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An Objective Method of Defining Spatial Accessibility Indicators for GNH Measurement System

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Abstract

The absence of any spatial-based indicators in the current Gross National Happiness (GNH) measurement system makes this holistic model incomplete for spatial planning purposes in Bhutan. Spatial indicators are generally related to geographic space where the location, distance or area of a spatial object is measured to capture the outcome of a spatial relationship or phenomenon. For instance, spatial indicators are essential in capturing the separation of human settlements from the nearest road point and in measuring the loss of forests cover due to human activities. This study presents an evidence-based approach to measuring road accessibility, remoteness accessibility and

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spatial accessibility to health, education and agriculture services in Bhutan, which can be potentially used as an indicator to facilitate proper planning of allocation of social service centres and road infrastructure in the country. This study indicates that about 75 % of the Bhutanese population are living within 1 kilometre from their nearest road access point and only about 6 % of the population are living farther than 5 kilometres from their nearest road point. About 52 % of the population lives in non-remote areas and only about 7 % of the population lives in very-remote areas. The sub-district's and district's spatial accessibility indices of the three different social service centres indicate a large disparity in the distribution of these service centres in the country where the distribution of service centres for the best-ranked sub-district is several times better than the worst-ranked sub-district. A large disparity in the spatial distribution of social service centres or road infrastructure within the country may potentially cause dissatisfaction of population living in the underserved regions. From a GNH perspective, it is essential to achieve equitable distribution of various social service centres and road infrastructure in the country to optimize the overall happiness of the Bhutanese people. One way of gauging the equity of spatial distribution of social service centres and road infrastructure is to use the proposed accessibility indicators.

Introduction

GNH is a holistic developmental model developed in Bhutan, which seeks happiness for all by balancing between the social, economic, environmental and cultural needs of the people. The four main pillars of GNH are sustainable and equitable socio-economic development, conservation of environment, preservation and promotion of culture and promotion of good governance (Ura et al., 2012). These pillars are further divided into nine domains, namely psychological well-being, health, time use, education, cultural diversity and resilience, good governance, community vitality, ecological diversity and resilience and living standard. Each domain is measured by some number of indicators which are in turn measured from several sub-indicators or variables. Each sub-indicator represents a specific survey question used for collecting data from the respondents. A total of 33 GNH indicators encompassing nine domains were proposed for calculating the GNH index using Alkire-Foster methodology, a multidimensional approach for measuring poverty or wellbeing index (Alkire & Foster, 2011). The goal of the GNH measurement system is to use the GNH index for framing developmental policies, planning and allocation of resources, measuring happiness and well-being of people and gauging developmental progress of sub-districts, districts and nation as a whole (Ura et al., 2012).

According to one of the results of the 2008 GNH survey, twenty different sources of happiness for the Bhutanese people were identified, which are shown in Figure 1 (Centre for Bhutan Studies, 2008).

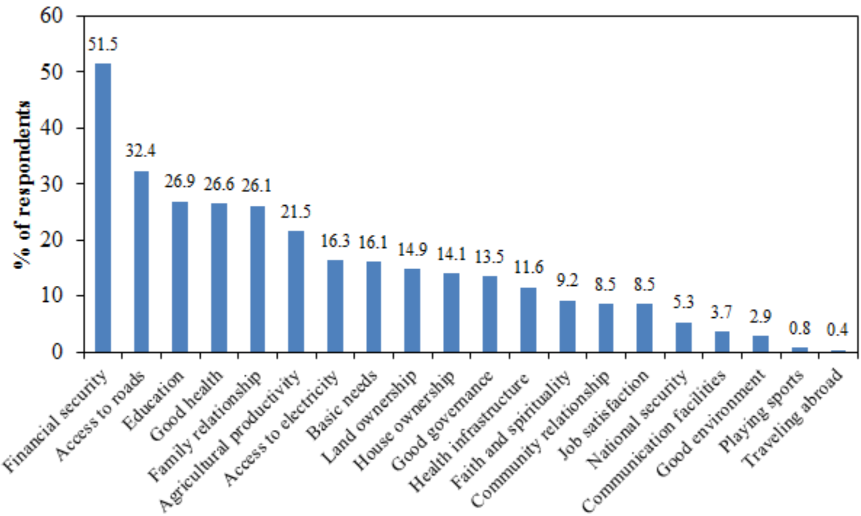


Figure 1: Sources of happiness for people of Bhutan

It indicates that access to roads, education, good health and agricultural productivity are within the top six sources of happiness for the Bhutanese people. Access to roads can be simply understood as the closeness of roads to a settlement such that people within that settlement can travel by a vehicle from one place to the other. It is possible to spatially quantify 'access to roads' by measuring the distance to the nearest road point from a particular dwelling location of the residents.

Nevertheless, there is no indicator included in the current GNH system to measure road accessibility despite it is being perceived as the second most important source of happiness by the people of Bhutan. On the other hand, education, health and agricultural productivity may very well depend on a number of factors. One important factor of these three variables could be spatial accessibility to the respective service centres.

Spatial accessibility measures the availability of service centres and accessibility to these centres based on the potential demand for services (Weibull, 1976). By measuring spatial accessibility to certain service centres, it is possible to identify spatial patterns of accessibility to various services and equity of distribution of service centres within a given region (Talen & Anselin, 1998). Spatial accessibility has been widely used for policy making purposes in the field of transport, urban, land use and infrastructural planning (Geurs & van Wee, 2004). Most notably, the importance of spatial accessibility to health services had been widely reported in literature (Aday & Anderson, 1981; Fortney et al., 2000; Joseph & Bantock, 1982; Khan & Bhardwaj, 1994; Luo & Qi, 2009; Luo & Wang, 2003; McGrail & Humphreys, 2014; Weibull, 1976). Other studies on accessibility include equity of distribution of public amenities (Jennifer et al., 2005; Smoyer-Tomic et al., 2004; Talen, 2002; Talen & Anselin, 1998), food stores (Dai & Wang, 2011) and transportation networks (Geurs & van Wee, 2004). Often accessibility measure can also be used as an economic indicator to assess the economic benefits of changes in land-use and transport planning and as a social indicator to evaluate access to various social and economic services for a disaggregated population (Geurs et al., 2015). There are a number of non-spatial indicators included in the GNH system to measure different aspects of education, health and agricultural services within the country, however, there is no indicator defined to measure the spatial distribution of these important social service centres within the country.

This study has three objectives. First, this study assesses equity of access to road transportation within the country by calculating a simple straight-line distance separation between the closest road point and the dwelling location of the residents. Second, the remoteness accessibility index of a population cluster was calculated based on the straight-line distance proximity of a population cluster to its nearest major and minor towns, health and educational centres, and road point. Third, this study examines spatial accessibility to education, health and agriculture service centres within the country using the modified floating catchment area (M2SFCA) model. In doing so, this paper presents an objective method of quantifying accessibility indicators using spatial and non-spatial data of the whole country. Hence, the proposed spatial indicators can potentially be included as the accessibility indicators within the GNH measurement system.

The structure of this paper is as follows. Section 2 and 3 present data sources and methodology for computing accessibility indices, respectively. The accessibility results are presented in Section 4. Section 5 and 6 present discussion and conclusion, respectively.

Data Sources

As Bhutan uses GNH indicators for measuring the developmental progress of a nation, this country has been chosen as the case study area. Being a small nation with a population of less than one million people, it is relatively easy to collect available data from various institutions. However, there is a lack of current and comprehensive infrastructure and village-level population data. The first ever nationwide population and housing census was conducted in 2005 and spatial data collection pertaining to a national health survey was conducted in 2011. Although road transportation is still not readily available in many far-flung rural areas, the road network data across the country was collected using GPS (Global Positioning System) receivers in or prior to 2012. All the data mentioned above were obtained from the National Statistical Bureau (NSB) in February 2013. Figure 2 shows the distribution of health, education and agricultural service centres and road infrastructure network in Bhutan. Health facilities data include locations of hospitals, basic health units and outreach clinics which provide primary level health care services across the country. Educational data only include primary and secondary level educational facilities. Agricultural service centre comprises of renewable and natural resource (RNR) centres, which provide various agricultural-related services across the country. A total of 356 primary and secondary level educational facilities, 208 health facilities and 206 RNR facilities were recorded in the NSB database as of 2012. There are 20 districts and 205 sub-districts in Bhutan.

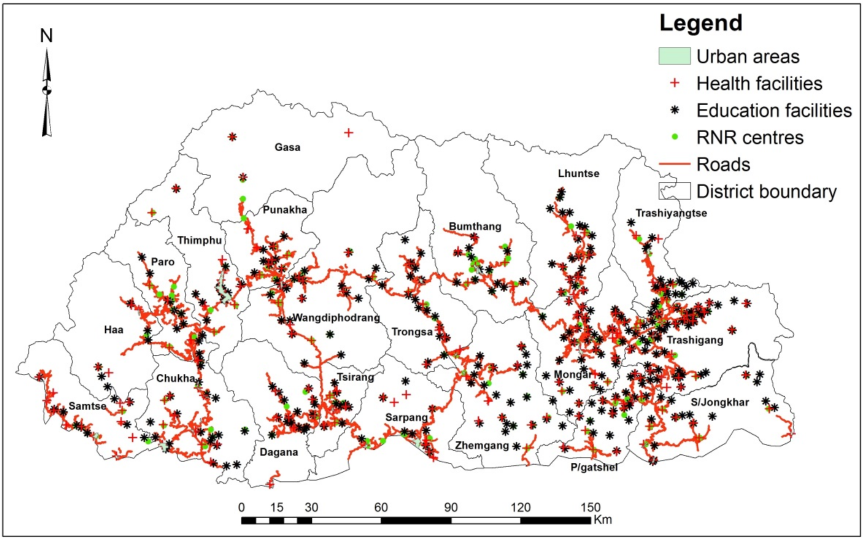


Figure 2: Data

One of the important data needed for this study is population clusters data at the village level. However, population data of Bhutan is only available at the sub-district level which is too highly aggregated to use for computing accessibility indices. Therefore, the aggregated population data was disaggregated using a population dasymetric mapping technique, whereby population data is distributed from source areal units to target units through areal interpolation mechanism aided by ancillary information. In the case of Bhutan, GPS housing data was used to aid the interpolation process by computing relative population distribution weights for each target units based on the density of the houses falling within these computational units. Then the distributed population data at the 100 metres cellular resolution was clustered at the village level by a proximity-based distance clustering method in which population point features were assigned to the nearest village point feature. Figure 3 shows the distribution of the modelled population clusters data. The population of Bhutan in 2012 and 2013 were about 720000 and 733000 respectively, which were predicted based on the actual population of 2005 (National Statistical Bureau, 2008). Figure 4 shows the population density map of Bhutan generated from the modelled population data.

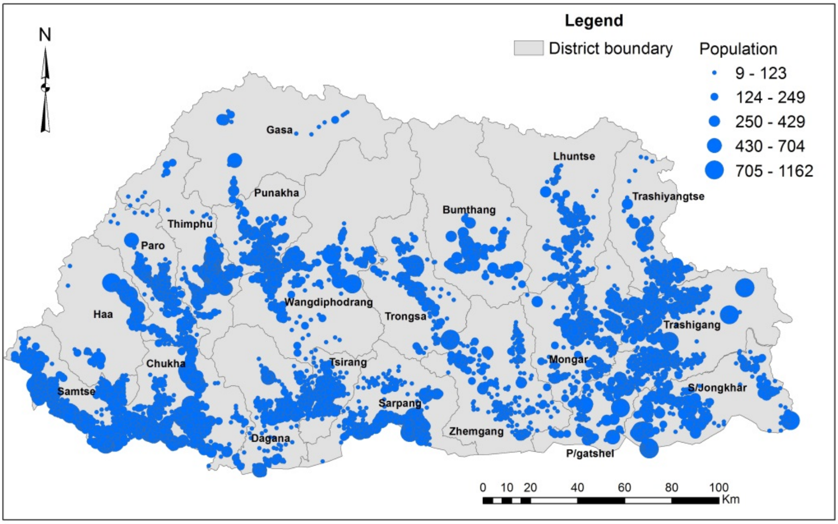


Figure 3: Village-level modelled population data for 2012

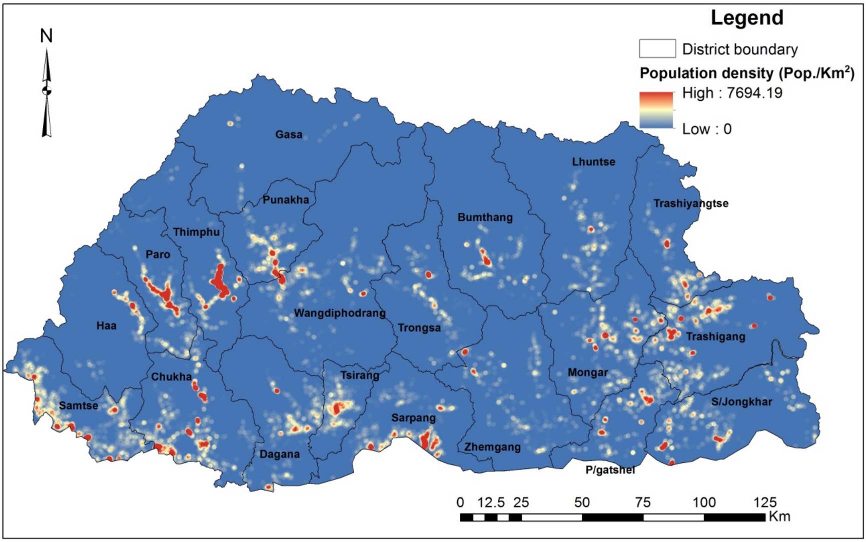


Figure 4: Population density map of Bhutan

Methodology

Accessibility, according to Hasen (1959), is the potential of interaction between population and the service centres using a specific mode of transportation. A simple 'crow-fly' or straight-line distance measure was used because of the lack of road accessibility in many parts of Bhutan. The road accessibility measure is simply computed as the straight-line distance between the population cluster and its nearest road point. The methodology for computing the remoteness and spatial accessibility indices are presented in the following sections.

Remoteness Accessibility Index

Faulkner and French (1983, p. 3) defined remote communities as "spatially defined communities which are distant from urban centres where supplies of goods and services, and opportunities for social interaction are concentrated". They proposed a geographical approach of computing remoteness accessibility based on distances to a number of different levels of urban hierarchy, which can be classified based on population size. Following a similar measurement approach of Faulkner and French (1983), Department of Health and Aged Care and National Key Centre for Social Applications of Geographic Information Systems (2001) developed a geographic measure of remoteness for the whole region of Australia, which is called the Accessibility/Remoteness Index of Australia (ARIA). The Remoteness Accessibility Index of Bhutan (RAIB) can also be computed by adopting the ARIA model with some modification in the usage of service centres. In the case of Bhutan, five different service centres were used for measuring remoteness indices, namely major towns (comprises of only Thimphu and Phuntsholing cities where major economic activities occurs in the country), minor towns (all other towns in Bhutan with relatively low economic activities), nearest road point, hospitals (districts and referral hospitals) and education centres (primary and secondary level schools). Towns were represented by a polygon feature, road by a line feature, and health and educational centres by a point feature.

The computation of accessibility indices is described as follows. The straight-line distance between each population cluster and its five nearest service centres were computed. In the case of towns, if a distance to the nearest minor town of a given population cluster is longer than the distance to the nearest major town of that cluster then the distance to the major town was used for both the towns because major town is at the higher level of hierarchical structure than the minor town, following the computational process of the ARIA model. The distances obtained for the other three service centres remained unchanged because of their exclusion from the hierarchical structure of towns. Then these distances were standardised by dividing each distance value by the mean value for the country for that service centre category. Each standardised value is curtailed to a maximum value of 4.0 to limit the effect of the extreme values on the computation of the overall remoteness index of a population cluster, which is equal to the sum of all the indices obtained from different service categories. The maximum remoteness index is 20, which is equal to the sum of all possible maximum values in each service category.

Spatial Accessibility Index

The spatial accessibility is measured by integrating the attractiveness component of the service centre, population demand for services and distance separation between the locations of the population cluster and the service centre. The attractiveness component of the service centre is generally defined by unity for a given service centre or by the number of service providers available in that centre. Population demand for services is defined by forming a finite and overlapping population catchment area around each service centre. There are different ways of delineating population catchment areas depending on the use of distance or travel-time measure. Following Jamtsho et al. (2015), the population catchment areas are defined by associating population clusters to their first- and second-nearest service centres, where distance between the location of population cluster and service centre is measured by a straight-line or 'crow-fly' distance. The distance impedance variable is generally defined by a distance decay function.

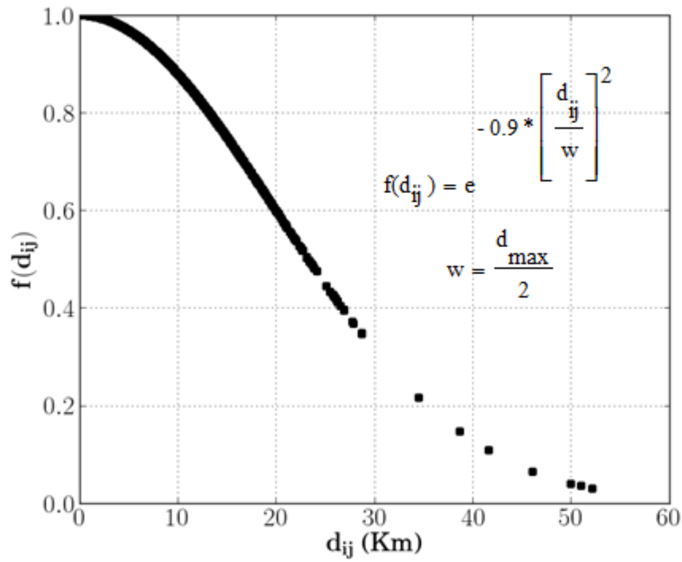


Figure 5: Exponential distance decay function

Figure 5 shows the exponential decay function used for computing spatial accessibility to various social service centres.

The three parameters of spatial accessibility mentioned above can be integrated within the modified two-step floating catchment area (M2SFCA) model (Delamater, 2013), which is given by

$$A_i = \sum_{j=1}^{n} \frac{S_j f(d_{ij}) f(d_{ij})}{\sum_{h=1}^{m} P_h f(d_{hj})}, \qquad (1)$$

where *Ai* is the spatial accessibility index at location *i*, *n* is the total number of service provider locations associated with population cluster *i*, *Sj* represents a unitary service centre at location *j*, *f(di*j) and *f(dh*j) are distance weights computed using an exponential decay function, *m* is the total number of population clusters associated to the service centre *j*, and *Ph* is the population at location *h*. The spatial accessibility measure for sub-district or district, G_k, is simply computed as the average of the accessibility values of all the individual population clusters located within the given sub-district or district region.

Results and analysis

Three different accessibility indices are presented and analysed in this section, namely road accessibility index, remoteness accessibility index and spatial accessibility index.

Road Accessibility Indices

In urban areas where multiple access roads are available this distance is very small whereas the distance to the nearest road point in rural areas may range up to several kilometres. Figure 6 shows the distance to the nearest road point from individual population clusters in the whole country. Table 1 shows the summary of population falling in different distance ranges. About 40 % of the population lives within 100 metres from the nearest road point, 42 % of the population lives within 100 metres to 1 kilometre from the nearest road point, 11 % of the population lives within 1 to 5 kilometres from the nearest road point and 7 % of the population lives farther than 5 kilometres from the nearest road point. The longest distance to the nearest road point is about 53 kilometres recorded for one of the population cluster in Lunana sub-district of the Gasa district.

The longest mean distance to the nearest road points from resident locations is about 45 kilometres recorded for Lunana sub-district of Gasa district followed by Laya sub-district of Gasa district and Lingzhi sub-district of Thimphu district with a mean distance of 26 kilometres. Gasetsho Wom sub-district of Wangdiphodrang district and Taklai sub-district of Sarpang district have the least mean distance to the nearest road points from their population clusters measuring at about 70 metres. At the district level, Paro district has the least mean distance to the nearest road points of about 400 metres with a maximum distance of 2.5 kilometres for Tsento sub-district and minimum distance of about

80 metres for Dopshari sub-district. Gasa district has the longest mean distances to the nearest road points of about 19 kilometres.

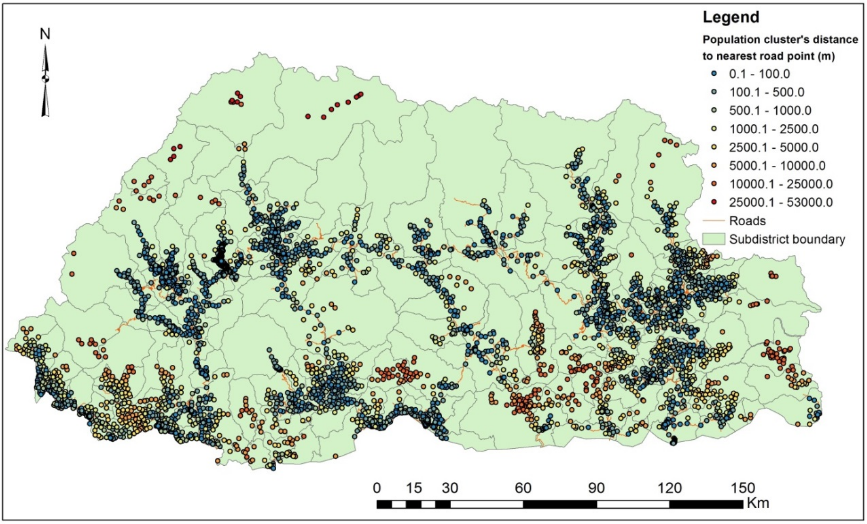


Figure 6: Distances between population clusters and nearest road points.

Table 1: Summary of distances between population clusters and nearest road points

Distance to nearest road point	Population (2013)	%
< 100 m	292952	39.96
100 to 500 m	263660	35.97
500 to 1000 m	48395	6.60
1 to 2.5 Km	47952	6.54
2.5 to 5 Km	35357	4.82
5 to 10 Km	24901	3.40
10 to 25 km	17438	2.38
25 to 53 Km	2377	0.32
Total	733032	100

Remoteness Accessibility Indices

The remoteness accessibility indices were calculated only at the location of population clusters. Therefore, the remoteness accessibility values of all regions across Bhutan were spatially interpolated using inverse-distance weighting method at 500 metres cell resolution using 6 nearest neighbours. These remoteness indices were arbitrarily classified into six different groups. Figure 7 shows the remoteness accessibility indices map of Bhutan. Table 2 shows the distribution of population between different remoteness groups. About 52 % of the population lives in non-remote areas, 41 % in remote areas and only 7 % in very-remote areas.

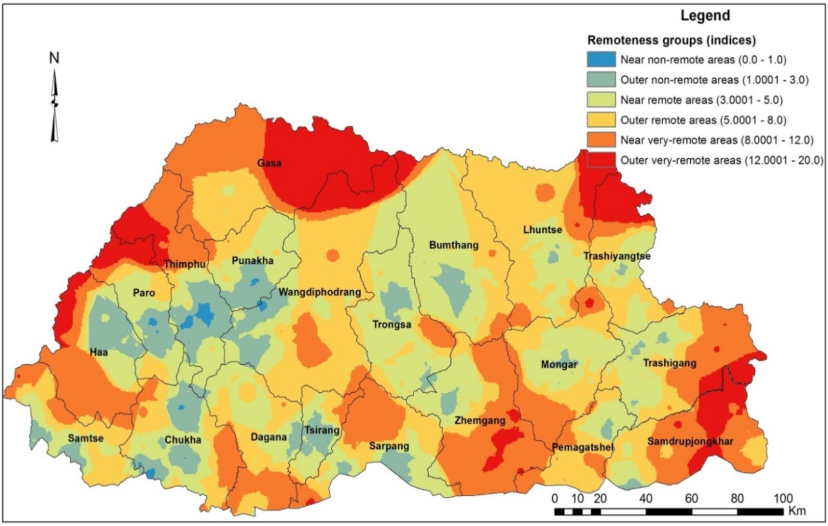


Figure 7: Remoteness accessibility indices map of Bhutan

Table 2: Population distribution between different remoteness groups

Groups	Population (2012)	%
Near non-remote areas	122729	17.03
Outer non-remote areas	250649	34.78
Near remote areas	195950	27.19
Outer remote areas	97507	13.53
Near very-remote areas	47420	6.58
Outer very-remote areas	6414	0.89
Total	720669	100

Spatial Accessibility Indices

Figure 8 shows the individual and mean spatial accessibility indices of sub-districts for the health, educational and agricultural service centres. Owing to space constraints, the sub-district names have been replaced by serial identification numbers. In 2012, the spatial accessibility to educational services was better than the accessibility to health and agricultural services because there were more educational facilities than other service centres in the country.

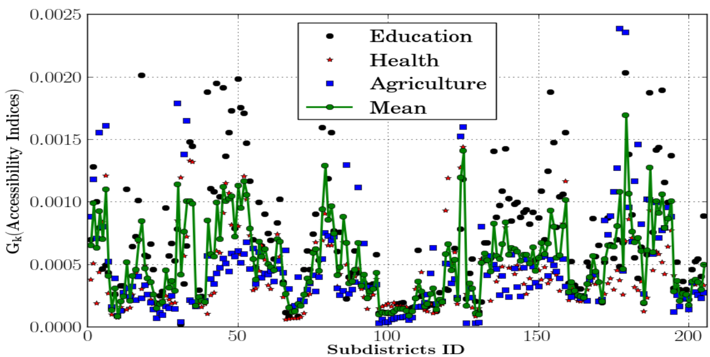


Figure 8: Spatial accessibility indices of sub-districts for education, health and agricultural services

Table 3: Maximum and minimum accessibility indices of sub-districts for different services

	Max	Min	Max	Min
Education	0.002218	0.000022	Chimung (Pemagatshel)	Lunana (Gasa)
Health	0.001442	0.00006	Lingzhi (Thimphu)	Doteng (Paro)
Agriculture	0.000239	0.00003	Gangtey (Wangdiphodrang)	Dagala (Thimphu)
Mean	0.001693	0.00009	Athang (Wangdiphodrang)	Sampheling (Chukha)

Table 3 shows the minimum and maximum accessibility indices of sub-districts for education, health and agricultural services. For educational services, Chimung sub-district of Pemagatshel had the highest accessibility index and Lunana sub-district of Gasa district had the lowest accessibility index with the highest ranking sub-district having hundred times better accessibility to educational services than the lowest ranking sub-district. Lingzhi sub-district of Thimphu district and Doteng sub-district of Paro district were the highest and lowest ranked sub-districts for spatial accessibility to healthcare services with the highest ranked sub-district having about twenty-four times better accessibility than the lowest ranked sub-district. Gangtey sub-district of Wangdi Phodrang district and Dagala sub-district of Thimphu district were the highest and lowest ranked sub-districts for spatial accessibility to agricultural services with the highest ranked sub-district having only about eight times better accessibility than the lowest ranked sub-district. The mean accessibility indices indicate that Athang sub-district of Wangdi Phodrang district and Sampheling sub-district of Chukha district as the highest and lowest ranked sub-districts for spatial accessibility to the combined services of the three centres with the highest ranked sub-district having about nineteen times better accessibility than the lowest ranked sub-district.

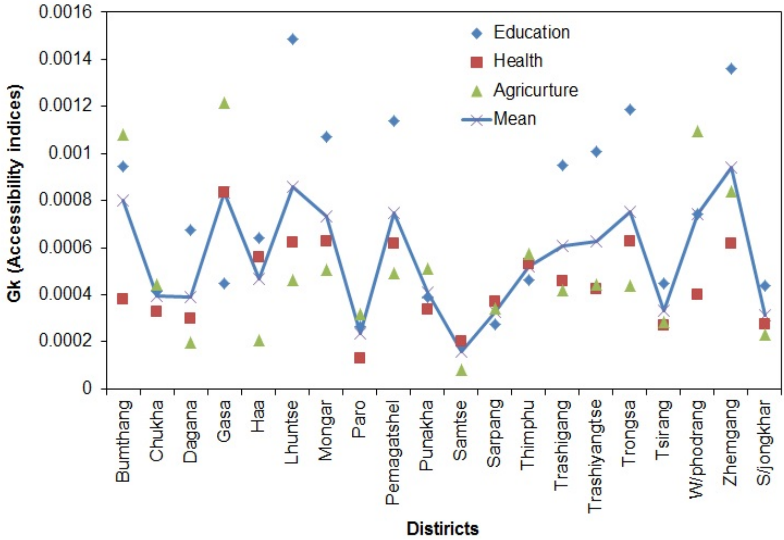


Figure 9: Spatial accessibility indices of districts for education, health and agricultural services

Figure 9 shows the accessibility indices of districts for education, health and agriculture service centres along with their mean accessibility indices. Lhuntse and Samtse districts had the highest and lowest accessibility indices, respectively, with the former district having about eight times better accessibility to educational services than the later district. Gasa district and Paro districts were having the highest and lowest accessibility to healthcare services, respectively, with the highest-ranked district having about six times better accessibility than the lowest-ranked district. Gasa district was also ranked highest for spatial accessibility to agricultural services while Samtse district was ranked lowest for this service with the former district having about fifteen times better accessibility than the later district. The mean accessibility values of the combined services of education, health and agriculture indicates Zhemgang as the highest ranked district and Samtse the lowest ranked district with the highest-ranked district having about six times better accessibility than the lowest-ranked district.

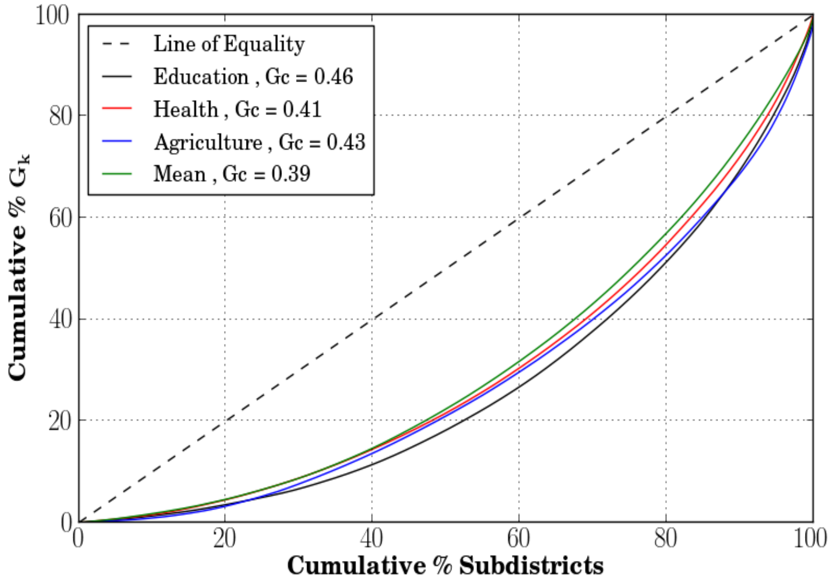
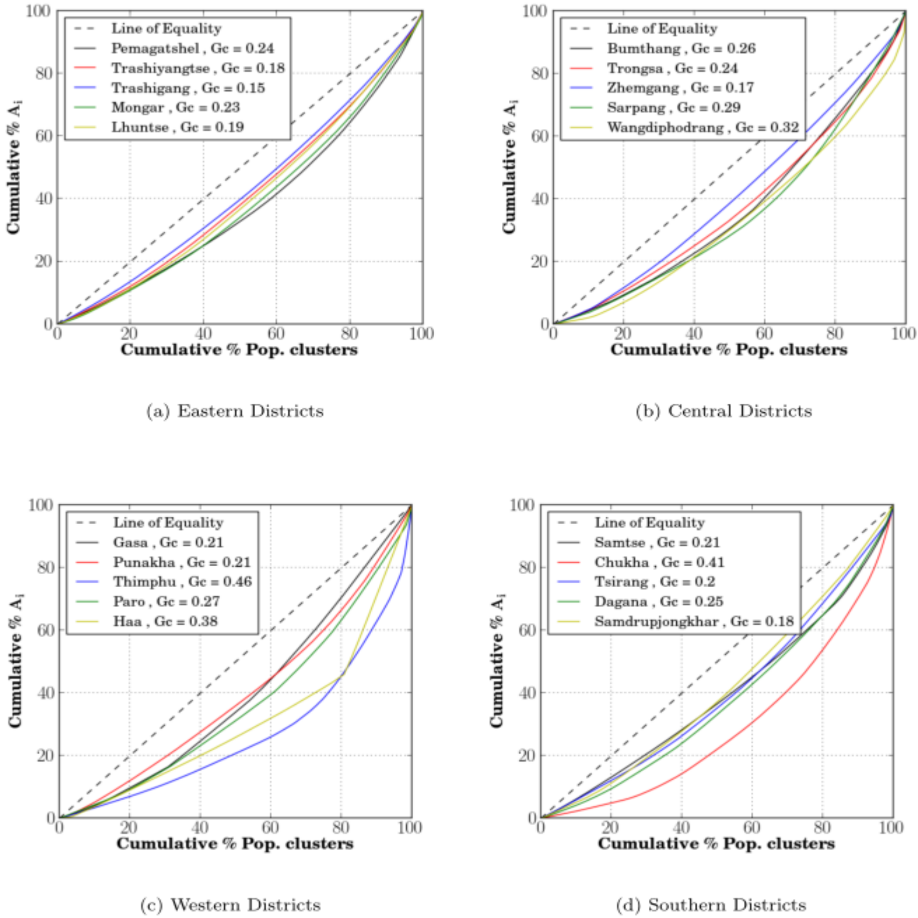


Figure 10: Lorenz curves and Gini coefficients of the mean spatial accessibility indices of sub-districts

Figure 10 shows the Lorentz curves and Gini coefficients (Gc) of the mean spatial accessibility to education, health and agriculture services computed using the sub-districts accessibility indices. A Lorenz curve is obtained by plotting the cumulative percentage of spatial units (population clusters or sub-districts) against the cumulative percentage of spatial accessibility values of the corresponding spatial units. The Gini coefficient is defined as the ratio of the area between the Lorenz curve and the Line of Equality and the area under the Line of Equality. There are no significant differences in the equality of distribution of the three service centres within the country as their Gini coefficients vary only by a small value from 0.02 to 0.05. However, the evenness in the spatial distribution of these service centres within the country is far from uniform as their Gini values are above 0.4, which is a mid-range value. A Gini value closer to 0 represents a fairer distribution of service centres while a Gini value closer to 1 represents the worst distribution of service centres. Figures 11(a) to 11(d) show the Lorentz curves and Gini coefficients of districts for the combined services computed using the mean accessibility indices. Trashigang district with Gini coefficient value of 0.15 has the best equality of distribution of these three service centres across the country whereas Thimphu district with Gini coefficient value of 0.46 has the worst equality of distribution of these service centres.



(a) Eastern Districts

(b) Central Districts

(c) Western Districts

(d) Southern Districts

Figure 11: Lorenz curves and Gini coefficients of the mean spatial accessibility indices of population clusters

As there was a lack of data for education and agriculture service centres for different years, it was not possible to assess the temporal changes in spatial accessibility to these services. Therefore, only health data from 2010 to 2014 were analysed to assess the temporal changes in spatial accessibility to primary health care services. In this case, the spatial accessibility indices are computed by using number of health care providers (doctors) available in each health centres as the attractiveness variable, S_j in Equation 1. Figure 12 shows the sub-districts' accessibility indices of the whole country from 2010 to 2014.

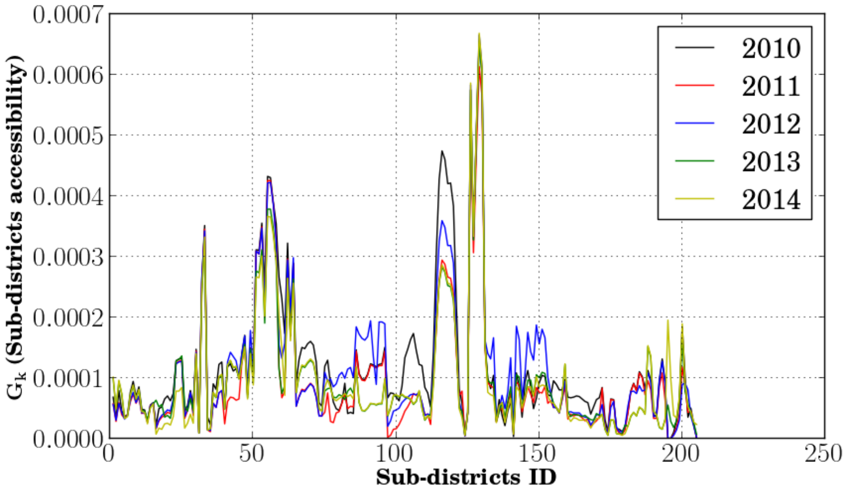


Figure 12: Spatial accessibility indices of sub-districts for health services from 2010 to 2014

In addition, the point-based accessibility indices are shown by a curve line to highlight the trend of the temporal changes in the spatial accessibility indices. The sub-district accessibility plot clearly indicates spatial and temporal changes in spatial accessibility to health care services between different sub-districts from 2010 to 2014. The trend of the temporal changes in spatial accessibility is not necessarily in positive direction towards the current years. Most of the regions have lower spatial accessibility for 2014 than the previous years, which indicates that the availability or distribution of health resources in those regions were not able to catch up with the growth in the population.

Figure 13 shows the district accessibility indices from 2010 to 2014.

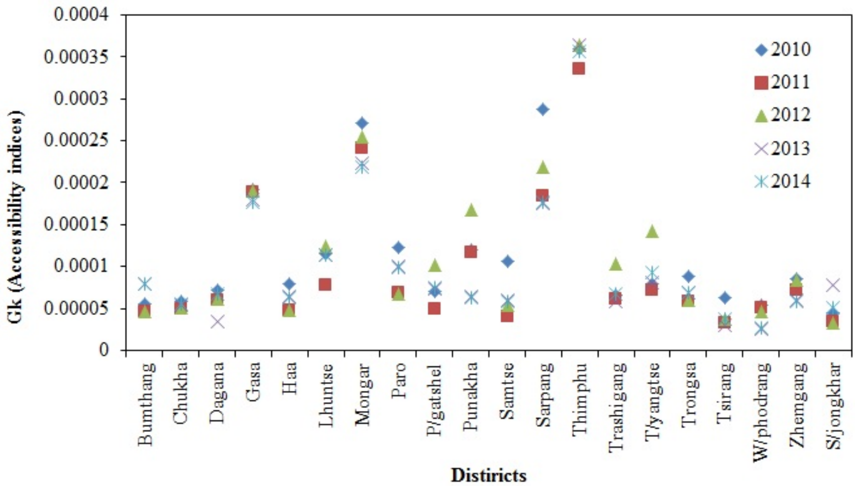


Figure 13: Spatial accessibility indices of districts for health services from 2010 to 2014

Thimphu district had the highest spatial accessibility to primary health care services in the country in 2012 followed by Mongar, Sarpang and Gasa districts. As the accessibility indices literally refers to opportunities per person, Thimphu district's accessibility indices from 2010 to 2014 indicates that this district has one doctor for every 2785 to 2801 people, which is the highest in the country. On the other hand, Samdrup Jongkhar district with spatial accessibility of one doctor for 21891 people in 2010, 29112 in 2011 and 29735 in 2012 and Wangdi Phodrang district with spatial accessibility of one doctor for 38699 people in 2013 and 37488 in 2014 had the worst accessibility to primary health care services in those years. Bumthang district with spatial accessibility of one doctor for 17937 people in 2010 and 12691 people in 2014 indicates the best improvement in the healthcare services whereas Wangdi Phodrang district with spatial accessibility of one doctor for every 18311 people in 2010 and 37488 people in 2014 indicates the worst deterioration in spatial accessibility to health care services in the country between 2010 and 2014. The deterioration of spatial accessibility to health care services in Wangdi Phodrang district is mainly attributed to having only one doctor in the district in 2014 compared to having two in 2010 and three in 2012, as the average distance between the locations of the population clusters and the health centre remained constant at about 19 kilometres between 2010 and 2014.

Discussion

GNH policies guided the development of the Tenth and Eleventh Five Year Plans of Bhutan (Gross National Happiness Commission, 2009, 2013). In doing so, the ministries and autonomous institutions around the country were required to formulate plans and activities and gauge those activities based on GNH indicators. Often there are no sensible indicators to gauge the progress of technically-related activities. For instance, the change in the coverage of forest area in the country can only be measured by calculating the acreage of the forest cover in certain time intervals. Similarly, the universal coverage of health care services can only be effectively determined by measuring the physical distances between the service centres and the dwelling locations of the populations. The current practice of measuring the progress of technical activities with the existing GNH indicators by indirect comparison is very much flawed because the relationship between the technical variables and the GNH variables cannot be ascertained. Therefore, there is a need to include specific technical variables, such as the accessibility indicators for measuring 'access to roads', within the GNH measurement framework to accurately gauge the progress of technical activities in various organizations.

It is also noteworthy to mention that the proposed accessibility indicators were computed objectively from administratively gathered data of the whole country. The use of objective data of the whole country indicates a gross representation of the population, unlike the current GNH indices which are derived from survey questionnaire responses from a sampled population. To undertake a general survey of the whole population is very expensive so other viable methods need to be explored to define indicators. For instance, like in the computation of proposed road, remoteness and spatial accessibility indicators, there is no need to conduct a survey to find out the distance measurement between two locations rather the distance metric can be computed using locations of the modelled population clusters and the road network data of the whole country. In a nutshell, this study shows the possibility of evidence-based measurement of accessibility indicators using both spatial and non-spatial data of the whole country. Likewise, such evidence-based indicators can also be developed for the GNH system. However, there is a need to restructure the measurement system of the GNH system and re-aligned closely to methods used by other countries. One viable way of measuring indicators is to use a causal framework, such as the pressure-state-response (PSR) system, like the ones used for defining sustainability indicators by the OECD (Organization for Economic Cooperation and Development) countries (OECD, 1998, 2001, 2008). Only through integration of GNH's indicators with internationally adopted indicators would make the GNH measurement system a viable alternative for measuring the social, economic and environmental progress of a nation.

One of the drawbacks of the proposed accessibility measurement approach for the computation of remoteness and spatial accessibility indices is the use of a simple straight-line distance measure between two locations instead of computing actual travel-time or distance from road transportation network data. Most of the urban-based studies on accessibility in developed countries have been done using travel-time measure, which is computed from transportation network data as places within their study region are well connected by road network (Dai & Wang, 2011; Delamater, 2013; Geurs & van Wee, 2004; Luo & Qi, 2009; Luo & Wang, 2003). However, in developing countries like Bhutan, road connection in most part of the rural areas is very much limited to a few places. Therefore, the computation of travel-time measure from road network data cannot be uniformly conducted throughout the country. Until road transportation is readily available in all the regions of Bhutan, the regional accessibility measurements can only be undertaken using a straight-line distance measure. If the simple straight-line distance measure is used uniformly across the study region then it would provide an unbiased basis for comparison between different regions.

Conclusion

The result of the first GNH survey conducted in 2008 indicates access to roads, education, good health and agricultural productivity as some of the important sources of happiness for the Bhutanese people. The ease of accessibility to road transportation, health services, educational and agricultural services can positively affect the outcome of the sources of happiness. Nonetheless, the existing pool of GNH indicators do not contain any spatial indicators, which are essential in quantifying spatial distribution of road network and social service infrastructure such as education, health and agricultural service centres. This study proposes simple straight-line distance-based accessibility indicator to quantify road accessibility, standardised distance-based remoteness accessibility to define degree of remoteness of a place within a country, and spatial accessibility indices to measure the equity of distribution of social service centres across the country.

Distance-based road accessibility indices of the whole country indicates about 40 % of the population lives within 100 metres from the nearest road point, 36 % of the population lives within 500 m to 1 kilometre from the nearest road point and 20 % of the population lives beyond 1 kilometre from the nearest road point. Only about 2.6 % of the population are living farther than 10 kilometres from the nearest road point. As per the remoteness accessibility classification, about 52 % of the Bhutanese population live in non-remote areas where accessibility to road transportation, towns, hospital and educational centres are better than for the 48 % of the population who live in the remote areas. Based on the mean spatial accessibility indicator of health, education and agriculture services, Athang sub-district of Wangdi Phodrang district and Sampheling sub-district of Chukha district were the highest and lowest ranked sub-districts in 2012, respectively, with the former sub-district having about nineteen times better accessibility than the later sub-district. Trashigang district with a Gini coefficient value of 0.15 had the best equality of distribution of these three service centres across the country whereas Thimphu district with a Gini coefficient value of 0.46 had the worst equality of distribution of these service centres. The spatial accessibility to primary healthcare services in the country between 2010 and 2014 indicates that the Thimphu district had the highest spatial accessibility to primary health care services in the country, followed by Mongar, Sarpang and Gasa districts. Furthermore, Bumthang district portrayed the best improvement in the health care services whereas Wangdi Phodrang district portrayed worst deterioration in the healthcare services between 2010 and 2014.

This study has exclusively considered the computational aspects of accessibility indices. It has not undertaken analysis of spatial or non-spatial relationships between accessibility indices and other socio-economic variables underpinning the developmental aspects of a country. For policy and planning purposes, it is crucial to understand the variation in accessibility indices between different regions based on their socio-economic status. Therefore, one of the future tasks is to conduct exploratory studies between various accessibility indices and socio-economic variables.

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