# A Robust Approach to Determining Under-served Settlements for Health Using Geographic and Spatial Coverage Modelling in Bauchi Local Government Area

Isah Mohammed Bello<sup>1\*</sup>, Kabiru Ibrahim Musa<sup>2</sup>, Atagbaza Ajiri Okpure<sup>3</sup> <sup>1</sup>Information Technology, Central University of Nicaragua, Managua, Nicaragua <sup>2</sup>Management Sciences, Abubakar Tafawa Balewa University, Bauchi, Nigeria <sup>3</sup>World Health Organization, African Regional Office, Congo -Brazzaville

### Abstract

Access to health care services with the assurance of affordable, low-cost, and quality services that is available to people is one of the core components of universal health coverage (UHC). The United Nations (UN) has included the achievement of UHC by the year 2030 as part of the 3rd component of the SDG, which is aimed at ensuring healthy lives and promoting well-being for all ages, in the overall Sustainable Development Goals (SDG). The number of people lacking access to essential health services continues to increase. Hence, the need for close monitoring of the mode and pattern of accessibility to basic health care services becomes crucial as population growth continues to expand in many of the low-and-middle-income countries (LMIC). This study examined the geographic and spatial accessibility of the primary health care network in the Bauchi Local Government area of Bauchi State – Nigeria through open data and geospatial analysis techniques. The study identified settlements/populations that are not covered (under-served) by any health facility (HF) in the local government and the geographical network coverage of the HFs in the LGA. It also highlights the factors that are influencing accessibility to guide policymakers on equal distribution of health care facilities towards reducing inequality in accessibility. Different data sets on HF locations, population, and settlement point was used. The study opens ways to closing inequality in access to health care services, which will further support the effective and efficient delivery of health care services in similar resource settings towards achieving UHC.

*Keywords*: Bauchi Local Government Area, Geographic Accessibility, Health Care Facilities, Spatial Coverage Modelling, Universal Health Coverage, Under-served Settlements.

## Introduction

Universal Health Coverage (UHC) is one of the main components of the health policy debate since the shift to Sustainable Development Goals, with heath care access being central to the entire concept of UHC. It is context-specific, having different definitions as regards to seeking care, the ability to get care, and the actual delivery of care. Penchansky's conceptual framework of availability, accessibility, affordability, acceptability, and accommodation includes accessibility as one of the issues linked to access and utilization [1], with spatial accessibility being encapsulated as part of the entire components. Accessibility is defined as the elements that stand between the feeling of need and the realization of utility [2]. To effectively determine accessibility to health care services, the need for having a reflection on the family/ individual's ability and mobility, including the time required to reach the service based on the need established by the potential user of the health service, this differs from prospective accessibility, which just indicates the availability of a service regardless of whether it is successfully accessible [3]. Meanwhile, the development from prospective to realized access is influenced by spatial accessibility, which measures trip impedance (distance or time) between patient location and service sites.

One of the United Nations' aims is to achieve the third target of the SDGs, which is to ensure healthy lives and promote the well-being of people of all ages, with the disparity in geographic access to health care services being one of the key hurdles to attaining these goals. There are an estimated 400 million people who do not have access to essential health services, prompting the United Nations (UN) to include the achievement of universal health coverage (UHC) in the SDGs by 2030, based on the two main components of equal access to high-quality health care services and financial protection [4]. Adequate access to health care services is one of the defining characteristics of a developed society since health is the most vital part of human life. However, in Sub-Saharan Africa, the availability of services is typically placed over accessibility, particularly by politicians and other decision-makers [5, 6].

The World Health Organization (WHO) has recommended the use of Geographic Information Systems (GIS) as part of information and communication technology solutions to address health system resilience and inefficiencies in universal health coverage [7]. The use of geospatial data is directly affecting the function of every country's public health system, which are monitoring community health, ensuring universal access to the most cost-effective and appropriate care, making policies in solving local and national health problems. Measuring accessibility generally lies within four general categories as documented by different studies; gravitational models for provider influences, service providerpopulation ratios, distance to the nearest service provider, and the average distance to a set of service providers [3, 8].

The study of spatial accessibility as related to health care services concentrates on the spatial potential approaches that is affected by time and distance. Measuring distance in a straight line does not provide the true picture of the accessibility to the service provider due to varied road distance, terrain, quality, seasonal variation, and the population that is within the catchment area of the health facility [9]. Therefore, the aspect of transport network elevation and other natural barriers provides a more accurate estimate. One study had opined that the efficiency of rasterbased techniques as compared to network analysis in areas with rudimentary/dilapidated infrastructure and road networks. Raster-based analvsis overcomes the limitations of straight-line distance models and network analysis by incorporating both network and off-network modes of travel and allowing for a complex array of barriers. It is hence, preferred in rural, remote, and topographically challenging settings [10].

Several studies have considered the use of 'spatial' or geographic access to health service provision. Some of these studies had considered distances to health facilities or services measured using straight lines or road distance, which were analyzed to quantify differences in accessibility, gaps in service provision, towards identifying inequality [11], examining equity of access to health services for different social groups [12, 13], modelling spatial patterns of accessibility and utilization of facilities [14, 15]. Use of GISbased technologies in the evaluation of geographic and or physical access to health facilities [16, 17], the use of spatial and geographic statistics in determining the best allocation of resources towards minimizing gaps in service provision, and identifying users with low access [18], exploring geographic variation in access models [19], and advanced heuristic search techniques for health facility location optimization [20]. All these studies have, in one way or another, recognized the different dimensions of health care accessibility and have generally used a specific model of the spatial or geographic definition of 'access' using quantitative analyses of distances and travel times to health caser services to define service accessibility. However, there were limited studies that attempt to provide a detailed analysis that will determine underserved settlements for health care services based on proximity and coverage using the Euclidean distance and Raster-based approach.

This study intends to use a robust approach to model the spatial accessibility and network coverage of the primary health care network in the local government area (LGA) towards determining under-served settlements. The spatial coverage and geographic accessibility in this study will provide a clear list of settlements that are not served by any health facility in the local government area and will serve as a powerful tool, which can be used to support policymakers in decision making for planning and resource allocation at the local government level and will also aid in addressing issues related to location-allocation in the LGA. The rationale of this study is to demonstrate the existence of significant spatial variations in spatial coverage and geographical accessibility of the health care facilities in the local government, it will enable health planners to identify potential locations for sighting new health facilities to maximize the achievement of increased accessibility.

#### **Materials and Methods**

#### **Study Area**

The study area is Bauchi Local government, which is the capital city of Bauchi state. It is one of the most populated local government areas in Nigeria, with twenty (20) political wards com-

prising both urban (9) and rural (11) wards. Bauchi state is geographically located in the North-Eastern part of Nigeria and referred to as the gate to the North-Eastern states, being the only state in the sub-region that is bounded by at least one state in the remaining three (3) Northern geopolitical zones (Kaduna, Jigawa and Kano States in North-West Zone, Plateau from North-Central Zone and Gombe, Taraba and the Yobe States in the North-East Zone). It is located between latitudes  $9^{\circ}$  3' and  $12^{\circ}$  3' north of the equator and longitudinally between 8° 50' and 11° east of the Greenwich meridian. It has two vegetation covers (Sahel and Sudan Savanna), with an altitude of 785.2 meters. Its average raining season is experienced from mid-June to mid-October, with the month of August having the most rainfall, at 340 mm. The average annual rainfall is 1,091.4 mm. The hottest temperature is experienced between the months of April - May, with the highest temperature of 40.56OC, while the coldest temperature (harmattan season) is between December - January having a minimum temperature of 6.11°C and 7.22°C, respectively.

Bauchi LGA is bounded by seven local governments, which include Kirfi, Ganjuwa, Alkaleri, Tafawa-Balewa, Dass, and Toro. According to the 2006 population census, the LGA has a population of 493,810, an estimated projected population of 693,700 with a 3.4% growth rate in 2016, and an area spanning 3,687 square kilometers with population density of 215.5 per square kilometer. The LGA has a literacy rate of 26.60% and has more than 19 different tribes. It is relatively impoverished with majority of its population leaving below poverty line.



Figure 1. Map of Study Area showing Political Wards

#### **Study Design**

The design employed in this study is the combination of vector and raster approaches to depict the spatial coverage network of the health care facilities and determine the under-served settlements in the study area (Figure 2). The analysis was conducted using datasets from different sources and taking into consideration different alternatives that ensure the delivery of health care packages, including childhood immunization.

Spatial data of health facilities was obtained from the GRID-3 project, including the population estimates, the local government and ward administrative boundaries, and the settlement points. Geoprocessing models for this analysis include the creation of Euclidean distance buffer zones (5km and 2km) generating catchments of physical distances from each settlement to a health facility using spatial vector analysis, overlaying spatial analysis to identify the relationship between settlements and the location of health facilities to ascertain accessibility for health care services, conducting geographic coverage analysis to show the spatial distribution of health facilities and the population to assess whether all settlements are served by the existing health facilities. These analyses were carried out using ArcGIS Pro.

#### Datasets

All the data sources used as input for the spatial analysis and for modelling accessibility, geographic coverage, and determining the underserved settlements in the local government were derived from the GRID-3 data hub. All input datasets were clipped to the administrative boundaries of the local government area by administrative wards.

Being the capital city of the state, the local government area houses other health facilities belonging to the federal and state government, respectively. The health care facilities represented in the study site are all public health facilities in the local government, area classified into teaching hospitals (TH), specialist hospitals

(SH), military/para-military hospitals, which provided tertiary services, General hospitals (GH) and Comprehensive health centers (CHC) which provides secondary healthcare, while Primary health centers (PHCs) serves as the first point of contact between the population and General Hospitals, and health centres/ health posts are available to the rural population at the lowest level. There are a total of 173 health facilities in the local government, comprising of 1 of the teaching hospital, specialist hospital, and general hospital, respectively. Two (2) Comprehensive health centers, (86) primary health care centres (94), dispensaries/health posts (45), maternities (19), educational, medical clinics (3), and 2 military/para-military hospitals.



Figure 2. Map of the study area showing Health Facility Coverage

#### **Spatial Modelling**

Feature-based Proximity analysis measuring physical accessibility was done by creating a two-ring buffer around the health facility location in ArcGIS Pro. This was done by employing a feature-based proximity tool to create vector polygons at two varied specified buffer distances enclosing the spatial location of settlements centroids. Euclidean buffers were chosen over Geodesic buffers as features were concentrated in small and scattered areas. The buffers circumscribed 2 km and 5 km distances for fixed and outreach for health care service delivery. Settlement layers were overlaid on the facilities buffer created (2km and 5km), and a spatial join was performed to discern settlements that are within 2km buffer (fixed delivery), 5km (outreach delivery), and outside the buffers indicating settlements that are not served by any of the health facility within the local government. The geographic coverage analysis defines catchment areas that are associated with each facility within the buffers created, and assessing the proportion of the under-served population was undertaken. This analysis does not consider the availability of services (i.e., the capacity of the health facilities to deliver the services) and travel time to reach the facilities, which are subjected to physical accessibility constraints.

#### Results

The simplest way of proximity analysis is encapsulated by Euclidean buffers by generating catchment-based maps, and it is based on physical distances from the settlement's centroids to the health facilities, as illustrated in Figure 3. The map depicts the number of settlements covered by each health facility, which are highlighted by overlaying the settlements within the facility 2km buffer for fixed services (where the catchment population visits the HF to obtain services), and a 5 km buffer for outreach services (the HF staff visit the population on selected days/time to provide services), defining the service areas covered by the health care facilities, suggesting adequate accessibility. The settlements in the catchment area of each health facility (both fixed and outreach services) are denoted by blue dots and black dots, respectively, while the settlements represented by red dots denote settlements that are not covered by any health facility in the local government (underserved).



Figure 3. Map showing HF Coverage and Location of Settlements Served and under-Served by Each HF

The findings summarized in Table 1 can be linked to Figure 3, where the actual number of settlements by political wards are listed, showing good accessibility for fixed and outreach services (within 2 km and 5 km radius). The settlements outside the 5km buffer are considered not served by either of the two (2) strategies of fixed and outreach. Using the 2km buffer, the proportion of settlements with no coverage (underserved) is 48%, with Kundum Durum ward having the highest percentage (73%), and Dan- Iya ward having only 1%. However, after extending the radius to 5 km, the proportion of settlements with no coverage reduces to 11.2%, with Tirwun and Birshi wards having 32% and 1.5%, respectively.

Wards	Total HF [N]	Total Settlements [N]	Settlements/HF Ratio [%]	Settlements for Fixed Services (2km) [N]	Settlements for Outreach Services (2km - 5km) [N]	Settlements Under- served (>5km) [N]	Proportion of Under- served Settlements [%]
Birshi	12	259	22	147	108	4	1.5
Dan Amar A	4	53	13	53	0	0	0.0
Dan Amar B	8	102	13	102	0	0	0.0
Dan Dango	4	132	33	53	72	L	5.3
Dan Iya	28	155	9	154	1	0	0.0
Dan Kade	4	71	18	71	0	0	0.0
Dawaki	3	67	32	97	0	0	0.0
Galambi	10	224	22	103	110	11	4.9
Gwaskwaram	5	125	25	41	60	24	19.2
Hardo	2	38	19	38	0	0	0.0
Kangere	11	300	27	<i>LL</i>	159	64	21.3
K/Durum	8	248	31	67	139	42	16.9
L/Katagum	9	150	25	82	64	4	2.7
Makama A	14	91	L	91	0	0	0.0
Makama B	7	80	11	80	0	0	0.0
Miri	6	187	21	66	76	12	6.4
Mun-Munsal	10	166	17	59	96	11	6.6
Tirwun	16	430	27	147	123	160	37.2
Yamrat	7	168	24	47	111	10	6.0
Zungur	5	102	20	31	63	8	7.8
Grand Total	173	3.178	18	1.639	1.182	357	11.2

Table 1. Summary of Settlement Analysis Indicating No of HF, Served Settlements, and under-served Settlements by Ward

Additionally, there were buffers that were overlapping (for both 2km and 5km buffers), suggesting sub-optimal allocation of services in all the urban wards (8), representing 40% of the total wards in the local government. However, an approach using isodistance in determining accessibility is prone to underestimating the actual population that is under-served. Therefore, to properly estimate travel time by adopting to the type of environment in which one is traveling while considering physical barriers, like the road network, elevation, and landscape variation will be undertaken in the next manuscript, which will factor these barriers to determine accessibility.

#### Discussion

Efforts to minimize the lack of accessibility to health care services through improving the availability and quality of services towards achieving UHC will not be achieved when barriers to accessibility (poor infrastructure, inadequate HF, long distances, transportation, etc.) are not addressed. Most populations are unable to physically access health facilities within the appropriate timeframes with ease. Geographical accessibility is difficult to measure for an entire population.

In this analysis, an investigation of geographic accessibility and spatial coverage modeling of the existing health facility network in the Bauchi Local government was conducted. The study illustrated how spatial data may be integrated and analyzed using GIS techniques to support policymakers in making decisions towards optimizing resource allocation. It brings out the number of settlements/villages that are not served by any of the existing health facilities in the local government, thereby defeating the efforts to limit disparity in access to basic health services, which is the main component of UHC. The results are convergent with other studies conducted in similar rural and remote settings [21-23]. Another important issue affecting inadequate accessibility is the number and location of health facilities providing services. In this

study, the urban wards have an average of 15 settlements to an HF, whereas, in the rural wards, it is 25 settlements to an HF, indicating more HF in the urban areas as compared to the rural areas. This is in line with studies that suggest greater accessibility in urban areas as compared to rural areas[24–26]. Moreso, it can be seen that there is good geographical access to health facilities in the urban wards, which are the most populated areas in the local government, with more health facilities located in the highly populated urban area compared as compared to the rural wards, which is in agreement with what has been reported in other studies [27]. The disproportionate distribution of HF is evident from the aggregation level, where the settlement to HF ratio tends to be higher in urban wards because they are mostly overpopulated and hence the need to consider demand as part of the characterization of accessibility. Therefore, there is the need to consider equity in the sighting and locating of health facilities, with more emphasis on rural, scattered, and hard-to-reach areas to address the inequality towards achieving UHC.

Although in the context of this study, coverage for accessibility is delineated by creating buffers at various levels of impedance based on the Euclidean (straight-line) distance. Hence, the results are sensitive to the choice of method because studies have shown that the distance method tends to over-estimate the population, as is widely emphasized by many pieces of literature [28]. Studies had also modeled distances traveled to health facilities, revealing that the Euclidean distance model tends to overestimate population by an average of 18% [29], and this could be explained by the use of isochrone maps in Euclidean measures, which assumed that everyone in close vicinity of the area has the same probability of access. This assumption is circumvented in the literature by employing a distance decay function with the more realistic premise that the facility serves a defined catchment area and that the population's pull to those services reduces as one moves away from the facility. But it has a limitation of ambiguity when selecting

the appropriate distance decay function in relation to the impedance coefficient. Hence, the need for estimating the travel time in relation to the distance as it gives the best indicator of travel impedance, especially in rural and scattered locations that have difficult terrain and multiple modes of transportation. Additionally, when relative access to suitable transportation and its associated cost in the local environment are considered, inaccessibility becomes more obvious.

In this study, an argument arises from a prudent assumption that the population will travel to the nearest health facilities since travel impedance to the nearest provider has been deemed to be an accurate measure of spatial accessibility in remote settings, especially when the choices are limited. This can fit in well with the context of Bauchi local government, where the majority of the population resides in the rural wards with access to only public health facilities and very limited or few private facilities operating in these wards, as they are mostly concentrated in the urban wards.

The scope of this study can be expanded to analyze to include travel times taking into consideration all the barriers to accessibility. Additionally, the study can further be enhanced to integrate temporal variation with different modes of travel scenarios to produce a complex multidimensional array of access possibilities, which will further support dynamic interactivity.

#### Conclusion

This study is conducted in one of the most populated local government areas in the northern region with a combination of both rural and urban settlements, and it is the capital city of Bauchi state with all the characteristics of settlements that are populated, scattered, hard to reach and geographically isolated where topographical adversities and institutional factors that affect access to healthcare services are present. The study is spatial modeling to determine an underserved settlement for health care services towards identifying barriers to equity inaccessibility. The study depicts the power of GIS and the need for an evidence-based geospatial approach in determining settlements that are not covered by any HF towards increased transparency in decision making and to better understand the geographical impediments that are retarding the achievement of UHC. The framework used in this study can be generalized since the LGA has a combination of both urban and rural (difficult) settings.

The findings from the study are like other studies that highlight accessibility problems being faced in many countries in sub-Saharan Africa. Hence, the findings may be used for advocacy to policymakers towards improving universal access to health coverage. Improving accessibility to health facilities could be achieved through the creation of new HF and appropriately locating HF in locations that have low accessibility and with may under-served settlements in the local government to ensure equitable access to health services by all populations.

#### **Authors' Contributions**

IMB conceptualized the study, wrote the original draft, and served as the guarantor for the paper. IMB and AAO compiled the data sets and did the analysis. KIM provided comments and edits. All authors contributed to reviewing and editing the manuscript. All the authors have read and agreed to the final manuscript.

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#### **Conflicts of interest**

None.

#### **Ethical Approval**

Not required. This analysis used data from GRID-3 which is publicly available.

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