A Geoinformatics-Based Competency Framework for Strengthening District Health System Management: Integrating GIS-Supported Decision Making in Primary Care Networks of Krabi Province, Thailand

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DOI: https://doi.org/10.52939/ijg.v22i6.5038

Abstract
District health system strengthening increasingly requires spatially informed decision making to address inequities in service accessibility, workforce distribution, and resource allocation. However, geoinformatics has often been applied as a technical mapping tool, with limited integration into governance structures and managerial competency development. This study proposes a Geoinformatics-Based Competency Framework to institutionalize GIS-supported spatial analytics within district-level health system management. A mixed-methods research design was employed in eight districts of Krabi Province, Southern Thailand. Quantitative data were collected from primary care managers using a quasi-experimental pre–post design, while qualitative data were obtained through participatory workshops and in-depth discussions. Spatial datasets, including population distribution, health facility locations, and health workforce deployment, were integrated into a GIS environment to support spatial overlay analysis and network-based accessibility assessment. Participatory learning activities were implemented to enhance geospatial literacy and spatial decision-making capability among district managers. The results demonstrate statistically significant improvements in district health management performance, particularly in planning, directing, and leading functions ($p < 0.05$). GIS-based spatial analysis revealed localized service accessibility gaps and resource mismatches that were not identifiable through conventional management information systems. Qualitative findings indicate that participatory engagement with spatial outputs strengthened managerial capacity to interpret spatial evidence, justify prioritization decisions, and support equity-oriented governance. This study advances applied geoinformatics by embedding spatial analytics within managerial competency development and routine governance processes. The proposed framework provides a transferable model for integrating geoinformatics into decentralized health systems, positioning GIS as a decision-support infrastructure that enhances spatially informed governance rather than a standalone technical application.

Keywords: District Health System, Geoinformatics, Geographic Information System, Primary Care Management, Spatial Decision Support

1. Introduction

District health systems represent the operational foundation of primary health care delivery in many low- and middle-income countries, particularly within decentralized governance structures. At this level, health managers are responsible for planning, coordinating, and monitoring health services for geographically defined populations. These responsibilities inherently involve spatial decision making, including the alignment of health facilities with population distribution, optimization of health workforce deployment, and identification of underserved areas. Despite this spatial nature, district health management has traditionally relied on non-spatial management information systems and aggregated administrative indicators, limiting the

capacity to address geographic inequities effectively [1].

Health system strengthening frameworks emphasize governance, leadership, and management capacity as critical components for improving system performance and equity [1] and [2]. The World Health Organization highlights the importance of district-level decision making in translating national health policies into effective local implementation [1]. However, conventional approaches to management capacity development rarely integrate spatial intelligence, even though geographic variation is a key determinant of service accessibility, efficiency, and health outcomes.

Recent advances in geoinformatics, including Geographic Information Systems (GIS), spatial analysis, and spatial decision-support systems, have expanded the role of geospatial technologies beyond visualization toward analytical and system-oriented applications [3][4] and [5]. In the health sector, geoinformatics has been applied to disease mapping, environmental health assessment, service accessibility modeling, and health surveillance [6][7][8] and [9]. These applications demonstrate that spatial analysis can reveal inequities and service gaps that remain obscured in tabular data. Nevertheless, most existing studies still apply GIS primarily as a descriptive or project-based tool rather than embedding it within routine management processes or institutional governance structures [10] and [11].

District health management is fundamentally a spatially constrained optimization problem, where limited resources must be allocated across heterogeneous geographic contexts. Decisions regarding facility coverage, referral networks, and workforce distribution require an understanding of spatial relationships between populations, infrastructure, and administrative boundaries. Without geospatial literacy and spatial decision-support mechanisms, district managers may struggle to identify mismatches between health needs and service provision, leading to inefficiencies and persistent inequities [8][12] and [13]. Although competency frameworks for primary care and district health managers increasingly recognize the importance of leadership, planning, and systems thinking, they rarely incorporate geoinformatics as a core managerial competency [10] and [14]. Consequently, GIS tools—when available—are often confined to technical units and are not fully integrated into managerial decision making. This separation limits the institutionalization of geoinformatics within health governance and constrains its potential contribution to system-level performance improvement.

Thailand provides an illustrative context for examining this challenge. The country has implemented district health system reforms aimed at strengthening primary care networks and improving equity in service delivery. District health managers are expected to coordinate health facilities, local government organizations, and community stakeholders within diverse geographic and socio-economic environments. Provinces characterized by population mobility, tourism, and heterogeneous settlement patterns face complex spatial challenges in planning and resource allocation, which cannot be adequately addressed using conventional reporting systems alone. Integrating geoinformatics into district health management represents a strategic shift from map-based visualization toward spatially enabled governance. Spatial decision-support systems can function as core management infrastructures that support planning, monitoring, and evaluation by transforming heterogeneous spatial data into actionable intelligence [5][13] and [15]. When embedded within competency development processes, geoinformatics enhances managers' capacity to interpret spatial evidence, identify service gaps, and support equity-oriented, evidence-based decision making.

This study addresses the gap between geoinformatics applications and managerial competency development by proposing a Geoinformatics-Based Competency Framework for district health system management. Using empirical evidence from primary care managers in Southern Thailand, the study examines how GIS-supported analytical workflows and participatory learning can strengthen spatial intelligence and management performance at the district level. By positioning geoinformatics as an integral component of system design and governance rather than a standalone technical tool, the study advances applied geoinformatics and demonstrates its potential role in institutionalized decision support for decentralized health systems.

2. Conceptual Framework

2.1 Conceptual Rationale

District health system management is increasingly required to operate within complex spatial environments characterized by heterogeneous population distribution, unequal service accessibility, and constrained health resources. Traditional management frameworks emphasize administrative competencies and organizational processes but often overlook the spatial dimension inherent in district-level decision making. Consequently, management actions are frequently

guided by aggregated indicators that fail to capture geographic inequities and spatial interdependencies.

This study conceptualizes district health management as a spatially enabled governance system, in which managerial competencies are strengthened through the systematic integration of geoinformatics. Rather than treating Geographic Information Systems (GIS) as auxiliary mapping tools, the framework positions geoinformatics as a core decision-support infrastructure embedded within routine management and governance processes. The proposed conceptual framework (Figure 1) integrates three interdependent domains:

(1) Spatial Data and Geoinformatics Functions,
(2) Managerial Competency Development, and
(3) District Health System Performance.

The interaction among these domains enables district health managers to translate spatial evidence into informed decisions, thereby strengthening planning accuracy, resource optimization, and equity-oriented governance.

2.2 Framework Structure

The conceptual framework operates through a cyclical and iterative process, consisting of four interconnected layers:

Spatial Data Environment: This layer comprises geospatial datasets relevant to district health management, including population distribution, health facility locations, workforce deployment, transportation networks, and administrative boundaries. These datasets represent the spatial reality within which district health systems operate.

Geoinformatics and Spatial Analytics Layer: Spatial data are transformed into actionable intelligence through geoinformatics functions such as spatial overlay analysis, accessibility modeling, catchment area delineation, and spatial visualization. This layer converts raw data into interpretable spatial patterns and decision-relevant indicators.

Managerial Competency Enhancement Layer: Through participatory learning and experiential use of spatial analytics, primary care managers develop geospatial literacy and spatial reasoning competencies. These competencies enable managers to interpret spatial outputs, identify service gaps, and integrate spatial evidence into planning, coordination, and monitoring activities.

Spatially Enabled Governance and System Performance: Enhanced managerial competencies support spatially informed decision making, leading to improved district health system performance. Key outcomes include optimized resource allocation, improved service accessibility, strengthened inter-sectoral coordination, and enhanced equity in health service delivery.

Feedback loops link system performance outcomes back to the spatial data environment, enabling continuous learning, adaptive management, and system refinement.

2.3 Conceptual Innovation

The novelty of this framework lies in its integration of geoinformatics with competency-based management, shifting GIS from a descriptive function toward an institutionalized decision-support role. By embedding spatial analytics within governance and management processes, the framework advances applied geoinformatics as a system design approach rather than a standalone technical application.

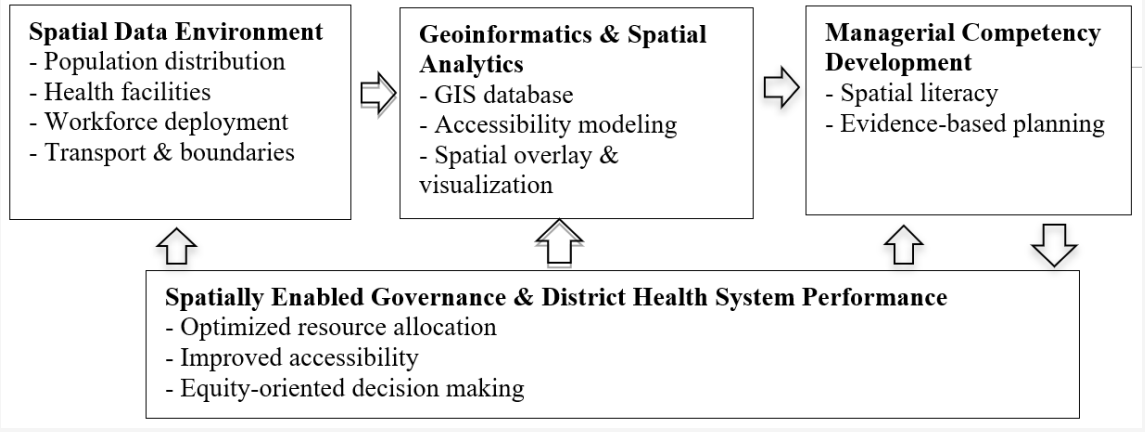

Figure 1: Conceptual framework of geoinformatics-based district health system management

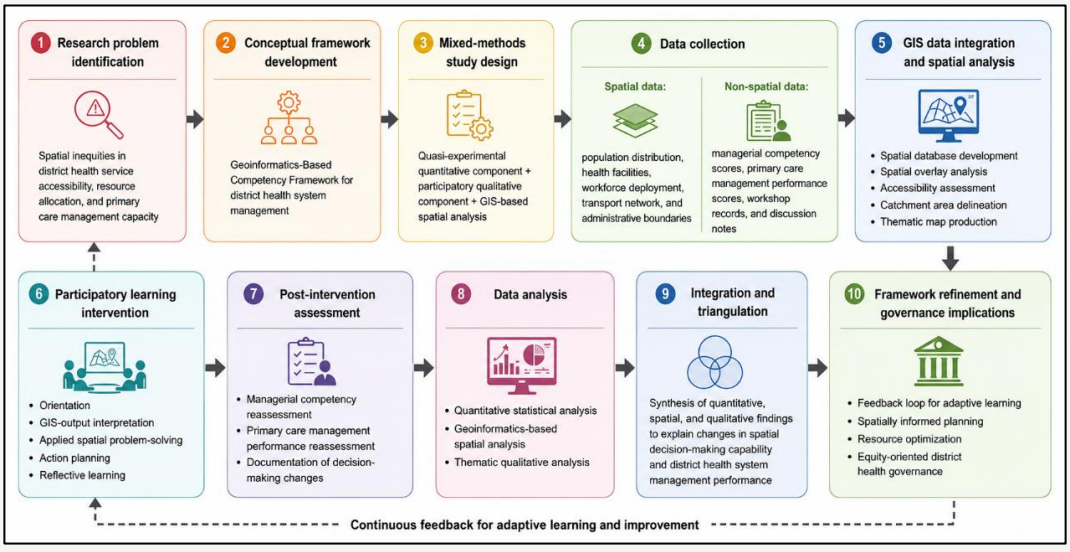

Figure 2: Methodological flowchart of the geoinformatics-based competency framework study

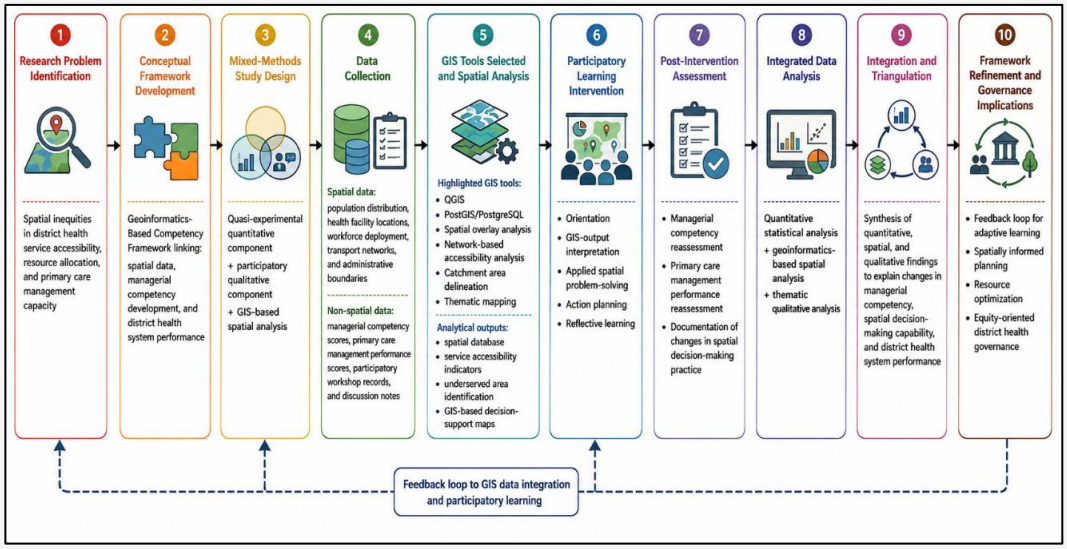

Figure 3: Methodological flowchart of the geoinformatics-based competency framework study, with GIS tools highlighted

3. Materials and Methods

3.1 Study Design

This study employed a mixed-methods research design to examine how the integration of geoinformatics-based decision support into primary care governance enhances managerial competencies and district health system performance. The design aligned with the proposed Geoinformatics-Based Competency Framework, emphasizing interactions among spatial data, GIS-based analytics, participatory learning, and spatially informed governance. Figures 2 and 3 illustrate the sequence of research design, data collection, GIS-based spatial analysis, participatory learning, post-intervention assessment, and integrated analysis. The flowchart also highlights the GIS tools used in the study, including QGIS, PostGIS/PostgreSQL, spatial overlay analysis, network-based accessibility analysis, catchment area delineation, and thematic mapping.

3.2 Study Area

The study was conducted in Krabi Province, Southern Thailand as presented in Figure 4, the province is located on the Andaman coast of southern Thailand and has a moderately sized population characterized by a mix of urban residents, rural communities, and migrant workers, particularly those associated with tourism, fisheries, and agriculture.

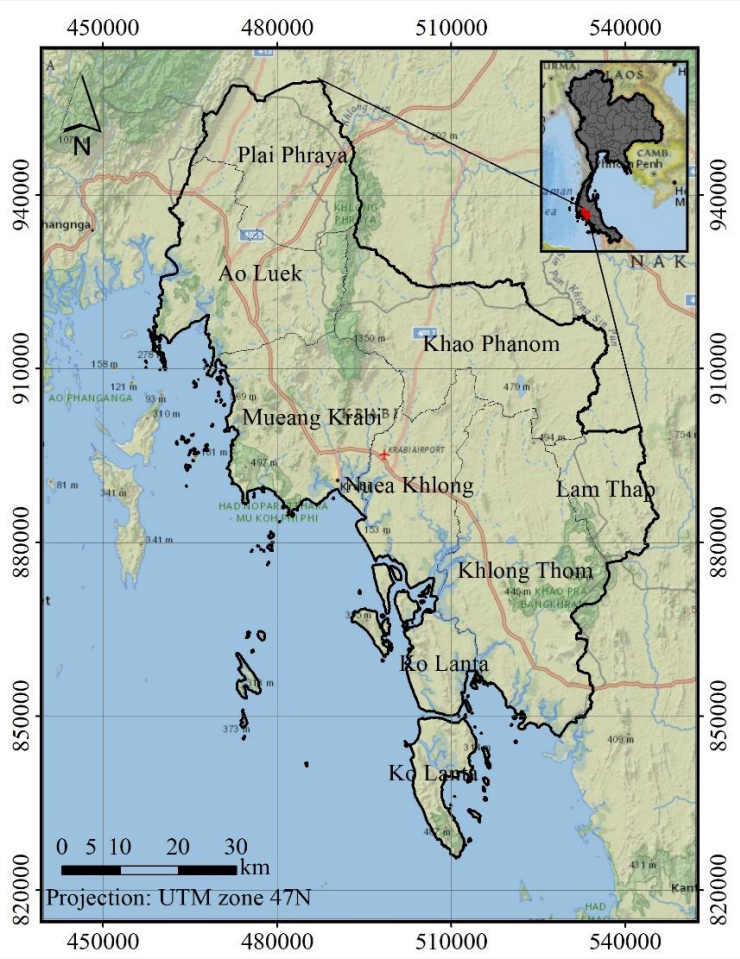

Figure 4: Krabi province, Thailand

The population is unevenly distributed, with higher concentrations in Mueang Krabi and coastal districts, while inland and island areas remain relatively sparsely populated. Krabi's healthcare system operates within Thailand's universal health coverage framework, ensuring basic health services for the majority of residents. Public healthcare is anchored by Krabi Hospital, a provincial referral hospital, supported by several district hospitals and subdistrict health-promoting hospitals that provide primary care and preventive services. Despite generally good access to essential healthcare, challenges persist, including shortages of specialized medical personnel, seasonal pressure on health services due to tourism, and geographic barriers affecting island and remote communities. These factors contribute to disparities in service accessibility and health outcomes across the province.

3.3 Study Population and Participants

The study population consisted of primary care managers responsible for planning, coordination, and management of primary health services. A total of 80 primary care managers participated, divided into an intervention group (41 managers) and a comparison group (39 managers).

3.4 Data Sources and Materials

Spatial datasets included population distribution, health facility locations, health workforce allocation, administrative boundaries, and transportation networks. Non-spatial data included management plans, performance indicators, and competency assessment instruments.

3.5 GIS Environment and Geoinformatics Tools

Spatial data integration and analysis were conducted within a GIS environment using geoinformatics tools for spatial overlay analysis, accessibility assessment, and visualization. The Spatial overlay analysis integrated population, facility, and workforce data. Accessibility and service coverage were assessed using GIS-based catchment modeling, and results were visualized through thematic maps. QGIS was selected as the primary desktop GIS platform because it supports spatial data management,

geoprocessing, visualization, and thematic map production within an open-source environment suitable for district-level health planning. PostGIS/PostgreSQL was selected as the spatial database environment because it enables systematic storage, indexing, and querying of geospatial datasets, including population layers, health facility locations, workforce attributes, transport networks, and administrative boundaries. Spatial overlay analysis was selected to identify geographic mismatches between population needs, service locations, and workforce deployment, while network-based accessibility analysis was selected to assess travel-based service coverage and delineate underserved catchment areas. These tools were therefore selected for their relevance to spatially informed primary care planning, reproducibility, and scalability in decentralized district health systems.

3.6 Participatory Learning and Competency Development

Participatory learning was applied to enhance geospatial literacy and spatial decision-making competencies among primary care managers. A participatory learning approach was employed as a core methodological component to enhance geospatial literacy and spatial decision-making competencies among primary care managers. The approach was designed to operationalize geoinformatics integration into routine district health governance by enabling managers to actively engage with GIS-based spatial evidence rather than passively receiving technical outputs.

3.6.1 Participants and target group

Participants in the participatory learning component were primary care managers from the intervention districts, including heads and acting heads of primary care units responsible for district-level planning, monitoring, and coordination. These managers were directly involved in decision making related to service coverage, workforce allocation, and resource distribution, making them key actors for integrating geoinformatics into governance processes.

3.6.2 Learning design and activities

Participatory learning activities were structured around experiential and problem-based learning principles, focusing on real management challenges within the district health system. The learning process consisted of the following key activities:

Orientation and Conceptual Briefing: Participants were introduced to the role of geoinformatics in district health system management, including basic concepts of spatial data, GIS-based analysis, and spatial decision support. Emphasis was placed on interpreting spatial information rather than technical GIS operation.

Hands-on Engagement with GIS Outputs: Participants worked with GIS-generated maps and spatial visualizations derived from district-level data, including population distribution, health facility locations, health workforce allocation, and service accessibility. Managers were guided to interpret spatial patterns, identify inequities, and recognize spatial mismatches between service provision and population needs.

Applied Spatial Problem-Solving Sessions: Small-group discussions were conducted in which participants applied spatial evidence to real planning scenarios, such as prioritizing underserved areas, reallocating health workforce, and improving service coverage. These sessions emphasized collaborative interpretation and decision making based on spatial evidence.

Reflective Learning and Knowledge Integration: Facilitated reflection sessions allowed participants to discuss how spatial insights influenced their understanding of district health system challenges and how GIS-based evidence could be integrated into routine planning, monitoring, and inter-sectoral coordination processes.

3.6.3 Competency domains addressed

The participatory learning process targeted specific managerial competency domains aligned with the study's conceptual framework, including:

Geospatial literacy: Ability to understand and interpret spatial data, maps, and visual analytics

Spatial reasoning: Capacity to analyze geographic relationships and spatial inequities affecting service delivery

Evidence-based spatial planning: Application of spatial evidence to planning, resource allocation, and prioritization decisions

Spatial decision-making in governance: Integration of GIS outputs into coordination and policy discussions at district level.

3.6.4 Duration and implementation timeline

The participatory learning intervention was implemented over a six-month period as part of the overall study timeline. Learning activities were

conducted in multiple phases to allow iterative application and reflection:

Phase 1 (Month 1): Orientation and baseline engagement with spatial concepts and GIS outputs

Phase 2 (Months 2–4): Repeated participatory learning workshops and applied spatial problem-solving sessions integrated with routine management activities

Phase 3 (Months 5–6): Consolidation of learning, reflective evaluation, and integration of geoinformatics into ongoing district planning and monitoring processes

This phased approach enabled participants to progressively develop competencies while applying spatial evidence to real governance contexts.

3.6.5 Role of facilitators and learning environment
Facilitators with expertise in health system management and geoinformatics supported the participatory learning process. Their role focused on guiding interpretation, facilitating discussion, and linking spatial evidence to management decisions, rather than providing technical GIS training. The learning environment emphasized collaboration, contextual relevance, and practical applicability.

3.7 Data Analysis
Data analysis was conducted using an integrated mixed-methods analytical approach to examine changes in managerial competencies, district health management performance, and the contribution of geoinformatics-based decision support to spatially informed governance. Quantitative, spatial, and qualitative analyses were performed in parallel and subsequently integrated to support comprehensive interpretation of findings.

3.7.1 Quantitative analysis of managerial competency and performance
Quantitative data derived from managerial competency assessments and district health management performance instruments were analyzed using descriptive and inferential statistical methods. Descriptive statistics, including means and standard deviations, were used to summarize baseline characteristics and competency scores of participants.

Inferential statistical analyses were conducted to evaluate changes in managerial competencies and management performance associated with the geoinformatics-based intervention. Within-group comparisons between pre-intervention and post-intervention measurements were performed for the intervention group to assess competency development over time. Between-group comparisons were conducted to examine differences in post-intervention outcomes between the intervention and comparison groups. Statistical significance was assessed at a confidence level of $p < 0.05$. These analyses enabled evaluation of the effectiveness of participatory learning combined with geoinformatics-based decision support in improving district health management performance.

3.7.2 Spatial and geoinformatics-based analysis
Spatial analysis constituted a central component of the data analysis process and was conducted to identify spatial patterns, inequities, and decision-relevant insights not observable through conventional management information systems. Geoinformatics-based analyses included spatial overlay analysis integrating population distribution, health facility locations, and health workforce allocation to identify geographic mismatches between service availability and population needs. Network-based accessibility analysis was performed to assess geographic access to primary health services across districts and to delineate service catchment areas. Spatial outputs were generated in the form of thematic maps and spatial indicators, which were used to support interpretation of service accessibility, workforce distribution, and resource allocation efficiency. These spatial analyses directly informed managerial decision-making processes during participatory learning activities and district-level planning discussions.

3.7.3 Qualitative analysis of participatory learning and decision-making processes
Qualitative data obtained from participatory learning workshops, group discussions, and observation records were analyzed using thematic analysis. Data were systematically coded to identify themes related to geospatial literacy development, spatial reasoning processes, and changes in managerial decision-making practices. Analysis focused on understanding how primary care managers interpreted GIS-based outputs, integrated spatial evidence into planning and coordination activities, and perceived the value of geoinformatics in addressing spatial inequities. Qualitative findings provided contextual explanations for observed quantitative and spatial analysis results.

3.7.4 Integration and triangulation of findings
Findings from quantitative, spatial, and qualitative analyses were integrated through a triangulation process to enhance analytical rigor and validity.

Quantitative improvements in managerial competencies and management performance were interpreted alongside spatial analysis results and qualitative insights to identify convergent and divergent patterns. This integrative analysis enabled assessment of not only whether improvements occurred, but also how and why geoinformatics-based decision support contributed to changes in governance practices. The triangulation process supported comprehensive interpretation of the role of geoinformatics in strengthening district health system management.

3.7.5 Alignment with conceptual framework and feedback loop

Data analysis was explicitly aligned with the study's conceptual framework. Analytical findings from management performance assessment and spatial analysis were used to inform iterative refinement of spatial datasets, analytical models, and decision-making strategies. This feedback-oriented analytical process supported adaptive learning and continuous improvement, reflecting the framework's emphasis on geoinformatics-enabled governance and system-level performance enhancement.

3.8 Ethical Considerations

Ethical approval for this study was obtained from the Ethical Review Committee of the Faculty of Public Health, Mahidol University (CAO No. MUPH 2017-168), and all procedures adhered to the Declaration of Helsinki. Informed consent was obtained from all participants.

4. Results

4.1 Quantitative Changes in Managerial Competency (Intervention Group)

Table 1 summarizes pre- and post-intervention competency scores among primary care managers in the intervention group (n=41). Significant improvements were observed in Analytical competency (p=0.001) and Planning and financial management (p=0.046). The overall competency mean score also demonstrated a significant change following the intervention (p=0.002). When expressed as total scores (Table 2), the Analytical domain and the overall total score remained statistically significant after the intervention (p=0.001 and p=0.002, respectively), consistent with improvements in managers' capability to use evidence for assessment and planning.

Table 1: Competency scores before and after intervention (n=41), mean scale (independent t-test within group)

Competency	Pre Mean	Pre SD	Post Mean	Post SD	Mean diff	*t*	*df*	*p*
Analytical	3.01	0.35	2.97	0.36	0.04	4.07	40	0.00
Communication	3.01	0.43	2.98	0.47	0.03	1.31	40	0.20
Cultural competency	2.91	0.44	2.88	0.48	0.02	1.64	40	0.11
Community dimensions of practice	2.96	0.49	2.96	0.49	0	0	40	1.00
Public health sciences	2.81	0.39	2.81	0.39	0	0	40	1.00
Planning and financial management	2.88	0.41	2.85	0.43	0.02	2.06	40	0.05
Leadership and systems thinking	2.94	0.37	2.93	0.38	0.02	1.53	40	0.13
Total mean	2.93	0.33	2.91	0.35	0.02	3.27	40	0.00

Table 2: Competency scores before and after intervention (n=41), total score scale

Domain	Pre Mean	Pre SD	Post Mean	Post SD	Mean diff	*t*	*df*	*p*
Analytical	42.12	4.86	41.54	5.1	0.59	4.07	40	0.00
Communication	15.07	2.15	14.9	2.37	0.17	1.31	40	0.20
Cultural competency	17.44	2.66	17.29	2.86	0.15	1.64	40	0.11
Community dimensions of practice	29.59	4.92	29.59	4.92	0	0	40	1.00
Public health sciences	22.49	3.12	22.49	3.12	0	0	40	1.00
Planning and financial management	40.27	5.78	39.95	6.09	0.32	2.06	40	0.05
Leadership and systems thinking	23.54	2.92	23.41	3.06	0.12	1.53	40	0.13
Total score	190.51	21.5	189.17	22.71	1.34	3.27	40	0.00

Table 3: Primary care management scores before and after intervention (n=41), mean scale

Primary care management	Pre Mean	Pre SD	Post Mean	Post SD	Mean diff	*t*	*df*	*p*
Planning	3.65	0.43	3.59	0.51	0.07	2.38	40	0.02
Organizing	3.78	0.47	3.73	0.58	0.05	1.58	40	0.12
Staffing	3.61	0.54	3.61	0.54	0	0	40	1.00
Directing	3.72	0.51	3.68	0.55	0.03	2.21	40	0.01
Leading	3.58	0.42	3.48	0.56	0.09	2.46	40	0.04
Total mean	3.68	0.42	3.63	0.5	0.05	2.46	40	0.02

Table 4: Primary care management scores before and after intervention (n=41), total score scale

Primary care management domain	Pre Mean	Pre SD	Post Mean	Post SD	Mean diff	*t*	*df*	*p*
Planning	47.51	5.6	46.66	6.68	0.85	2.38	40	0.02
Organizing	52.93	6.51	52.17	8.15	0.76	1.58	40	0.12
Staffing	36.12	5.42	36.12	5.42	0	0	40	1.00
Directing	52.02	7.09	51.59	7.67	0.44	2.68	40	0.01
Leading	39.34	4.57	38.32	6.13	1.02	2.21	40	0.03
Total score	227.93	25.88	224.85	30.74	3.07	2.46	40	0.02

Table 5: Post-training comparison of competency scores between intervention and comparison groups (independent t-test)

Competency (post)	Intervention Mean	Intervention SD	Comparison Mean	Comparison SD	*t*	*df*	*p*
Analytical	3.01	0.35	2.97	0.35	0.48	75	0.63
Communication	3.01	0.43	2.96	0.35	0.66	75	0.51
Cultural competency	2.91	0.44	2.86	0.43	0.5	75	0.62
Community dimensions of practice	2.96	0.49	2.93	0.47	0.3	75	0.76
Public health sciences	2.81	0.39	2.78	0.4	0.37	75	0.72
Planning and financial management	2.88	0.41	2.84	0.4	0.42	75	0.68
Leadership and systems thinking	2.94	0.37	2.9	0.39	0.5	75	0.62
Total mean	2.93	0.33	2.89	0.33	0.54	75	0.59

4.2 Improvement in Primary Care Management Performance (Intervention Group)

Table 3 presents primary care management performance scores before and after the intervention (n=41). Statistically significant differences were observed in Planning (p=0.022), Directing (p=0.011), and Leading (p=0.033). The total mean management score also changed significantly (p=0.018). Table 4 shows the same outcomes as total scores. Significant changes were again observed for Planning, Directing, Leading, and the overall total score (p<0.05), supporting the conclusion that the participatory learning intervention strengthened decision-oriented management functions.

4.3 Post-Training Comparison Between Intervention and Comparison Groups

Post-training comparisons indicated no statistically significant differences between the intervention (n=41) and comparison group (n=36) across competency domains (Table 5). Similarly, primary care management performance scores did not differ significantly between groups after training (Table 6), suggesting that the intervention effects were most clearly observed as within-group improvement trajectories.

4.4 Geoinformatics-Based Outputs Supporting Decision Making

Figures 5 to 8 summarize the geoinformatics-enabled decision-support workflow embedded in the competency framework. The figures illustrate (i)

integration of population, facility, and workforce layers into a GIS database; (ii) accessibility and service catchment modelling; (iii) participatory learning processes translating GIS outputs into action; and (iv) feedback loops for adaptive governance.

Table 6: Post-training comparison of primary care management scores between intervention and comparison groups (independent t-test)

Primary care management (post)	Intervention Mean	Intervention SD	Comparison Mean	Comparison SD	*t*	*df*	*p*
Planning	3.65	0.43	3.6	0.41	0.52	75	0.60
Organizing	3.78	0.47	3.75	0.49	0.3	75	0.7
Staffing	3.61	0.54	3.61	0.56	0.01	75	0.99
Directing	3.72	0.51	3.68	0.52	0.27	75	0.79
Leading	3.58	0.42	3.48	0.4	0.98	75	0.33
Total mean	3.68	0.42	3.63	0.42	0.43	75	0.67

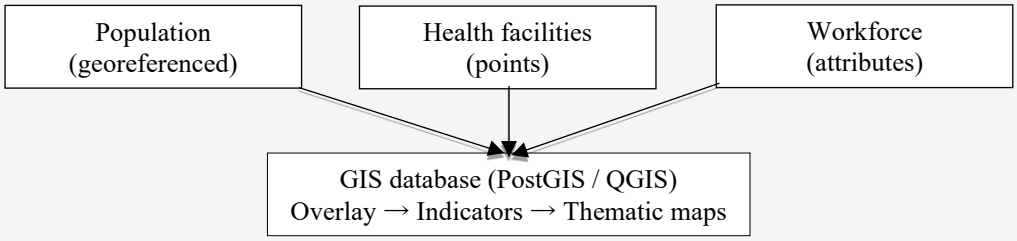

Figure 5: Spatial layer integration and overlay analysis in the GIS environment

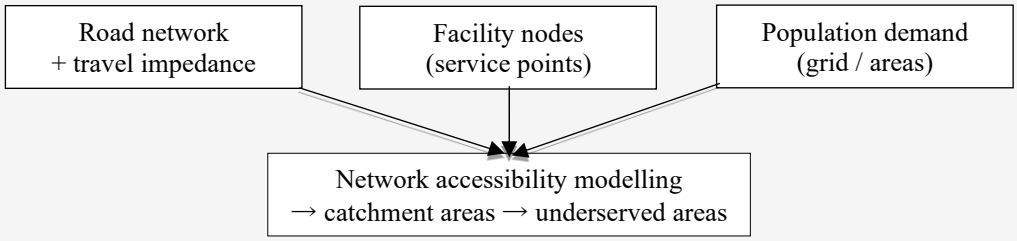

Figure 6: Network accessibility modelling and catchment analysis for identifying underserved areas

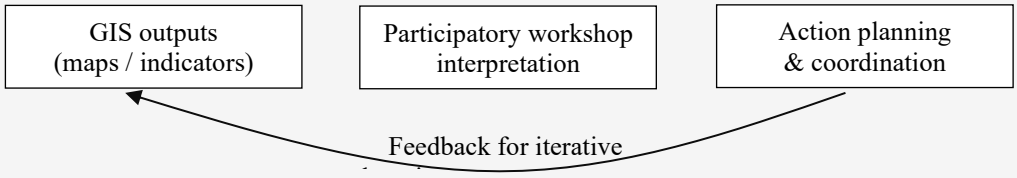

Figure 7: Participatory learning cycle integrating GIS outputs into planning and coordination, with iterative feedback

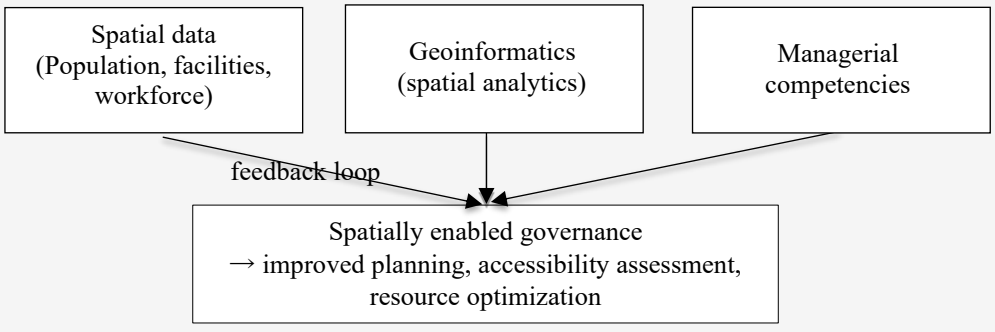

Figure 8: Geoinformatics-based competency and governance framework

4.5 Qualitative Findings

Qualitative findings were derived from participatory workshops, group discussions, and reflective sessions conducted with primary care managers across the study districts. The analysis revealed how geoinformatics-based tools were progressively integrated into managerial practice through experiential learning and collective interpretation of spatial evidence.

1. Transition from Descriptive Mapping to Spatial Reasoning: Participants initially perceived GIS outputs primarily as visual maps for reporting purposes. Through facilitated interpretation and discussion, managers gradually developed spatial reasoning skills, enabling them to analyze spatial relationships between population distribution, facility locations, and service accessibility. This transition marked a shift from passive map viewing toward analytical use of spatial information for decision making. *"Previously, we looked at maps as pictures. Now we use them to ask why some areas are underserved and what can be done differently."*

2. Enhanced Decision Confidence through Spatial Evidence: Engagement with GIS-based spatial analysis strengthened managers' confidence in decision making. Spatial outputs provided an objective and shared reference that supported justification of planning priorities and resource allocation decisions. Managers reported that spatial evidence reduced ambiguity in discussions and facilitated consensus among stakeholders. *"Having spatial data made it easier to explain and defend our decisions, especially when coordinating with other sectors."*

3. Participatory Learning as a Catalyst for Competency Development: Participatory learning activities played a critical role in transforming geoinformatics from a technical tool into a practical governance instrument. Hands-on interaction with spatial datasets and collective interpretation fostered geospatial literacy, collaborative learning, and adaptive problem-solving capabilities. Rather than focusing on technical GIS proficiency alone, the process emphasized contextual understanding and application.

4. Visibility of Spatial Inequities and Equity-Oriented Thinking: GIS-based visualization made previously hidden spatial inequities visible at the sub-district level. Managers reported increased awareness of service accessibility gaps and vulnerable areas, prompting a more explicit consideration of equity in planning and coordination. Spatial evidence supported the reframing of resource distribution discussions toward equity-oriented governance.

5. Integration of Geoinformatics into Routine Governance Processes: Over the course of the intervention, geoinformatics was increasingly incorporated into routine management activities, including planning meetings, monitoring discussions, and inter-sectoral coordination. Managers emphasized that the iterative use of spatial outputs encouraged reflective learning and continuous improvement, reinforcing the feedback loop between analysis, action, and reassessment.

5. Discussion

This study was designed to address the limited integration of geoinformatics-based decision support within district health system governance and managerial competency development. By embedding GIS-supported spatial analytics into participatory learning and routine management processes, the study provides empirical evidence that geoinformatics can function as a governance-enabling infrastructure rather than a purely technical mapping tool.

5.1 Geoinformatics and Spatially Informed District Health Governance

Consistent with the first research objective, the findings demonstrate that the integration of population distribution, health facility locations, and health workforce data within a GIS environment significantly enhanced managers' ability to identify spatial inequities in service accessibility. Spatial overlay analysis and network-based accessibility modelling revealed localized service gaps that were not detectable through conventional management information systems relying on aggregated tabular data. Recent geoinformatics research emphasizes that the value of GIS in health systems lies not merely in visualization, but in its capacity to support spatial reasoning and evidence-informed governance [16][17] and [18]. The present findings extend this literature by showing that when spatial analytics are embedded within routine district governance structures, they directly influence planning priorities, coordination mechanisms, and resource allocation decisions.

The findings of this study are consistent with recent studies published in the International Journal of Geoinformatics, which demonstrate the growing role of GIS in health service accessibility assessment, spatial equity analysis, disease surveillance, and public health decision support. Previous studies have shown that GIS can reveal travel-distance barriers and spatial service gaps that are not apparent in

conventional tabular data [19] and [20]. Participatory GIS has also been applied to combine expert and public perspectives in spatial health-risk assessment, supporting the present study's emphasis on participatory learning and managerial interpretation of spatial evidence [21].More recent studies have extended GIS applications to disease surveillance, real-time public health preparedness, dengue prevention and control, and elderly health-service planning [22][23]and [24].Collectively, these studies strengthen the argument that GIS should be institutionalized not only as a technical mapping tool but also as a decision-support mechanism for equity-oriented planning, resource prioritization, and decentralized health system governance.

5.2 Effects of Geoinformatics Integration on District Health Management Performance

In relation to the second research objective, quantitative results showed statistically significant improvements in planning, directing, and leading functions among managers in the intervention group. These domains are closely associated with spatial decision-making processes, including prioritization of underserved areas, inter-facility coordination, and optimization of limited resources. The lack of statistically significant post-intervention differences between intervention and comparison groups suggests that the impact of geoinformatics integration manifested primarily as within-group performance improvement trajectories. This pattern is consistent with contemporary health systems and implementation research, which recognizes that governance-oriented interventions often produce incremental and context-dependent effects rather than immediate between-group contrasts [25] and [26]. Importantly, such within-group improvements are meaningful in decentralized district health systems where baseline managerial practices and contextual constraints vary substantially.

5.3 Managerial Competency Development and Decision Capability

Although quantitative competency scores demonstrated limited between-group differences, qualitative findings provide crucial insight into how managerial competencies were strengthened in practice. Participatory learning activities facilitated the development of geospatial literacy, spatial reasoning, and the ability to translate spatial.

These findings align with recent competency-based and systems-oriented approaches to health workforce development, which emphasize decision capability and adaptive learning over isolated skill acquisition [27][28] and [29]. Rather than producing immediate changes in generic competency metrics, the intervention enhanced managers' capacity to use spatial evidence collaboratively, reflectively, and contextually-capabilities that were reflected in improved management performance outcomes.

5.4 Geoinformatics, Equity, and Accountability in Health Service Planning

A major contribution of this study lies in demonstrating how geoinformatics supports equity-oriented and accountable governance. GIS-based identification of underserved and hard-to-reach areas enabled managers to justify prioritization decisions transparently and to communicate spatial evidence effectively with local administrative organizations and community stakeholders. Recent literature highlights the growing importance of spatial approaches for advancing equity in health systems, particularly in geographically heterogeneous and resource-constrained settings [30][31] and [32]. The present findings confirm that geoinformatics can serve as a shared decision-support platform that strengthens accountability by making inequities visible, measurable, and contestable within governance processes.

5.5 Contribution to Applied Geoinformatics and Health Systems Research

From an applied geoinformatics perspective, this study advances the field by demonstrating how spatial analytics can be institutionalized within competency development frameworks and governance system design. Unlike studies that focus primarily on technical GIS methods or descriptive mapping, this research positions geoinformatics as an integral component of managerial practice and organizational learning. The proposed *Geoinformatics-Based Competency Framework* offers a transferable model for decentralized health systems seeking to operationalize spatial analytics for governance improvement. The feedback loop linking spatial data, geoinformatics analysis, participatory learning, and management performance reflects recent systems-thinking perspectives that conceptualize health systems as adaptive and learning-oriented entities [28][33] and [34].

5.6 Policy and Practice Implications

The findings suggest that investments in geoinformatics should extend beyond hardware, software, and data infrastructure to include managerial capacity building and participatory learning mechanisms. Strengthening geospatial literacy among district health managers is essential to ensure that spatial data are meaningfully integrated into decision making rather than remaining underutilized. For policymakers, the results provide

evidence that geoinformatics can support decentralized primary health care reforms by improving planning accuracy, inter-sectoral coordination, and equity-oriented resource allocation. These implications align with recent global policy frameworks emphasizing data-driven, people-centered primary health care and district-level system strengthening [35][36][37] and [38].

6. Conclusion

This study demonstrates that geoinformatics can play a substantive role in strengthening district health system governance when spatial analytics are embedded within managerial competency development and routine decision-making processes. By integrating GIS-supported spatial analysis with participatory learning among primary care managers, the proposed *Geoinformatics-Based Competency Framework* enabled spatially informed planning, improved assessment of service accessibility, and more transparent resource allocation at the district level.

Rather than functioning solely as a technical mapping tool, geoinformatics emerged in this study as a governance-enabling infrastructure that supports decision capability and organizational learning. Quantitative improvements in management performance, together with qualitative evidence of enhanced geospatial literacy and collaborative decision making, underscore the value of coupling spatial data infrastructure with managerial capacity building. From the perspective of applied geoinformatics, this research extends the application domain of GIS from descriptive analysis toward institutionalized decision support in decentralized health systems. The framework and findings offer a transferable model for integrating geoinformatics into governance structures where spatial inequities and resource constraints remain persistent challenges.

Importantly, GIS served as a critical decision-support mechanism by transforming fragmented spatial and administrative data into actionable evidence for district health management. The use of GIS enabled managers to visualize service accessibility gaps, identify underserved areas, and examine mismatches between population needs, health facility distribution, and workforce allocation. These functions strengthened evidence-based planning, improved transparency in resource prioritization, and supported equity-oriented decision making within primary care networks. Therefore, GIS should be viewed not merely as a mapping tool, but as a strategic infrastructure for strengthening spatial intelligence, managerial competency, and decentralized health system governance.

Overall, the study contributes empirical and conceptual insights that advance geoinformatics as a strategic component of system design and decision support, with relevance for both researchers and practitioners seeking to operationalize spatial analytics for governance improvement.

7. Limitations and Future Work and Recommendations

The limitation of this study are the quasi-experimental design limits causal inference due to non-randomized group allocation, and existing competency measurement instruments may not fully capture context-specific spatial decision-making capabilities. Furthermore, the study was conducted in a single province, which may limit generalizability. Future research should examine longitudinal impacts of geoinformatics-integrated governance, explore applications in diverse geographic and institutional contexts, and assess how emerging approaches such as GeoAI and real-time spatial analytics can further enhance district health system decision support

Acknowledgements

The authors gained valuable lessons from this study, particularly in time management, systematic thinking, and perseverance. The study also provided important insights for the development of primary care in Krabi Province. The authors would like to express their sincere gratitude to Dr. Narongsakdi Angkasuvapala, former Deputy Secretary of the Ministry of Public Health, and Dr. Suwat Wiriyapongsukit, Deputy Director of the Division of Primary Care Support, Ministry of Public Health, for their valuable comments and constructive suggestions, which greatly contributed to the completeness of this research. We also sincerely thank Associate Professor Orathai Ard-am for her kindness and helpful guidance in improving and refining the study. In addition, we are grateful to Dr. Kannikar Ruangdej Chaosuansrichareon and Dr. Paisit Boonyakawee for their insightful suggestions in strengthening the research proposal and developing the research instruments. Finally, the authors would like to express their sincere appreciation to Dr. Nonglak Pagaiya for her continuous support and valuable comments, which were instrumental in enhancing the quality and completeness of this study.

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