Applications of GIS in Analyzing Health Disparities Among the Elderly and Health Center Service Area Coverage: Community Model, Lahansai District, Buriram, Thailand

Piwpong, R.,[1] Sujayanont, P.[2,3] Jundaeng, J.,[3] Krates, J.,[4] Kijphati, R.[4] and Nithikathkul, C.[1,2,3*]
[1]Health Science Program, Faculty of Medicine, Mahasarakham University, Muang District, Mahasarakham 44000, Thailand
[2]Department of Preclinic, Faculty of Medicine, Mahasarakham University, Muang District, Mahasarakham 44000, Thailand
[3]Tropical Health Innovation Research Unit, Faculty of Medicine, Mahasarakham University, Muang District, Mahasarakham 44000, Thailand, E-mail: nithikethkul2016@gmail.com*
[4]Bureau of Public Health Research and Innovation Administration, Division of Academic Affairs, Department of General Secretary, Ministry of Public Health, Nonthaburi 11000, Thailand
**Corresponding Author*

DOI: https://doi.org/10.52939/ijg.v21i4.4075

Abstract
Thailand's aging population has led to a growing demand for healthcare services, particularly for elderly individuals with chronic conditions or physical limitations. Geographic Information Systems (GIS) offer valuable tools for healthcare planning and management by providing spatial data that can improve resource allocation. This study utilized GIS to assess the healthcare needs of the elderly population in rural Thailand, specifically focusing on the Nong Waeng Sub-district of Lahansai District, Buriram. The study targeted 2,244 individuals aged 60 and above, from which 495 participants were randomly selected. GIS tools were used to map elderly households through GPS coordinates, while health assessments were conducted, including cognitive impairment screening (Mini-Cog), Activities of Daily Living (ADL) evaluations, and fall risk assessments. A GIS-based database was created to analyze the spatial distribution of elderly residents and their associated health risks. Spatial mapping revealed significant disparities, such as the prevalence of chronic diseases (hypertension: 22.42%, diabetes: 11.92%), cognitive impairment (dementia rates ranging from 7.52% to 41.00% across villages), and high fall risks (56.6% overall, with a peak of 52.47% in Nong Wa Mai). While most elderly individuals were independent in daily activities (96.99–99.50% ADL scores), clusters of high fall risk and chronic disease were identified. Healthcare coverage was uneven, with the Nong Ta Yao Health Center serving the majority of residents within a 3-kilometer radius. The study demonstrated that GIS can be a powerful tool for targeting interventions, such as prioritizing fall prevention and chronic disease management, while also revealing gaps in caregiver coverage. Stakeholders expressed high satisfaction with the GIS-driven insights (mean score: 4.32). This approach offers a valuable framework for evidence-based strategies to improve long-term care systems and enhance the quality of life for the elderly in Thailand.

Keywords: Community Health, Elderly, Geographic Information Systems, Long-Term Care, Resource Allocation

1. Introduction

Global increases in the number of older adults have caused significant demographic changes. By 2050, the population of elderly people is expected to account for 16.4% of the global population [1]. Thailand has fully become an aging society because more than 20% of the country's population is elderly [2]. Demographic changes have created numerous challenges, particularly in the field of health, where elderly people are more likely to face dependence and non-communicable chronic diseases [3], causing the healthcare system to shoulder the burdens of complex and expensive care [4][5] and [6]. Economically, the government has had to allocate higher budgets for healthcare and social welfare, while tax income declines proportionate to the working-age population [7].

Socially, families and communities have had to adapt to support long-term care for elderly people, particularly in the case of dependent elderly people [8]. These changes have led to a need to develop effective and sustainable care systems for elderly people with consideration given to integration of the healthcare system, social welfare system, and community participation [9], including implementation of technology and innovations to enhance care efficiency [10].

Long-term care (LTC) is a key system and mechanism for supporting elderly care in communities [11]. An effective long-term care system consists of integrated healthcare services in health promotion, disease prevention, treatment and rehabilitation [12], personnel development in terms of increases in care quantity and quality [13], support for family and community participation in care, and allocation of sufficient essential resources to meet care needs [14]. Furthermore, financial policy planning in support of the establishment of care facilities, home-based care, and reductions in family expenses [15], as well as LTC system development for maximum efficiency, require accurate and complete information concerning elderly population characteristics and distribution, including available care support resources in each area.

Geographic Information Systems (GIS) are powerful tools that facilitate effective analysis and understanding of local long-term care situations for elderly individuals [16] and [17]. GIS can visualize important local data, such as the distribution of elderly populations, the number of healthcare teams, and available community resources. Implementing GIS in elderly care offers several benefits, including increased accuracy in data collection and analysis, environmental risk assessments, health care needs estimation [18][19][20][21] and [22]and enhanced strategic planning and emergency preparedness [23]. GIS is also used for a variety of purposes, such as creating databases on elderly populations [24], analyzing chronic disease risks [25], conducting epidemiological studies on chronic diseases among the elderly [26], monitoring medication adherence [27], and supporting community-based healthcare for elderly individuals [28]. In addition, GIS has applications in emergency medical service systems for elderly individuals [29] and nutritional care [30], helping to reduce costs, increase healthcare access, and improve the overall quality of life for both elderly people and their caregivers [5][6][22] and [31]. Despite the many benefits of GIS in analyzing and planning elderly care [32], its implementation in long-term care for elderly people in rural Thai communities remains limited [28]. This is also true in terms of integrating local data with healthcare data, social welfare systems, and community resources, which results in care planning that does not fully address all relevant dimensions [33]. Additionally, the use of GIS can be challenging for healthcare teams, leading to inconsistent or minimal usage [34]. To address these challenges, this study aimed to develop an innovative GIS-based system to support long-term care for elderly individuals in communities. This system integrates local data with quantitative data on elderly populations, enabling the analysis of distribution patterns, resource availability, and service access. The goal is to provide actionable insights that can inform policy proposals for the effective and sustainable management of long-term care resources, ultimately improving the quality of life for elderly individuals and promoting better health outcomes in the future.

The objectives of this study focused on applying GIS to investigate the distribution of elderly individuals with chronic diseases, living conditions, activities of daily living (ADL), cognitive impairment, and fall risk in rural areas, specifically Nong Ta Yao, Nong Wa Mai Moo 4, and Nong Wa Moo 13, located in Nong Waeng Sub-district, Lahansai District, Buriram Province, Thailand. The study also examined the service areas of healthcare facilities to assess their coverage within the study region. Additionally, the performance of the GIS application in identifying the distribution of elderly individuals with health conditions, ADL limitations, cognitive impairment, and fall risks was evaluated. This approach could be beneficial for improving elderly care management in the study area.

2. Method

This study was a research and development study for developing a geographic information system (GIS) innovation for long-term care of elderly people in communities. This study was carried out in Nong Waeng Sub-district, Lahansai District, Buriram Province, which has a total of 3 villages and 6 healthcare facilities.

2.1 Study Area

In this study, the sample was elderly people living in Nong Waeng, Lahansai, Buriram, located in northeastern Thailand, Universal Transverse Mercator (UTM) Reference Coordinates in Zone 43N, Easting: 361,650 – 362,100, Northing: 177,850 – 1,781,500. In terms of spatial distribution, elderly people in the sample were distributed in three areas consisting of Nong Wa village Moo 13 (Blue Point),

Nong Wa Mai village Moo 4 (Orange Point), and Nong Ta Yao Village (Green Point).

According to Figure 1, Nong Wa Village (Blue Point) is located in the north of the study area with high sample density in a small area close to the main road (Buriram Rural Highway 4,063), Nong Wa Mai Village (Orange Point) is located in the center of the study area with sample distribution in a narrower area than Nong Wa Village, and Nong Ta Yao Village (Green Point) is located in the south of the study area. This village was shown to have regular sample distribution in a broader area. This area is far from the main road and surrounded by agricultural land. The locations of the samplings and Tambon Health Promotion Hospital (THPH) depicts in Figure 2. Studying healthcare facility assessment and disparities in healthcare for the elderly in rural areas is essential because rural communities often face unique challenges in accessing healthcare services, including limited resources, fewer healthcare providers, and geographic isolation. These factors can lead to significant health disparities, particularly for elderly individuals who may have chronic conditions or mobility limitations. Understanding the availability, accessibility, and quality of healthcare services in these areas is crucial for identifying gaps and improving healthcare delivery. By studying these issues, we can develop targeted interventions, ensure more equitable healthcare access, and enhance the quality of care for elderly populations, ultimately contributing to better health outcomes and an improved quality of life for rural elderly residents.

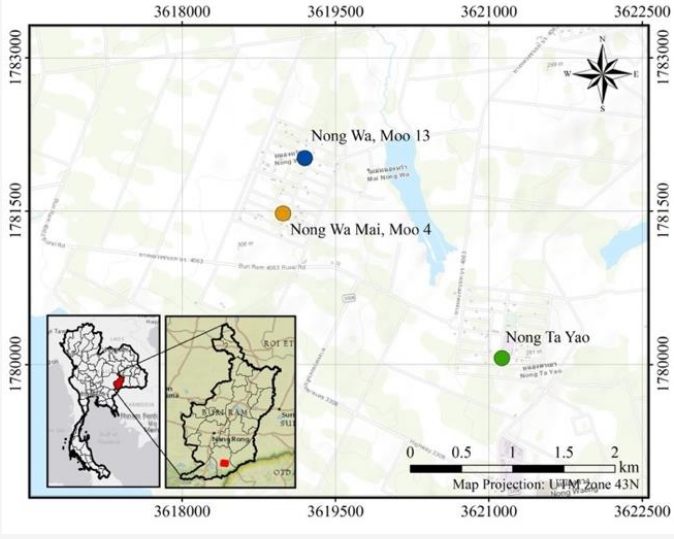

Figure 1: Locations of Nong Wa, Nong Wa Mai, and Nong Ta Yao villages

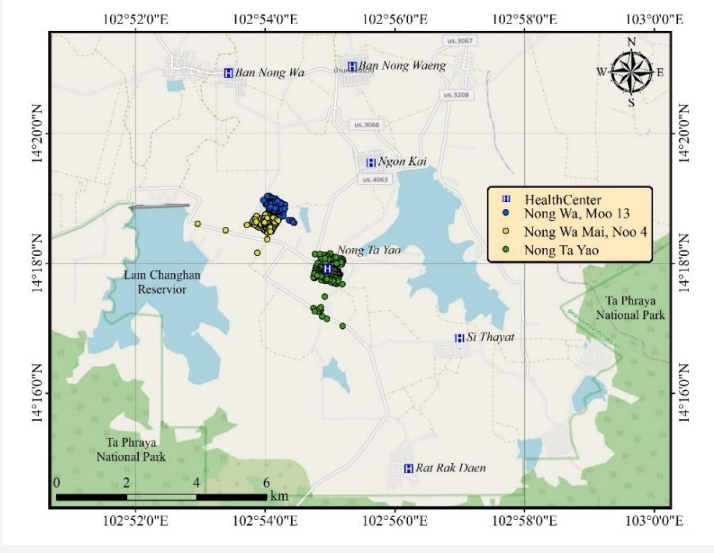

Figure 2: The distributions of data samplings and THPH

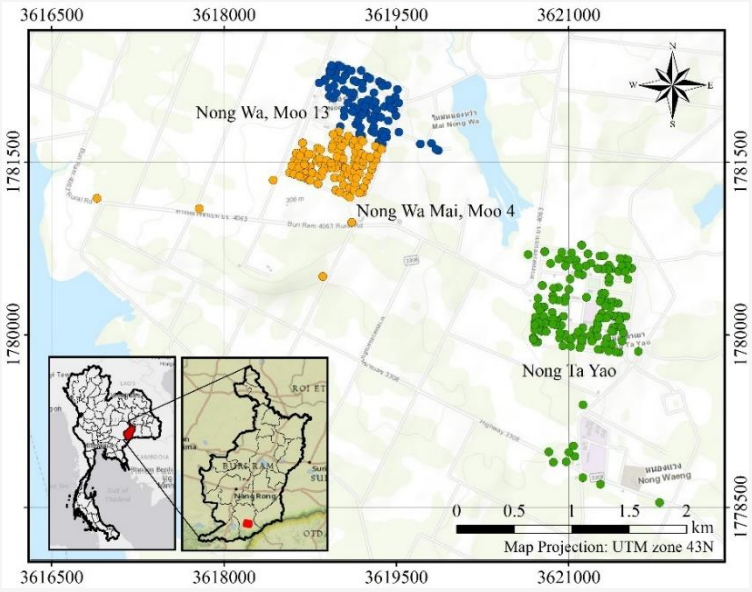

Figure 3: The sampling locations in the 3 villages

2.2 Population and Sample

The population in this study was 2,244 elderly people living in Nong Waeng Sub-district, Lahansai District, Buriram Province. The sample size was calculated using Taro Yamane's equation as defined in Equation 1.

$$n = \frac{N}{1 + Ne^2}$$

Equation 1

Where: n is sample size, N is the population numbers, and e is confidence interval which is 0.05.

According to equation 1, the sample size is 400. To prevent data attrition, the researcher expanded the sample by 20%, or 80 samples. The researcher also expanded the sample size by another 15 samples for flexibility in data collection and a as a contingency in the event of data collection errors. Therefore, the final sample size used in the study was 495 subjects. The sample locations were selected randomly involving drawing lots for the names of elderly people from three villages. Data on healthcare teams were collected from a total of healthcare facilities consisting of Nong Wa Health Station, which is responsible for providing healthcare services for people in Nong Wa Village and Nong Wa Mai Village, and Nong Ta Yao Health Station, which is responsible for providing healthcare services for people in Nong Ta Yao Village. The health stations were transferred from the Ministry of Public Health to be under the control and supervision of local administrative organizations in Nong Waeng Municipality.

Data were collected from January to April 2024. The locations of the samples within the 3 villages illustrates in Figure 3.

2.3 Instrumentation

The following instruments were used in this study:

1) A geographic information collection form was used to collect spatial data such as elderly peoples' home coordinates, chronic diseases, and living characteristics.
2) In developing the GIS database for long-term care of elderly people in communities by using ArcGIS software which was effective in showing distribution of elderly people in various areas by using GPS coordinates to collect positional data of elderly peoples' houses in each area, the collected data were combined with health information of elderly people in the area such as activities of daily living (ADL) assessment results and Mini-Cog assessment results, which were used to assess elderly peoples' mental condition and health.
3) The Mini-Cog assessment form developed by Borson et al. was translated into Thai [35] and used to assess cognitive impairment. This assessment form was assessed to have an interrater reliability score of 0.80 and the concurrent validity score of Mini-Cog had a positive r correlation of 0.47 with MMSE-Thai 2002. The instrument had a scoring range of five points. A total score < 3 points indicated risk of cognitive impairment. Patients with scores of three points and up had no risk of cognitive impairment.

4) The activities of daily living assessment form contains ten questions, the form was used to assesse elderly peoples' activities of daily living based on real activity. It awarded scores based on level of ability in each activity with a scoring range of 0 – 20 points. Scores of less than 12 points meant elderly people were active, scores of 5 – 11 points meant elderly people were homebound, and scores of < 4 points meant elderly people were bedridden.
5) The Thai Falls Risk Assessment Test (Thai FRAT) assessed risk of falls among Thai elderly people living in communities [36] with six risk factors consisting of: 1) gender; 2) vision impairment; 3) abnormal balance; 4) medication use; 5) record of falls; and 6) housing condition. In data analysis, a total score of 4 – 11 points indicated risk of falling and a score of 0 – 3 points indicated no risk of falling.
6) The satisfaction and utilization assessment form was developed by the researcher based on reviews of relevant literature. The form contains 14 questions divided into two sections with nine questions in the satisfaction assessment form and five questions in the utilization assessment form. Responses were rated on a 5-level Likert scale from 1 (Strongly Disagree) to 5 (Strongly Agree). The specified data frequency equation was able to calculate as follows: (maximum score-minimum score)/number of ranges = (5-1)/5 = 0.80. Mean scores were interpreted in ranges based on set criteria. In general, scores can be interpreted as follows: 1.00 – 1.80 = very low satisfaction, 1.81 – 2.60 = low satisfaction, 2.61 – 3.40 = medium satisfaction, 3.41 – 4.20 = high satisfaction, and 4.21 – 5.00 = very high satisfaction.

2.4 Research Procedure

The study workflow in Figure 4 outlines a systematic approach to investigating the distribution and healthcare needs of elderly individuals in rural areas using GIS technology. It begins with the identification of key study areas, including Nong Ta Yao, Nong Wa Mai Moo 4, and Nong Wa Moo 13, located in Nong Waeng Sub-district, Buriram Province, Thailand. The workflow includes gathering data on elderly residents' health conditions, such as chronic diseases, cognitive impairment, and fall risks, as well as their living conditions and abilities to perform activities of daily living (ADL). The next step involves mapping the service areas of healthcare facilities to determine their coverage and accessibility for the elderly population. The GIS application's effectiveness in analyzing and visualizing this data is then assessed to improve elderly care management strategies. This structured workflow ensures a comprehensive approach to understanding and addressing the needs of elderly individuals in rural communities. The details of the research process were as follows:

1) Focus group meetings were held to collect opinions from stakeholders regarding the problems of elderly people in communities and long-term care systems in communities.
2) Spatial data were collected, consisting of data with identification of locations in the area, such as the locations of villages and the sample. Universal transverse Mercator (UTM) coordinates were used on maps, and numerical data were collected for use in calculations and analysis. These were quantitative data on the number of elderly people in each village and the ratios of elderly people in each group, such as active, homebound, or bedridden elderly people, data on health risks such as risk for falling or cognitive impairment, and the ratio of healthcare teams in each sample area.
3) In designing and developing the GIS innovation for elderly people, the researcher and GIS experts designed and developed the GIS innovation using data collected from elderly people in the sample area. Point symbols were used to represent the homes of elderly people and location coordinate data from global positioning system devices were entered. Spatial data was presented and displayed on a static map and quantitative data were shown using circular graphs in the image displaying GIS information of the sample area.

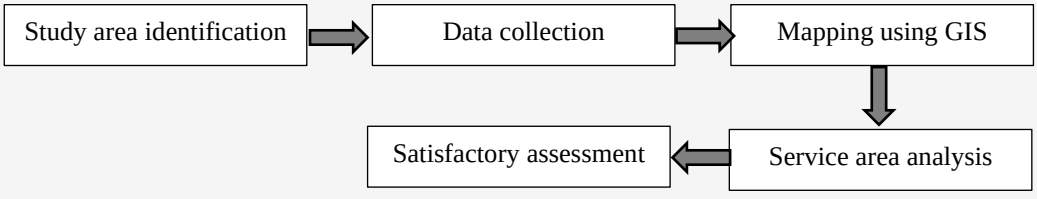

Figure 4: Application of GIS in elderly healthcare study workflow

4) When GIS spatial data combined with quantitative data has been developed, the researcher analyzed and prepared policy recommendations for presentation to executives of Nong Waeng Sub-district Municipality to use in making decisions and planning management of long-term care systems for elderly people in communities.
5) The results of utilization were assessed by assessing satisfaction and utilization of the innovation.

2.5 Data Analysis

The data in the findings were analyzed as follows:

1) Spatial data analysis was performed by using displays of the elderly locations to show the distributions of the samplings and their health conditions along with fall risk, ADL, and cognitive imparity in the area.
2) The THPH coverage areas were investigated using "Buffer" analysis with the radius of 1 km, 2 km, and 3 km radiated from the 6 THPH located within the study area. In GIS, a buffer is a zone of a specified distance around a geographic feature, such as a point, line, or polygon. It is used to analyze the proximity of features to one another. Buffers are commonly employed to assess the impact of nearby features or to identify areas that fall within a certain distance of a specific feature. Buffers are often used in spatial analysis, such as determining service areas for facilities, environmental studies, or planning and zoning. The buffer distance can be adjusted depending on the analysis needs [37][38][39] and [40].
3) The quantitative data were analyzed by using descriptive statistics consisting of frequency distribution and percentage. The graphics used were the GIS map and the circular graph containing activities in daily living (ADL), living characteristics, fall risks, cognitive impairment, prevalence of chronic diseases such as hypertension and diabetes, mean scores for satisfaction and utilization among people involved in long-term care.

2.5 Ethics Approval and Consent to Participate

This study was approved by the Institutional Review Board, Mahasarakam University (No. 444-401/2023, 31 October 2023) and Buriram Provincial Public Health Office (No. BRO 2023-135, 20 December 2023). The researcher sought cooperation from the agencies involved in collecting data from the sample, explained the research objectives and expected benefits, and affirmed data confidentiality. The participants signed informed consent forms and were able to withdraw from the study at any time.

3. Results

The findings are presented in two parts consisting of geographic information system (GIS) innovation development for long-term care of elderly people in communities and assessment of results from the geographic information system (GIS) innovation for long-term care of elderly people in communities:

3.1 Activities of Daily Living (ADL)

Activities of Daily Living (ADL) are essential tasks that individuals perform daily to care for themselves, including bathing, dressing, eating, toileting, transferring (moving from one place to another), and maintaining continence. ADL assessments are often used to evaluate a person's ability to live independently. Based on an individual's ability to perform these activities, they can be classified into three categories: active, homebound, and bedridden. Those in the active category can perform most or all ADLs independently; individuals in the homebound category may need assistance with some tasks but can manage others, often staying at home for most activities; and those who are bedridden require significant help with nearly all ADLs, typically being unable to move or perform basic self-care tasks. Figure 5(a) clearly illustrates that the majority of elderly individuals in all three villages have an active ADL status, with 489 individuals classified as active. In contrast, there was 1 homebound individual and 5 bedridden individuals. The homebound individual was found in Nong Wa Mai village, while the bedridden individuals were located in Nong Wa (4 individuals) and Nong Ta Yao (1 individual). The ADL distribution map is a valuable tool for visualizing the locations of bedridden patients as illustrates in Figure 5(b), which can be crucial for effective healthcare service management. In studying the ability to perform activities in daily living among elderly people, most of the elderly people in every village were active at 99.50% in Nong Ta Yao village, 99.38% in Nong Wa Mai village, and 96.99% in Nong Wa village. Bedridden elderly people were found in Nong Wa Village at 3.01% and 0.50% in Ban Nong Ta Yao while homebound elderly people were found in Nong Wa Mai Village at 0.62% as illustrated in Figure 6.

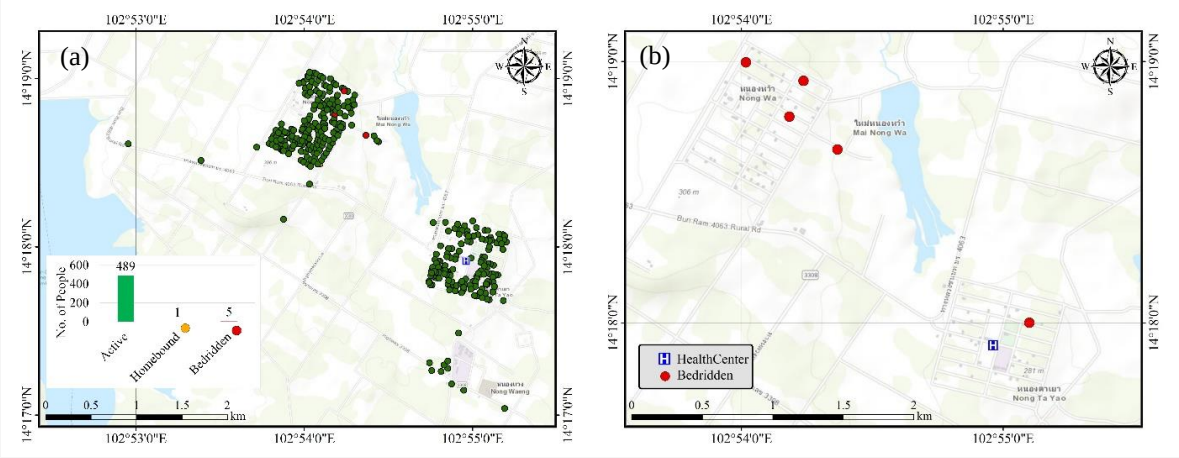

Figure 5: The spatial distribution of the elderly with ADL: (a) overall situation (b) bedridden patients

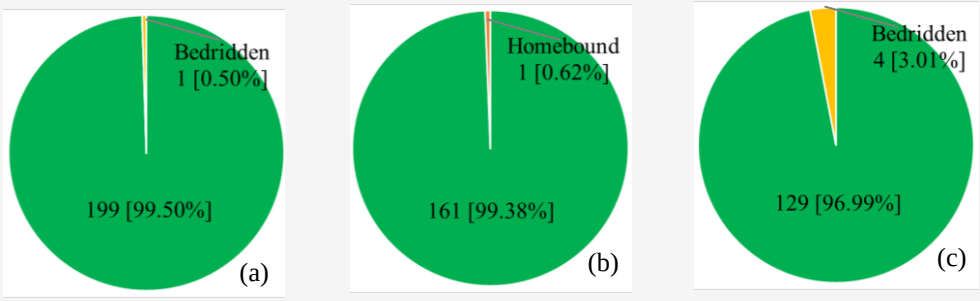

Figure 6: Numbers of the elderly with ADL class: (a) Nong Ta Yao (b) Nong Wa Mai (c) Nong Wa

3.2 Types of Livings

The types of living arrangements are classified into five categories: living alone, living with a spouse and descendants, living with descendants, living with a spouse, and others. The spatial distribution of these living arrangements among the sampled elderly is depicted in Figure 7. Figure 7 shows that most elderly individuals live with their descendants, totaling 345 people, followed by those living with both a spouse and descendants (74), those living with a spouse (65), and those living alone (9). There is one individual living in Nong Ta Yao village. The red circles in Figure 7 indicate the locations of elderly individuals who live alone. This information is crucial for THPH to provide targeted care, such as home visits, to those living alone. Figure 8 clearly shows that more than half of the elderly live with descendants in all three villages, particularly in Nong Wa Mai, where 80.75% of the elderly live with descendants. Among them, 14.91% live with a spouse, 3.73% live alone, and 0.62% live with both a spouse and descendants. The diversity of living arrangements is greatest in Nong Ta Yao village, where all types of living arrangements are represented, while the diversity is lower in Nong Wa Mai. It's evidence that many elderly people live alone due to a combination of social and economic factors. One of the main reasons is the migration of younger family members to urban areas like Bangkok in search of work. This migration leaves elderly parents or grandparents behind, often in rural villages, while their children support them through remittances but are unable to return home permanently.

3.3 Risk of Falling

The spatial distribution of fall risk is shown in Figure 9. The red dots represent the locations of elderly individuals at risk of falling. Approximately 56.6% of the elderly are at risk of falling, meaning that more than half of the elderly in the study area are at risk. A cluster of risk is observed in Nong Wa Mai Moo 4, while less cases are found in Nong Ta Yao village. When comparing Figures 8 and 9, it is evident that most elderly individuals at risk of falling do not live alone. This information is crucial for the people who live with the elderly and THPH to ensure proper care for the elderly and to make necessary adjustments to their living environments, such as installing handrails in bathrooms, to enhance safety. The pie charts in Figure 10 illustrate the proportion of elderly individuals with a risk of falling (in orange) compared to those with no risk (in blue) across three different groups or conditions.

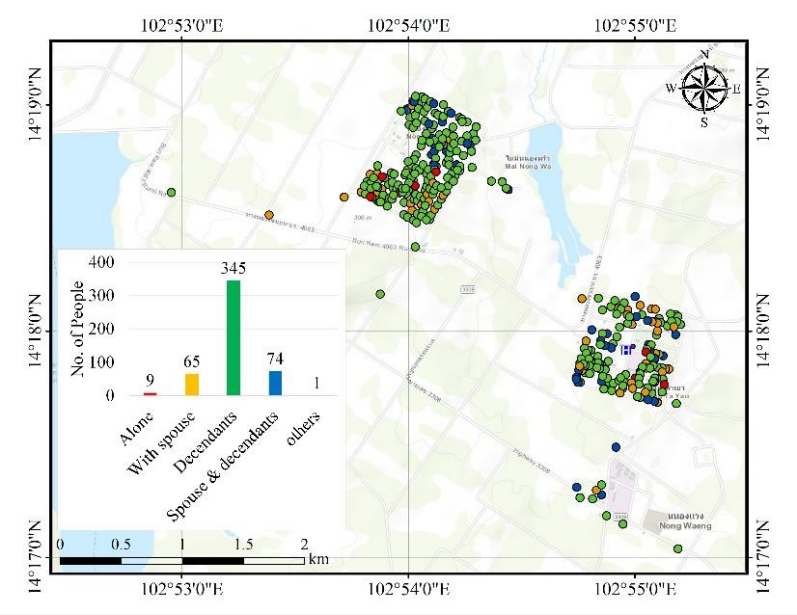

Figure 7: Spatial distribution of type of living

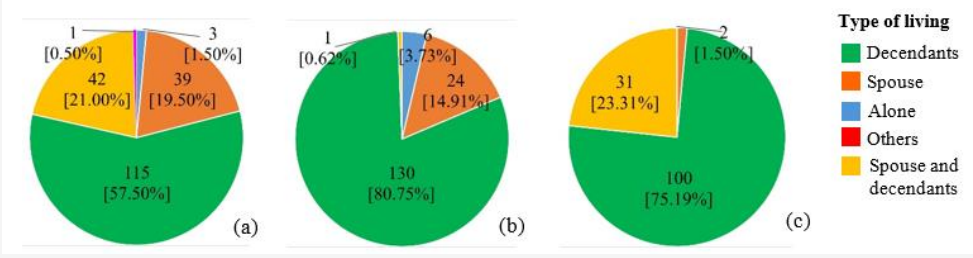

Figure 8: Numbers of the elderly with type of livings class:(a) Nong Ta Yao (b) Nong Wa Mai (c) Nong Wa

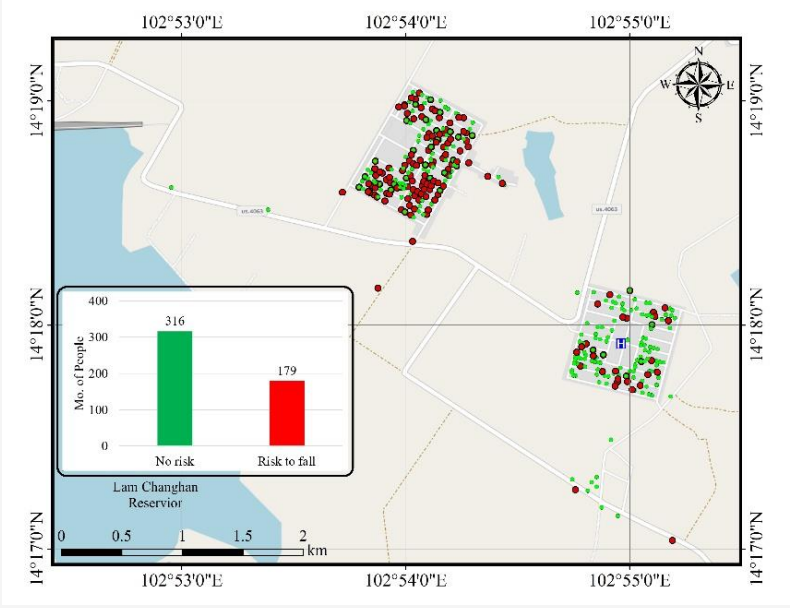

Figure 9: Spatial distribution of falling risk

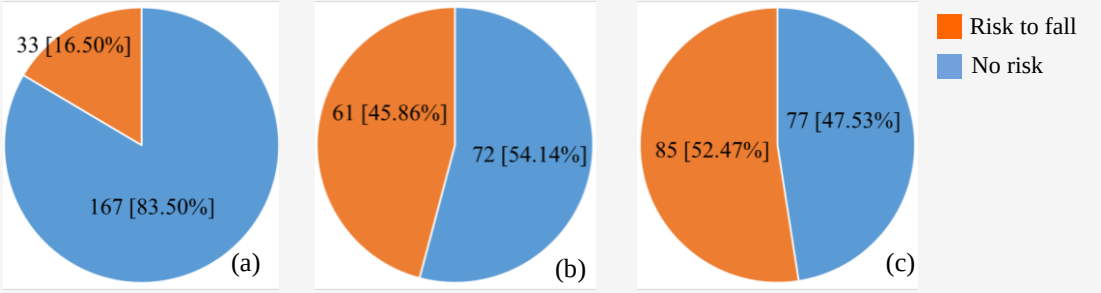

Figure 10: Numbers of the elderly individuals at risk of falling:
(a) Nong Ta Yao (b) Nong Wa Mai (c) Nong Wa

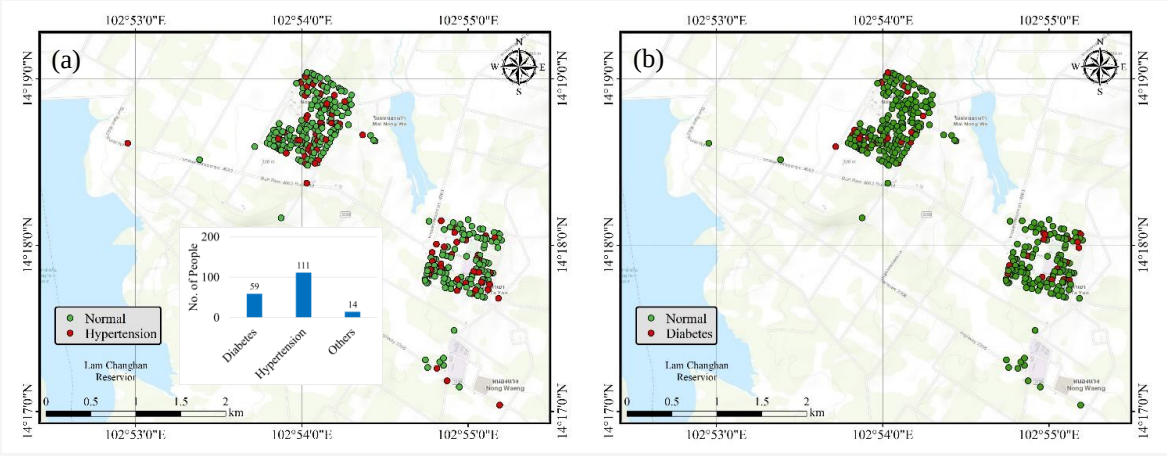

Figure 11: Spatial Distribution of elderly with chronic diseases (a) hypertension (b) diabetes

In Figure 10(a), the majority of elderly individuals 167 people (83.50%) are categorized as having no risk of falling, while only 33 individuals (16.50%) are at risk. Figure 10(b) shows a more balanced distribution, with 85 people (52.47%) at risk and 77 people (47.53%) not at risk. In Figure 10(c), the proportions are also relatively close, with 72 individuals (54.14%) having no risk and 61 individuals (45.86%) at risk. Overall, the data suggests that while most elderly in Nong Ta Yao are not at risk, the risk level increases in Nong Wa Mai and Nong Wa indicating varying fall risk factors among different populations or conditions.

3.4 Chronic Disease

A chronic disease is a long-lasting condition that typically persists for a year or more and requires ongoing medical attention or limits daily activities. These diseases often progress slowly and can be managed but not fully cured. Diabetes and hypertension are common examples of chronic diseases. Diabetes affects the body's ability to regulate blood sugar, while hypertension involves high blood pressure, both of which can lead to severe complications if left untreated. The spatial distribution of the elderly with chronic diseases (hypertension and diabetes) is illustrated in Figure 11. In total, 39 elderly individuals have diabetes, 111 have hypertension, and 14 have other chronic diseases across all three villages. The percentage of elderly with these chronic conditions is 11.92% for diabetes, 22.42% for hypertension, and 2.83% for other chronic diseases. Figure 11 shows that elderly individuals with chronic diseases are present in all three villages. Hypertension is the most prevalent, with nearly twice as many cases as diabetes (59 individuals), while 14 individuals are affected by other chronic diseases such as tuberculosis, mental illness, cancer, chronic hepatitis, asthma, musculoskeletal disorders, stroke, and chronic obstructive pulmonary disease. The prevalence of chronic diseases among elderly individuals in each village presents in Figure 12. In all 3charts, hypertension consistently has the highest proportion, ranging from 52.83% to 65.31%, followed by diabetes, which accounts for 22.45% to 41.51%. Other diseases represent the smallest share, varying between 5.66% and 12.24%. This data highlights that hypertension is the most common chronic condition among the elderly, while other diseases are relatively less prevalent.

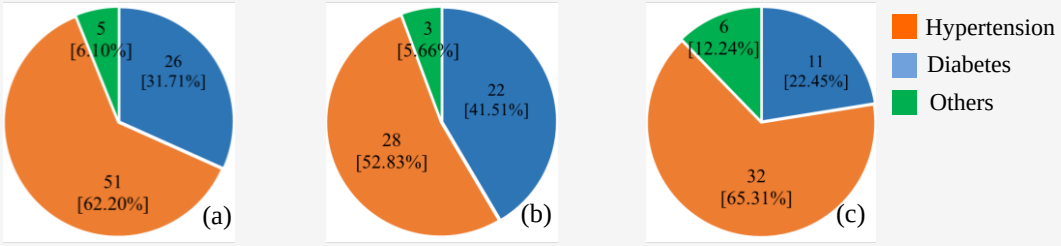

Figure 12: Numbers of the elderly individuals with chronic disease: (a) Nong Ta Yao (b) Nong Wa Mai (c) Nong Wa

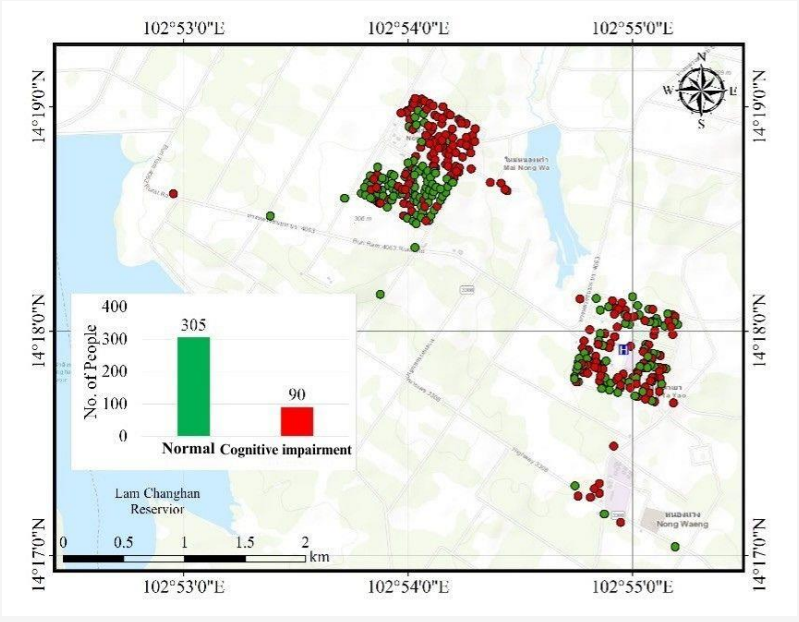

Figure 13: Spatial distribution of cognitive impairment and normal elderly

3.5 Cognitive Impairment

Cognitive impairment refers to a decline in memory, thinking, reasoning, and decision-making abilities that is more severe than normal age-related changes. It can affect various aspects of daily life, making tasks like problem-solving, remembering appointments, or managing finances difficult. Cognitive impairment can range from mild, where individuals may struggle with specific tasks, to more severe conditions like dementia. It is often caused by underlying factors such as aging, neurological diseases (e.g., Alzheimer's), brain injuries, or chronic conditions like diabetes or hypertension. Early detection and management are important to help slow its progression and improve quality of life. The spatial distribution of normal elderly (green dots), and elderly with cognitive impairment (red dots) presents in Figure 13. The total number of elderly individuals without cognitive impaired is 305, while 90 individuals have cognitive impairment. The spatial distribution of cognitive impaired reveals a cluster in Nong Wa Moo 13 and in the lower part of Nong Ta Yao (lower right corner of Figure 13)

Cognitive impaired among the elderly appears randomly distributed in Nong Ta Yao, while Nong Wa Mai Moo 14 has a lower incidence of cognitive impaired compared to the other two villages. The number and percentage of elderly individuals with and without cognitive impaired across three villages present in figure 14. Nong Ta Yao shows a significant proportion of elderly individuals with dementia, accounting for 41.00% of the population, while 59.00% are normal. In Nong Wa Mai, the percentage of elderly with cognitive impaired decreases to 24.07%, with 75.93% being normal. Nong Wa exhibits the lowest percentage of cognitive impaired cases at 7.52%, and the highest percentage of normal elderly individuals at 92.48%. In summary, the prevalence of cognitive impaired varies considerably among the 3 villages. Nong Ta Yao has the highest proportion of cognitive impaired, while Nong Wa shows the lowest, indicating a healthier cognitive status among its elderly population. Nong Wa Mai falls in between, with a moderate cognitive impaired prevalence compared to the other 2 villages.

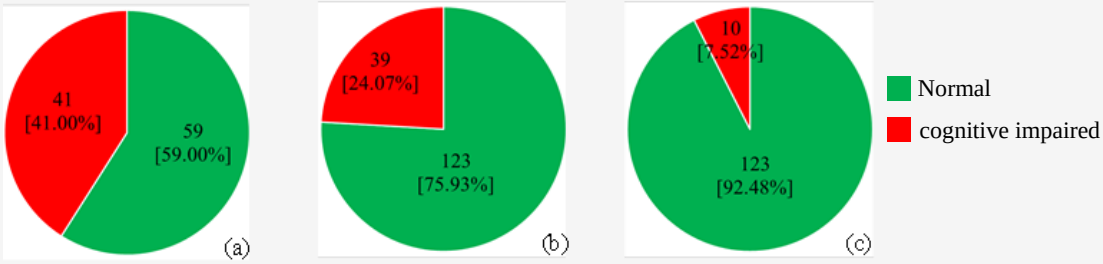

Figure 14: Numbers of the elderly individuals with and without cognitive impaired: (a) Nong Ta Yao (b) Nong Wa Mai (c) Nong Wa

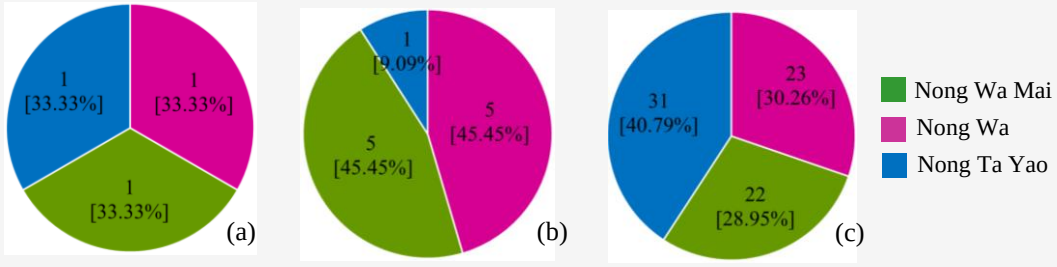

Figure 15: Numbers of healthcare staffs in each village (a) CM (b) CG (d) VHV

3.6 Healthcare Teams

Figure 15 illustrate the distribution of healthcare staff across three villages: Nong Ta Yao (blue), Nong Wa (magenta), and Nong Wa Mai (green) in to 3 categories: care managers (CM), caregivers (CG), and village health volunteers (VHV). In Figure 15(a), all three villages have equal representation, with 1 care manager each (33.33% per village). For Figure 15(b), Nong Wa Mai and Nong Wa dominate, each with 5 caregivers (45.45% each), while Nong Ta Yao has fewer. In Figure 15(c), Nong Wa Mai leads with 23 volunteers (30.26%), followed closely by Nong Ta Yao with 22 (28.95%), and Nong Wa with fewer. Overall, Nong Wa Mai and Nong Wa have stronger representation in caregiving roles, while Nong Ta Yao contributes significantly in health volunteers.

3.7 Service areas of THPH

The service area for each THPH in the study area was determined using the "buffer" geoprocessing tool available in ArcMap software. This tool allowed for the creation of buffer zones around each health facility, with radii of 1 km and 3 km, providing a clear indication of the coverage area of each THPH. Specifically, buffer zones were generated around six THPHs in the study area, as illustrated in Figure 16(a). Upon analyzing the data, it was found that the Nong Ta Yao Health Center serves nearly all individuals residing in the three villages located within its 3 km buffer zone. The coverage area of this health center is notably extensive, ensuring that most of the population is within easy reach of healthcare services. However, there are two individuals who are located just outside the 3 km buffer zone of the Nong Ta Yao Health Center. The distances of these individuals from the health center are 3.04 km and 3.83 km, respectively, which are slightly beyond the optimal coverage range.

The Ngon Kai Health Promoting Hospital, located at a different point in the study area, provides healthcare services to some individuals living in the villages of Nong Wa and Nong Wa Mai. While this health facility covers a portion of the population in these villages, it does not extend coverage to individuals in the three other villages that are located more than 3 km away from the Si Thayat Health Center, as illustrated in Figure 16(b). Consequently, individuals in those villages are left without easy access to healthcare services from the Si Thayat Health Center due to its distance. Given this analysis, it becomes clear that all individuals in the study area are able to access healthcare services at the Nong Ta Yao Health Center, as it is the closest health facility for the majority of the population. This accessibility is crucial for ensuring that individuals in the study area have timely access to healthcare. The proximity of Nong Ta Yao Health Center makes it the most accessible option for those living within its coverage area, as depicted in Figure 17. This highlights the importance of strategic placement of health centers to ensure that the population can easily reach essential healthcare services when needed.

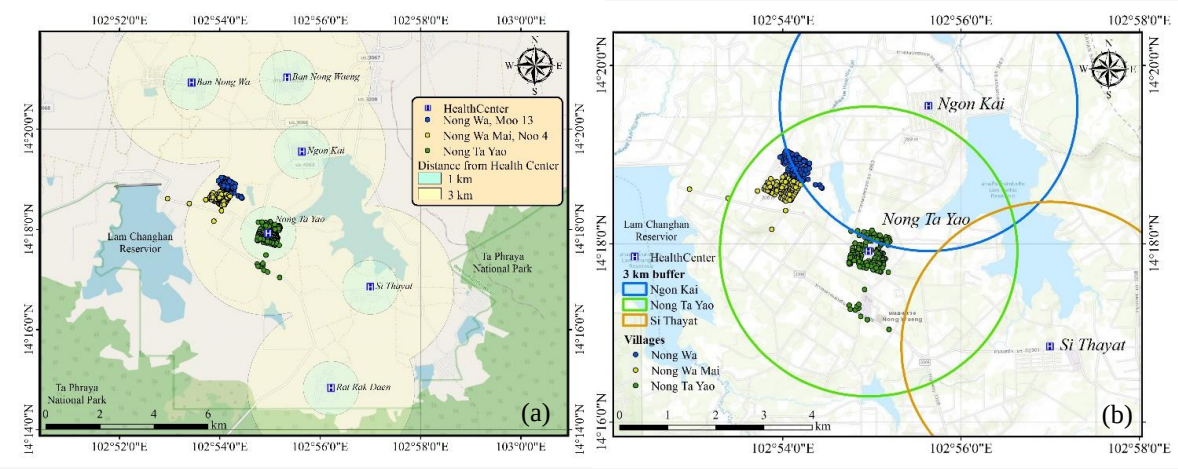

Figure 16: Service area of health centers:
(a) coverage areas of all THPH (b) coverage areas from the 3 closest health centers

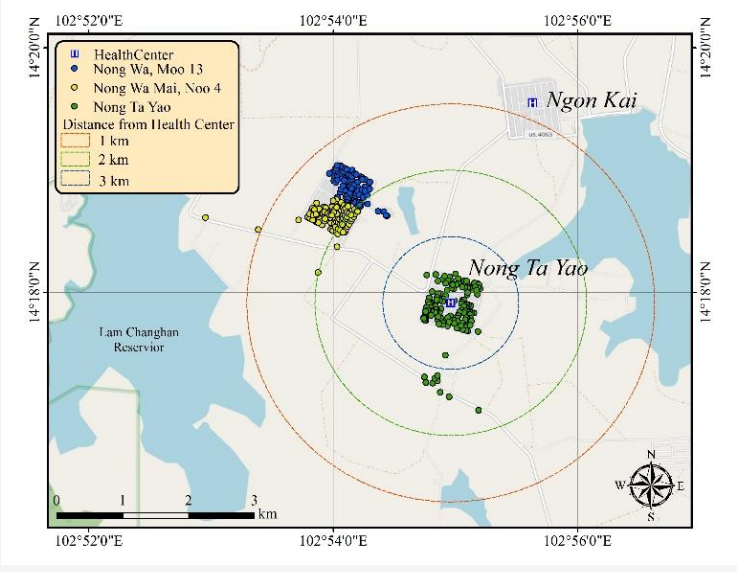

Figure 17: Service area of Nong Ta Yao health center

Most of the residents of Nong Ta Yao are situated in close proximity to the Nong Ta Yao Health Center, which is located at the heart of the village. Many individuals live within a 2-kilometer radius of the health center, while those residing in the nearby areas of Nong Was and Nong Wa Mai are generally located within a 3-kilometer radius. This proximity to the health center plays an important role in ensuring that the community has relatively easy access to essential healthcare services. According to [41], the maximum speed allowed for emergency medical services (EMS) vehicles in Thailand is 80 kph. However, maintaining this maximum speed is often unrealistic due to road conditions and other factors along the route from an incident location to the health center. As a result, the optimal average speed for EMS vehicles is considered to be around 40 kph. With this speed in mind, the longest possible travel time for all individuals to reach the Nong Ta Yao Health Center is estimated to be approximately 4.5 minutes.

3.8 Satisfaction and Utilization

According to the results from assessing satisfaction and utilization among local administrative organization executives, public health division directors, CMs, CGs, and VHVs, overall satisfaction was found to be at a mean of 4.32 (S.D. = 0.68), the highest level, and the result of the assessment of overall utilization yielded a mean of 4.41 (0.61), the highest level. Table 1 presents a detailed assessment of user satisfaction and utilization of a GIS in the context of aged care planning.

Table 1: Average satisfaction and utilization of executives and stakeholders in long-term elderly care

	Average (S.D.)
1. satisfaction	
1.1 Easy to understand and use.	4.24 (0.65)
1.2 Ease of using data from GIS for planning	4.09 (0.71)
1.3 Completeness of the data presented in the GIS system	4.21 (0.64)
1.4 Meeting the need for information for aged care	4.35 (0.65)
1.5 Accuracy of the data displayed by the system	4.47 (0.56)
1.6 The Proper Aspects of GIS Design	4.32 (0.68)
1.7 Policy Decision Support	4.50 (0.66)
1.8 GIS can provide complete reports covering all issues	4.35 (0.69)
1.9 Overall satisfaction with GIS performance	4.32 (0.68)
2. Utilization	
2.1 Information from GIS developed is useful to you.	4.38 (0.60)
2.2 The developed GIS can be used in long-term elderly management planning	4.38 (0.60)
2.3 The developed GIS can promote participatory care for the elderly	4.26 (0.62)
2.4 You can use the knowledge gained from the display system. GIS can be transferred to other people	4.35 (0.60)
2.5 Overall utilization	4.41 (0.61)

The satisfaction section evaluates various aspects of the GIS, including ease of use, data completeness, accuracy, design, and decision support. All items in this section received high average scores, ranging from 4.09 to 4.50 on a Likert scale, indicating strong user satisfaction. Notably, Policy Decision Support scored the highest at 4.50, followed closely by Accuracy of the data at 4.47, suggesting users highly value the system's reliability and utility in decision-making. The low standard deviations (0.56 to 0.71) reflect consistent agreement among respondents. The utilization section focuses on the practical benefits of the GIS, such as its usefulness in elderly management planning and promoting participatory care. Scores here were similarly high, with Overall utilization leading at 4.41 and other items closely aligned, ranging from 4.26 to 4.38. The narrow standard deviations (0.60 to 0.62) further underscore consensus among users about the system's effectiveness. Overall, the results demonstrate that the GIS is well-received, with high satisfaction and utilization scores across all measured dimensions, highlighting its success in supporting aged care planning and policy decisions.

4. Discussion

GIS innovation development for long-term care of elderly people in communities by using UTM coordinates, and still-picture displays combined with quantitative data helped to increase data analysis and presentation capacity. The use of circular graphs in GIS displays helped to make analyses of elderly population density and distribution in the area clearer [42], reflecting health status and independence in each area. Integration of area data and quantitative data helped to clarify the overview of elderly people's situation. In addition, combining the area and quantitative data enabled identification of areas with health risks and made care planning effective [10]. Therefore, GIS implementation helped to make resource management and health planning consistent with community needs [42] and enabled informed decision-making, particularly among high-risk elderly people. Implementation of the geographic information system (GIS) innovation also helped with health resource allocation planning by using area data to determine target areas and effectively allocate resources to meet the needs of each area [43]. Analysis of data on elderly people distribution and chronic disease data found Nong Ta Yao Village to have the highest rate of elderly people with chronic diseases with high risk of complications from the diseases. Therefore, care planning in this area should have projects focused on preventing complications from chronic diseases along with improvement of healthcare team personnel in the village in terms of knowledge and skills in caring for patients with chronic diseases to ensure care has the highest efficiency. This showed use of GIS helped to make resource and personnel allocation effective and led to on-point care planning [5][6][22] and [44] reflecting healthcare success in communities. Furthermore, GIS utilization also helped with identification of areas in need of urgent care [45]. From this study, Nong Wa Mai Village was found to have the highest rate of elderly people living alone, reflecting the need to increase care resources in this area.

Use of GIS data also enabled estimation of risks and problems for elderly people including problem management. In this study, data on fall risks and chronic disease risks were found to be significant. Fall risk management should be carried out in many areas such as muscle strengthening and education for caregivers. GIS data integration helped to improve strategic decision-making concerning care for elderly people in communities by preparing appropriate health programs for high-risk areas, such as by creating community fall monitoring systems. Use of GIS helped to identify areas with high rates of elderly people who have chronic diseases such as Nong Ta Yao Village, which had the highest rate of chronic diseases in elderly people (42%). Use of GIS data helped healthcare teams identify areas in need of urgent care, enable effective holistic care planning, and support decision-making for policy development.

The GIS-based analysis uncovered critical spatial patterns in elderly care needs. The high prevalence of hypertension and diabetes (notably in Nong Ta Yao) aligns with global aging trends, necessitating localized chronic disease management programs. The concentration of fall risks in Nong Wa Mai (52.47%) despite most elderly living with descendants suggests environmental hazards (e.g., inadequate home safety measures) rather than social isolation as a primary factor. Cognitive impairment varied sharply, with Nong Ta Yao's high cognitive impaired rates (41%) potentially linked to limited healthcare access or genetic/environmental factors, warranting further study. These data reflect the need to improve healthcare services, boost personnel capacity, search for factors affecting health problems, and plan on-point prevention of problems. Furthermore, use of GIS in presenting information helped healthcare teams see the overview of risks in various areas and utilize information to plan care for elderly people effectively. This enabled appropriate resource allocation and healthcare measures according to community needs. This GIS system development mainly focused on health data, which may not reflect the problems and needs of elderly people in other areas. The data used in this study is local and quantitative data from a certain period. This data may not be applicable if changes occur to the elderly's information in the future

The uneven distribution of healthcare teams, with Nong Wa Mai and Nong Wa having more caregivers but fewer volunteers, underscores the need for balanced workforce allocation. the Nong Ta Yao Health Center is the most accessible healthcare facility for the majority of individuals in the study area, ensuring that most people within its 3 km buffer zone can easily access healthcare services. The strategic location of this health center plays a critical role in ensuring timely access to healthcare. Proximity to the center is essential, as it significantly reduces travel time and increases the likelihood of individuals receiving necessary medical attention quickly. The longest travel time for individuals within this zone to reach the Nong Ta Yao Health Center is estimated to be approximately 4.5 minutes, assuming an optimal average speed of 40 kph for emergency medical services. These findings emphasize the importance of strategically placing health centers to ensure the population's access to essential healthcare services. The proximity of health facilities, like the Nong Ta Yao Health Center, is key to maintaining a high level of healthcare accessibility, particularly in rural areas.

5. Conclusion

This study underscores the significant role of Geographic Information Systems (GIS) in enhancing the management and planning of long-term care for elderly individuals in communities. By integrating local data with quantitative GIS information, the study was able to identify high-risk areas and urgent care needs more clearly, which proved crucial for effective decision-making and resource allocation. The use of GIS enabled a more efficient distribution of healthcare resources, ensuring that interventions could be targeted where they were most needed. Furthermore, the study emphasizes the importance of collaboration between healthcare providers, caregivers, and community networks in supporting the long-term care needs of elderly individuals. This collective effort is essential for creating a comprehensive and sustainable care system for the elderly population.

One of the key takeaways from the study is the need for regular updates to GIS data, especially with regard to the number of elderly residents and any changes in their health conditions. As the health status of elderly individuals can change rapidly, maintaining up-to-date data is vital for ensuring that interventions remain relevant and timely. In addition, expanding the use of GIS to other communities or regions would enhance our understanding of the diverse care needs of elderly populations in different areas. This expansion would allow for a broader, more comprehensive approach to elderly care, as it would account for regional variations in healthcare infrastructure, access, and socio-economic factors that can impact elderly care.

Moreover, widespread adoption of GIS in healthcare systems could facilitate the development of more robust policies for elderly care, both at the local and national levels.

Policymakers would be able to use GIS-generated insights to identify gaps in care services, allocate resources more efficiently, and design more effective interventions. Ultimately, the integration of GIS into elderly care planning can drive improvements in healthcare systems, ensuring that elderly individuals receive the support they need to live healthier, more fulfilling lives in their communities.

6. Recommendation

Future research should focus on the quantitative analysis of health data across various dimensions. This could include examining mental health, nutrition, and social support, as well as assessing the broader societal and economic factors that affect elderly individuals. A multidimensional approach would provide a more complete picture of the challenges faced by the elderly population, leading to more effective and targeted care strategies. Additionally, training healthcare personnel and caregivers to effectively utilize GIS technology is crucial for improving the quality and accuracy of decision-making in elderly care. By equipping these stakeholders with the tools to analyze spatial data, it would be possible to make more informed decisions that enhance the quality of care for the elderly. Furthermore, because elderly health conditions change over time, a longitudinal study would provide deeper insights into GIS applications for long-term care.

Acknowledgments

This study was made possible with support from the Bureau of Public Health Research and Innovation Administration, Division of Academic Affairs, Department of General Secretary, Ministry of Public Health and Research Affair Division, Faculty of Medicine, Mahasarakham University for providing essential funding. The researchers wish to extend their sincere gratitude to the public health volunteers, the Nong Waeng Sub-district Municipality officers, and the healthcare team from the Nong Waeng Sub-district Municipality. We also extend our thanks to the Faculty of Nursing and Buriram Rajabhat University for their support of the study.

References

[1] United Nations. (2022). World Population Prospects 2022: Summary of Results. [Online]. Available: https://www.un.org/development/desa/pd/content/World-Population-Prospects-2022. [Accessed: Feb. 11, 2025].

[2] National Statistics Office. (2023). Statistic Yearbook 2023. [Online]. Available: https://www.nso.go.th/public/e-book/Statistical-Yearbook/SYB-2023/5/. [Accessed: Feb. 11, 2025].

[3] World Health Organization. (2024). World Report on Ageing and Health. [online]. Available: https://iris.who.int/handle/10665/186463. [Accessed: Feb. 11, 2025].

[4] Panriansaen, R., Suksee, S., Siladlao, S., Kingkaew, M. and Prabsangob, K., (2024). Behavioral Patterns and Recreational Preferences among Elderly Individuals in the Lower Central Region of Thailand. *International Journal of Geoinformatics*, Vol. 20(3), 44–53. https://doi.org/10.52939/ijg.v20i3.3129.

[5] Kitphati, R., Watanawong, O., Wongsaroj, T. and Nithikathkul, C., (2021). National Program of Opisthorchiasis in Thailand; Situation and Policy Strategy. *International Journal of Geoinformatics*. Vol. 17(2). 61-68. https://doi.org/10.52939/ijg.v17i2.1759.

[6] Wongsaroj, T., Nithikathkul, C., Rojkitikul, W., Nakai, W., Royal, L. and Rammasu, P., (2014). National Survey of Helminthiasis in Thailand. *Asian Biomedicine*. Vol. 8(6). 779-783. https://doi.org/10.5372/1905-7415.0806.357.

[7] Ministry of Finance. (2024). Ministry of Finance Annual Report 2023. [Online]. Available: https://mof.go.th/th/ebooks/viewfilp/acfc8760d24cec569ff4a29d2a8aab4cd9176cfed3f782bd57/th. [Accessed Jan.15, 2025].

[8] Siladlao, S., Rojanabenjakun, P., Songsin, N., Panrinsaen, R., Jummaree, T., Chusuton, S., Sawetsenee, K., Khonraengdee, P. and Mekwimon, W., (2024). Factors Related to Health Literacy in the Prevention of COVID-19 Disease in the Elderly in Lad Yai Subdistrict, Mueang District, and Samut Songkhram Province. *International Journal of Geoinformatics*, Vol. 20(3), 74–80. https://doi.org/10.52939/ijg.v20i3.3137.

[9] Public Health System Development Group (PSDG), Ministry of Public Health. (2024). Developing an Integrated and Sustainable Elderly Care System: Health, Welfare, and Technology Integration. [Online]. Available: https://psdg.anamai.moph.go.th. [Accessed Jan.15, 2025].

[10] Kim, J., Kim, D. H., Lee, J., Cheon, Y. and Yoo, S., (2022). A Scoping Review of Qualitative Geographic Information Systems in Studies Addressing Health Issues. *Social Science & Medicine*, Vol. 314. https://doi.org/10.1016/j.socscimed.2022.115472.

[11] World Health Organization. (2021). *Global Patient Safety Action Plan 2021-2030: Towards Eliminating Avoidable Harm in Health Care*. [Online]. Available: https://www.who.int/publications/i/item/9789240032705. [Accessed: Feb. 11, 2025].

[12] Bureau of Geriatric Health, (2019). Manual to Support the Management of Long-Term Care Services in Public Health. [Online]. Available: https://eh.anamai.moph.go.th/th/elderly-manual/201572. [Accessed: Feb. 11, 2025].

[13] Meskó, B., Kristóf, T., Dhunnoo, P., Árvai, N. and Katonai, G., (2024). Exploring the Need for Medical Futures Studies: Insights from a Scoping Review of Health Care Foresight. *Journal of Medical Internet Research*, Vol. 26. https://doi.org/10.2196/57148.

[14] Thappha, J., Yuenyong, N. and Krasang, P., (2021). The Concept of Public Participation in Community Health Promotion. *PTU Journal of Science and Technology*, Vol. 2(2), 86-96.

[15] Ministry of Social Development and Human Security. (2024). Strategic Plan for the Development of a Long-Term Care System for the Elderly 2024-2028. [Online]. Available: https://www.m-society.go.th/home.php. [Accessed; Feb. 14, 2025].

[16] Cheng, L., Yang, M., De Vos, J. and Witlox, F., (2020). Examining Geographical Accessibility to Multi-Tier Hospital Care Services for the Elderly: A Focus on Spatial Equity. *Journal of Transport & Health*, Vol. 19. https://doi.org/10.1016/j.jth.2020.100926.

[17] Taran, A., (2023). Measuring Accessibility to Health Care Centers in the City of Al-Mafraq Using Geographic Information Systems. *International Journal of Geoinformatics*, Vol. 19(1), 43–55. https://doi.org/10.52939/ijg.v19i1.2499.

[18] Khashoggi, B. F. and Murad, A., (2020). Issues of Healthcare Planning and GIS: A Review. *ISPRS International Journal of Geo-Information*, Vol. 9(6). https://doi.org/10.3390/ijgi9060352.

[19] Mohd Ali, A., Masron, T., Junaini, S., Ahmad, A. and Soda, R., (2025). Ethnic Disparities and Demographic Shifts in Sarawak's Aging Population: A Comprehensive Longitudinal Analysis (1980-2020). *International Journal of Geoinformatics*, Vol. 21(2), 106–122. https://doi.org/10.52939/ijg.v21i2.3943.

[20] Mala, M., Meenongwar, C., Jundaeng, J., Osman, M., Viegus, Z., Nithikathkul, C., (2024). Dengue Hemorrhagic Fever Prevention and Control: DHF-Solve Model using Linebot-Application and GIS. *International Journal of Geoinformatics*, Vol. 20(11). 162-176 https://doi. org/10.52939/ijg.v20i11.3717.

[21] Noradee, S., Uthaipibull, S., Kanjaras, P. and Nithikathkul, C., (2023). Spatial Analysis and Modelling of Malaria Trend in Si Sa Ket Province, Thailand. International Journal of Geoinformatics. 19(6), 49-60. https://doi.org/10.52939/ijg.v19i6.2695.

[22] Zhao, T. T., Feng, J., Doanh, P. N., Sayasone, S., Khieu, V., Nithikathkul, C., Qian, M. B., Hao, Y. T., and Lai, Y. S., (2021). Model-Based Spatial-1 Temporal Mapping of Opisthorchiasis in Endemic Countries of Southeast Asia. *eLife*, Vol. 10, 1-35 https://doi.org/10.7554/eLife.59755.

[23] Wang, X. and Liu, Z., (2024). Navigating Aged Care Services with GIS: Trends, Developments, and Future Directions. *BMC Geriatrics*, Vol. 24(1). https://doi.org/10.1186/s12877-024-04799-4.

[24] Suwan, C. and Thongpaen, R., (2019). An Elderly Population Database Development with the GIS Application: A Case of Nam-Jo Municipality, Mae-Tha District, Lampang Province. Journal of Graduate Research. Vol. 10(1), 219-23. https://so02.tci-thaijo.org/index.php/banditvijai/article/view/183673.

[25] Turnbull, N., Som-Ard, J., Yoosook, W., Ratanaopad Suwanlee, S., Chaiyakarm, T., Yukalang, N. and Mattra, S., (2020). Application of Geographic Information Systems (GIS) to Analyse and Detect the Risk of Chronic Diseases in the Elderly. *Studies in Health Technology and Informatics*, Vol. 272, 131-134. https://doi.org/10.3233/SHTI200511.

[26] Su, B., Li, D., Xie, J., Wang, Y., Wu, X., Li, J., Prieto-Alhambra, D. and Zheng, X., (2023). Chronic Disease in China: Geographic and Socioeconomic Determinants among Persons Aged 60 and Older. Journal of the American Medical Directors Association, Vol. 24(2), 206-212. https://doi.org/10.1016/j.jamda.2022.10.002.

[27] Teerakulkittipong, N., Meepradist, Y., Muongmee, S. and Sukpornsawan, P., (2019). Management of Non-Chronic Drug Utilization Behavior of the Adult Elderly Database Model and Utilization Data for Mapping Geographic Information in the Eastern Coastal Areas. [Online]. Available: https://buuir.buu.ac.th/xmlui/handle/1234567890/3980. [Accessed: Jan.15, 2025].

[28] Taburee, W., Hoomhong, C. and Narongrit, C., (2020). Prototype of Internet GIS Supporting the Community-Dwelling Elderly Healthcare. *Srinagarind Medical Journal*, Vol. 35(1), 59-65. https://li01.tci-thaijo.org/index.php/SRIMEDJ/article/view/239906.

[29] Nithikathkul, C., Meenorngwar, C., Krates, J. and Kijphati, R., (2024). Mobile Application for Improving the Quality of Life and Elderly Health Care. *International Journal of Geoinformatics*, Vol. 20(7), 93–110. https://doi.org/10.52939/ijg.v20i7.3409.

[30] Sudsawart, J., Korsanan, N., Pochanakul, K. and Wattanaprapa, N., (2024). Forecasting Elderly Well-Being through Decision Tree Modeling Techniques: Integrating Google Maps for Community Engagement in Bang Jakreng, Samut Songkhram Province, Thailand. *International Journal of Geoinformatics*, Vol. 20(10), 1–9. https://doi.org/10.52939/ijg.v20i10.3625.

[31] Chi, N. C. and Demiris, G., (2015). A Systematic Review of Telehealth Tools and Interventions to Support Family Caregivers. *Journal of Telemedicine and Telecare*, Vol. 21(1), 37-44. https://doi.org/10.1177/1357633X14562734.

[32] Kruse, C. S. and Beane, A., (2018). Health Information Technology Continues to Show Positive Effect on Medical Outcomes: Systematic Review. *Journal of medical Internet research*, Vol. 20(2). https://doi.org/10.2196/jmir.8793.

[33] Rahimi, B., Nadri, H., Afshar, H. L. and Timpka, T., (2018). A Systematic Review of the Technology Acceptance Model in Health Informatics. *Applied Clinical Informatics*, Vol. 9(03), 604-634. https://doi.org/ 10.1055/s-0038-1668091.

[34] Laosupap, K., Wongpituk, K., Butsorn, A., Boonsang, A., Thammaboribal, P., Chankong, W., and Pokomnird, C. (2024). Advancements in Disease Surveillance: The Role of GIS in Global Health Preparedness. *International Journal of Geoinformatics*, Vol. 20(10), 95–108. https://doi.org/10.52939/ijg.v20i10.3663.

[35] Trongsakul, S., Lambert, R., Clark, A., Wongpakaran, N. and Cross, J., (2015). Development of the Thai Version of Mini-Cog, a Brief Cognitive Screening Test. *Geriatrics & Gerontology International*, Vol. 15(5), 594–600. https://doi.org/10.1111/ggi.12316.

[36] Nilnate, N., Jirapornkul, C., and Limmongkon, Y. (2022). Spatial Factors Associated with fall among the Elderly in Thailand. *International Journal of Geoinformatics*, Vol. 18(5), 105–113. https://doi.org/10.52939/ijg.v18i5.2391.

[37] Tanthanapanyakorn, P. and Areesantichai, C., (2024). Spatial Distribution Analysis of Cannabis-Infused Food and Drink Establishments in Pathum Thani Province, Thailand through Geographic Information Systems. *International Journal of Geoinformatics*, Vol. 20(1), 25–39. https://doi.org/10.52939/ijg.v20i1.3023.

[38] Weschasat, T., Tanthanapanyakorn, P., Hongkul, R., Chonsin, K. and Leenatham, N. (2024). Analysis of the Spatial Distribution of Cannabis Establishments Based on Usage Patterns in Mueang District, Surat Thani Province of Thailand. *International Journal of Geoinformatics*, Vol. 20(9), 83–97. https://doi.org/10.52939/ijg.v20i9.3549.

[39] Thipthimwong, K. and Noosorn, N., (2023). Analysis of Accident Sites from Motorcycles among High School Students Using Geographic Information Systems, Sukhothai Province. *International Journal of Geoinformatics*, Vol. 19(3), 45–56. https://doi.org/10.52939/ijg.v19i3.2603.

[40] Thipthimwong, K., Panawathanapisuit, S., Thonthong, T., Yamsri, T. and Plubplatong, T., (2024). A Geographic Information Systems-Based Analysis of Response Time and Hospital Coverage Area in Sukhothai Province, Thailand. *International Journal of Geoinformatics*, Vol. 20(8), 46–55. https://doi.org/10.52939/ijg.v20i8.3449.

[41] Chen, Y., Cui, X. and Li, H., (2022). A Study on the Spatial Distribution and Optimization Strategies of Day Care Centers for the Elderly: An ArcGIS Analysis Based on the Data of Xuhui District in China. *International Healthcare Review (online)*. https://doi.org/10.56226/69.

[42] Wang, X. and Liu, Z. (2024). Navigating Aged Care Services with GIS: Trends, Developments, and Future Directions. BMC Geriatrics, Vol. 24(1). https://doi.org/10.1186/s12877-024-04799-4.

[43] Yi, M., Peng, J., Zhang, L. and Zhang, Y., (2020). Is the Allocation of Medical and Health Resources Effective? Characteristic Facts from Regional Heterogeneity in China. *International Journal for Equity in Health*, Vol. 19(1), 1–21. https://doi.org/10.1186/S12939-020-01201-8.

[44] Pan, J., Deng, Y., Yang, Y., & Zhang, Y. (2023). *Location-allocation modelling for rational health planning: Applying a two-step optimization approach to evaluate the spatial accessibility improvement of newly added tertiary hospitals in a metropolitan city of China*, Vol. 338. https://doi.org/10.1016/j.scscimed.2023.116296

[45] Scerpella, D., Adam, A., Marx, K. and Gitlin, L. N., (2019). Implications of Geographic Information Systems (GIS) for Targeted Recruitment of Older Adults with Dementia and their Caregivers in the Community: A Retrospective Analysis. *Contemporary Clinical Trials Communications*, Vol. 14. https://doi.org/10.1016/J.CONCTC.2019.100338.