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MAPA: Mapping Access for Public Health Assessment Through Geographic Information System (GIS) and Catchment Area Analysis

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MAPA: Mapping Access for Public Health Assessment Through Geographic Information System (GIS) and Catchment Area Analysis

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ABSTRACT

Access to healthcare remains crucial in determining the well-being of a community especially in urban and rural areas. This study aims to assess the spatial accessibility of hospitals in Tagum City using the Quantum Geographic Information system (QGIS) application, a type of Geographic Information System (GIS), and the Enhanced Two-Step Floating Catchment Area (E2SFCA) method. Utilizing four main datasets which are the administrative boundaries, population distribution, road networks, and hospital location. The datasets were processed in QGIS and with the E2SFCA model accessibility scores were calculated for population groups, children (ages 0-9), adolescents (ages 10-19), adults (ages 20-59), and elderly (ages 60 & above), these were then visualized through maps. It is found that those with higher E2SFCA scores have better access to healthcare facilities, barangays located in the southern and peripheral zones have the lowest scores indicating that their access to hospitals is limited. Barangays such as Magugpo Poblacion, Canocotan, and Magugpo North showed high accessibility, meanwhile over half the city showed low accessibility, specifically the rural barangays like Pandapan, New Balamban, San Agustin, and Cuambogan. This emphasizes that due to longer travel times, poor connection, and the lack of infrastructures are major barriers in healthcare accessibility. Though interestingly, central barangays also ranked low due to their population size, 56.52% of the city scores low, overall, distance alone does not determine healthcare accessibility. The findings highlight the unequal distribution of hospitals in Tagum City, emphasizing the need to target health infrastructure planning for the better development of the city.

Keywords: Geographic Information System (GIS), Enhanced Two-Step Floating Catchment Area (E2SFCA), Healthcare Accessibility, Spatial Accessibility, Population, Road Networks, Maps

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INTRODUCTION

Rationale

Access to healthcare remains a major factor on the well-being of a community. In Tagum City, there are noticeable disparities in healthcare access, particularly between urban and rural barangays. While hospitals and clinics exist across the city, many residents in remote areas still face challenges such as long travel distances, limited transportation, and inadequate road networks, all of which reduce their chances of receiving timely medical care. Previous studies on healthcare accessibility in the Philippines have often focused on regional or national scales, overlooking the barangay level where local accessibility issues are more visible. Through the use of Geographic Information System (GIS) technology, these disparities can be analyzed spatially to determine which communities are most underserved.

This study aims to assess the spatial accessibility of healthcare facilities in Tagum City using GIS and the Enhanced Two-Step Floating Catchment Area (E2SFCA) method. Specifically, it seeks to identify the level of healthcare accessibility across barangays, determine areas with insufficient access, and generate maps that visualize these findings. The research makes use of datasets including administrative boundaries, population distribution, hospital locations, and road networks, all processed through QGIS. By integrating population data with travel time and facility capacity, the study provides a comprehensive overview of healthcare accessibility in the city.

The scope of this study is limited to analyzing physical accessibility and does not include factors such as healthcare quality, socioeconomic status, or medical service efficiency. Despite these limitations, the results of this research are expected to provide valuable insights for local government units, city planners, and health officials. By identifying underserved areas and accessibility gaps, the study contributes to data-driven planning and equitable resource allocation. Ultimately, this research emphasizes the importance of GIS as a tool for promoting inclusive and sustainable healthcare systems in Tagum City.

Research Questions

This study aims to answer the following questions:

1. Which barangays in Tagum City have the greatest need for improved healthcare access based on spatial accessibility data?

2. How does spatial proximity to healthcare facilities influence accessibility levels among barangays in Tagum City?

REVIEW OF RELATED LITERATURE

Spatial Accessibility

Spatial accessibility is defined as the capability of individuals or communities to access healthcare facilities, especially hospitals. Studies indicate that increased travel times and distances decrease access to services, particularly during emergencies (Delamater et al., 2019). GIS can be used to model the travel times and service gaps which underserved areas (McGrail et al., 2017). Rural populations are usually left behind because they lack facilities, inadequate infrastructure, and transport restrictions (Kanuganti et al., 2015). These differences frequently delay the diagnosis and treatment (Vallee et al., 2020), and accessibility is also influenced by road networks, the presence of public transport, and the capacity of facilities (Neutens, 2015).

Geographic Information System (GIS)

The Geographic Information System (GIS) is essential in determining the accessibility of healthcare through the integration of both spatial and non-spatial data. It enables the mapping of travel distance, travel time, and population distribution, revealing differences in the service coverage (Leyso & Umezaki, 2024; Salvacion, 2022). Catchment area analysis and accessibility modeling methods indicate regions with poor healthcare delivery. GIS in this study is applied to map the location of hospitals in Tagum City and analyze the accessibility of these hospitals in terms of distance, speed of travel, and population. These can equip policymakers with facts to fill healthcare gaps and serve underserved communities.

Quantum Geographic Information System (QGIS)

The open-source GIS software QGIS has become increasingly prominent in spatial analysis due to its flexibility, plugin ecosystem, and compatibility with multiple data formats (Rosas-Chavoya et al., 2022). Studies of spatial accessibility to health facilities demonstrate the utility of QGIS for deriving network distances and catchment-based analyses such as the enhanced two-step floating catchment area (E2SFCA) method (Salvacion, 2022). Furthermore, recent research in urban dynamics uses QGIS to model land use change, vegetation indices (NDVI) and surface temperature, illustrating its capacity for predictive and scenario-based spatial modelling (Isinkaralar et al., 2024). Overall, QGIS serves as a cost-efficient, robust platform for spatial assessment and policy-oriented mapping, making it suitable for interdisciplinary research in geography, health, environment and planning.

Catchment Area Analysis

Catchment area analysis is a widely used method in health geography and spatial accessibility. It is a strategic evaluation of a geographic region in which a facility or service is expected to draw a population (Brown, 2021). The idea is that people tend to visit facilities over a specific travel distance or time limit that can be used to recognize differences between population demand and service supply (McGrail et al., 2017). Mapping these regions will allow the researchers to approximate the percentage of the population that can access the services of a hospital and indicate gaps in healthcare services.

Travel Time, Distance, and Population Distribution

Demographic and spatial factors, as well as availability of facilities, determine healthcare access. Overcrowding and increased waiting times are frequent problems in populated areas (Khan et al., 2019), whereas in sparsely populated areas, the problem of travel distance is enormous because of the scarcity of facilities (Guo et al., 2020). Accessibility can also be assessed further through travel speed and catchment area analysis (Salvacion, 2022). When population distribution is included in GIS mapping, the healthcare resources planning becomes more effective (Flores et al., 2020). Different age groups have varying health needs, healthcare planning must consider population structure to ensure accessibility and efficient allocation of healthcare facilities (WHO, 2020). In this study, the travel time, distance, and population density are studied to determine the level of accessibility in Tagum City at the barangay level.

QNEAT3

QNEAT3 is a plugin written in Python and integrated within QGIS, which enables users to perform advanced network analysis algorithms from simple shortest path solving to more complex tasks like Isochrone Area (aka service areas, accessibility polygons) and Origin-Destination-Matrix computation (Raffler, 2018). QNEAT3 considers factors such as road network, travel speed, and direction, compared to traditional methods. QNEAT3 creates a precise accessibility assessment. Recent studies applying QNEAT3 in health geography and urban planning have shown its accuracy in identifying underserved areas and optimizing healthcare accessibility (Leyso & Umezaki, 2024; Salvacion, 2022). In this study, it is used to calculate the travel time and distance of barangays in Tagum City to the nearest healthcare facility.

Enhanced Two-Step Floating Catchment Area (E2SFCA)

The Enhanced Two-Step Floating Catchment Area (E2SFCA) is a GIS-based method that considers the two main factors: supply, the hospital capacity, and demand, which is the population distribution. It also takes into consideration the distance decay, the declining probability of access with increasing distance or travel time (Salvacion, 2022). Being more specific than the conventional distance-based measurements, E2SFCA has come in handy to determine the gaps in healthcare accessibility in the Philippines. This paper uses E2SFCA on Tagum City to give a barangay-scale analysis of hospital accessibility and create more specific insights that can be used in policy interventions related to underserved groups.

Mode-of-Transportation

The modes of transportation play a significant role in determining the accessibility of healthcare, because the use of a single mode of transportation (e.g., personal vehicles) tends to overestimate the real accessibility, especially in places where people rely on slower or less efficient modes. The E2SFCA method is used to demonstrate that transportation constraints increase healthcare disparity in an area (Leyso & Umezaki, 2024). In the same way, efficiency in transport decreases as travel time and cost rise (Lopez & Biona, 2020). This study compares various modes of transport at the barangay level in Tagum City to find out how distance, speed of travelling, and mode choice influence the accessibility of hospitals.

Synthesis

The reviewed literature highlights the importance of Geographic Information Systems (GIS) and the Enhanced Two-Step Floating Catchment Area (E2SFCA) approach to the study of healthcare accessibility. Research always demonstrates that the distance and travel time, as well as the population distribution, are spatial elements that directly affect the ability of communities to use hospital services. Moreover, recent studies highlight that transportation modes have a major impact on the results of accessibility because the use of one mode of travel frequently results in overestimating the coverage of services. Together, these publications make GIS-based modeling a very strong instrument in the determination of underserved areas and in the facilitation of more equitable healthcare planning.

THEORETICAL FRAMEWORK

This study is grounded on three theories, the Theory of Spatial Accessibility which was first developed by William Hansen, states that the availability and the geographic proximity of services determine an individual's access to resources like healthcare (Chen *et al.*, 2022; Garcia & Nguyen, 2024). Supporting this is the Central Place Theory developed by Walter Christaller, which explains that rural and urban settlements are formed in a hierarchical structure, while central places like cities offer specialized services to its surrounding smaller areas (Li *et al.*, 2023; Das & Basu, 2021). The Health Belief Model by Irwin Rosenstock is also a basis of this study as it suggests that an individual's decision to seek healthcare is based on their perceived accessibility, benefits, and barriers (Abdelrahman *et al.*, 2023; Al-Hassan *et al.*, 2024).

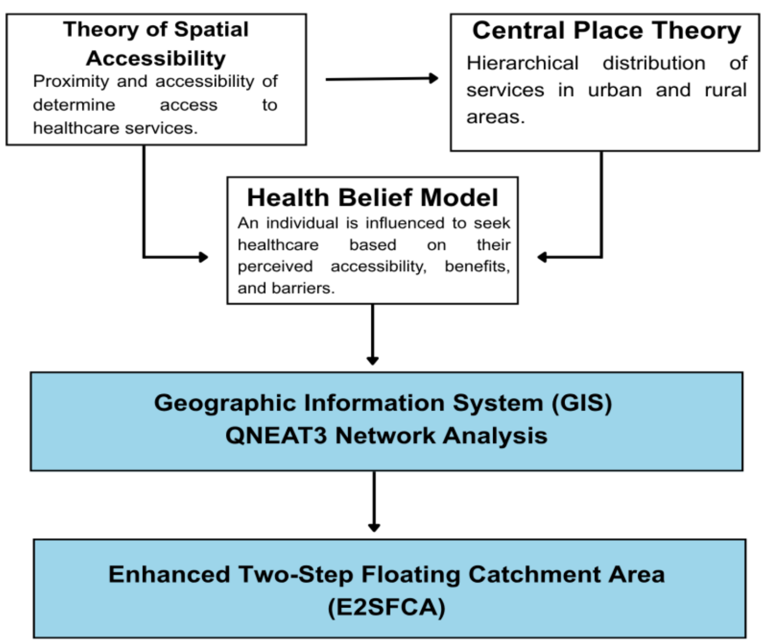

Figure 1. The figure shows the *Theoretical Framework of the study*

ENGINEERING GOALS AND EXPECTED OUTCOMES

Engineering Goals

This study aims to create a healthcare accessibility map for Tagum City using QGIS and barangay-level data. The system will use multiple map data layers, including barangay centroids, road networks, locations of health facilities, and administrative boundaries with population data (Delamater et al., 2019). It will use tools such as heat maps, buffer analysis, and spatial overlays to identify areas with a lack of services and greater risk (McGrail et al., 2017).

The application will serve as a tool to help in decision-making for local planners and health officials by visualizing travel distances, service coverage, and accessibility scores (Nsiah et al., 2024). Specifically, the study applies the Enhanced Two-Step Floating Catchment Area (E2SFCA) method to measure healthcare accessibility, including both facility supply and population demand. This approach uses data and spatial analysis to improve healthcare planning in a low-cost, repeatable way (Mshana et al., 2023).

Expected Outcomes

The mapping system will display barangay-level population and health data, including map layers such as roads and healthcare facilities. It will create heat maps, buffer zones, and coverage areas to locate communities with limited healthcare access and calculate travel distances and times. As a decision-support tool, it will help planners focus on priority areas and can be applied in other urban or regional settings.

MATERIALS AND METHODS

Area of the Study

The study is grounded in the barangays of Tagum City, the capital of Davao del Norte. The city was chosen as the study area due to its urban and rural characteristics; because of this, the city is seen as an ideal location to analyze healthcare accessibility.

Phase 1 - Preparation and Input of Datasets

1.1 *Data Collection and Preparation.* The project utilizes 4 main datasets which are the Administrative Boundaries (Vector), Population Data (CSV), Road Networks (Line), and Hospital Locations (Point). These datasets were gathered from the Tagum City Planning and Development Office. To ensure compatibility with QGIS each dataset was cleaned and formatted for input in the application.

The Administrative Boundary data in this study defines the barangay divisions and the spatial extent of the analysis. Population data is provided as the demographic basis in order to estimate demand for healthcare services population data. It is categorized by age, children (ages 0-9), adolescents (ages 10-19), adults (ages 20-59), and old age (ages 60 and above). To represent possible travel routes, road network data is used in computing realistic travel times and distance.The hospital location data is used as endpoints in the analysis, allowing us to identify the nearest healthcare facility for each barangay centroid.

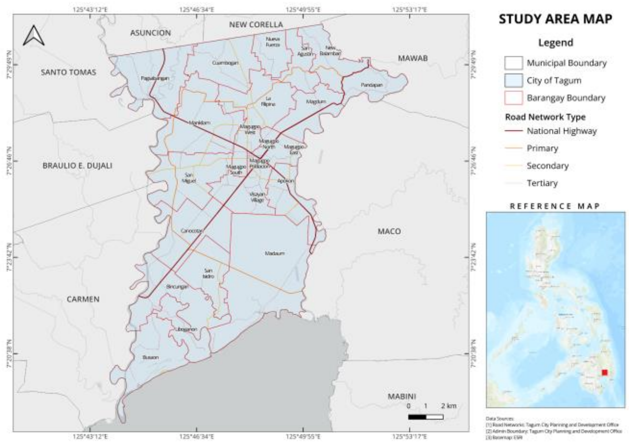

Figure 2. *Map of the Study Area*

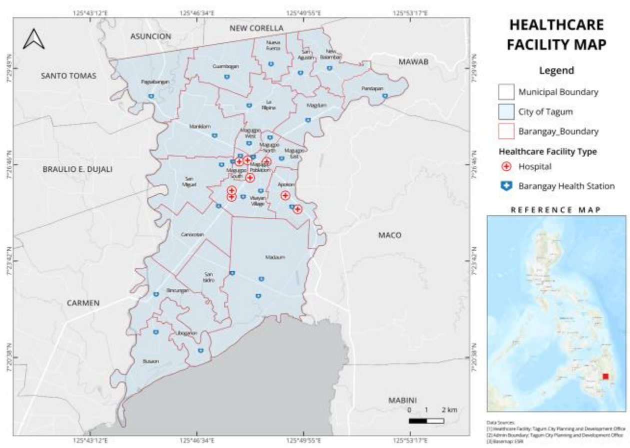

Figure 3. *Healthcare Facility Map of Tagum City*

1.2 ***Joining Attributes by Barangay.*** Using the Join Attributes by Field Value in QGIS, the population data was combined with the barangay shapefile. This process allowed the tabular population attributes to link with their corresponding geographic boundaries. The results of this process is showcased by the figures below, which displays the population distribution per barangay in Tagum City.

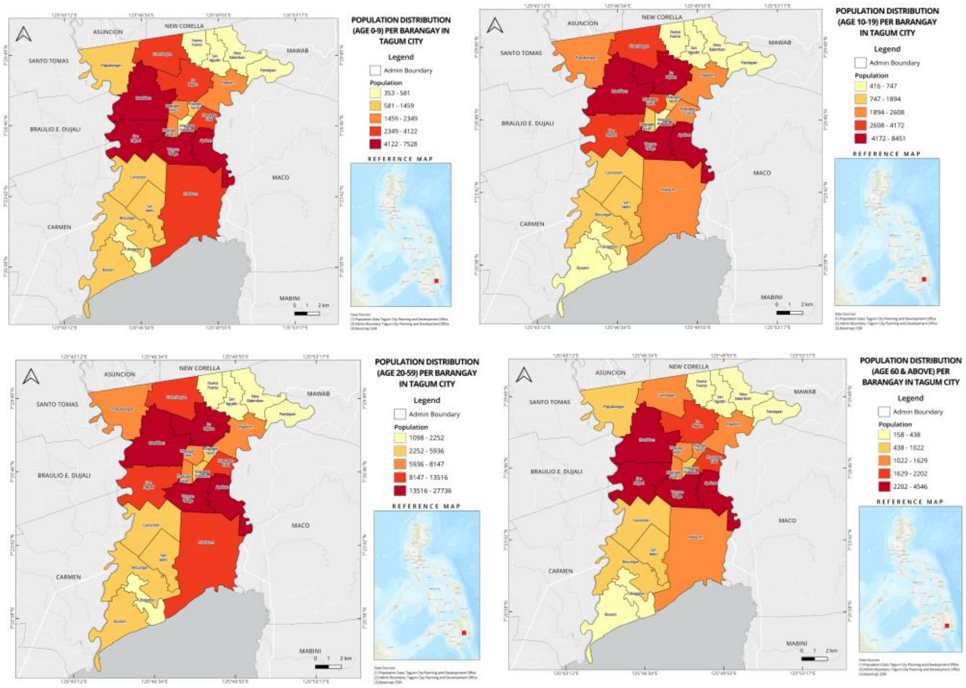

Figure 4. *Population Distribution per Barangay*

1.3 ***Generation of Barangay Centroids.*** To represent the approximate center point of each barangay, centroids were generated after joining the population data with the barangay boundaries. This process was done by calculating the geometric center of each polygon feature using the "Polygon Centroids" tool in QGIS.

Phase 2 - Network Analysis and Computation

2.1 ***Network Analysis Using QNEAT in QGIS.*** Using the QNEAT3 plugin in QGIS, the shortest travel time and distance were determined from each barangay centroid to the nearest hospital. The barangay centroids were used as the origin points and the hospital location were the destination points. The minimum distance and time travel from each barangay centroid to the nearest hospital were computed by the "Shortest Path (Point to Layer) function". This allowed the study to identify which barangays have more or least accessibility to healthcare facilities

2.2 ***Aggregate Result using Statistics by Category.*** During this process, the computed results of the travel distance and time were grouped and averaged by barangay and population category (children, adolescents, adults, and elderly) through Microsoft Excel's statistical functions.

2.3 ***Computation of Travel Time per Vehicle.*** The travel times per vehicle were calculated through the formula T=D/S, where T= Time, D= Distance, and S= Speed. The average vehicle speed was assigned as: tricycle (15 kph), jeepney (20 kph), motorcycle (30 kph), and private car (40 kph). Utilizing the Attribute Calculator in QGIS, the travel time for each vehicle was computed.

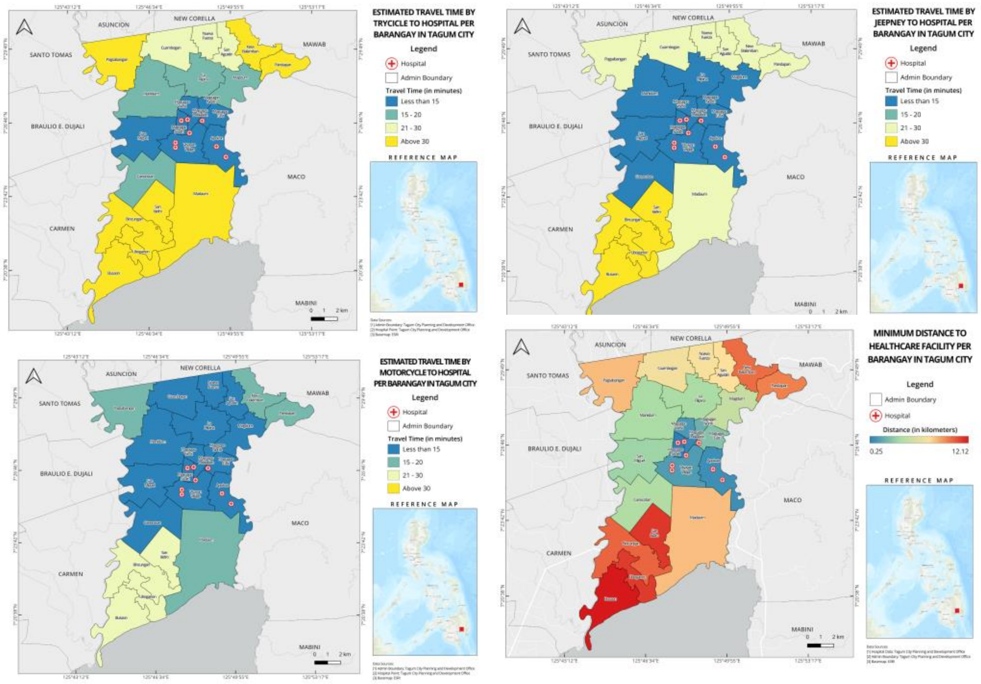

Figure 5. *Estimated travel time per vehicle*

2.4 *Estimation of Minimum Distance to Hospital.* The minimum distance of each barangay to a hospital was generated through the QNEAT3 network analysis in QGIS. The distance obtained from the network analysis was used to determine the fastest route between each barangay to a hospital. The values serve as a base parameter for accessibility measurement.

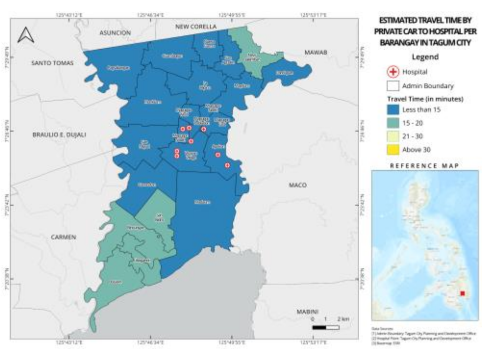

Figure 6. *Minimum Distance to Healthcare Facility per Barangay*

Phase 3 - Modelling

3.1 *Accessibility Modelling Using E2SFCA.* Using the Enhanced Two-Step Floating Catchment Area (E2SFCA) by Nakamura et al., and the study of Arnold R. Salvacion as a basis, the accessibility levels were measured by using both distance decay and population-to-provider ratio. The equations used are given below:

Equation 1. Travel Distance

$$d_t = v \times \frac{t}{60}$$

Where d_t represents the travel distance in km, v is the average travel speed in kph, and t is the travel time in minutes.

Equation 2. Distance Decay Weight Function

$$W_{i,j} = \begin{cases} 1, & d_{i,j} < d_{10} \\ \frac{d_{20} - d_{i,j}}{d_{20} - d_{10}}, & d_{10} \leq d_{i,j} \leq d_{20} \\ 0, & d_{20} > d_{i,j} \end{cases}$$

Where W_{ij} represents the effect of the distance of a barangay i and a hospital j. Thus, $d_{i,j}$ represents the distance between a barangay and a healthcare facility, and d_{10} *and* d_{20} are the average distances to reach a healthcare facility within 10 and 20 minutes.

Equation 3. Provider-to-Population Ratio

$$P_j = \sum_i W_{ij} \times P_i$$

Where P_j represents the population around a hospital j, meanwhile W_{ij} represents the weighing coefficient, and P_i represents the population of a barangay i.

Equation 4. Accessibility Index

$$E2SFCA_i = \sum_i \frac{W_{i,j} \times S_j}{P_j}$$

Finally, in this equation $E2SFCA_i$ represents the E2SFCA score of the barangay i, P_j represents the population around the hospital j, $W_{i,j}$ represents the weighing coefficient, and S_j represents the number of healthcare facilities.

3.2 Spatial Data Validation and Correction*.* In this phase, before generating the final output, all map layers were checked for any errors such as missing attributes, overlaps, or unconnected road segments. These were properly observed and corrected to ensure a reliable computation and spatial alignment.

3.3 *Calculation and Generating of Accessibility Scores Maps.* Finally, the computation and generating of maps for the accessibility of scores per population group in Tagum City was done using the E2SFCA method. The accessibility scores were calculated separately for each age group. The calculated E2SFCA scores represent the accessibility of each barangay to a healthcare facility, indicating that the higher score.

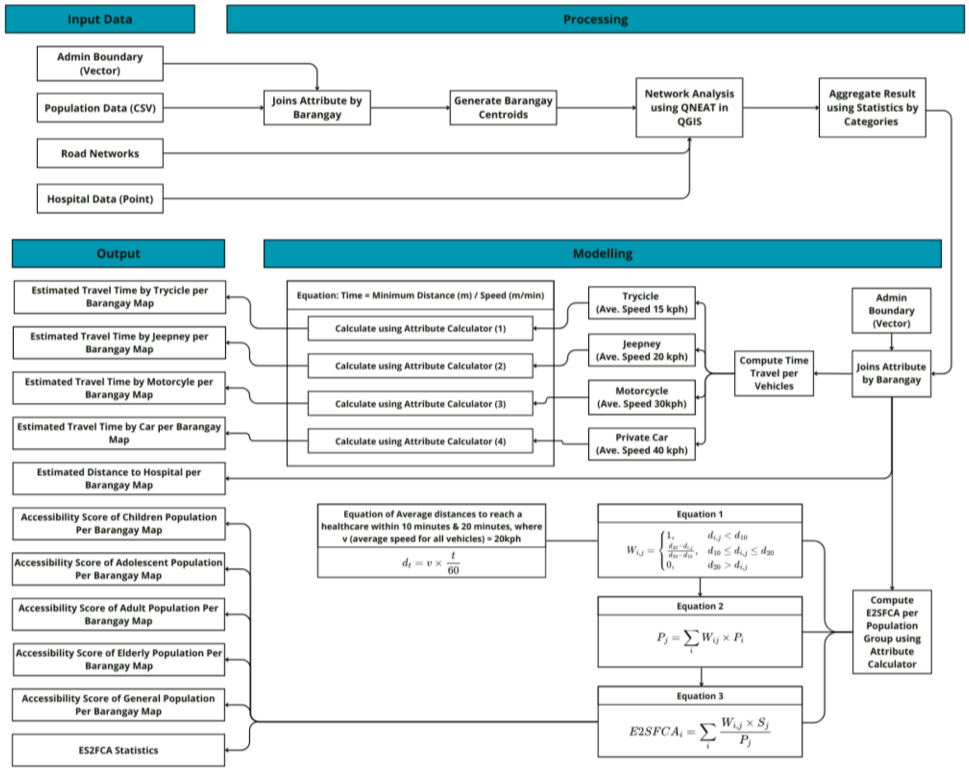

Figure 7. The figure shows the *Methodological Framework of the study*

RESULTS

This section presents the computed baranggay-level healthcare accessibility scores of Tagum City. The results are categorized by population group – children (0-9 years), adolescents (10-19 years), adults (20-59 years), elderly (60 years and above)– and the general population. The mapped E2SFCA results used legends to provide a smoother understanding, using a classic red cross hospital icon to pinpoint the location of the 8 tertiary hospitals around Tagum City, while using colors to categorize the access quality in each barangay, with yellow areas indicating very low access, green meaning low access, cyan meaning moderate, light blue indicating high access, and dark blue indicating a very high health care access, and then the admin boundary was left plain white.

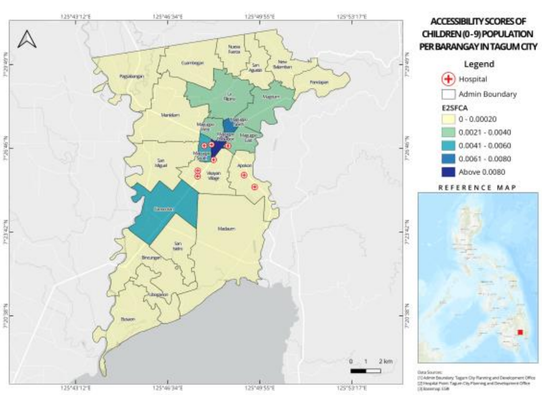

Figure 8. *Accessibility Score of Children (0-9 years)*

Healthcare accessibility among children is generally limited in peripheral barangays, while central barangays exhibit higher accessibility. There are 15 barangays who belong to the very low category while a barangay near the city center, Magugpo Poblacion, tops alone in the very high category.

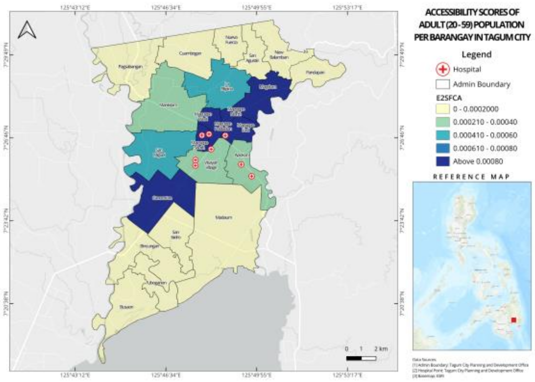

Figure 9. *Accessibility Score of Adolescents (10-19 years)*

Adolescent populations show a similar trend, with higher accessibility concentrated in barangays close to healthcare facilities. This age group has the most count of very low healthcare access tallying at 16 baranggays while Magugpo Poblacion consistently tops.

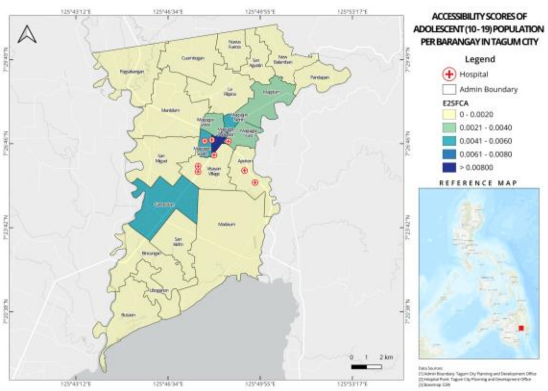

Figure 10. *Accessibility Scores of Adults (20-59 years)*

Adults demonstrate improved healthcare coverage in central and semi-central barangays. This age group shows the most elevated scores having 11 yellow-colored baranggays and a total of 7 barangays colored in dark blue.

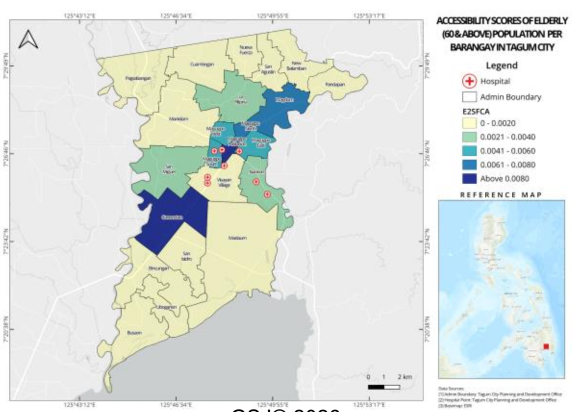

Figure 11. *Accessibility Scores of Elderly (60 years and above)*

Elderly populations generally experience lower accessibility, particularly in peripheral rural barangays. In this age group there are 13 baranggays under very low access while Magugpo Poblacion and Canocotan topping the E2SFCA indicating a very high access.

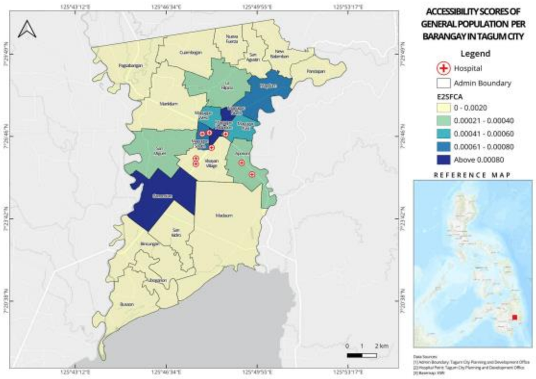

Figure 12. *General Accessibility per baranggay*

Overall accessibility patterns across all age groups show consistently higher access in central barangays, whereas peripheral and rural areas remain underserved. This reflects persistent spatial inequities in healthcare provision throughout the city.

DISCUSSION

Following the spatial analysis conducted through the MAPA model, there are noticeable spatial patterns and major variations in healthcare accessibility across Tagum City. Favorable accessibility has been observed in areas near the city center, while areas further away face longer travel times and limitations on healthcare reach. However, the data show that not all areas near the city center have sufficient healthcare access, and areas further out actually demonstrate greater reach, implying proximity alone cannot ensure availability. These results highlight how distance, road network quality, transportation mode, and population pressure influence healthcare access across the city.

The general accessibility map in Figure 12 illustrates the general accessibility scores of all four of the population groups across Tagum City. Barangays Magugpo Poblacion, Canocotan, and Magugpo North show the highest values, while 13 out of 23 of the baranggays are yellow-colored, indicating they scored the lowest. The fact that 56.52% of the city scores low simply indicates that Tagum City has a systematic issue of accessibility inequality.

More often than not, areas that have very low access face the same obstacles; they all rank poorly due to longer travel times and limited connectivity. With utmost consistency Pandapan, New Balamban, San Agustin, Nueva Fuerza, Pagsabangan, Cuambogan, Busaon, Liboganon, Bincungan, Madaum, and San Isidro rank low in all 5 categories, implying a great need for these eleven barangays to receive upgrades or the addition of new facilities capable of providing broader healthcare services and better accessibility. These are predominantly rural and mostly located within the city's boundary.

Although outer areas generally ranked low, the data reveals exceptions. Barangays Visayan Village, Mankilam and Barangay Apokon– despite their proximity to city facilities– still scored low or very low, never reaching moderate accessibility. In contrast, Canocotan, with a similar travel time, ranked high. This contrast underscores that population pressure, not just distance, greatly affects healthcare accessibility.

Physical proximity doesn't always translate to true accessibility. Population density, road network quality, transportation, and distance all influenced the reliability of the data. The results can guide the city toward more efficient health planning and infrastructure development. Eleven barangays, Pandapan, New Balamban, San Agustin, Nueva Fuerza, Pagsabangan, Cuambogan, Busaon, Liboganon, Bincungan, Madaum, and San Isidro– consistently scored poorly, along with Visayan Village, Mankilam, and Apokon, which were greatly affected by population pressure. This study recommends that the local government of Tagun provide these areas additional health services or smaller interventions.

While the MAPA model effectively identifies disparities in healthcare accessibility across Tagum City, it is limited by the use of static population and facility data, as well as the E2SFCA method's assumption of uniform travel behavior and equal access within catchment areas. Despite this, the MAPA model remains a reliable tool, as its conclusions are grounded in professionally supported numerical data. Overall, the findings highlight that accessibility is shaped by population density, facility capacity, and infrastructure—not distance alone—and underscore the importance of spatial, data-driven planning to achieve equitable healthcare access.

CONCLUSION

Determining the best locations for healthcare facilities is important to ensure fair and efficient access for all residents (Flores et., 2021). This study used GIS and the E2SFCA method to analyze healthcare accessibility in Tagum City, considering travel time, distance, population age groups, and transportation networks. The results show that physical proximity alone does not guarantee access, especially when travel mode and population demand are both important factors.

Although this study offers a clear foundation for identifying underserved areas and potential locations for new health facilities, decision-making should also consider other important factors, such as available land for construction (Tonato et al., 2021), the capacity of healthcare facilities (such as number of doctors and beds; Diaz et al., 2021), and local socioeconomic conditions that affect people's ability to seek care (Willows, 2025). Models like E2SFCA can help narrow down possible sites (Su et al., 2024), but policymakers must use multiple criteria to make final decisions (GOV.UK, 2024).

This study is limited to healthcare accessibility based on facility locations and does not include facility capacities, population willingness to use services, or private clinics, using only the available data as of 2025. Barangay-level socioeconomic and health data, as well as information on government-owned idle or unutilized lands, were not included, making it harder to evaluate access and plan new healthcare sites (Abisado et al., 2020). The model's distance decay was not adjusted to the local conditions, and factors like land availability and transportation improvements were not included, though they are important for thorough healthcare planning.

Future research could expand this by including more healthcare providers, adjusting the model for local conditions, and considering transportation and infrastructure to better understand healthcare access.

RECOMMENDATION

Based on the results, it is recommended that the Tagum City local government prioritize healthcare development in the 14 barangays that did not reach moderate access– Pandapan, New Balamban, San Agustin, Nueva Fuerza, Pagsabangan, Cuambogan, Bosaon, Liboganon, Bincungan, Madaum, San Isidro, Visayan Village, Mankilam, and Apokon. Establishing additional health centers or health clinics can significantly improve reach and service coverage, especially for vulnerable groups such as children and the elderly.

Improving road networks and transportation systems is also vital to enhancing healthcare mobility, particularly in rural and boundary areas. Integrating GIS-based analysis like the MAPA into local health planning can provide an evidence-based foundation for equitable resource allocation and infrastructure expansion. Coordination between the city government, health departments, and urban planners should be strengthened to ensure that spatial data are regularly updated and utilized in policy development.

Finally, future studies should consider incorporating dynamic variables other than population density, road network, distance, and transportation modes, such as socioeconomic conditions, transportation access, and population growth to further refine the MAPA model. With these enhancements, Tagum City can move toward a more data-driven, inclusive, and resilient healthcare system that ensures equal access for all the town's people.

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