A geospatial approach to assess health coverage and scaling-up of healthcare facilities

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The UN Sustainable Development Goals seek universal health coverage and accessibility to quality healthcare services by 2030 for creating a healthier and equitable world. This study highlights the role of geospatial model in assessing the geographic coverage of healthcare facilities in Manipur, India, and the need for scaling-up of the existing health centres in the region. A geodatabase on the existing healthcare facilities has been developed in the study. Mapping of health centre facilities, coverage analysis and scaling-up assessment are carried out using ArcGIS and AccessMod. The model results show that locations of the existing healthcare services are significantly spatially clustered amongst themselves, with an observed mean distance of 2.62 km. Scaling-up analysis considering the projected population of 2020 indicates the requirement of 66 new health facility centres, mostly in the hill districts of Manipur. This study indicates the need for scaling-up healthcare facilities that can cover the entire population in each district of Manipur. It also indirectly addresses one of the fundamental aspects of the healthcare system, i.e. equity in the distribution of healthcare facilities and their accessibility to all sections of the society.

Keywords: Geospatial model, health care facilities, scaling-up analysis, universal health coverage.

ACCESS is defined as 'the ability to secure a specified set of healthcare services, at a specified level of quality, subject to a specified maximum level of personal inconvenience and cost, while in possession of a specified amount of information'[1]. The main principle of nearest for equity is equal access for those in equal need for healthcare[2].

The UN Sustainable Development Goals (SDGs) seek universal health coverage and accessibility to quality healthcare services by 2030, for creating a healthier and equitable world. According to India's vision for health and its perspectives from the XII five-year plan (2012–17), it has been documented that the focus remains on public provisioning of quality healthcare at affordable cost and bridging disparities in accessibility to healthcare services across regions and communities[3]. However, it is observed that the distribution of public and private healthcare facilities in many developing countries is always a challenge due to variations in health facility coverage and population density, which are found to occur at different geographic levels. Understanding the spatial relationship between locations of existing healthcare centres and physical accessibility to them are considered to be important factors for decision-making by the policy makers[4,5].

For the establishment of any new healthcare centre, the major task is to identify the most appropriate location so that local populations can access it without any difficulty. Various factors like existing healthcare facilities, land use land cover (LULC), road network, human population of the region, topography, physical barriers like rivers, lakes, etc. should be taken into account. This will help decision makers to determine the distribution of the existing network of healthcare facilities of a region and how much of the population of the region is covered.

Geospatial technology (GIS, remote sensing and GPS) has a potential role in monitoring and mapping the distribution of healthcare services and understanding the prevalence of diseases in a region[6–11]. Various past studies have highlighted developments in the areas of health GIS, i.e. particularly where it is effectively used for mapping and monitoring the geographic accessibility of healthcare centres by population groups to address the disparities and inequalities; study the prevalence of disease burden and map the spread of any epidemic in a particular region both in spatial and temporal domains[12–16]. Various techniques like hotspot analysis, floating catchment area method, nearest neighbour method, buffer zone analysis, location-allocation analysis, Moran's I method, ordinary least square (OLS) and geographically weighted regression (GWR) method are found to be effective to address various public health-related issues, both in the spatial and temporal context in past studies[17,18].

A literature survey showed that there was lack of detailed studies regarding the spatial characteristics of health facilities in Manipur, North East India, particularly the geographic patterns and accessibility. Considering the topography of the region, it often takes an average of about 2–3 h for a patient to reach any healthcare location, specially tertiary/district hospitals in remote and hilly regions. Hence it is important to study the spatial

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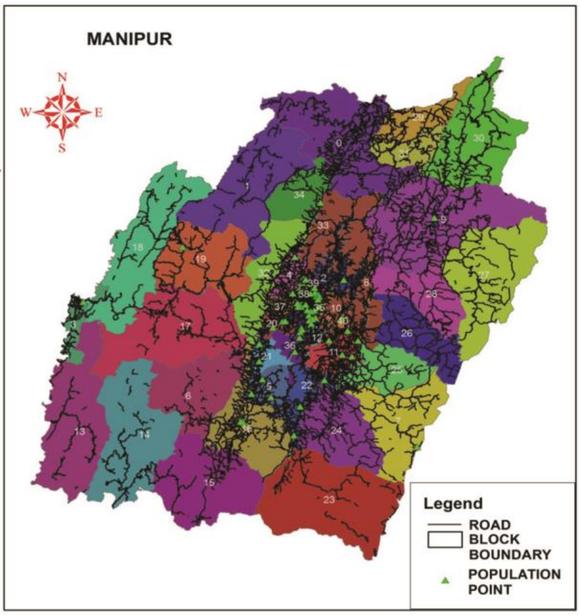

BLOCK NAME

FID	BLOCK	FID	BLOCK
0	MAO MARAM	20	NAMBOL
1	TAMEI	21	BISHNUPUR
2	SWOMBUNG	22	KAKCHING
3	JIRIBAM	23	CHAKPIKARONG
4	LAMSANG	24	CHANDEL
5	MOIRANG	25	MACHI
6	HENGLEP	26	KASOM KHULLEN
7	TENGNOUPAL	27	KAMJONG
8	SADAR HILLS E	28	PHUNGYAR
9	UKHRUL	29	PAOMATA
10	SADAR HILLS E	30	CHINGAI
11	THOUBAL	31	PURUL
12	LILONG	32	SAITU GAMPHAZOL
13	TIPAIMUKH	33	SADAR HILLS EAST
14	THANLON	34	SADAR HILLS WEST
15	SINGNGAT	35	KEIRAO BITRA
16	CHURACHAND	36	WANGOI
17	NUNGBA	37	PATSOI
18	TOUSEM	38	LAMPHELPAT
19	TAMENGLONG	39	POROMPAT
		40	KEIRAO BITRA

Figure 1. Map of India showing the location of Manipur with block boundary, road network and population concentration centres.

distribution of existing healthcare facilities and the need for identification of locations where new healthcare facilities may be established to increase population coverage of the region. In this study, AccessMod (ver. 5) developed by the World Health Organization (WHO) was used to evaluate the physical accessibility analysis of the existing network of healthcare facilities and the need for scaling them up based on geographic coverage analysis in Manipur[19,20].

Methods

Study area

Manipur lies between 23°50′–25°41′N lat. and 92°58′–94°45′E long. with an area of 22,327 sq. km (Figure 1). Majority of the population is found to be concentrated in the valley region which is about 10% of the total geographical area, while the remaining population is found in the hilly region which is almost 90% of the geographical area of the state[21].

Geographically, this region comes under complex terrain, and is characterized by poor infrastructure, economic underdevelopment and disturbed area status. According to the Census of India, 2011, Manipur has a population of 2,855,794, of which 57.2% lives in the Imphal valley (10% of total area) and 42.8% resides in the hilly region (90% of the total area). There are nine districts in Manipur, of which four are located in the valley region and five districts make up the hilly region. On 8 December 2016, seven new districts were created by bifurcating the existing districts (five hill districts and two valley districts). This study considers the administrative boundaries that correspond to nine districts. Figure 2 shows the urban–rural population distribution for each district.

The State Programme Implementation Plan (SPIP) 2010–11, State Health Society, Manipur under National Rural Health Mission (NRHM), India mentions that ‘the existing physical infrastructure of health institutions in the state, which should be further augmented by NRHM, were actually in abysmal position to begin with. To that extent, the onus on NRHM was huge, as the task of having standard physical infrastructure of health institutions was to begin from the scratch effectively. For creation of physical infrastructure of health institutions, preference is given to inaccessible and most difficult areas. This may ensure better attendance of healthcare personnel, which, in turn, is expected to enhance delivery of health services to the underserved and the neediest’[22,23].

In light of the above discussion, Manipur was selected as the study area in which there is large inequality in the existing healthcare infrastructure. According to the ‘Rural Health Statistics 2012’ report under the Division of Statistics, Ministry of Health and Family Welfare, Government of India (GoI), there is a shortfall of 213 Primary Health Sub-Centres (PHSCs), 14 Primary Health Centres (PHCs) and 7 Community Health Centres (CHC) in rural areas of the state[24]. It is to be noted that since Manipur is included under the Hill Area Development Programme, the total rural population was considered to

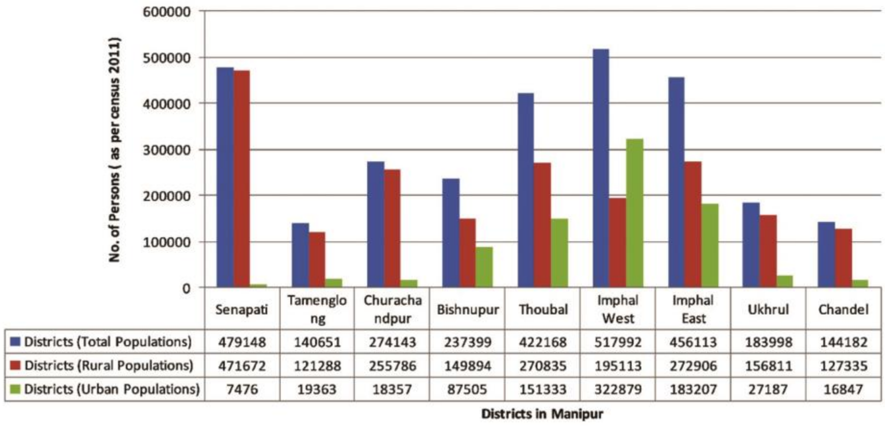

Figure 2. Population by residence in the districts of Manipur (according to Census 2011, Government of India).

Table 1. Distribution of public and private healthcare facilities in different districts of Manipur, India

District	Primary Health Sub-Centres (PHSCs)	Primary Health Centres (PHCs)	Community Health Centres (CHCs)	Sub-divisional hospital (SDH)	Districts hospitals (DH)	State and central government-run hospitals	Private/ clinics/ hospitals
Bishnupur	33	7	2	0	1	0	3
Chandel	26	6	1	1	1	0	1
Churachandpur	65	11	1	0	1	0	12
Imphal East	54	11	2	0	0	1	20
Imphal West	51	9	2	0	0	1	55
Senapati	66	14	2	0	1	0	1
Tamenglong	29	6	1	0	1	0	0
Thoubal	57	13	5	0	1	0	6
Ukhrul	40	8	1	0	1	0	2
Total	421	85	17	1	7	2	100

be from hilly/tribal areas. In total, there are 420 PHSCs, 80 PHCs and 16 CHCs in the rural areas of Manipur state.

Geodatabase and methodological approach

For this study, primary data and information on location of health facilities were collected by conducting GPS survey in different parts of Manipur. In addition, secondary data on healthcare facilities (both public and private) were collected from various health organizations in the state like the State Health Society, Manipur under NRHM and the Health Directorate, Government of Manipur. From the data about healthcare facilities, a geodatabase on their location was generated in which 421 PHSCs, 85 PHCs, 17 CHCs, One Sub-Divisional Hospital (SDH), seven District Hospitals (DH) and two State/Centrally funded public hospitals have been geo-tagged and field-verified for use in the study. For private hospitals and clinics registered under the Medical Directorate, Government of Manipur, locations of 54 out of 100 private healthcare facilities have been geo-tagged and updated in the geodatabase. Table 1 shows the distribution of healthcare facilities used in this study.

Tertiary-level hospital infrastructure data of Regional Institute of Medical Sciences (RIMS), Imphal were collected for 2015 and 2017. In addition, elevation data (SRTM DEM, spatial resolution of 30 m), LULC map (Landsat 8–30 m spatial resolution), road network data and districts/sub-districts base vector layer of Manipur obtained from North Eastern Space Applications Centre, Government of India, Shillong, demographic/census data (according to Census 2011) and gridded population data for 2015 and projected for 2020 (1 km) were extracted from Gridded Population of the World (GPWv4)[25].

The conceptual framework described and implemented in AccessMod (ver.5) software has been implemented in this study. It utilizes analytical capabilities of GIS to examine geographic aspects of the healthcare system[19,20].

Various geospatial parameters like LULC layer, road network layer, elevation layer, population coverage capacity (PCC), settlement layer, and geodatabase of the location of existing healthcare facilities are generated using ArcGIS. All these generated data layers, i.e. both raster and vector data are used as primary inputs for the model. For this study, spatial resolution of 30 m and projected coordinate system (UTM) are used for all the data

Table 2. Travel scenario requirement for accessibility to existing healthcare centres in Manipur

Class	Description	Speed (km/h)	Mode
1	Water bodies# (small streams and ponds along roadways)	3	Walking
2	Settlement areas	8	Walking
3	Vegetation	4	Walking
4	Agricultural land	5	Walking
5	Barren land	5	Walking
6	Main road	60	Motorized
7	Secondary road	40	Motorized
8	Tertiary road	30	Motorized
9	By foot	2	Walking

#Small streams and ponds which are connected with small bamboo bridges can be traversed by foot only. Information on travel speed on a motorized roadways has been obtained from the Transport Department, Government of Manipur.

layers. Generation of each raster and vector layer for the model is described in the Supplementary Table 1.

Input data on travelling scenario and population coverage capacity in tabular form were generated. To incorporate the mode of transportation and travelling speed of a patient through varying topography of the region, a travelling scenario text file was prepared. Based on the mode of accessibility in different LULC classes found in the region, this file describes the modes of transportation – as walking or motorized – along with their speed (Table 2).

PCC for different types of healthcare facilities was computed. For population coverage estimation, norms issued by the high-level expert group report on universal health coverage for India, instituted by the Planning Commission, GoI during 2011 were adopted. It has been recommended that a PHSC should cover a population of 5000 (or 3000 in a remote, dangerous location); PHC about 30,000 or more (20,000 in remote areas) and CHC about 120,000 people in urban areas or 80,000 people in remote/tribal areas[26]. It is to be noted that PCC for CHC according to the norms is 120,000, but as given in the Rural Health Statistic report, a CHC in Manipur covers a population of 1–3 lakhs.

Health infrastructure data for the year 2015 and 2017 from RIMS, Imphal were obtained to compute PCC for 2015 and 2017. PCC was computed using the formula provided in AccessMod 5 (ref. 20).

Here we provide an example to estimate PCC for 2015 (Table 3). PCC capacity of a tertiary-level hospital = $(A \times B \times C)/(D \times E \times F)$, where A is the average no. of beds (1000 nos at RIMS), B the occupancy rate (55%), C the number of days in a year (365 days), D the total number of patients visiting RIMS per year divided by total population of Imphal valley (0.21), E the assumption that 15% of patients seek admission at tertiary-level hospitals (15%) and F is the average length of stay at the hospital (5 days).

Therefore, average PCC of RIMS (corresponding to 2015) = 1000 × 55 × 365/0.21 × 15 × 5 = 1,274,603.1.

PCC for a tertiary-level hospital (RIMS) for 2017 was computed as 900,886.36 using occupancy rate of 48.87% and average length of stay as six days. For the projected year 2020, PCC was computed as 1,801,772.72 by considering the projected population of 2020.

The model was set-up for spatial catchment analysis of the existing healthcare facilities in the region using the generated input parameters as discussed earlier. The model integrates the travelling time, PCC and population distribution to generate the catchment area of each health facility. Maximum travel time of 60 min for PHSC, 90 min for PHC and 120 min for CHC has been assigned in the model. The results represent catchment areas of the existing healthcare network. Based on this analysis, a population grid layer has been generated which indicates the spatial location of the populations not covered by the existing healthcare facilities of the region.

Subsequently, scaling-up analysis was performed to assess the requirement of establishing new healthcare centres in the region. This analysis seeks to address the requirement of new healthcare centres in the region to meet the expanded population. Catchment area and scaling-up analysis were performed for 2015, 2017 and the projected year 2020.

Results

Spatial data analysis of the existing healthcare facilities network

An exploratory spatial data analysis was carried out to determine the distribution of the existing healthcare facilities (Figure 3). Standard distance analysis, directional distribution analysis, kernel density mapping and nearest neighbour analysis were carried out[18]. It was found that most of the existing healthcare facilities in the region are concentrated within a radial distance of 4.75 km from a mean centre located at the central part of Imphal valley. From directional distribution analysis, the direction of the

Table 3. Population coverage capacity corresponding to 2015

Health facility type	Minimum population	Maximum population	Population coverage capacity
PHSCs	0	20,000	5000
PHC	20,001	80,000	30,000
CHC + SDH	80,001	1,400,000	300,000
Research institute and hospitals (RIMS, Imphal, as a model)	1,400,001	3,000,000	1,274,603.17

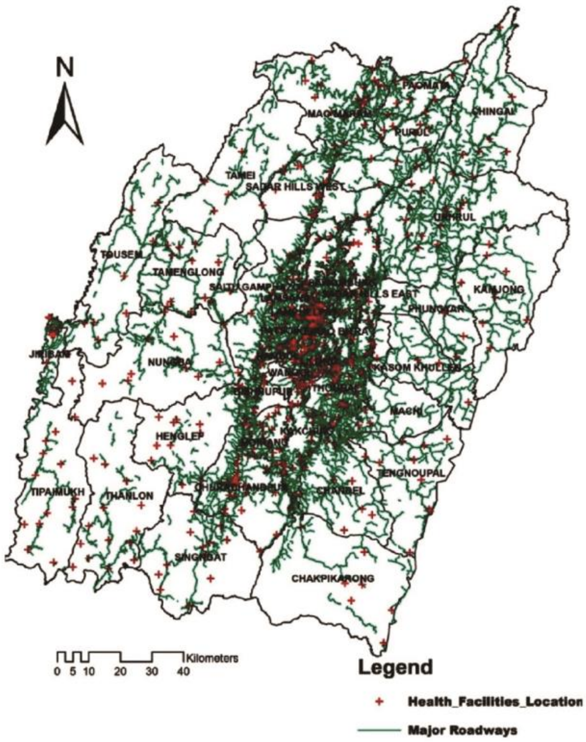

Figure 3. Locations of existing healthcare facilities in different sub-districts of Manipur.

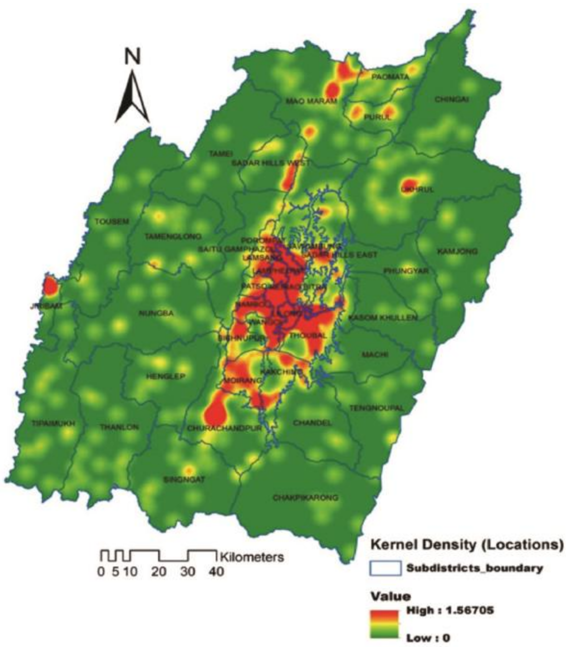

Figure 4. Density mapping of healthcare facilities in Manipur.

axis of standard deviation ellipses appeared that the skewed distribution towards the northeast–southwest of the region, which is indicative of higher distribution of existing healthcare facilities in the northeastern and southwestern regions of the state. As shown in Figure 4, the output from the kernel density estimation of the existing healthcare facilities in the state is found to be highly concentrated in the Imphal valley. This is largely attributed to the very high population density in the valley compared to the hilly region of the state. It was observed from the nearest neighbour analysis that the locations of healthcare facilities are significantly spatially clustered amongst themselves, i.e. with an observed mean distance of 2.62 km and an expected mean distance of 3.56 km. It can be concluded from the analysis that given a *Z*-score of –12.16, there is less than 1% likelihood that this clustered pattern observed in the distribution of healthcare facilities is a result of any random choice.

Existing healthcare facilities location coverage analysis

Figure 5 shows the results of location coverage analysis for the existing healthcare facilities in Manipur.

Based on this analysis, it can be clearly observed that all the districts in the valley area of Manipur are well covered and connected with existing healthcare facilities, i.e. Imphal East, Imphal West, Bishnupur and Thoubal districts. On the contrary, population in the hilly districts, i.e. especially in the northeastern, northwestern and southern parts of Manipur, and particularly the border areas was found to be insignificantly covered by the existing catchment area of the healthcare network. This may be attributed to the absence of proper serviceable road network connectivity in the interior border areas and sparse population density in the hilly region compared to the valley area. The state government has highlighted that lack of proper roadways poses hindrance to providing necessary healthcare facilities to people in the interior villages of the hilly districts in Manipur. Ukhrul, Churachandpur, Chandel, Tamenglong and Senapati are such hilly districts that need intervention towards provision of basic medical facilities and opportunities, in addition to providing road and air ambulance services to the interior villages in these districts. The model results clearly show the spatial distribution and coverage area of the existing network of healthcare facilities in the region.

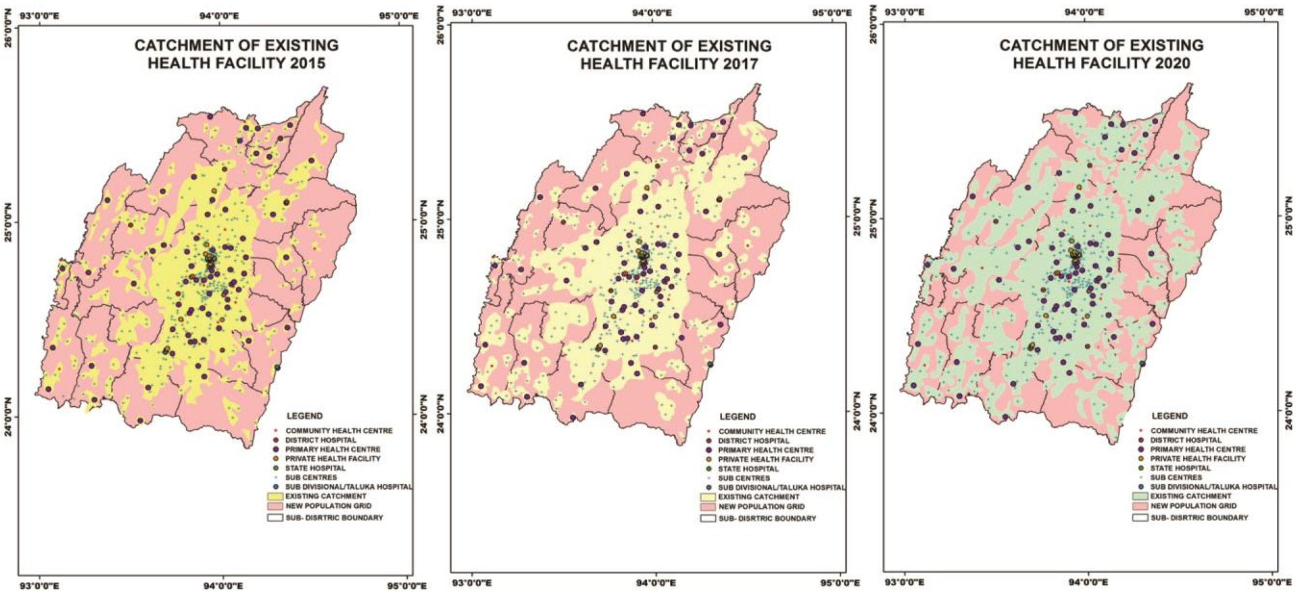

Figure 5. Catchment areas of the existing healthcare facilities in different sub-districts of Manipur for 2015, 2017 and 2020.

Using a travel-time grid with maximum duration of 60 min, accessibility of the existing healthcare network to the local population was analysed for two districts in Manipur, viz. Imphal West (valley district) and Ukhrul (hill district; Figure 6). We found that large populations of Imphal West district could access the existing healthcare facilities within a travel-time duration of 60 min. One of the reasons is the availability of a large number of private health facilities in this district, in addition to the government healthcare facilities. In case of Ukhrul district, accessibility of healthcare centres by the population is rather limited within the travel-time duration of 60 min. A time duration exceeding 60 min was necessary, except for the population residing within 10–15 km radial distance of the healthcare centres. This may be attributed to the rugged terrain configuration, non-uniform/sparse population density within the district, as well as poor road network connectivity between the existing healthcare centres and interior villages/population centres.

This assessment on catchment area and accessibility to existing healthcare centres indicates the need for scaling-up of the existing healthcare facilities so that the entire population in each district of Manipur can be covered.

Scaling-up analysis of healthcare facilities

Using the generated population grid layer and the corresponding PCC studied for each type of health facility, scaling-up analysis was performed to assess the need for establishing new healthcare centres in different districts of Manipur.

Table 4 summarizes the scaling-up analysis of healthcare centres in Manipur. It was found that there is need for establishing new healthcare centres in Ukhrul, Chandel, Senapati, Churachandpur and Tamenglong districts, regardless of their type. For all the assessment years, it was found that Ukhrul district requires maximum scaling-up of healthcare facilities ranging from 7 in 2015 to 17 in 2020. On the other hand, the valley districts of Manipur, i.e. Thoubal, Imphal West, Imphal East and Bishnupur need lesser scaling-up of healthcare facilities compared to the hilly districts. There was no requirement for scaling-up healthcare facilities in Imphal West district for 2015 and 2017, except for the projected year 2020, with requirement of just two more such facilities.

Scaling-up assessment provides us a clear understanding on the existing network of health facilities of the region and the need to provide new healthcare facilities in different districts of Manipur. A detailed assessment of the geographic locations of the new scaled-up healthcare facilities corresponding to 2017 is provided in the Supplementary Table 2. Assessment of the proposed healthcare locations was carried out by checking for the presence of any existing healthcare centres within a buffer of 5 km from the proposed scaled-up facilities. Referring to the spatial distribution of scaled-up locations for year 2017 (Figure 7), most of the proposed scaled-up healthcare facilities are situated close to existing PHSCs and some of the new centres are situated near existing PHCs.

Since the assessment takes into account topographic factor, existing road network of the region, existing LULC distribution, population distribution and location of existing health facilities, the predicted results of the model will provide first-hand information for expansion of facilities in the region. Some of the locations predicted by the model have been cross-checked and verified on the ground using GPS.

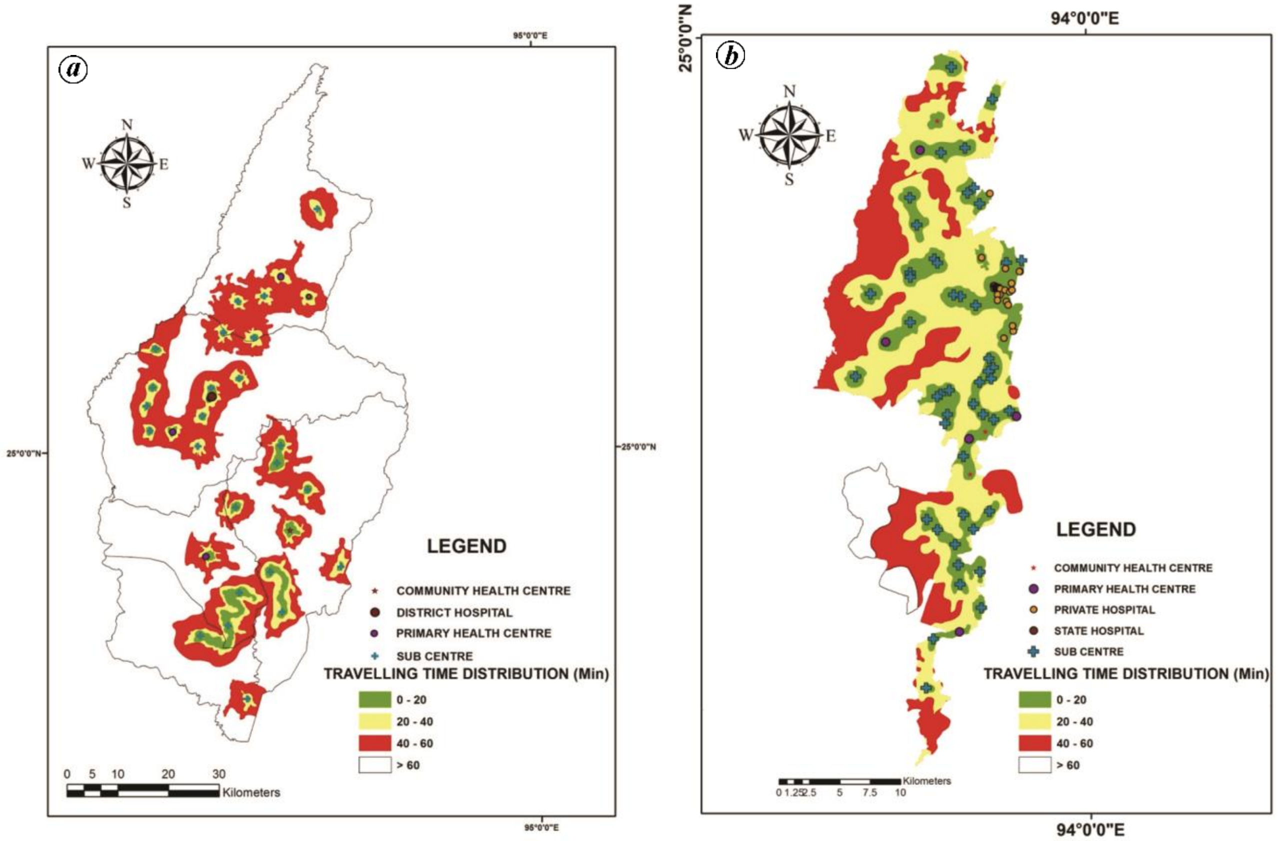

Figure 6. Accessibility of the existing healthcare network to local population in (***a***) Ukhrul district and (***b***) Imphal West district of Manipur.

Table 4. Summary of existing and scaled-up healthcare facilities in various districts of Manipur

District	PHSCs	PHCs	CHCs	SDH	DH	State and central government-run hospitals	Private clinics/ hospitals	Scaled-up healthcare centre (2015)	Scaled-up healthcare centre (2017)	Scaled-up healthcare centre (2020)
Bishnupur	33	7	2	0	1	0	3	2	4	4
Chandel	26	6	1	1	1	0	1	6	7	13
Churachandpur	65	11	1	0	1	0	12	5	7	8
Imphal East	54	11	2	0	0	1 (JNIMS)	18	2	2	4
Imphal West	51	9	2	0	0	1 (RIMS)	54	0	0	2
Senapati	66	14	2	0	1	0	1	3	4	8
Tamenglong	29	6	1	0	1	0	0	4	4	8
Thoubal	57	13	5	0	1	0	6	0	0	2
Ukhrul	40	8	1	0	1	0	2	7	9	17
Total	421	85	17	1	7	2	101	29	37	66

JNIMS, Jawaharlal Nehru Institute of Medical Sciences, Imphal; RIMS, Regional Institute of Medical Sciences, Imphal.

Discussion

This study demonstrates the role of geospatial technology in the monitoring and assessment of distribution of the healthcare facilities network. It addresses the need for timely update of health geodatabase and monitoring the spatial and temporal distribution of the existing healthcare facilities. It also addresses the need for scaling-up healthcare facilities to increase population coverage in remote areas and inaccessible regions. AccessMod (ver. 5) was used to evaluate physical accessibility analysis of the existing healthcare facilities network, and geographic coverage and scaling-up analysis in Manipur.

The assessment of catchment area analysis and accessibility to existing healthcare centres in different districts of Manipur indicates the need for scaling-up the existing healthcare facilities, so that the entire population in each district of Manipur can be covered. It was observed that all the districts in the valley area of Manipur were well covered and connected with the existing healthcare

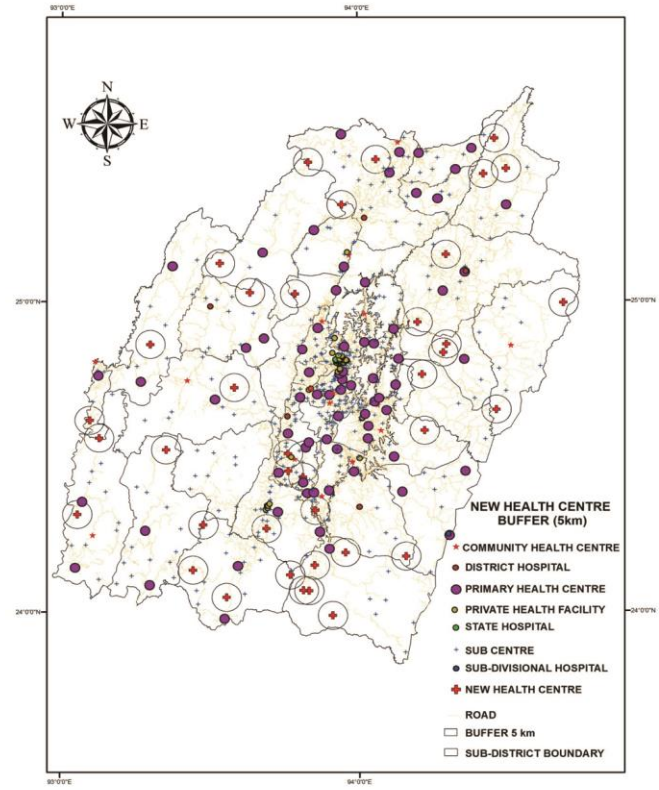

Figure 7. Spatial distribution of the existing and scaled-up healthcare facilities for 2017.

facilities, while the population in the hilly regions/ districts, especially in the northeastern, northwestern and southern parts of Manipur, and particularly the border areas were found to be insignificantly covered by the existing catchment area of the healthcare network. The scaling-up analysis shows that there is need for establishing new healthcare centres in Ukhrul, Chandel, Senapati, Churachandpur and Tamenglong districts.

Analysis on the financial budgeting and manpower requirements for the expansion and setting up of new healthcare centres in the region has not been done in the present study. Under SPIP 2010–11, it is categorically mentioned regarding the financial as well as non-financial incentives for health personnel working in inaccessible and most difficult high-focus districts of Tamenglong, Churachandpur, Chandel and Ukhrul[22]. This measure will ensure the presence of health personnel at their respective healthcare centres, which is critical to the success of healthcare services. As an extension of this study, socio-economic factors can be intergrated within the model framework to access the feasibility and cost–benefit analysis of setting up new healthcare centres.

Conclusion

This study addresses the need for geospatial-based assessment of the existing healthcare facilities at both spatial and temporal scales, which will provide a clear understanding towards addressing better health planning and policy development in Manipur. The outcome from this type of study will help policy makers and planners to take effective decisions and allocate funds in a rational way for development of new healthcare facilities. This study also addresses one of the fundamental aspects of primary healthcare system, i.e. equity in the distribution of healthcare facilities and their accessibility to all sections of the society.

Conflicts of interest: The authors declare no conflict of interest.

Ethical approval statements: ‘This research does not involve any human subjects and only secondary data on health facilities and GPS locations data were utilized for mapping purpose.’- Not Required: Exemption from IEC Review (IEC-NIT MANIPUR).

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