

GIS-BASED SITE SUITABILITY ANALYSIS FOR HEALTHCARE FACILITY DEVELOPMENT IN TACLOBAN CITY, PHILIPPINES

*Marian Stephanie R. Lao¹, Maria Cecilia R. Paringit², and Stephen Ross L. Roleda³

^{1,2,3} Department of Civil Engineering, De La Salle University, Philippines

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ABSTRACT: The suboptimal distribution of healthcare facilities in the Philippines causes issues of inequity in access and sufficiency. Even within Metro Manila, this concentric distribution is evident, wherein most of the facilities are located within the central business districts. Within Tacloban City, the same concentric pattern can be observed, with six of the seven total healthcare facilities located within the south and situated close to the urban core. This study had focused on the spatial distribution of the different healthcare facilities to identify the most vulnerable communities. By utilizing GIS and the Modified Huff Three-Step Floating Catchment Area (MH3SFCA) model, the spatial accessibility of each community had been quantified. Site Suitability maps were then generated using different criteria, considering spatial accessibility index (SPAI), designated institutional land, and designated non-producing agricultural land as suitable areas for future healthcare facility development. These criteria were considered by the local government policies on land which may be used for the development of healthcare facilities. The results of the study had determined that the city experiences issues in spatial accessibility, specifically in terms of medical access and sufficiency. Through the addition of a northern test facility, as determined through the site suitability map, it had shown significant improvement in the overall probability of interaction, supply-demand ratio, and SPAI of each community. The implementation of GIS-MCDA and the MH3SFCA model has shown significant potential for creating a framework for healthcare development that is sustainable and efficient in terms of medical provision and accessibility.

Keywords: Healthcare Facility, GIS, Spatial Accessibility, MH3SFCA, Site Suitability

1. INTRODUCTION

The uneven distribution of healthcare facilities (HCFs) is still prevalent across the Philippines. Issues of inequity in access and sufficiency have surfaced due to the spatial maldistribution of HCFs [1]. This is counterproductive to fulfilling the right to quality health care that every individual is entitled to [2]. In Metro Manila, the hospitals depict a concentric distribution pattern, meaning most are in the urban core (Fig. 1) [3]. Tacloban City in Eastern Visayas mirrors the same trend. Across Tacloban's 138 barangays (i.e., smallest political unit in the Philippines), six of the seven major HCFs are located downtown. (Fig. 2). Notably, the most populous barangays are in the north while only having one hospital in proximity. The single northern facility in Eastern Visayas Regional Medical Center – Cabalawan (EVRMC-C), is also known for its high service capability (Level 3) and large bed capacity (500) [4-6]. Therefore, it was found to have the highest referral cases locally and from the neighboring areas, resulting in overcapacity [4]. Numerous development plans in the north have already commenced decentralizing the downtown [4, 5]. Thus, it is expected to have a significant increase in the potential demand in EVRMC-C. With the spatial distribution of HCFs, ever-increasing and surging demand (e.g., COVID-19 cases), and rapid

urbanization within Tacloban City, the city's health system is at risk.

Recognizing that there is inequity in access and sufficiency due to the uneven spatial distribution of HCFs, the underserved shall be given utmost priority in healthcare planning. Currently, the only existing policy in local hospital zoning states that HCF site selection (HSS) is upon the discretion of the local government unit (LGU) [7]. Therefore, this study aims to assess the spatial

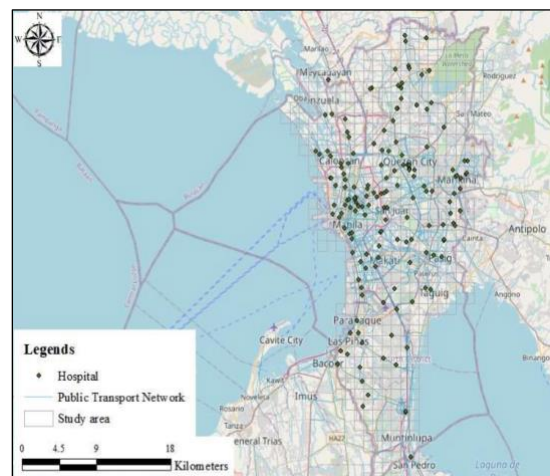


Fig. 1 Distribution of Hospitals within Metro Manila, Philippines [3]

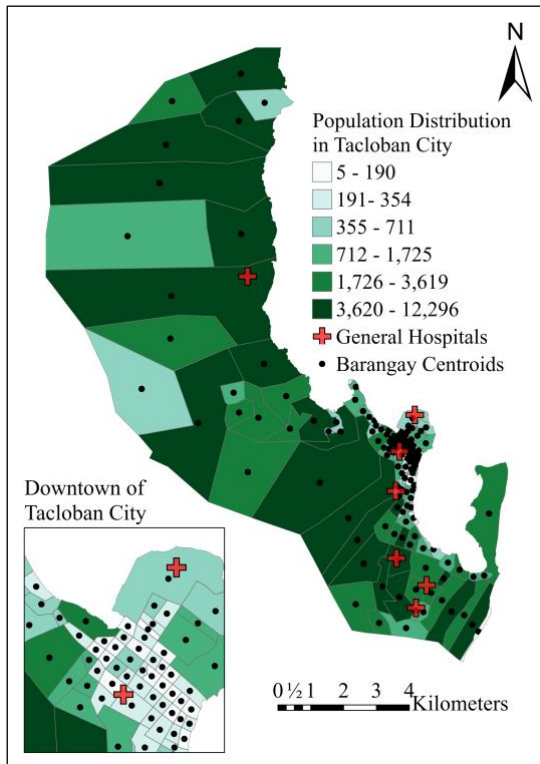


Fig. 2 Distribution of Tacloban City hospitals

distribution of HCFs to identify the underserved areas, leading towards developing a data-driven HSS process.

1.1 Healthcare Facility Site Selection

HSS requires a rigorous decision-making process to achieve an efficient allocation of medical services [8-11]. Hence, the multicriteria decision analysis (MCDA) was employed within a geographic information system (GIS) tool, hereinafter called GIS-MCDA. Among the typical criteria in HSS [12], this study has mainly considered the potential medical demand, location (barangays and HCFs), and governmental direction. In brief, the map criteria were narrowed into two: a) spatial accessibility index (SPAI) and b) land use.

In this study, the spatial aspects of access to health services, specifically accessibility and availability (bed capacity), are primarily considered in identifying the underserved [13, 14]. Conversely, nonspatial dimensions are excluded in the analysis due to the lack of relevant data from the LGU (e.g., barangay socioeconomic data). The previous approaches that have been used to address the issues of inequity have primarily centered around spatial accessibility [15, 16]. Hence, overestimation and underestimation of supply

(HCF) have been evident in earlier studies [15, 16]. The common methods such as Floating Catchment Area (FCA) fall under the most acceptable measure of spatial accessibility which is the gravity model [17]. Various derivations of the FCA method have been widely used in healthcare studies to quantify the accessibility to HCFs [18-25]. 2SFCA and E2SFCA are two-step processes of calculating the supply-demand ratio and the accessibility [24, 25]. Although both methods account for the demand within a predetermined service threshold, weights are applied to E2SFCA to depict the effect of distance decay [20]. To further refine the earlier models, the competition among service sites was accounted for to better delineate the accessibility of HCFs. Thus, the 3SFCA includes measuring the probability of interaction between consumers and service sites to quantify accessibility based on competition and the supply-demand ratio [19, 23].

However, the 3SFCA posed the same deficiency as the 2SFCA. Thus, Luo [22] resolved this by applying Gaussian weights, which can be denoted as the Modified Huff Three-Step Floating Catchment Area (MH3SFCA). Although Gaussian weights have already been used in previous methods, this implements a continuous Gaussian distance decay function to effectively delineate the most realistic healthcare-seeking behavior [10, 20, 22]. Generally, health consumers are willing to visit hospitals that may be farther depending on the available services, bed capacity, affordability, medical specialists, and hospital reputation [10, 26].

Since this study considers the same general medical consumer behavior, the MH3SFCA can best depict the current spatial accessibility of communities to the HCFs. Therefore, the resulting SPAI is used to identify the highly suitable sites for HCFs, along with the allocated land areas for HCF development.

2. RESEARCH SIGNIFICANCE

Since every individual has the right to quality health care, medical services shall be strategically deployed. Thereby, focusing on sufficiency and accessibility as two spatial dimensions of access to health care would aid in the effective distribution of health sites to accommodate the ever-increasing demand. Recognizing the areas with poor access to healthcare facilities would also be beneficial in proactive hospital site selection. Thus, this approach may be integrated into initiating a data-backed healthcare planning within a region. Therefore, equity in access and sufficiency could be attained, contributing to health equity.

3. METHODOLOGY

To properly examine the distribution of HCFs in Tacloban City, the local City Health Officer (CHO) and City Planning Development Office (CPDO) were consulted accordingly. CHO and CPDO were also the main sources for the pertinent local data: a) hospital information (quantity, address, bed capacity, and service capability), b) city and land use shapefiles, and c) peak traffic data [5, 27, 28]. The hospital coordinates and the peak traffic condition were also cross-referenced to OpenStreetMap and Google Maps, respectively. Meanwhile, the 2020 census track was lifted from the Philippine Statistics Authority (PSA). Further, a qualitative needs assessment was conducted to magnify the root causes of drastically varied accessibility to HCFs among barangays (communities).

Before conducting the MH3SFCA and GIS-MCDA, the study area was set up by importing the pertinent shapefiles (i.e., administrative city map, hospitals, and land uses) within ArcGIS. Which, the network analysis was carried out in the software to obtain the OD (origin-destination) travel time matrix and 30-minute catchments (per barangay and hospital). For the concept of catchments in the study, this was likened to the service area. It shall be noted that the peak traffic data (6 p.m. on Mondays) was also applied in the network analysis. The adopted travel time threshold to hospitals of 30 minutes was lifted from Deiters and Voigtländer's [29] study, being the concluded general standard. Further, this study is limited to private vehicles as the transit mode. The network analysis outputs were then inputted in the spreadsheet to perform the MH3SFCA.

3.1 Modified Huff Three-Step Floating Catchment Area

The MH3SFCA method consists of calculating the following:

Step 1 (Probability of Selection):

This step computes for the probability of interaction ($Prob_{ij}$) between the population locations (i) and HCFs (j) within the catchment of i , depicting the competition among HCFs (Fig. 3). Furthermore, hospital selection is also dependent on the magnitude of attractiveness (S_j , S_k) and the distance decay effect (W_{ij} , W_{ik}).

Step 2 (Supply-Demand Ratio):

To quantify the sufficiency of HCFs, the supply-demand ratio is obtained, with $Prob_{ij}$ factored in (Fig. 4).

Step 3 (Spatial Accessibility Index):

Lastly, the SPAI is computed to obtain the respective spatial accessibility index of each population location to HCFs. Thereby, this incorporates the principles of availability within a threshold (30-minute catchment) and distance decay effect (Gaussian weight) (Fig. 5).

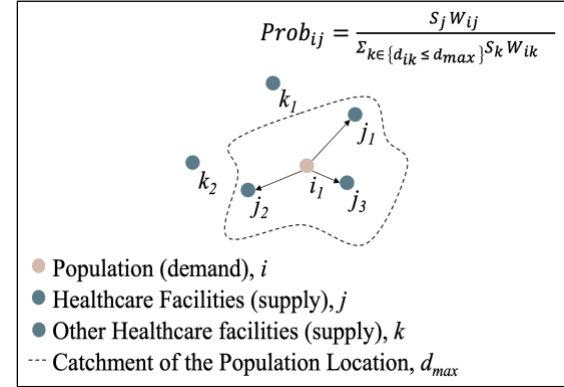


Fig. 3 Visualization and equation for the probability of selection of the MH3SFCA

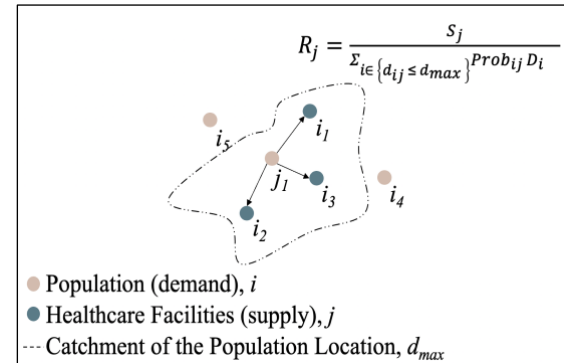


Fig. 4 Visualization and equation for the supply-demand ratio of the MH3SFCA

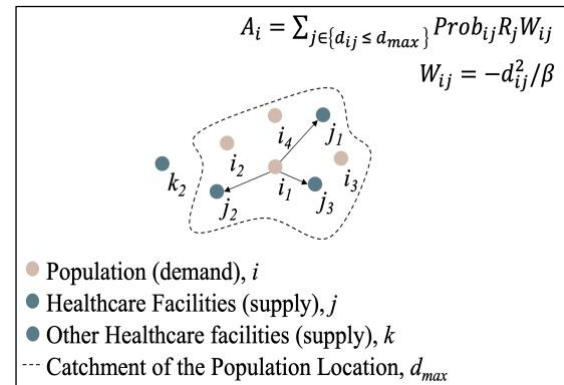


Fig. 5 Visualization and equation for the spatial accessibility index of the MH3SFCA

3.2 Modeling the Site Suitability Map

The site suitability map was then generated in ArcGIS by integrating the criteria (i.e., GIS-MCDA), SPAI map, and land use map. In this study, two cases were prepared to deduce the more viable scenario according to the city's land-use plan for HCF zoning [27, 28]. The primary site suitability map, however, strictly considers the currently designated land parcels for HCFs (i.e., institutional).

3.3 Healthcare Site Selection Process

Consequently, an arbitrary site among the resulting candidate sites was selected to plot an HCF test point. The test point was set to have similar characteristics with the most in-demand and advanced HCF within the city. Particularly, the test point was designated in an area where most barangays have poor accessibility to HCFs. This was conducted to validate the hospital site selection (HSS) process in this study. In which, the metric of success is an increased SPAI in the underserved areas.

4. RESULTS AND DISCUSSION

The data on the proposed land use plan of the city from 2017 to 2025 and the healthcare status of the city were obtained from the local City Planning and Development Office (CPDO) and the City Health Officer (CHO). Specifically, the policies of the local government had specified that institutional land may be converted for hospital or healthcare site development. This same policy applies to idle or non-producing agricultural land plots.

Network analysis was conducted through ArcGIS software to produce the OD travel time matrix. The origin and destination considered for the study included each barangay centroid and healthcare facility. Travel time results had determined that the minimum and maximum travel time had been 0.37 minutes and 34.95 minutes, respectively. Figure 6 shows the catchment (i.e., service) area, with the origin based on each barangay centroid. The threshold for the catchment area was set at a 30-minute driving time. This had been conducted to pinpoint which HCFs were considered for the computation of probability of interaction (i.e., MH3SFCA Step 1). The travel time results from each OD pair and the catchment areas had been utilized within the MH3SFCA model. The catchment areas of each healthcare facility had also been determined with a 30-minute threshold. Figure 7 shows the barangays which are within the service area of each healthcare facility.

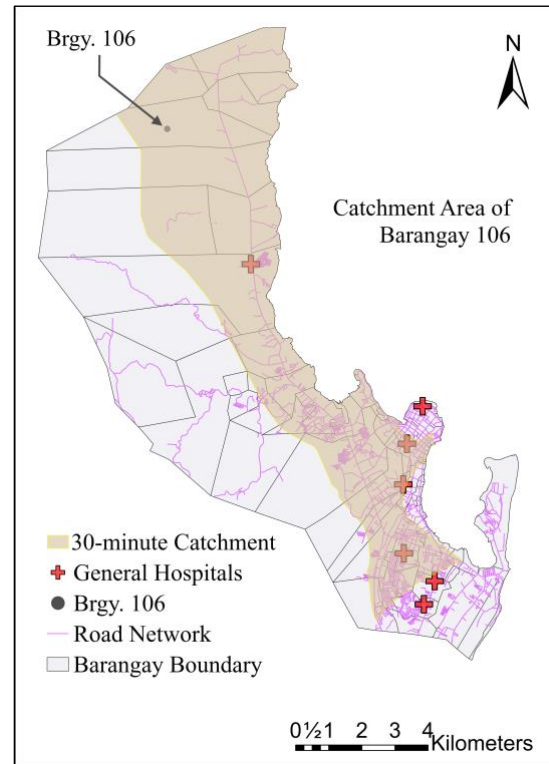


Fig. 6 30-min. catchment of Barangay 106

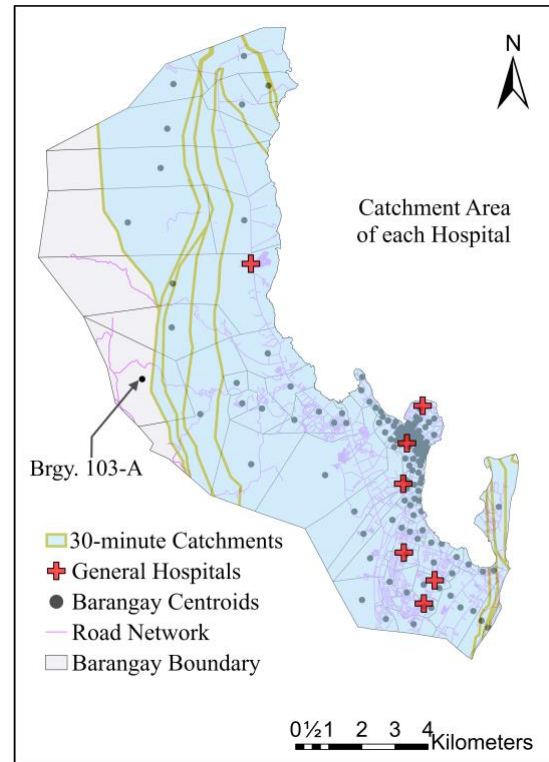


Fig. 7 Catchment areas of the healthcare facilities

Notably, Barangay 103-A is not serviceable within 30 minutes for any HCFs within the city.

The results of the MH3SFCA model are the SPAI indices, which are indicators of the spatial accessibility from each barangay towards the HCFs. Figure 8 is the generated SPAI map, wherein the red land plots represent communities with low spatial accessibility and green indicates high spatial accessibility.

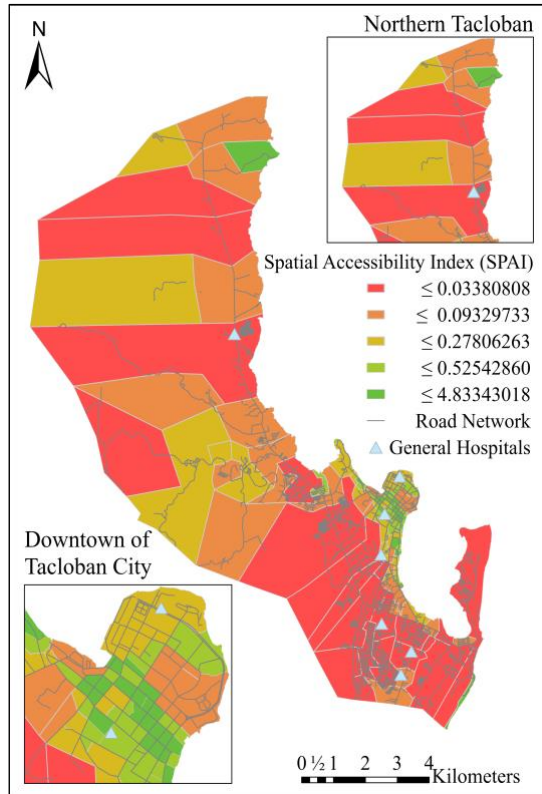


Fig. 8 Spatial Accessibility Indices of each barangay

4.1 Generated Site Suitability Maps

The generated site suitability maps considered the land use and the SPAI of each barangay within the city. For the first scenario (i.e., Case A) the criteria included areas with low SPAI and only the institutional land plots. For the second scenario (i.e., Case B), similar considerations were included with the addition of the agricultural land areas. The site suitability maps are shown in Figures 9 and 10. Based on the generated site suitability map for Case A, the determined suitable areas are generally towards the north. While there are areas that are determined as suitable within the central business district, the development of healthcare facilities in these sites would be suboptimal due to the lower number of catered patients.

The addition of the agricultural land areas in the analysis had greatly increased the number of suitable sites. While greater potential is shown in Case B, this scenario is more volatile and

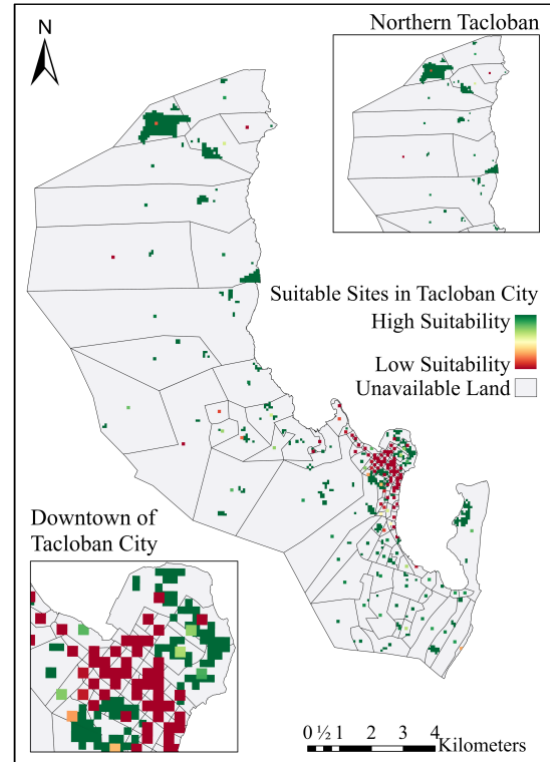


Fig. 9 Site Suitability map for case a

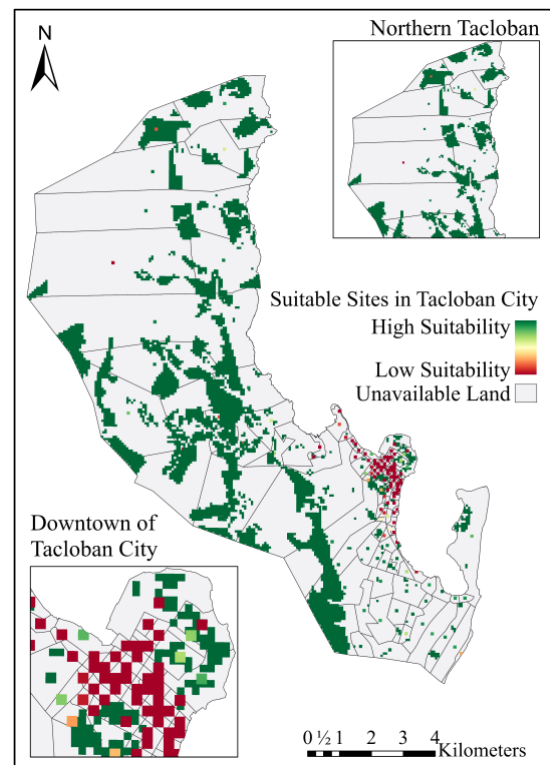


Fig. 10 Site Suitability map for case b

unreliable due to the policies and lack of accurate field data. Since the policy of the local government indicates that only non-producing agricultural

areas may be converted for healthcare site use, more research is required. Since this scenario considers even the active agricultural land areas, the suitable sites are reduced.

4.2 Addition of a Healthcare Facility in Northern Tacloban

To test the validity of the generated site suitability map, a test healthcare facility had been introduced into the network. For the addition of the test facility, Case A was considered as the primary site suitability map. The introduced HCF had been arbitrarily determined to be within the northern portion, having similar characteristics as EVRMC-C. The test facility would feature a Level 3 general hospital classification, with a public ownership type, and a bed capacity of 1,500. The process of conducting the MH3SFCA and re-generating the SPAI map had been conducted with the addition of the test HCF.

The results of the addition of the test healthcare facility are shown in Figure 11. The map shows the proposed scenario with the northern test facility represented by the white circle.

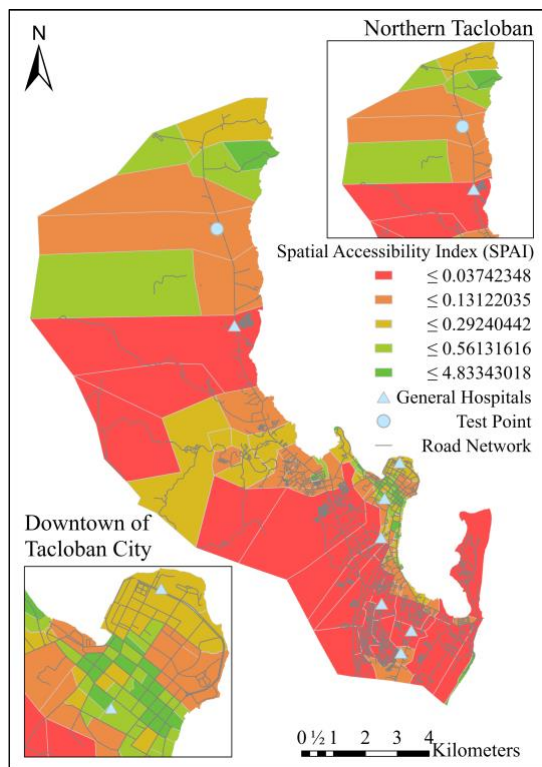


Fig. 11 SPAI map of the test scenario after inclusion of test HCF

Having introduced the test facility, the generated SPAI map had shown significant improvement within the northern sections, as compared with the base scenario (Fig. 9).

The summary of the catchment data is shown in Table 1. It was determined that only 127 out of 138 barangays had access to all HCFs within a 30-min. driving time for the base scenario.

Table 1 Catchment results summary

HCF reached in 30 minutes considering barangay as origin	Num. of Barangays (base)	Num. of Barangays (test)
8	N/A	124
7	127	4
6 or fewer	11	10
Total	138	138

Compared to the base scenario results, the accessibility had improved. It was determined that 124 out of 138 barangays were able to reach all the eight healthcare facilities, while only 10 barangays had access to six or fewer.

Furthermore, it was determined that the supply-demand ratio and the accessibility indices had increased. Figure 12 displays the superimposed results for both the base and the proposed scenario. Having introduced the test facility, the supply-demand ratio had increased and had become more evenly distributed. Since the supply-demand ratio quantifies the relationship between the potential medical demand based on barangay population and the overall supply (i.e., bed capacity), increased ratio values indicate increased capability for medical provision. Moreover, the improved distribution among the different communities shows that more barangays are serviced due to the addition of the test healthcare facility.

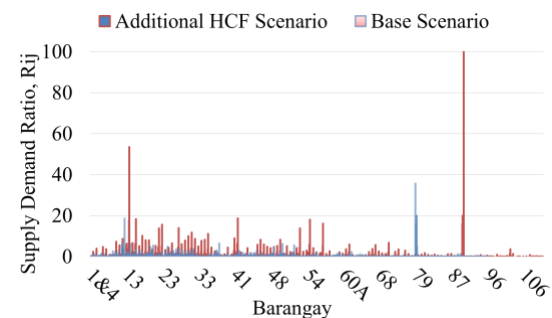


Fig. 12 Supply-demand ratio for base and test scenario

The same pattern is observed for the accessibility indices, as shown in Figure 13. While the results show minimal improvements in the accessibility indices, the highlight of this graph is the increased accessibility of the northern communities. The

blue bars, representing the base scenario values, are observed to be left-skewed. Since the lower numbers on the x-axis indicate areas closer to the central business district, it supports the original idea wherein the areas farther from the city's urban center generally have lower spatial accessibility. Compared to the test scenario values, the data had shown improvements, more specifically towards the areas which are farther from the central business district.

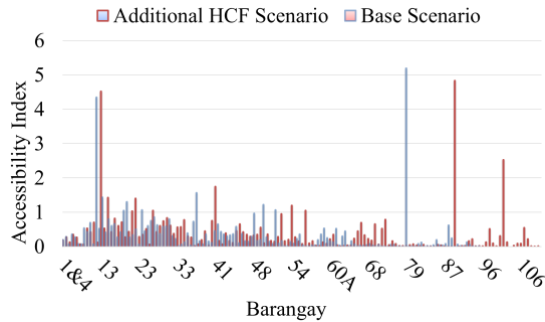


Fig. 13 Accessibility index for base and test scenario

The improvements which were observed from the generated SPAI map, and the charts have proven that the addition of an HCF within a suitable site is highly beneficial. Particularly, the study highlighted the potential improvements to the distribution of healthcare facilities.

5. CONCLUSION

The results of the study had determined the issues in spatial accessibility of the different healthcare facilities in Tacloban City, specifically issues of inequity in terms of access and sufficiency. With the use of the MH3SFCA model, the generated SPAI map and Site Suitability maps had been generated. The spatial accessibility index values for barangays (i.e., community) in the city were generally low, with the highest SPAI values located within or close to the city's central business district. The trend of SPAI values was observed to be decreasing as the distance from the central business district increased and approached the northern portion of the city. In addition, the generated Site Suitability maps had indicated that the most suitable areas for development are towards the north and away from the central business district. Having introduced a test facility in one suitable site located in the northern portion of the city, significant improvements were observed. These improvements include better interaction probability, a higher supply-demand ratio, and higher spatial accessibility indices.

Through the conducted site suitability analysis of the different HCFs, it was revealed that the issues of the inequity of access and sufficiency may be aided by data-backed procedures. Specifically, through the implementation of the MH3SFCA model and strict policies on suitable sites, the issues of spatial accessibility and insufficiency may be significantly improved. Ultimately, development may become more sustainable and more efficient in terms of medical service provision and distribution.

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