EVIDENCE BASED PUBLIC HEALTH POLICY AND PRACTICE

Methodology for optimising location of new primary health care facilities in rural communities: a case study in KwaZulu-Natal, South Africa

Frank Tanser

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Correspondence to: Dr F Tanser, The Africa Centre for Health and Population Studies, University of KwaZulu-Natal, PO Box 198, Mtubatuba, 3935, South Africa; tanserf@africacentre.ac.za

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Study objective: To develop a quantitative methodology to optimally site new primary health care facilities so as to achieve the maximum population level increase in accessibility to care. The study aims to test the methodology in a rural community characterised by considerable heterogeneity in population distribution and health care access.
Design: A geographical information system was used to estimate travel time to the nearest primary health care facility for each of the 26 000 homesteads in the subdistrict. The homestead's travel time estimate was then converted into an impedance to care estimate using distance decay (in clinic use) data obtained from the subdistrict. A map of total person impedance/km^2 was then produced using a 3 km standard Gaussian filter. The resulting map was used to site a test clinic in the largest contiguous area of high person impedance.
Setting: Hlabisa health subdistrict, KwaZulu-Natal, South Africa.
Main results: The population level increase in accessibility that would be achieved by the construction of the test clinic would be 3.6 times the increase in accessibility achieved by the construction of the newest clinic in the subdistrict. The corresponding ratio for increasing clinic coverage (% of the population within 60 minutes of care) would be 4.7.
Conclusions: The methodology successfully identifies a locality for a new facility that would maximise the population level increase in accessibility to care. The same principles used in this research could also be applied in other settings. The methodology is of practical value in health research and practice and provides a framework for optimising location of new primary health care facilities.

Community based primary health care is the mainstay of health care delivery to persons in developing countries. In these countries, primary health care must be accessible to the vast majority of the population to be successful. Poor access to primary health care is associated with adverse pregnancy outcomes,[1] infant mortality,[1–3] decreased vaccination coverage,[4 5] and decreased contraceptive use.[6–8] Inaccessibility of clinics may also affect adherence to treatment regimens for chronic diseases, such as those used for TB DOTS.[9] The successful attainment of at least three of United Nation's Millennium Development Goals,[10] (reduce child mortality, improve maternal health, and combat HIV/AIDS, malaria, and other diseases) is contingent on improved access to primary health care.

Geographical information systems (GIS) are often used in ''location-allocation'' problems to efficiently allocate finite resources.[11] Increasing the efficiency of the spatial distribution of health care facilities may focus on increasing access (mean travel time or distance to health facilities) or increasing coverage (the proportion of the population within a distance/travel time threshold to a facility). These approaches may yield differing results. A disadvantage of the former approach is that it is possible to achieve population level improvements in access by targeting populous areas with reasonable access to care, while neglecting the minority of persons living in more sparsely settled areas.[12] This approach thus assumes a linear relation between travel time/distance and ease of access (impedance). A disadvantage of the latter approach is that the Boolean threshold value that is used to denote ''reasonable access'' (typically 5 km or one hour[13]) can be contentious and should be population specific and it is sometimes possible to meet national targets by focusing on populations living marginally beyond the stipulated threshold at the expense of populations in remote areas. Poorer populations are more likely to exclusively use the nearest health care facility irrespective of discrepancies in standard of delivery.[14] This makes the placement of health care facilities in deprived settings particularly important and it is therefore vital that facilities are sited in such a way that as many people as possible have access to the services they offer. However, deciding on how to allocate primary health care resources is difficult and can be based on many epidemiological, sociogeographical, and ethical criteria.

There is a need for a quantitative methodology that will allow health planners to identify potential localities for new primary health care facilities and to evaluate and rank the relative merits of each competing locality. Here I report the development of a methodology that uses GIS technology to efficiently site new facilities to achieve the maximum population level increase in accessibility to primary heath care. I use the methodology to site a test clinic in the Hlabisa subdistrict and compare the population impact on access achieved through the placement of this test clinic with that achieved by the actual placement of the newest clinic in the Hlabisa subdistrict. Extreme heterogeneities in population distribution make the Hlabisa subdistrict a good candidate for the testing of the new methodology.

METHODS

Study area

Hlabisa health subdistrict is part of the rural district of Umkhanyakude in northern KwaZulu Natal and is 1430 km^2 in size. It is situated about 250 km north of the city of

Durban—the third largest city in South Africa. The population consists of about 220 000 Zulu speaking people of which 3.3% are located in a formal urban township (KwaMsane), 19.9% in peri-urban areas (>400 people/km^2), and the remainder (76.8%) are classified as living in a rural area. The rural population lives in scattered homesteads that are not concentrated into villages or compounds as is the case in many other parts of Africa. The area is transected by a Hluluwe-Umfolozi game reserve and surrounded by hard boundaries in the form of large perennial rivers, nature reserves, forestry areas, and commercial farmland. Elevation ranges between 30 and 600 metres above sea level. The population distribution is characterised by extreme heterogeneities and density ranges over two orders of magnitude (20–2500 people/km).

A district hospital and 13 fixed primary health care clinics provide the bulk of the primary health care in Hlabisa. In addition, there are 30 mobile clinic points that are visited twice monthly and 130 community health workers, each of whom is expected to regularly visit a group of assigned homesteads.[15] To access primary health care, 60.8% of the population walk to clinic, 38.8% use public transport, and 0.4% use their own transport.[16]

GIS data

The Africa Centre GIS Unit maintains a digital database of 1:50 000 topographical maps and high resolution orthorectified aerial photographs of the Hlabisa subdistrict. The 26 000 homesteads, and all facilities (including clinics) in the health subdistrict were geolocated by global positioning systems to an accuracy of <2 m.[15]

Travel time model

Previously, I designed a model to estimate average travel time to nearest clinic.[16] Briefly, I used a cost analysis within Idrisi Kilimanjaro (Clark University, Worcester, MA, USA) to compute travel time to clinic. The cost analysis uses the friction values (corresponding to differing travelling speeds across differing surfaces) to compute the path of least resistance from every cell on a 30 m×30 m grid to the most accessible target clinic. The resulting cost surface measures the least cost (in terms of travel time) in moving over the friction surface to the nearest clinic. Using this approach a walking model for pedestrian access and a travel time model for people using public transport were created. These models were calibrated using reported travel times (using a 1% random sample of homesteads) and combined according to the proportion of people predicted to be using public transport (as a function of walking time) to form a hybrid model. This hybrid model thus estimates average travel time from homestead to nearest clinic and takes into account the quality and distribution of the road network, natural barriers such as perennial rivers, and the proportion of the population likely to be using public transport. Using this model, for the Hlabisa subdistrict the estimated median travel time to nearest clinic is 81 minutes and 65% of homesteads travel ⩾1 hour to attend clinic. The model was then used to derive clinic catchments and there was a 91% agreement between predicted and reported clinic use.[16]

Person hours of travel time (PHTT) methodology

Estimated average travel times for each of the 26 000 homesteads in the subdistrict were extracted and multiplied by the number of people in the homestead. The resulting values were superimposed onto a 30 m grid in Idrisi Kilimanjaro and subjected to a moving 3 km standard Gaussian filter. The Gaussian filter weights the contribution of cells in the 3 km neighbourhood according to a standard Gaussian (normal) distribution. The greater the distance from the central cell the less contribution of that cell to the final PHTT/km^2 estimate. The PHTT estimate is then assigned to the central cell and process repeated for the next cell. In the resulting image, the value of each pixel is an estimate of total PHTT/km^2 and highlights densely populated areas comprising people who have to travel for long periods of time to reach the nearest clinic. I applied an adjustment factor near the boundaries of the subdistrict to ensure that all areas were comparable at a km^2 scale.

Person impedance methodology

In previous work,[16] we showed there to be a logistic relation between decay in attendance of a specific clinic and travel time. At 50 minutes travel time, use of the clinic is 91% but thereafter decays rapidly to 50% at 81 minutes, and 1% at 150 minutes. I used the mirror of this curve to calculate a measure of impedance (fig 1). At 0 minutes from a facility where 100% of homesteads use that facility, a person is said to be totally unimpeded in physically accessing clinic (impedance factor = 0) and at 180 minutes travel time a person is said to be totally impeded (impedance factor≈1) with a logistic continuum between these two extremes. The logistic relation means that people living<50 minutes from a clinic are assigned virtually no impedance, but thereafter the impedance increases sharply until saturation starts to occur at about two hours travel time.

Impedance factors for each of the 26 000 homesteads were extracted and multiplied by the number of people in the homestead. The results were then superimposed onto a 30 m raster grid. I then used the Gaussian filter approach as outlined above (with associated boundary adjustment factor) to calculate the total person impedance/km^2. This output highlights areas where the placement of the clinic can have a large population level reduction in impedance to care.

Comparing the population level changes in travel time and impedance

I used the outputs of the PHTT and person impedance analyses to identify potential locations for the test clinic. I then derived the predicted catchments for the test clinic and the most recently built clinic in the subdistrict (Gunjaneni) by allocating each cell in the travel time model to its most accessible clinic. The catchment boundaries thus constitute a line of equal travel time between neighbouring clinics. I then used the resulting predicted catchments of each clinic to compare the population level changes in travel time and travel impedance respectively, that would result from the construction of each clinic.

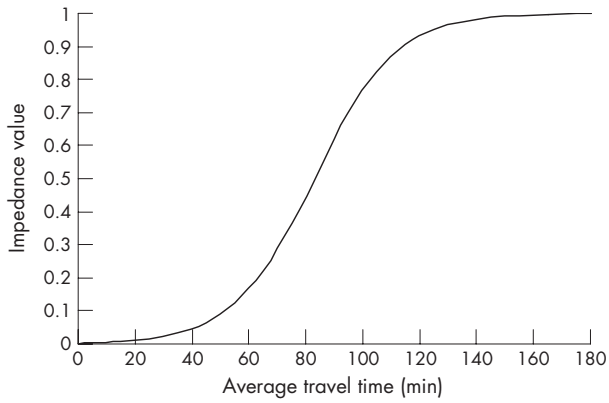

Figure 1 Graph showing the relation between impedance (y) and travel time (t) to clinic; $y = 1 - \left(1 \Big/ (1 + (0.00293 \times 1.07^{t})) \right)$

RESULTS

The mean travel time to nearest clinic is shown (fig 2A). As distance to nearest clinic is increased, roads play more of a part in determining access as a result of the proportion of people making use of public transport also increasing.[16]

A map of the population density is shown (fig 2B). The population is mainly concentrated along the eastern boundary of the area along the national road. The largest population concentration occurs around the southernmost clinic in the urban township of KwaMsane.

Maps of PHTT and person impedance/km^2 are shown in figure 2C and figure 2D respectively. While the PHTT map identifies several areas in the south of the subdistrict with high PHTT, the majority of persons live<1 hour's travel time to clinic (fig 2B) and the high PHTT is attributable to the high population concentration in these areas. The person impedance approach is conceptually better than the PHTT approach as it takes into account the non-linear variation in ease of access (impedance) with increasing travel time. The output clearly delineates the areas where high levels of impedance correspond with high population concentrations. As a result the highly populous areas in the south with reasonable access to care (<1 hour) are not highlighted. In this study case, the outputs of both the PHTT and person impedance analyses identified the same locality for optimal placement of the test clinic. As a result, I selected only one site for the test clinic within this locality that was approximately equidistant from the nearest boundaries of

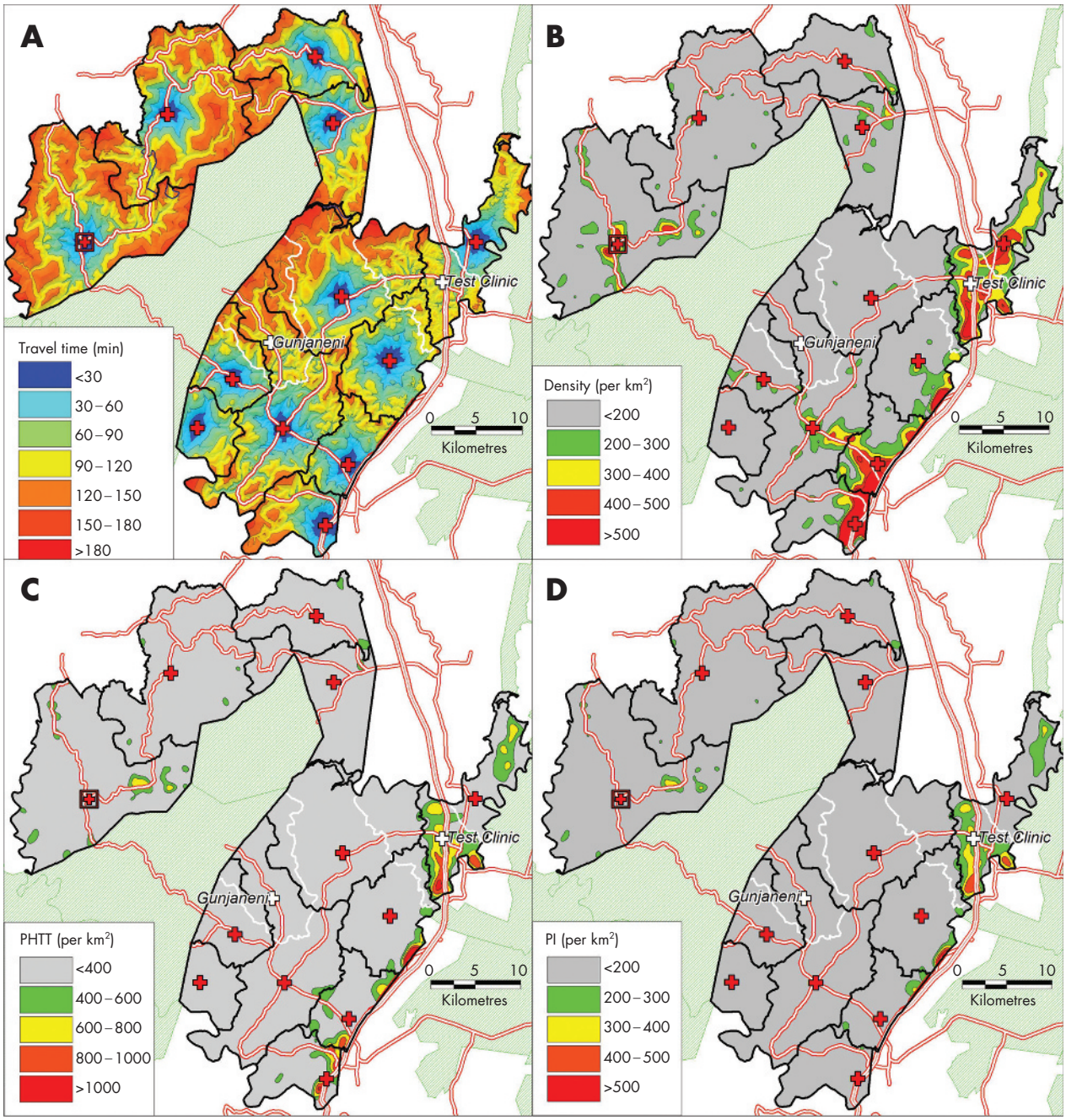

Figure 2 Mean travel time (minutes) to nearest clinic (A), population density/km^2 (B), person hours travel time (PHTT)/km^2 (C), and person impedance (PI)/km^2 (D). The study area is transected by a nature reserve. Clinic catchments (before the construction of Gunjaneni) are shown in black and catchments of the test clinic and Gunjaneni are shown in white.

Table 1 Comparison in travel times and travel impedance between populations living in Gunjaneni and test clinic catchments. Travel times are reported in minutes

	Gunjaneni	Test clinic
Catchment size	7100	20800
Mean travel time (before clinic construction)	110.2	99.8
Mean impedance (before clinic construction)	0.78	0.68
Mean travel time (after clinic construction)	78.5	64.3
Mean impedance (after clinic construction)	0.44	0.26
Reduction in PHTT	3750	12300
Reduction in person impedance	2200	8100
Reduction in % of total population>1 hour from care	1.2%	5.6%

the subdistrict and was located near the intersection of two main roads. The site for the test clinic and actual placement of Gunjaneni (the most recently built clinic in the subdistrict) are shown with resulting catchments superimposed (fig 2C, 2D).

Although the two clinics being compared are equidistant from their nearest respective clinics, the Gunjaneni population were 14% more impeded in accessing health care in comparison with the population living within the test clinic catchment (mean impedance value of 0.78 compared with 0.68) and lived an additional 10 minutes away from the nearest facility (table 1). However, the differences in population concentration mean that the test clinic would achieve an 8100 person impedance reduction compared with only the 2200 person impedance reduction achieved by the construction of Gunjaneni Clinic (table 1). This would translate into a mean reduction in population level impedance to health care of 0.047 for the test clinic, compared with only 0.013 achieved by Gunjaneni, a 3.6 times difference. The corresponding ratio for population level travel time reduction would be 3.3 (4.1 minutes compared with 1.2 minutes). In terms of clinic coverage (% population>1 hour from care), the construction of the test clinic would achieve 4.7 times the population level impact in comparison with Gunjaneni.

There are other considerations. The test clinic would reduce the burden on the clinic that serves the largest catchment population in the subdistrict (located to north east of the test clinic (fig 2C)) by 55%. By contrast, the construction of Gunjaneni Clinic has further reduced the demands placed on a clinic serving one of the smallest catchment populations in the subdistrict (located to the south of Gunjaneni). However, the proportion of the population in the catchment surrounding Gunjaneni (before its construction) that reported using a clinic was lower than that of the population residing in the catchment of the test clinic.[15]

DISCUSSION

The research has devised a methodology that aids the health planner in efficient placement of a new health facility by maximising the impact of the location of a new clinic on reducing population level impedance to health care. The methodology takes into account both the distribution of the health services (and quality and distribution of the road network, natural barriers, and proportion of the population likely to be using public transport) and the distribution of populations that they serve. The test clinic sited using this methodology would produce 3.6 times the reduction in mean population impedance (defined as function of travel time to clinic and rate of decay in clinic use within the subdistrict) and 4.7 times the increase in coverage (% of the population within one hour of care) in comparison with the most recently built clinic in the subdistrict.

The approach presented has focused on the spatial efficiency (defined as achieving the maximum population level reduction in impedance to care) of clinic location and has not tried to address spatial equity (defined as achieving equal distribution of access to care among population subgroups). There is a growing appreciation of the trade off between equity and efficiency in delivery of health care.[17] The geographical dispersion of the population makes inequalities in access to healthcare facilities inevitable, especially in areas like rural KwaZulu-Natal, which has no village structure. Efforts to increase equity will often lead to a reduction in efficiency. An efficient health service might provide the greatest aggregate ease of access for a given level of resources, but will not always be an equitable one because access may not be distributed fairly between groups.[18] A single minded pursuit of efficiency in the spatial allocation of health care resources in societies ''can serve to intensify general disparities in the quality of life''.[19] For example, it might be considered more important to make the health services more equitable by reaching small numbers of vulnerable populations living in remote areas. In this regard, Gunjaneni might represent the more equitable site for clinic placement because of the lower clinic usage previously reported in that area.[15] Nevertheless, it may not be financially viable to build new primary health care facilities to service remote areas of minimal population size and the Department of Health has instituted a network of mobile clinic points throughout the subdistrict to provide some level of care to these populations. The proposed methodology therefore provides an empirical basis for optimising location of new facilities that can form one important part of the decision making hierarchy.

In addition to issues of physical access to health care by patients, there are other important considerations in placement of a clinic. How accessible a facility is for health care personnel, many of whom are unlikely to live within the catchment area of the clinic is one such consideration.

What this paper adds

The paper outlines a methodology for efficient placement of new health facilities by maximising the impact of the location of a new facility on increasing population level accessibility to primary health care.

Policy implications

The methodology is of practical value to rural health planners and district managers and provides a framework for optimising location of new primary health care facilities that ensures the maximum population access to the services they offer.

Although it may be a principled approach to insist that professional staff travel to remote locations, there is in Hlabisa subdistrict (as in most developing and industrialised countries) a shortage of professional staff, and they are likely to choose to work in areas that are accessible to them. There are also issues of critical mass—it may make sense for service facilities to situate themselves close together, so that when persons travel (very often at considerable expense relative to income) they not only obtain health care but can do shopping, banking and get other government services. There are also important political considerations, with local polities and politicians vying (as elsewhere in the world) for new public facilities. In the end, placement of health facilities is not guided entirely by rational and measurable considerations.

The potential interaction between any populations and health care facilities can be calculated using gravity models.[20] Gravity models sum (at every location) the potential accessibility (discounted for distance on the basis of a hypothetical distance-decay function) to each health care centre to derive a single index of accessibility. Such models are advantageous to use in urban or other environments where catchments are ill defined and catchment boundaries blurred and there is considerable interfacility interaction. In contrast with the gravity model, which assumes a multiplicity of health care facilities and the opportunity for the population to reasonably choose from a number of these facilities, the model I use is well suited to areas where choice is limited regarding care. As such, the model that uses population distribution as well as accessibility to care to achieve maximum population level impact, is more suited to rural settings where patient choice of health care facility is limited. Thus the model defines accessibility with respect to the nearest clinic and not on hypothetical interactions with all clinics within a reasonable distance. The impedance value is not a theoretical concept but is derived from empirical data on distance-decay derived from the analysis of the clinic use patterns of 23 000 homesteads.[16] The result is a methodology that achieves a large population impact on health care accessibility by selecting the most efficient (in terms of person impedance) locality for clinic placement. In industrialised countries, patients typically have greater choice of health care facilities, and greater mobility. The decay in use with increasing travel time is much faster with respect to a single facility because patients choose (and are able) to attend more distant facilities. This has led to the use of a negative exponential function to describe the distance-decay in many such settings.[20]

The method described here could easily be adapted to other settings, or where available data differ. For example, a Euclidean distance model, rather than the travel time model, could be used to derive a less precise (but none the less useful) person impedance estimate. Similarly, person impedance could be calculated at a census tract level and populations proportionally allocated to clinic catchments to derive an estimate of the population level impact. In settings where census data are not available (as is often the case in rural areas of developing countries) high resolution satellite imagery (available at moderate cost) can accurately estimate and geolocate populations. In urban settings where facilities are closer together and the catchment boundaries are blurred the methodology would have to be adapted. One way to do this would be to transform a gravity model's accessibility estimate into an impedance value and combine it with the population distribution through the use of a Gaussian filter to locate areas of high person impedance.

Better physical accessibility to primary health care is likely to promote increased utilisation of these services. Such increased use may improve the care commonly associated with primary care clinics, such as antenatal care and childhood immunisation, but may also improve compliance with increasingly important chronic diseases, including HIV, that are being treated at these clinics. As the necessary technology continues to become less expensive and more accessible, the proposed method may have an important part to play in the placement of primary health care facilities in rural settings.

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