a dichotomous measure (i.e., all locations outside the catchment have no access at all).

Wei Luo& Yi Qi (2009), applied weights to 2SFCA method in both first and second steps to differentiate travel time zones, thereby coming up with Enhanced 2SFCA (E2SFCA), which is implemented in two steps as follows:

Step1: The catchment of physician location j is defined and a search conducted on all population locations (k) that are within a threshold travel time zone (Dr) from location j (this is catchment area j), and then the weighted physician-to- population ratio, Rj, within the catchment area is computed as:

$$R_j = \frac{S_j}{\sum_{k\in\{d_{kj}\in D_r\}} P_k W_r} = \frac{S_j}{\sum_{k\in\{d_{kj}\in D_1\}} P_k W_1 + \sum_{k\in\{d_{kj}\in D_2\}} P_k W_2 + \sum_{k\in\{d_{kj}\in D_3\}} P_k W_3} \quad (1)$$

where P_k is the population of grid cell k falling within the catchment j ($d_{kj} \in D_r$), S_j the number of physicians at location j, d_{kj} the travel time between k and j, and D_r the r^{th} travel time zone (r = 1–3) within the catchment. W_r is the distance weight for the r^{th} travel time zone calculated from the Gaussian function, capturing the distance decay of access to the physician j.

Step2: For each population location i, search all physician locations (j) that are within the thresh hold travel time zone from location i (that is, catchment area i), and sum up the physician-to- population ratios (calculated in step1), Rj, at these locations as follows:

$$R_j = \frac{S_j}{\sum_{k\in\{d_{kj}\in D_r\}} P_k W_r} = \frac{S_j}{\sum_{k\in\{d_{kj}\in D_1\}} P_k W_1 + \sum_{k\in\{d_{kj}\in D_2\}} P_k W_2 + \sum_{k\in\{d_{kj}\in D_3\}} P_k W_3} \quad (1)$$

Where A_i^F represents the accessibility of population at location i to physicians, R_j the physician-to-population ratio at physician location j that falls within the catchment centred at population i (that is, $d_{kj} \in D_r$), and d_{ij} the travel time between i and j. The same distance weights derived from the Gaussian function used in step1 are applied to different travel time zones to account for distance decay (Wei Luo and Yi Qi, 2009). Just as 2SFCA has proven to be a special case of the gravity model, where the friction-of-distance exponent equals 1 in the catchment and 0 outside (Luo and Wang, 2003b), E2SFCA is also a special case of gravity model. The Gaussian weight used in E2SFCA is away to implement the distance decay term in gravity model.

The advantage of E2SFCA is that multiple distance decay weights substitute the dichotomous 0 and 1 in 2SFCA; so it solves the problem of not differentiating accessibility within the catchment and thus is theoretically more analogous to the gravity model. The discretized consideration of distance decay (by travel time zones) in E2SFCA is a reasonable approximation to the continuous gravity model because, in reality, people would not mind a few minutes of difference in travel time to seek care. This approximation makes the result of E2SFCA straightforward to interpret and easy to use, because it is essentially a weighted physician-to-population ratio. This project applied the E2SFCA due to its numerous advantages as highlighted above.

3 Methodology

The methodology used involved healthcare provision data collection, inventory mapping, and accessibility analysis. Spatial accessibility was mainly based on straight line distances and the ability of the population to pay for the health services. Two-step floating catchment area method was used to generate spatial accessibility indices which were then overlaid onto poverty-based accessibility index map to provide an overall health facility accessibility index map. Most of the data processing was achieved through ArcGIS suite. However, the two-step floating catchment computations were formulated in Microsoft Excel®, while the necessary interpolations were carried out in ArcScene® of ArcGIS® software suite.

The data used included administrative boundaries, roads and towns, administrative sub-location centroids (used to represent village point data), health facilities location and their attribute data, and poverty data. The location of the health facilities and their attribute data were obtained from district health records office. A visit to each of the health facilities, provided the opportunity to verify their spatial location using hand held GPS, while additional attributes such as the number of staff manning a facility, level of service provided, source of water used, availability of laboratory, availability of maternity, source of power, bed capacity, among other attributes were verified or collected. Poverty mapping data, described as percentage of population living below the poverty line, was obtained the Kenya National Bureau of Statistics' district offices.

3.1 Data pre-processing and inventory mapping

As each data set was obtained from different sources, some pre-processing was necessary to enable them be in one platform / system while others needed to be cleaned or converted to digital form. The facility spatial location (x, y) data from the hand-held GPS was cleaned and integrated with the non- spatial attribute data for each facility in a table form ready for use in ArcGIS® software. The administrative boundaries data, as well as other geographical data such as towns and roads had to be converted from geographic coordinate system to projected coordinate system, so as to be in the same system as the health facility location data. For each administrative sub-location, the polygon centroid was determined in ArcGIS® suit, and used to serve as population points. The poverty data, available at the sub-location level, was added as an extra field and linked as attribute to the sub-location shape files. The facilities location data together with the other geographical data were assembled together in the ArcGIS® environment. The descriptive data for the health facilities included information such as the number of staff, level of service provided by the facility, availability and condition of the laboratories, sources of power available to the facility, availability of maternity services among others.

3.2 Accessibility analysis

Based on the government requirement of health provision that people should be within an average distance of 2.5 km of a health facility, two floating buffers were generated at 2.5 and 5.0 km to help in determining the demand side for the smaller facilities. For the district hospital it was necessary to have more floating buffers at intervals of 2.5 km as in reality it caters for all the residents of the district and thereby requiring their input with appropriate impedances depending on the distance from the facility. Anybody within the 2.5 km buffer is assumed to have absolute accessibility. Straight line distances were used as the area of study was basically rural area with not much road network. Village points falling within the first and the second 2.5 km were then found. These were then used to compute the ratio of number of medical workers at the facility to the number of population being served with those falling in the second 2.5 km buffer attracting impedance factor of 0.5.For the district hospital, a series of floating buffers were generated each at 2.5 km interval up to the furthest village point and impedances of 1, 0.875, 0.75, 0.625, 0.5, 0.375, 0.25, 0.125 applied from the innermost floating buffer. This was to take care of all the demand from the district, as in essence it is the referral hospital of all the other smaller health centres and facilities.

For each village point, two rings of floating buffers were generated at 0 – 2.5 km and 2.5 – 5.0 km, and health facilities falling within these buffers found. The ratios from above for each facility was summed with impedances applied to those ratios falling on the 2.5 -5.0 km buffer. The total sum of these ratios per facility formed the spatial accessibility index. The accessibility indexes at each village point were then used in ArcScene® together with the boundaries to produce a surface of accessibility index through Kriging, and the resulting surface reclassified to give them meaningful values. Poverty values were also used together with the boundary to generate a poverty surface of the district and the resultant surface reclassified to give it meaningful values.The two surfaces were then overlaid with spatial accessibility surface given a weight of 70%, while the poverty based given 30%, resulting into final health accessibility index map for the whole district.

4 Results and analysis

The data collected from the field described the individual facilities in their entirety, with an up-to-date situation of the facility. This data was used to produce an inventory database that could be used to display any queried information and produce required maps as need arose. Visual inspection of spatial distribution of health facilities in relation to population distribution showed that all the village points (sub-location centroids) were within 2.5 km of a health facility except for the village of North-Kanyabala. A skewed distribution of health centres was also clearly visible. Most of the health facilities were located on the northern part of the district around the largest town, Homa-bay town, while the eastern and western parts had fewer or no health centres.

All the facilities except Homa–Bay DH were found to be understaffed with most of the centres serving a population approximately double the recommended.The District Hospital had uncharacteristically high number of medical staff in comparison with the other health centres; some for instance had a staff of two serving a population of over 2500 people. Querying the created inventory could reveal other areas that needed to be addressed, such as which facility was in bad state and required attention.

1.3 Health facility accessibility analysis

Accessibility indexes derived for the area could not on their own, in tabular format, give much meaning and had to be mapped in order to see how they compare spatially. On plotting them, a surface was generated by Kriging. To enhance interpretation and visualisation, a six-category classification was adopted to enable quick visual comparison, with the lowest class index showing lower accessibility, while the highest showed the best accessibility (see Figure 1).Accessibility is seen to vary radially from Homa-Bay town, the largest town in the district, and reducing as one moved further away. The eastern side is seen to have lowest accessibility.

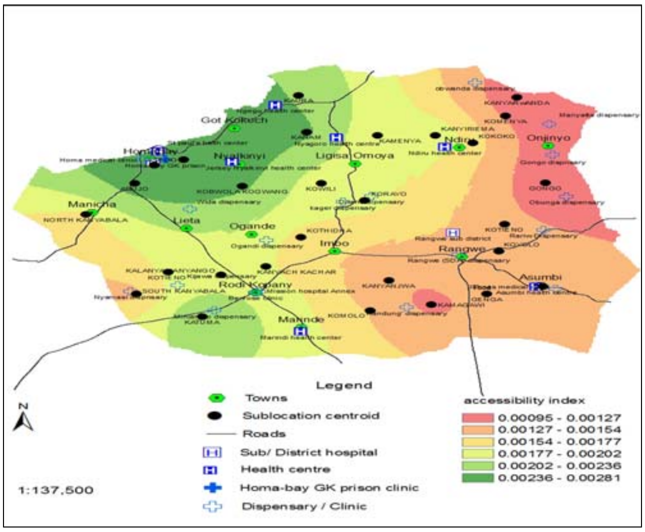

Fig. 6: Spatial accessibility index map from E2SFCA method

The poverty data showing percentages living below poverty line was also Krigged to produce a poverty surface of the district. The data was also reclassification into six categories to match the six categories used in the accessibility map. The scale represented the ability to afford healthcare, therefore places where 37% of the population lived below poverty was allocated higher ability i.e. six (6) as compared to areas where 74% lived below the poverty level which were allocated the lowest rank of one, with the other areas in between being fitted within this scaling. In overlaying the two data sets, spatial accessibility was given more weight than poverty index as spatial accessibility is taken as the primary factor in this analysis. This is due to the fact that cost increases with increase in distances irrespective of the facility charges. This was in tandem with other research such as Luo& Wang (2003b) who noted that in integrating spatial and nonspatial factors in accessibility studies, spatial factors are usually given higher weighting with nonspatial factors allocated a maximum of 30%. In line with this argument, spatial accessibility was allocated 70% while poverty was allocated 30% in this research, resulting into a final accessibility shown in Figure 2.

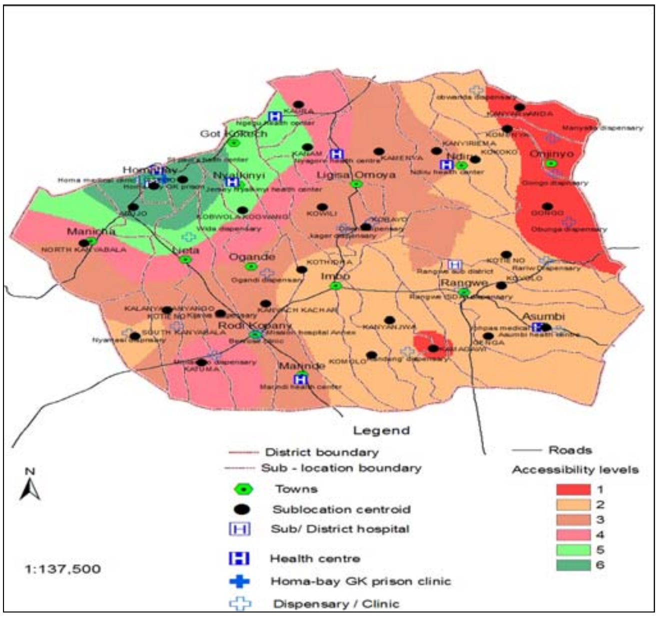

Fig. 7: Healthcare accessibility index map

The accessibility index map shows two sub locations, Homa-Bay town and Asegoto have the highest level of accessibility to healthcare, with a number of highly staffed facilities including the district hospital located there. On the eastern side of the district there is a comparatively low level of accessibility due to high population (high demand) and low number of staff manning the facilities. Integration of poverty with spatial accessibility is also seen to alter the pattern slightly since, with only distance, any one close to a facility is assumed to have accessibility but with purchasing power introduced; this complicates the situation as you can be near but cannot afford. The overall accessibility pattern between spatial accessibility and health accessibility with poverty integrated however does not change much, but on closer examination is found to have reassigned some areas from higher accessibility to relatively lower accessibility and vice versa. This redistribution effect maintains the overall pattern but changes the internal dynamics.

5 Conclusion and recommendations

The research demonstrated the power of GIS in analyzing positional related data and its enormous potential in solving healthcare planning and provisional problems. GIS provide simple tools like selection by attribute and location that were seen to solve the coordination and mismatch problems of healthcare systems based on the inventory map. Also, the visual display provides a powerful focus to aid decision making on what should happen where e.g. from the inventory mapping it was clear that there is imbalance in staffing. A very high percentage if not all the facilities are ill equipped to provide the level of service expected from them, when compared against those provided by norms and standards for health service delivery. Some dispensaries like Oneno and Kijawa have no water storage facility and power; this substantially reduces the services that can be offered from these facilities. Visual inspection also showed a very high correlation between the poverty patterns of the district and the spatial accessibility patterns. The relationship is an inverse relation where the higher the poverty the lower the accessibility.

The results of accessibility analysis is in line with other researches elsewhere that accessibility will generally be higher in town/urban centres and tends to be lower in rural areas due to fewer facilities and lower staffing coupled with relatively high population. Accessibility to healthcare was also seen to be influenced by the number of people in a given area (demand), available health facility and medical staff (supply) and socioeconomic status of the people.

Based on the inventory map, an upgrade of some dispensaries on both eastern and western part of the district would greatly improve accessibility. The government should either build many more facilities or increase medical staffing in the existing facilities in order to match supply with the demand. Elevating Nyamasi and Rariw dispensaries to health centres would greatly improve the situation.

The research could be improved by incorporating larger areas for the variations in healthcare accessibility to be appreciated much more clearly. Other non spatial factors like literacy, age, sex and ethnicity could also be incorporated to check their influence on healthcare.

References

A. M Noor, PW Gikandi, SI Hay, R. O Muga, and R. W Snow 2004. Creating spatially defined databases for equitable health service planning in low income countries; the example of Kenya. *Journal of tropical medicine international health.*

Birkin, M., Clarke, G., Clarke, M. And Wilson A., 1996, Intelligent GIS, *Geoinformation Int.*, Cambridge.

Brown P., Hirschfield A, and Batey P., 1991, Applications of geodemographic methods in the analysis of health condition incidence data, Papers in *Regional Science*, vol. 70, pp 329-44.

Forbers H; and Todd P; 1995, Review of cancer services,. Northwest regional health authority, urban research and policy evaluation regional research laboratory, university of Liverpool.

Fortney, J., Rost, K., & Warren, J. 2000. Comparing alternative methods of measuring geographic access to health services. *Health Services & Outcomes Research Methodology,* 1(2), 173–184.

Fryer, G., Drisko, J., Krugman, R., Vojir, C., Prochazka, A., Miyoshi, T., et al. 1999. Multi-method assessment of access to primary medical care in rural Colorado. *Journal of Rural Health, 15(1), 113–121.*

Gatrell A: and Senior M., 1991, Health and Health care application in Longley P, Goodchild M, Maguire D and Rhind D, *Geographical information system principles and application*, John Wily & Sons, U.K., pp. 925-938.

Goodman, D. C., Mick, S., Bott, D., Stukel, T. A., Chang, C.-h., Marth, N., et al. 2003. Primary care service areas: a new tool for the evaluation of primary care services. *Health Services Research,* 38(1 Part 1), 287–309.

Guagliardo, M. F. 2004. Spatial accessibility of primary care: concepts, methods and challenges. *International Journal of Health Geographic, 3, 3.*

Hewko, J., Smoyer-Tomic, K. E., & Hodgson, M. J. 2000. Measuring neighbourhood spatial accessibility to urban amenities: does aggregation error matter? *Environment and Planning A, 34(7), 1185–1206.*

Hyndman, J. C., Holman, C. D., & Pritchard, D. A. 2003. The influence of attractiveness factors and distance to general practice surgeries by level of social disadvantage and global access in Perth, Western Australia. *Social Science & Medicine, 56(2), 387–403.*

Joseph, A. E., & Phillips, D. R., 1984. *Accessibility and utilization: Geographical perspectives on health care delivery.* Harper & Row publisher. New York, US.

Kenya Service Provision Assessment Survey 2004 – Ministry of Health

Luo, W. (2004). Using a GIS-based floating catchment method to assess areas with shortage of physicians. *Health & Place, 10(1), 1–11.*

Luo, W. and Wang, F., 2003b. Measures of spatial accessibility to health care in a GIS environment: synthesis and a case study in the Chicago region. *Environment and Planning B: Planning and Design 30, 865–884.*

Luo, W., & Wang, F. (2003). Measures of spatial accessibility to health care in a GIS environment: synthesis and a case study in the Chicago region. *Environment and Planning B, 30(6), 865–884.*

McGrail, M.R. 2008. The McGrail Index of Access to primary care for rural Australians. Unpublished PhD, Monash University, Moe, Australia.

Ministry of Health, 2008, Norms and standards for health service delivery.

Nicol J; 1991, Geographic Information System within the national Healths, the scope for implementations, *planning outlook, vol. 34, No. 1, pp. 37-42.*

Peng, Z.-R. 1997. The jobs-housing balance and urban commuting. *Urban Studies, 34(8), 1215–1235.*

Radke, J., & Mu, L. 2000. Spatial decompositions, modeling and mapping service regions to predict access to social programs. *Geographic Information Sciences, 6(2), 105–112.*

Rosero-Bixby, L. 2004. Spatial access to health care in Costa Rica and its equity: a GIS-based study. *Social Science & Medicine, 58(7), 1271–1284.*

Rushton, G., and Armstrong, M.P., 1997, Improving Public Health Through Geographic Information Systems, CD-ROM, Version 1.8. Department of Geography, GIS & Public Health Project, The University of Iowa, Iowa City, IA.

Talen, E. 2003. Neighborhoods as service providers: a methodology for evaluating pedestrian access. *Environment and Planning B, 30(2), 181–200.*

Wei Luo and Yi Qi 2005 .An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians. *Health and place, 15, 1100 - 1107*

Weibull, J. W. 1976. An axiomatic approach to the measurement of accessibility. *Regional Science and Urban Economics, 6(4), 357–379.*

Wrigley N., 1991, Market-based systems of health-care provision, the NHS Bill, and geographical information system, *Environment and Planning A, vol. 23, pp 5-8.*