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Determining of Watershed Level using Geographic Information Systems. Case Study: Nam Sa Sub-basin of Bolikhamxai Province, Lao PDR.

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Abstract

Background and Aim: This study investigates the development and application of a watershed classification model for the Sa River Basin, which covers an area of 248.2 km² in the Lao People's Democratic Republic. It provides a critical foundation for sustainable watershed management and emphasizes the importance of data-driven, localized approaches in the planning of environmental resources.

Materials and Methods: The classification criteria include factors such as slope, Digital Elevation Model (DEM), geology, landform, soil, and forest cover. The overlay process integrates these thematic layers, utilizing spatial data analysis through Geographic Information Systems (GIS), specifically the ArcGIS software. This method combines multiple data layers to analyze and classify watershed quality effectively.

Results: resulting in six detailed basin class maps: 1A, 1B, 2, 3, 4, and 5. The use of GIS technology significantly enhanced the efficiency of this process, reflecting the advantages of modern technological advancements in environmental modeling. To evaluate the method's effectiveness, the GIS-based approach was tested for its potential to enable efficient water and land resource management within the basin, ultimately aiming to support sustainable development.

Conclusion: The Nam Sa Sub-basin spans an area of 248.2 km² and exhibits a wide variety of watershed characteristics. These are classified into five distinct Watershed Classes (WSC): WSC 1: 23.51 km², WSC 2: 21.10 km², WSC 3: 47.59 km², WSC 4: 144.18 km², WSC 5: 11.77 km². Among these, WSC 4 is the largest, covering a substantial portion of the sub-basin. This class is characterized by particular features that exert a significant influence on water flow, sediment transport, and land-use suitability.

Keywords: Watershed Classification (WSC); Nam Sa River Sub-basin; Blikhamxay Province; Lao People's Democratic Republic

Introduction

The Lao People's Democratic Republic (Lao PDR) has a total area of 236,800 square kilometers, comprising 230,800 square kilometers of land and 6,000 square kilometers of water (Ministry of Commerce, 2011). Lao PDR is classified as a developing country with significant economic growth, particularly in the rapidly advancing hydropower industry. However, this development has introduced complex challenges related to natural resources, the economy, and society.

Despite the Lao PDR's abundant water resources, concerns about future water availability arise due to potential mismanagement. Improper management could result in inadequate water supply, especially during the dry season. Additional global challenges, such as climate change, population growth, and land use changes, further exacerbate these issues. Development activities that lack proper regulation, combined with laws and management practices that do not align with sustainable development goals (SDGs), contribute to inefficiencies in resource utilization. This mismanagement impacts not only water resources but also other natural resources, with lasting effects on the quality of life for the people.

Lao PDR has delineated 62 watersheds, categorized into three levels: regional (14 basins), provincial (19 basins), and district (29 basins) (Department of Water Resources, Lao PDR, n.d.). These watersheds are rich in biodiversity and encompass various environments, including tropical rainforests, highlands, wetlands, agricultural ecosystems, and communities. These areas provide critical ecosystem services that support agriculture, maintain ecological balance, and ensure water availability for various human activities. However, managing these natural resources to meet current and future demands sustainably presents significant challenges.

Effective watershed management is complex due to the interconnected nature of resources. For example, forests act as watersheds, storing water in the soil and preventing erosion through tree roots, which stabilize the soil and facilitate water infiltration. The interplay between ecological, meteorological, hydrological, and socio-economic factors complicates resource management, and the

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absence of appropriate measures can lead to resource degradation. Issues such as deforestation in highland areas, reduced water quality, erosion, and soil loss can directly and indirectly affect downstream communities, agriculture, and livelihoods. Furthermore, the lack of monitoring and follow-up systems hinders the implementation of sustainable management practices.

Watershed management is essential for achieving sustainable development and environmental conservation. It involves using integrated tools and strategies to enable river basins to provide ecosystem services, support communities, and maintain environmental stability. In Thailand, water resource management is conducted through integrated approaches based on geographic features. The country has designated 22 river basins, each with unique geographical, economic, and social characteristics, necessitating tailored management strategies (Thailand's 20-Year Water Management Master Plan (2018–2037)).

Watersheds in Thailand are classified into quality levels based on geographic and hydrological characteristics as well as the impact of environmental changes. This classification guides appropriate land use and resource management strategies for each area, addressing environmental, economic, and social challenges systematically. Rather than focusing on individual resources or watersheds, the management approach considers all components of the ecosystem, including the people within each area.

The goal of watershed management extends beyond local or specific areas, emphasizing a holistic system-level approach. Current national and global watershed management guidelines advocate for quality-based classifications and tailored management measures for each basin. This study seeks to explore the concept and methodology of watershed quality classification to adapt and apply it in the Lao PDR. By integrating interdisciplinary studies, participatory processes, and spatial management, the aim is to develop resource management strategies aligned with the Lao PDR's developmental goals. These strategies will address various threats, promote sustainability, and support the continued development of the country.

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Objectives

The following research objectives were formulated to guide the study:

To analyze to watershed class in the Nam Sa sub-basin area, Bolikhamxai Province, Lao PDR.

Literature review

1. Watershed and Watershed Management

Designating areas for the sustainable use of natural resources, based on conservation principles rather than merely workable techniques, is a key aspect of watershed management. This approach involves dividing land into zones that allow different types of activities in designated development areas while protecting reserves from resource exploitation. Since resources vary in their characteristics, some being robust and flexible while others are fragile and vulnerable, it is crucial to employ practical conservation techniques to prevent misuse. These techniques include zoning, grouping, and setting usage limits.

Moreover, the diverse social, economic, physical, racial, and cultural characteristics of resource users add complexity to sustainable watershed management. Without clear rules and controls, achieving sustainable outcomes becomes challenging. Therefore, two critical elements for successful conservation practices are:

1) Zoning establishes defined zones for specific activities to ensure sustainable resource use.
2) Identification of Areas for Resource Exploitation, designating areas where resource use is permissible while adhering to conservation principles.

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Effective resource management in a watershed also relies on implementing laws, regulations, restrictions, and enforcement mechanisms. These measures ensure that resource utilization aligns with conservation goals and sustainability.

As Chankaew (2008) emphasizes, the integration of zoning and conservation principles, combined with robust legal frameworks and enforcement strategies, is essential for sustainable watershed resource management.

2. Watershed Classification

The determination of watershed quality levels by the Water Resources and Agricultural Information Institute requires that land use within watersheds complies with the Cabinet resolution dated November 19, 1991, and adheres to established watershed quality standards. Land use and natural resource management, including forest resources within national reserve forests, must also follow the "Measures for the Use of Forest Resources and Land in National Reserved Forests," as stipulated in the Cabinet resolution dated February 21, 1995, which aligns with the resolution of the National Environment Committee (Water Resources and Agricultural Information Institute, 2012).

Watershed classification serves a similar purpose to land-use planning for forests. While traditional land-use planning often prioritizes areas around large urban centers, watershed classification emphasizes the integrated management of agricultural and grazing lands alongside forest areas. The primary goal of watershed classification is to understand and guide human interactions with the environment, thereby minimizing adverse effects on-site and off-site (Natural Resource and Environmental Policy and Planning, 1996).

Land capability classification is a crucial tool for land-use planning. It ensures that soil data is systematically collected and made accessible to planners and stakeholders in an organized manner (Hudson, 1971). This classification process is the first step in determining optimal land use. It supports decision-making and provides insights for repurposing land to achieve sustainable development.

Steps in the Watershed Classification Process Watershed classification involves several systematic steps:

❖ Mapping: Creating maps that categorize watershed areas.

❖ Impact Analysis: Assessing the effects of soil conservation methods and sustainable productivity both on-site and off-site.

❖ Sustainability Assessment: Evaluating the long-term productive capacity of the land.

❖ Technology Development: Designing and implementing technologies to maintain or enhance land productivity.

The process of watershed classification relies on a system that determines potential land uses based on the physical and environmental attributes of landscape units. These attributes, referred to as "landscape units," include stable factors such as long-term average climate, elevation, slope, landform, geology, and soil characteristics. Landscape units are defined as mappable areas with similar physical traits.

To effectively categorize land for potential uses, a method must be established to evaluate the significance of physical and environmental variables within landscape units. This method should ensure the following:

Each variable is numerically ranked according to the watershed class.

The method evaluates the functional relationships between variables and the watershed class number.

The independent contribution of each variable is numerically analyzed within the overall watershed classification framework (Natural Resource and Environmental Policy and Planning, 1996).

3. Criteria for Determining Watershed Quality Classes

The water quality assessment conducted by the Institute of Water Resources Information and Agriculture employs a classification system that prioritizes areas within the basin. This system establishes criteria for using natural resources in each region, guided by conservation principles and environmentally sound management techniques. Each basin possesses unique characteristics and ecological potential, influenced by factors such as land type, rock and soil composition, altitude, slope, and weather conditions.

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As a result, identifying the environmental potential and characteristics of each area and delineating boundaries based on these factors is essential for determining water quality levels. Resource areas are typically classified based on their physical attributes and the potential of their resources. This approach supports pollution management, enhances resource utilization, and provides a framework for land-use planning.

These principles of agricultural and water resource management are critical for setting effective planning and management targets, ensuring sustainable development, and better utilization of natural resources (2012).

4. Classification of Watersheds in Thailand

The classification of river basins in Thailand has been accepted for more than 20 years. In January 1975, the Ministry of Agriculture and Cooperatives submitted to the Cabinet the criteria for demarcating or classifying the Ping River basin. These criteria propose that approximately 60 percent of the upper upland area of the Ping River Basin be designated Level 1 and protected from any natural resource use. Except for the restoration and protection of watersheds. All residents within this zone will be evacuated if approved by the Cabinet. This is because there is already significant mining activity in the area proposed to be classified as Category 1, and conflicts arise between government agencies. The Ministry of Industry, therefore, requested that the proposed criteria for watershed classification be revised. Compensation recipients for the watershed classification project were established in October 1979. The National Economic and Social Development Board awarded a grant to Kasetsart University through the National Environment Board to carry out the project. In Thailand, an equation was proposed. Prediction of watershed layers by the Natural Resources and Environmental Policy and Planning (1996).

The classification of river basins in Thailand has been recognized and utilized for over 20 years. In January 1975, the Ministry of Agriculture and Cooperatives submitted criteria to the Cabinet for demarcating or classifying the Ping River Basin. These criteria proposed that approximately 60% of the upper upland area of the Ping River Basin be designated as Level 1, prohibiting any use of natural resources except for watershed restoration and protection. If approved by the Cabinet, all residents within this zone would be relocated to ensure the preservation of the watershed.

This proposal faced challenges due to ongoing mining activities in the area designated as Category 1, leading to conflicts between government agencies. The Ministry of Industry requested a revision of the proposed watershed classification criteria to address these issues. Consequently, compensation plans for affected residents were initiated.

In October 1979, the National Economic and Social Development Board (NESDB) awarded a grant to Kasetsart University through the National Environment Board to conduct a project addressing watershed classification. As part of this effort, an equation for predicting watershed layers was developed by the Natural Resources and Environmental Policy and Planning (1996).

5. Measures Policies for Land Use of the Lao PDR

Between 1989 and 1990, the Stop Agricultural Deforestation Project was launched to promote the cessation of deforestation for agricultural purposes. The project aimed to accelerate the efficient and sustainable management of land, forests, and water resources. It sought to protect existing forest areas while gradually increasing forest cover, thereby reducing and ultimately ending forest clearing for agriculture. The initiative also focused on defining land types and clarifying land use rights for users nationwide, ensuring that landowners had confidence and security in managing and utilizing their land.

To support this effort, a unified mechanism for managing agricultural and forestry land was established across the country. This system facilitated the inspection of land use practices and enabled efficient land tax collection. By 1995–1996, the government expanded its policies to accelerate the development of remote rural areas into small towns, emphasizing food security, commodity farming, and the prohibition of forest clearing for agriculture.

In 2019, the Lao PDR introduced a new land law amendment, which divided land into three main geographic areas: plains, plateaus, and mountains. Additionally, it categorized land into eight types:

1. Agricultural land
2. Forest land
3. Water source land
4. Industrial land
5. Transportation land
6. Cultural land

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7. Land for national defense and security
8. Construction land

This land classification system aimed to provide a clear framework for land management and ensure alignment with national development goals (Land Law, 2019).

The National Allocation Master Plan for 2030 has established two key goals:

❖ Reserve and conserve 70% of the country's land as forested areas, including water resources within these regions.

❖ Utilize and develop 30% of the land for various purposes, including areas surrounding water bodies.

These areas also include water resource zones integral to agricultural and environmental management. The goals and land allocations align with the National Economic and Social Development Plan (2021) to support sustainable development and balanced land use.

Conceptual Framework

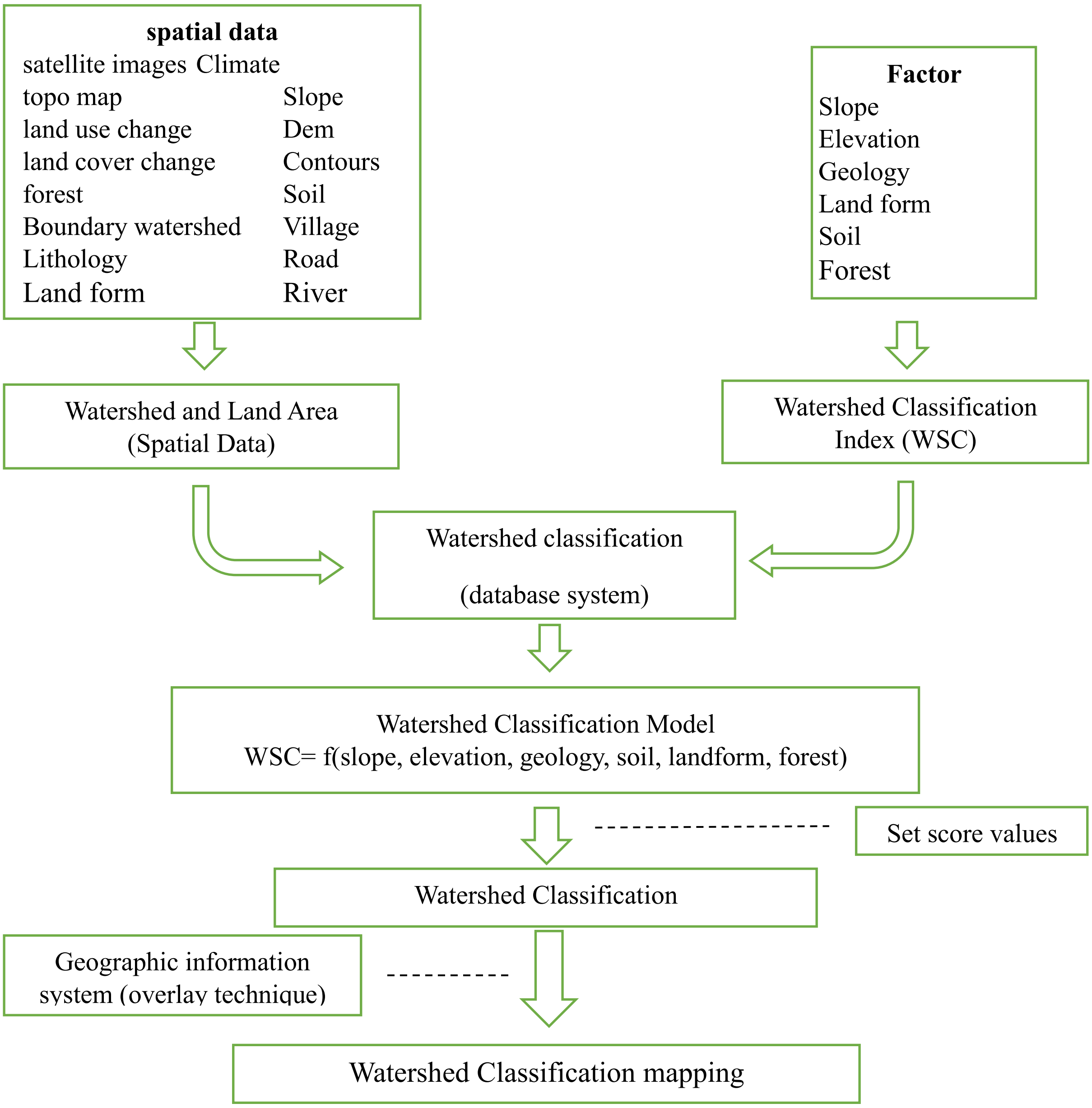

Figure 1 Research Conceptual Framework

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Methodology

This research is qualitative. The study was conducted through a mixed-methods research approach, combining interviews and observations. The research process is as follows:

1. Check the Documents from the Literature Review and Related Research

The study involves examining documents, literature reviews, and related research to achieve the following objectives: (1) Understand the Principles and Factors influencing watershed quality classification, including the development of standard equations and classification methods. (2) Explore Methods for Determining Watershed Quality Classes and the integration of GIS in the classification process. (3) Study land use measures and resource management strategies within watershed areas. (4) Analyze Policies and Various Development Approaches relevant to watershed management and sustainable development. This comprehensive approach aims to provide a deeper understanding of watershed management principles, tools, and techniques to support effective policy-making and resource conservation.

2. Collection and Preparation of Information

2.1 Secondary Data: Collect data from various agencies, both maps and databases, and prepare the data for analysis in the next step.

2.2 Data Preparation: The second phase of processing within a GIS involves the collection and storage of data. Spatial data can exist in various formats, such as analog, graphic, or tabular, and may originate from sources like original map manuscripts, field surveys, or remote sensing analysis. These datasets are then input into a structured digital file using a computer terminal with a formatted screen interface. The techniques for data collection and storage typically include the following:

- Manual Capture involves recording both spatial and attribute data on a grid-cell basis. The data is then overlaid and converted into digital values, represented in matrix form. This process is achieved by inputting information through a terminal keyboard and computer system.

- Semi-automatic capture begins by defining two control points: the first at the upper left corner (x-min, y-max) and the second at the lower right corner (x-max, y-min). These points define the extent of the area on the base map. The area is then spatially encoded through digitization and represented graphically. In the final stage, a graphical display allows users to easily access and analyze the data, as well as make necessary amendments before integrating it into the computer system.

- Automatic Capture refers to the process of converting both spatial and attribute data by encoding or digitizing analog images into digital formats through a scanner. Thematic classification and rectification are performed before the data is analyzed within the GIS system.

- Contour Lines: Contour line data from topographic maps at a 1:50,000 scale, provided by the Department of Maps, Lao PDR, are in digital map format. This data is used to calculate elevation (Elevation, ELE), slope (Slope, SLP), and landform (Landform, LFM) variables.

- Soil Series: Soil series data from the soil series maps provided by the Department of Agriculture Land Management, Lao PDR, are in map database format. These are used to prepare agronomic characteristic variables (soil, SOIL).

- Geological Characteristics: Geological data from the geological maps provided by the Department of Agriculture, Land Management, Lao PDR, are in map data format. These are used to create geological variables (Geology, GEOL).

- The Vector Data Structure is described by Hastings as a directed line segment that represents a physical quantity, including location, with magnitude and scale. More simply, a vector can be thought of as a unit of information traveling from one point to another. It is not fixed; it has both length and direction (Hasting, 1990).

- Constructing a spatial database involves three primary types of spatial entities depicted on the map: points, lines, and polygons. Points represent specific locations or features at a given scale, such as houses or villages. Lines, or arcs, illustrate directional flow, connectivity, or linear features like streams, roads, and utility lines. Polygonal entities, on the other hand, define closed areas and represent features such as soils, land uses, and forest stands within a defined coordinate system.

- Spatial entities are converted into computer-compatible formats through a process called digitization. This process involves transforming the entities into computer-readable formats by

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converting the tracings into either a string representation or a set of X and Y coordinates based on the map.

- The raster data structure can be viewed as grid data, consisting of fixed-size or pixel-based cells with digital values that cover a specific region. These values are typically derived from digital terrain models, scanned maps, satellite images, and other visual data sources. The raster data model and analysis process incorporate three compression mechanisms:

1) Block Codes: This technique encodes raster information by manually converting a regular grid from a sketch map, with each grid cell assigned a class that represents the predominant characteristic within the cell.

2) Chain Codes: These organize raster data into sequences of cardinal directions, which represent the grid cells.

3) Run-Length Codes: This compression technique is used by the Grid to achieve optimal compression by adjusting to each cell individually.

3. Setup Criteria Classification

3.1 Slope and Elevation: In the study area, Slope and Digital Elevation Model (DEM) data were utilized to obtain the elevation data. The DEM provided a detailed representation of the topography of the area, which was essential for understanding the elevation and terrain characteristics illustrated in Table 1.

The GIS program was employed to process this data, specifically using the Reclassify Command. This command was applied to reclassify the elevation data into 5 distinct layers. Each layer was assigned a classification based on the elevation or slope characteristics, allowing the study to categorize the terrain into meaningful classes for further analysis and decision-making.

By using the Reclassify function in GIS, the data was grouped into categories that help to interpret the suitability of different areas within the watershed for various uses, based on their slope and elevation attributes.

Table 1 Criteria Elevation, Slope, Landform, and Geology in Watershed Classification

Watershed Classification	Elevation	Slope	Landform	Geology
5	<200	0-6	Flat, Pit	Fans, Fluvial, Mosaic, Unconsolidated
4	200-300	6-12	Footslope	Shale, Mosaic, Limestone, Sandstone, Unconsolidated
3	300-400	12-25	Shoulder, Peak, Valley	Acid metamorphic, Mosaic, Limestone, Sandstone, Schist, Slate, Unconsolidated
2	400-500	25-35	Hollow	Mosaic, Limestone, Sandstone, Schist, Slate
1	>500	>35	Spur, Slope, Ridge	Acid rhyolite, Gabbro, Gneiss, Granite, Igneous, Interbedded Extrusive, Mosaic, Sandstone, Schist, Slate

3.2 Geology: Comparing a geological map stored in a digital database with a standard geological map ensures that the rock formations are accurately represented and that the scoring system for geological data is correctly applied. This process is essential for data validation, error detection, and ensuring the reliability of geological analyses in various applications such as land-use planning, environmental studies, and resource management, illustrated in Table 1.

3.3 **Landforms:** The Geomorphon Landforms tool is a powerful tool used to classify terrain based on its geomorphological characteristics. This tool analyzes the surrounding terrain patterns and generates a geomorphic (geomorphic feature) pattern for each cell in a DEM. It mimics the process of how we interpret and classify landforms in the field, helping to categorize terrain more systematically illustrated in Figure 1.

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In the Geomorphon tool, there are over 498 unique geomorphic patterns identified, which are grouped into 10 main landforms. These landforms are defined as:

a) Flat: Areas with little or no slope, such as plateaus or level plains.
b) Peak: The highest point of an area, often a mountain peak.
c) Ridge: A long, narrow elevated landform, often formed by tectonic forces or erosion.
d) Shoulder: An area on the side of a hill or mountain, often a steep slope near a ridge.
e) Spur: A short ridge descending from a mountain or hill.
f) Slope: A steep or gradual incline, typically between two landforms.
g) Hollow: A small depression or concave area, often associated with valleys or basins.
h) Footslope: The bottom of a slope, typically forming a transition zone between hill and valley.
i) Valley: A low area between hills or mountains, often formed by rivers or glaciers.
j) Pit: A very low depression, such as a crater or sinkhole.

3.2 Soil: The soil data derived from the 1:50,000 scale soil map of Lao PDR (2021), based on the World Reference Base for Soil Resources (WRB) by the Food and Agriculture Organization (FAO), is a critical resource for understanding and managing land resources. This detailed and scientifically structured dataset supports various applications in land-use planning, agriculture, and environmental management.

The classification system of the WRB provides an internationally recognized framework for categorizing soils based on their physical and chemical properties, ensuring consistency and comparability in soil studies. When combined with a scoring system, this data enables the evaluation of soil suitability for specific purposes, such as agriculture or construction, by assigning quantitative or qualitative values to soil characteristics like texture, fertility, drainage, and pH levels.

Such a scoring system simplifies decision-making processes, offering a practical tool for stakeholders to assess the potential and limitations of different soils in a region. For example, soils with high fertility and balanced pH might be prioritized for crop cultivation, while well-draining soils may be better suited for certain types of infrastructure.

Table 2 Criteria Soil (Soil Groups, Drainage, Organic Matter (OM), and Texture) in Watershed Classification.

Criteria Classification				
Watershed Classification	**Soil Groups of the WRB**	**Drainage**	**OM**	**Texture**
5	CAMBISOLS GLEYSOLS SOLONCHAK, SOLONETZ ARENOSOLS	<2	>26	Silty Clay, Silty Clay Loam, Clay, Clay Loam, Sandy Clay.
4	LUVISOLS, LIXISOLS, ALISOLS, ACRISOLS, FERRALSOLS, FLUVISOLS, NITISOLS, REGOSOLS	2	16-25.	Silty Clay, Silty Clay Loam, Clay, Clay Loam, Sandy Clay.
3	LUVISOLS, LIXISOLS, ALISOLS, ACRISOLS, FERRALSOLS, FLUVISOLS, NITISOLS, REGOSOLS	3	6-15.	Loam, Silty Loam, Silty, Sandy Clay Loam.
2	LUVISOLS, LIXISOLS, ALISOLS, ACRISOLS, FERRALSOLS, FLUVISOLS, NITISOLS, REGOSOLS	4	<5	Loam, Silty Loam, Silty, Sandy Clay Loam.
1	LEPTOSOLS, FERRALSOLS	5	<5	Rock, Loam, Silty Loam, Silty, Sandy Clay Loam.

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3.3 Forest: The classification of forest data involves comparing and integrating multiple data sources, such as forest maps, satellite imagery, and topographic maps, to accurately identify and categorize different forest areas.

a) Data Sources Used in Forest Classification:

- Forest Maps: These maps represent the distribution and types of forests across a specific area. Forest maps are typically created from field surveys and remote sensing data and stored in a geospatial database.
- Satellite Imagery: Satellite imagery is a powerful tool for assessing land cover changes, identifying forest cover, and distinguishing between different types of vegetation. High-resolution satellite images (e.g., from Landsat, Sentinel, or commercial providers) allow for detailed analysis of forest health, structure, and extent.
- Topographic Maps: These maps provide elevation data, landforms, and other terrain-related features that can help in understanding the ecological characteristics of forest areas, as well as influencing factors like slope, aspect, and drainage.

b) Forest Classification into Two Groups:

The classification process typically divides the forest areas into two broad categories:

- Group A: Intact Forest Cover:
- Group B: Degraded or Converted Forest Cover:

3.4 Setup Score: The overlay process integrates various thematic layers, including slope, elevation, landform, geology, soil, and forest cover, to generate a comprehensive assessment of the watershed. Through this process, these data layers are merged to produce five quality layers that correspond to the Watershed Classification (WSC). These layers are categorized as WSC 1 through WSC 5, reflecting variations in watershed quality and characteristics.

- WSC 1 typically represents areas with the highest conservation value or sensitivity, often requiring strict protection.
- WSC 5, on the other hand, denotes regions with lower sensitivity, potentially suitable for various land-use activities.

The classification derived from this overlay process provides a spatially explicit framework for effective watershed management, guiding conservation priorities, and sustainable land-use planning.

Table 3 Criteria Setup Score in Watershed Classification.

Criteria	
Watershed Classes	**Setup Score**
1	<10
2	<13
3	<16
4	<20
5	<24

4. Data Analysis: Data analysis includes a variety of analytical operations, such as reclassification, overlay, and statistical analysis, illustrated in Figure 1.

Reclassification involves regrouping or aggregating map attribute data to create a new map. This process assigns thematic values to categories within an existing digital map set. A typical reclassification procedure includes simplifying, dissolving, and merging data to achieve a more generalized map. For example, a crop suitability map can be generated from a soil map by assigning values to each soil polygon based on the specific soil requirements of different crops.

The overlay process involves creating new boundaries or maps by assigning coverage values to the existing map content, resulting in a set of values for the intersecting areas. This process includes operations such as union, intersection, and area measurement to combine spatial data from multiple layers and analyze the information. For example, intersecting a soil map with a land use map can reveal the soil types and properties within different land use categories, as determined by the new coverage.

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Statistical analysis offers users a deeper understanding of the data collection process, particularly when interpreting aggregated data rather than individual data points (Freeman, C., 1987). This analysis involves calculating frequencies, averages, standard deviations, means, regressions, correlations, distributions, and other statistical parameters for both spatial and attribute data. Understanding the functions involved is essential for correctly interpreting the results of the analysis.

5. Watershed Quality Classification: To classify watershed quality classes, a database is prepared for use in GIS. This database includes several data layers, such as slope, elevation, land characteristics, geological features, soil type, and forest area. The analysis process is illustrated in Figure 1.

5.1 Preparing Import Data: In this study, the input data for determining watershed quality classes were prepared by converting vector format data into raster format with a grid size of 30x30 meters (600 square meters or 0.25 rai). This step aimed to assess the accuracy of the DEM. It was found that using a smaller grid size resulted in less deviation between the DEM data and the contour data compared to using a larger grid. Additionally, when comparing this grid size with the one used in the study project to determine watershed quality classes, based on the Cabinet resolution (Thailand), which utilizes a 1 square kilometer grid, the 30x30 meter grid provided more detailed data for the analysis.

5.2 **Overlay Spatial Data Analysis or Overlay Technique:** Overlay spatial data analysis using GIS, such as the ArcGIS 10.4 program, involves combining multiple data layers to analyze and classify watershed quality. The process begins by overlaying the following layers:

1. Slope data layer
2. Elevation data layer
3. Land from the data layer
4. Geological data layer
5. Soil type information layer

These layers can be defined as five quality layers according to the Watershed Classification system (Layers 1–5). After overlaying these layers to generate a watershed quality layer, it is then combined with the forest information layer. This allows the watershed to be classified into two groups: Group A or Group B, based on the resulting analysis.

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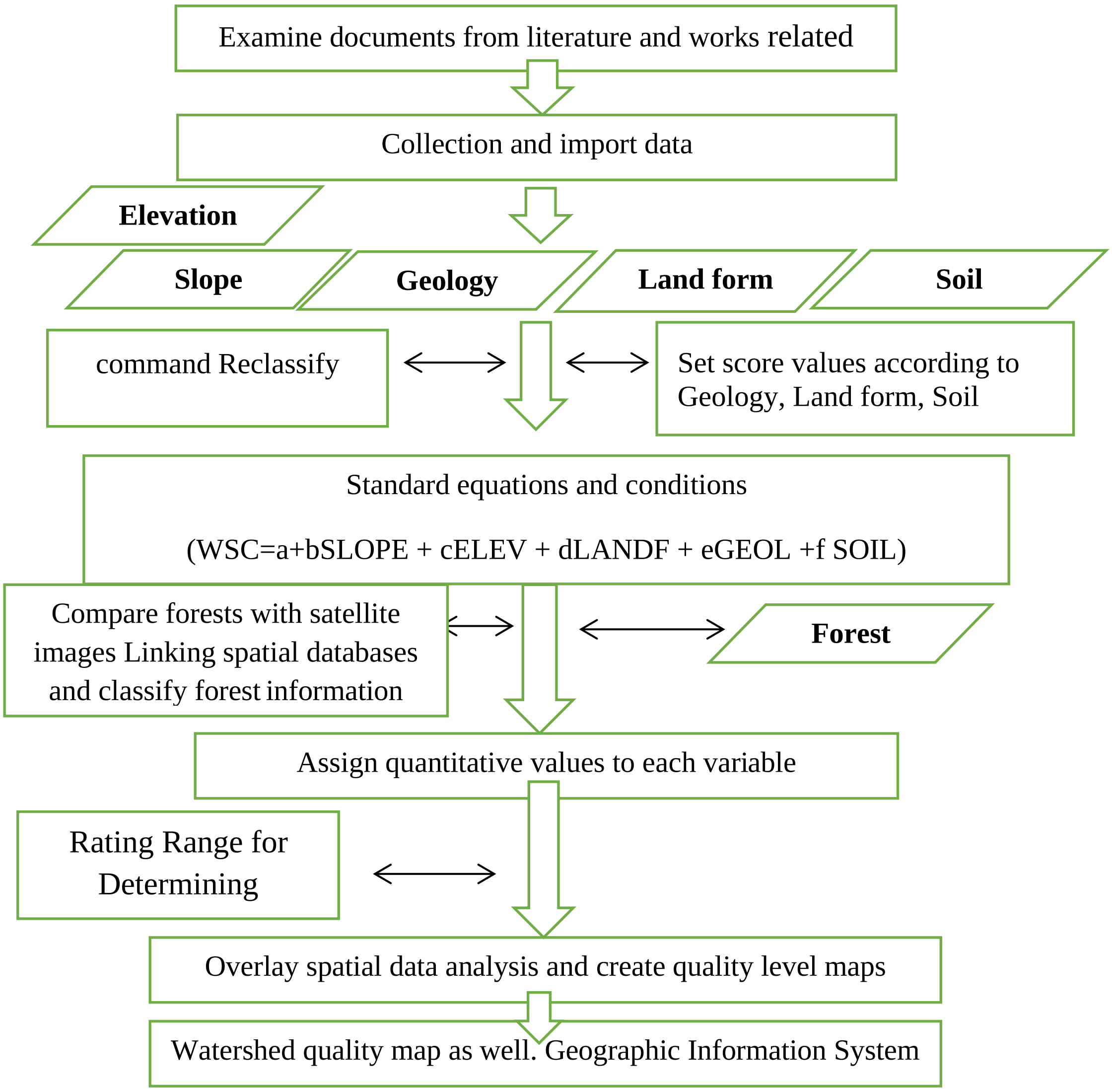

Figure 2 Research Materials and Methods Diagram

Results

1. Slope and Elevation

1) Elevation Map

This map shows the elevation levels within the Nam Sa sub-basin, reclassified into four categories (1-4), represented by distinct colors:

- **Blue (1)**: Likely represents the lowest elevation range.
- **Green (2)**: Represents a slightly higher elevation.
- **Red (3)**: A moderate elevation range.
- **Purple (4)**: The highest elevation range.

2) Slope Map

This map shows the slope (steepness) within the Nam Sa sub-basin, reclassified into five categories (1-5), represented by distinct colors:

- **Black (1)**: Indicates the flattest areas.
- **Green (2)**: Slightly steeper slopes.
- **Blue (3)**: Moderate slopes.
- **Pink (4)**: Steeper terrain.
- **Cyan (5)**: The steepest regions.

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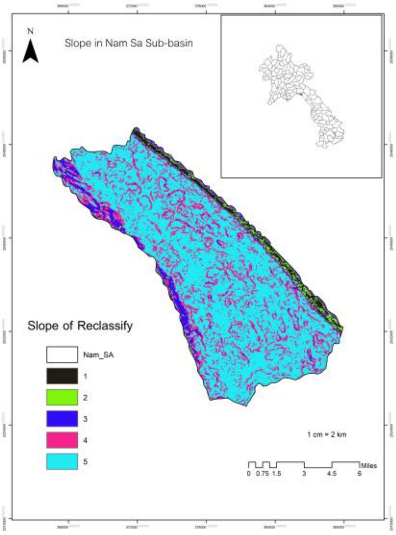

Figure 3 Slope of Reclassify

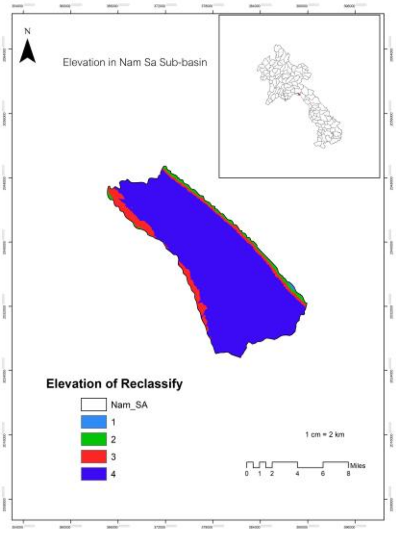

Figure 4 Elevation of Reclassify

2. **Geology and Landform**

1) The Geology Map in the Nam Sa sub-basin is reclassified into three main categories, as indicated by the legend:

- Purple (Sandstone, Greywacke): Indicates regions composed of sandstone and greywacke rock types, which are generally hard and resistant to erosion.
- Green (Shale): Represents areas dominated by shale, a softer sedimentary rock that is more prone to erosion and weathering.
- Red (Fluvial = Floodplain): Shows fluvial deposits, typically found in floodplains and riverbeds, composed of loose sediments such as sand, silt, and clay deposited by water flow.

2) Landforms Map in the Nam Sa sub-basin. The map uses different colors to represent different landforms, such as peaks, valleys, ridges, and slopes. The legend on the right side of the map explains the meaning of each color. The map also shows the scale and the location of the Nam Sa sub-basin within the larger context of Nam Sa. Overall, the map provides a visual representation of the terrain and landform characteristics of the Nam Sa sub-basin.

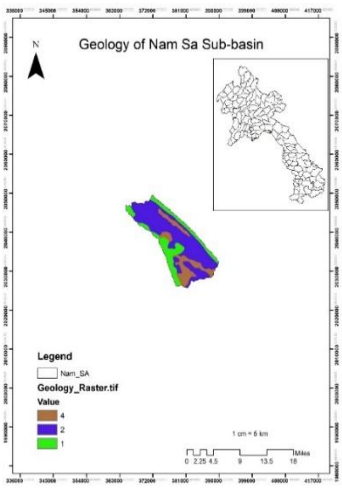

Figure 5 Geology of Reclassify

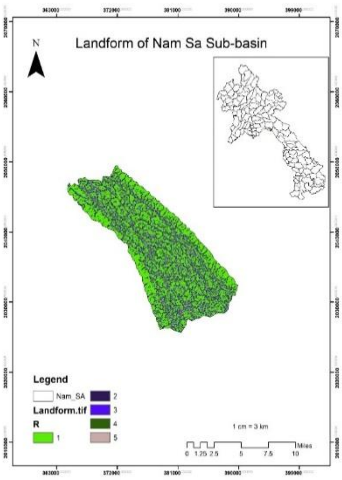

Figure 6 Landform of Reclassify

Citation
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3. Soil

The soil map depicts the Nam Sa sub-basin, specifically focusing on the distribution of soil types within the region. The map utilizes different colors to represent various soil types. The legend on the right side of the map provides the following classification:

- **Brown:** This soil type likely has characteristics suitable for agriculture or other land uses.
- **Green:** This soil type might be associated with specific vegetation or drainage patterns.
- **Purple:** This soil type could have unique properties related to its formation or composition.
- **Red:** This soil type might be particularly well-drained or have a higher clay content.

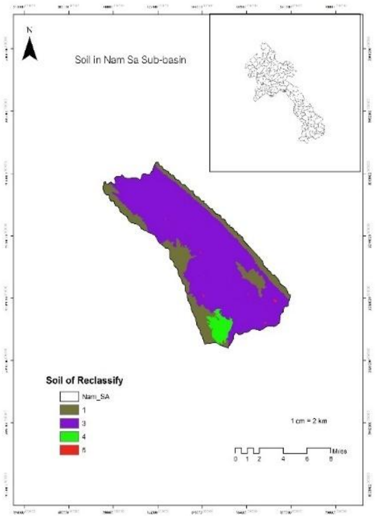

Figure 7 Soil of Reclassify

4. Watershed Classes Score and Watershed Classes

The **Watershed Classes score** in the Nam Sa sub-basin. The map uses different colors to represent different WSC scores, with higher scores indicating better water supply capacity. The legend on the right side of the map explains the meaning of each color. The map also shows the scale and the location of the Nam Sa sub-basin within the larger context of Nam Sa.

The **Watershed Classes** depict the Nam Sa sub-basin, specifically focusing on the watershed classes within the region. Watersheds are areas of land that drain into a common body of water, such as a river, lake, or ocean.

The map utilizes different colors to represent various watershed classes. The legend on the right side of the map provides the following classification:

- **Green:** This watershed class likely has specific hydrological characteristics, such as drainage patterns or water flow rates.
- **Blue:** This watershed class might have different hydrological properties compared to class 1.
- **Red:** This watershed class could be associated with certain land use practices or vegetation types that influence water flow and quality.
- **Light Blue:** This watershed class might have unique hydrological features, such as the presence of wetlands or specific soil types.
- **Dark Blue:** This watershed class could be characterized by particular hydrological conditions, such as high water flow or water retention capacity.

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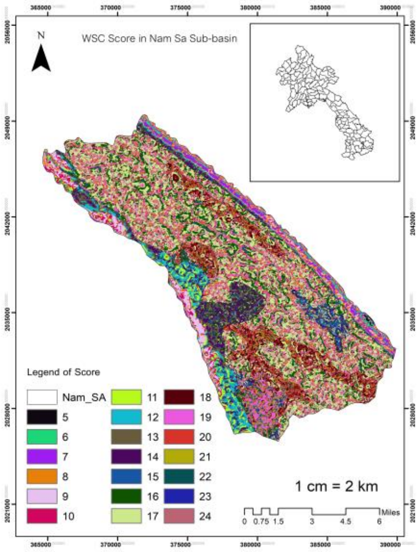

Figure 8 Watershed Classes Score

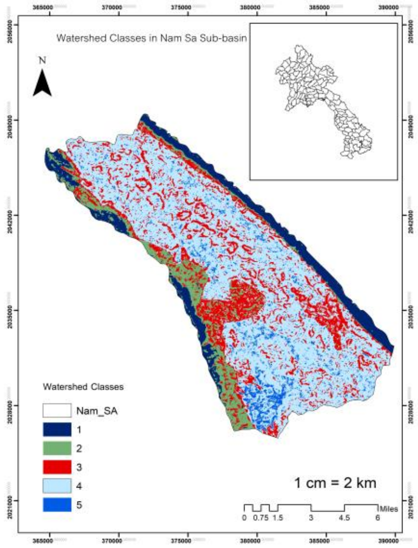

Figure 9 Watershed Classes

Conclusion

In conclusion, the Nam Sa Sub-basin, encompassing an area of 248.2 km², demonstrates a diverse range of watershed characteristics, categorized into five distinct WSC. These classes are integral to the sub-basin's hydrological dynamics and ecological balance.

The largest class, WSC 4, represents a significant portion of the sub-basin, characterized by specific features that influence water flow, sediment transport, and land-use suitability. This class demands management strategies that support its expansive role in maintaining the overall health of the sub-basin.

The smaller watershed classes, while covering less area, possess unique hydrological and ecological traits that require targeted conservation and management efforts. These efforts aim to preserve their distinctive characteristics and ensure their contributions to the sub-basin's sustainability.

Understanding these classifications provides a foundation for implementing tailored resource management strategies to enhance the Nam Sa Sub-basin's ecological resilience and sustainable development.

Discussion

The results of the Nam Sa sub-basin study reveal a landscape of remarkable diversity and complexity, characterized by variations in elevation, slope, geology, soil types, and watershed features. These observed patterns align with broader research on the influence of these factors on erosion, water flow, and land use. The findings resonate with global studies, such as those by Croke et al. (2005) and Foley et al. (2005), which underscore the significant role of terrain and geology in shaping watershed behavior and ecosystem services.

Watershed Class 1: This class represents regions with high water flow or excellent water retention capacity. These areas may include major rivers, reservoirs, or regions with significant aquifers that support both water flow and storage. Vital for maintaining year-round water availability, these areas can sustain larger agricultural operations, urban centers, and wildlife by providing reliable water access. The diverse and productive aquatic ecosystems in these regions also thrive. The high-flow and high-storage characteristics of these areas, often depicted in dark blue, align with findings by Sivapalan et al. (2003), who highlighted that large river systems serve as water corridors, supporting agricultural activities and human populations. Additionally, Van der Wateren et al. (2010) emphasized the crucial role of watersheds with high retention capacity in managing droughts and water scarcity.

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Watershed Class 2: Representing regions with moderate water flow and distinct drainage patterns, these areas play a key role in maintaining groundwater recharge, controlling erosion, and preserving water quality. Vegetation cover, such as forests or grasslands, helps stabilize the soil, reduce surface runoff, and enhance water infiltration. This finding aligns with research by Adeel et al. (2005), who emphasized the role of vegetated watersheds in improving water retention and mitigating flood impacts. Molle et al. (2007) further noted that natural landscapes with vegetation significantly reduce sediment transport, ensuring more consistent water flow.

Watershed Class 3: This class is typically associated with human activities like agriculture, urban development, or deforestation, which often disrupt the natural hydrological regime. These regions may exhibit altered drainage patterns due to land use and vegetation changes. Such modifications can result in increased runoff and decreased water retention capacity. In areas where forests have been replaced by agriculture, the exposure of soil can lead to higher erosion rates, adversely impacting water quality. Bierman & Steig (1996) found that agricultural and urbanized watersheds tend to have higher runoff and lower infiltration, often leading to sediment erosion, nutrient pollution, and degraded water quality in rivers and streams. Furthermore, Molle et al. (2007) highlighted that land use changes, particularly in floodplain areas, can significantly alter watershed behavior, increasing both flood risks and water scarcity.

Watershed Class 4: This class includes areas with wetlands, swamps, or floodplains, which exhibit distinct hydrological features, such as high water retention and the ability to buffer floods. Wetlands and similar ecosystems contribute to water storage, filtration, and streamflow regulation. These regions play a critical role in reducing flood risks by absorbing excess water during the rainy season, while also providing vital habitats for biodiversity. Wetlands help improve water quality by filtering out pollutants. Mitsch & Gosselink (2015) highlighted the importance of wetland ecosystems in regulating water flow, storing water, and enhancing water quality through natural filtration processes. Adeel et al. (2005) also underscored the importance of wetlands in providing essential hydrological services and supporting biodiversity, making them crucial in water management strategies.

Watershed Class 5: Areas in this class exhibit distinct hydrological properties compared to other classes, often characterized by more rapid water flow or seasonal water fluctuations, potentially influenced by underlying geological features or human activities such as agriculture or urbanization. These areas may experience faster runoff due to their geological structure or land use. The hydrological behavior of WSC 5 regions may vary significantly depending on precipitation patterns or other climatic factors, affecting both water quality and quantity downstream. The role of water flow rates in watershed management is discussed by Sivapalan et al. (2003), who noted that areas with rapid water movement may face higher erosion potential but also contribute to flooding risks. Nixon et al. (2010) stressed the importance of effective water management in these regions to prevent waterlogging and poor-quality runoff.

Recommendation

Based on the analysis of the Nam Sa Sub-basin's geology, elevation, slope, landforms, and watershed classifications, the following recommendations are proposed for enhancing its ecological resilience, sustainable development, and resource management:

1. Watershed Management and Protection:

- **For WSC 4 (largest class):**
  - Flood Control and Erosion Mitigation: Given its extensive coverage, WSC 4 likely plays a crucial role in water flow regulation and sediment transport. Implementing erosion control measures such as vegetation restoration, riparian buffer zones, and terracing can minimize sediment runoff and protect water quality.
  - Water Storage Infrastructure: Since WSC 4 is significant in terms of size, consider building water storage structures, such as small reservoirs or check dams, to better manage water distribution during dry seasons and prevent flood damage during rainy seasons.
  - Land-Use Planning: Develop sustainable agricultural practices in this area, considering its importance for both hydrology and ecosystem services.
- **For Smaller Watershed Classes:**

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- Targeted Conservation: Smaller WSCs, with unique hydrological and ecological features, require more focused conservation efforts. Create protected areas to conserve biodiversity and enhance the ecological health of these regions.
- Water Quality Monitoring: Regular monitoring of water quality, especially in smaller WSCs near riverbeds or floodplains (red class), is essential for detecting and addressing potential contamination from agricultural runoff or other human activities.

2. Community Engagement and Capacity Building:

Community Involvement: Engage local communities in watershed management and conservation activities. Promote awareness of sustainable land-use practices, water conservation, and the importance of protecting ecosystems for long-term ecological balance.

Training and Capacity Building: Provide training programs for local farmers, landowners, and community leaders on sustainable agricultural practices, erosion control, and conservation techniques. This will empower the community to play an active role in the sustainable management of the sub-basin.

3. Sustainable Development:

Ecotourism: The Nam Sa Sub-basin's diverse topography, geology, and landforms could support ecotourism initiatives. Develop ecotourism plans that highlight the region's natural beauty and biodiversity, while ensuring minimal environmental impact.

A comprehensive, multi-faceted approach is necessary to ensure the sustainable management of the Nam Sa Sub-basin. By focusing on targeted conservation, community engagement, hydrological monitoring, and adaptation to climate change, the region's ecological health and long-term viability can be preserved, ensuring that both the natural environment and local communities thrive.

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