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Mapping the future: Leveraging GIS to analyze rainfall, groundwater, and temperature variability in the Tampakan-Lutayan Watershed

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Abstract

The Tampakan-Lutayan Watershed is a vital hydrological system in the southern part of the Philippines that supports agricultural, settlement, and environmental activities. However, there is limited integrated spatial assessment of the watershed to identify the physical and environmental characteristics in the upstream, midstream, and downstream areas of the watershed. This study aimed to characterize the Tampakan-Lutayan Watershed using Geographic Information System (GIS), remote sensing technology, and Digital Elevation Model (DEM) analysis. Specifically, this research investigated the elevation, slope, rainfall, temperature, groundwater potential, soil erosion, and land use/land cover characteristics in the Tampakan-Lutayan Watershed. Watershed delineation using a Digital Elevation Model (DEM) and ArcSWAT was conducted to characterize the Tampakan-Lutayan Watershed. Moreover, the study estimated soil erosion using the Revised Universal Soil Loss Equation (RUSLE). The results revealed significant spatial variability in the Tampakan-Lutayan Watershed. The upstream area in Tampakan exhibited higher elevation, steeper slope, higher rainfall, lower temperature, and greater soil erosion potential. In contrast, the midstream and downstream areas in Koronadal and Lutayan had lower elevations, gentler slopes, warmer temperatures, and relatively lower erosion risk. LULC analysis from 2017 to 2023 also indicated notable landscape changes associated with vegetation shifts, agricultural transition, and changes in built-up and inland water areas. These findings highlight the importance of integrated watershed management, particularly in promoting sustainable land-use planning, reforestation, erosion control, and community-based conservation for long-term watershed sustainability.

Introduction

Watersheds are fundamental ecological units that play a vital role in regulating freshwater resources, sustaining biodiversity, and maintaining ecosystem services. A watershed is a land area in which all precipitation drains to a common outlet, such as a river, lake, or ocean, and includes physical features such as hills, valleys, and streams that influence water quality and water availability (Flotemersch et al., 2015; National

Oceanic and Atmospheric Administration, 2019). Because watersheds integrate topographic, hydrologic, climatic, and land use processes, their characterization is essential for understanding environmental change and guiding sustainable resource management.

Specifically, the Tampakan-Lutayan Watershed is a component of the Marbel River Basin in the southern Philippines, covering the provinces of South Cotabato, Sultan Kudarat, and the surrounding upland areas. The Tampakan-Lutayan Watershed is ecologically and socio-economically important, with fertile lowlands suitable for rice, corn, and other crops, as well as upland areas used for agroforestry and the development of perennial crops. However, with the current expansion of agricultural lands, increased land conversion, and development of settlements, there are issues that need attention, including soil erosion, sedimentation, land degradation, and the condition of the watershed.

Past studies have established that the degradation of the watershed is attributed to topographic factors, loss of vegetation, improper use of the land, and climate change (Hazbavi & Sadeghi, 2017; Prashanth et al., 2023). GIS and remote sensing are effective tools for watershed assessment because they enable the integration of spatial data on topography, rainfall, temperature, land use, and erosion, which are essential for identifying environmentally sensitive areas and supporting watershed management.

However, there is a scarcity of information with regards to the spatial assessment of the environmental characteristics of the Tampakan-Lutayan Watershed. Most existing information within the area is based on the general initiatives for watershed management and other environmental concerns. There are also fewer studies conducted with regards to the combined analysis of the topography, climate, groundwater potential, soil erosion, and land use/land cover of the different sections of the watershed. This study was conducted with the aim of spatially analyzing the characteristics of the Tampakan-Lutayan Watershed using GIS and remote sensing technologies. Specifically, the study included the elevation, slope, rainfall, temperature, groundwater potential, soil erosion, and land use/land cover characteristics of the watershed.

Materials and Methods

Study Area

The study area is located in Tampakan-Lutayan Watershed in the southern Philippines covering some areas in South Cotabato and Sultan Kudarat provinces. Three sections in the watershed were identified as representative study areas in this study. These sections are: the upstream area in Tampakan, South Cotabato; the midstream area in Koronadal City, South Cotabato; and the downstream area in Lutayan, Sultan Kudarat. The locations of the sampling plots are presented in Figure 1, while Table 1 presents their geographic coordinates.

Table 1: Geographic Coordinates of the Plots

Location		Plot geographic coordinates
(a)	**Lutayan, Sultan Kudarat**	6°34′53.16″N, 124°49′24.63″E; 6°35′0.20″ N, 124°49′20.94″ E; 6°35′7.70″ N, 124°49′17.55″ E

Table 1: *Continued...*

(b) Koronadal City, South Cotabato	6°29′16.43″ N, 124°53′42.39″ E; 6°29′16.74″ N, 124°53′33.83″ E; 6°29′16.53″ N, 124°53′25.93″ E
(c) Tampakan, South Cotabato	6°26′13.33″ N, 125°2′24.89″ E; 6°26′18.42″ N, 125°2′18.49″ E; 6°26′22.49″ N, 125°2′11.76″ E

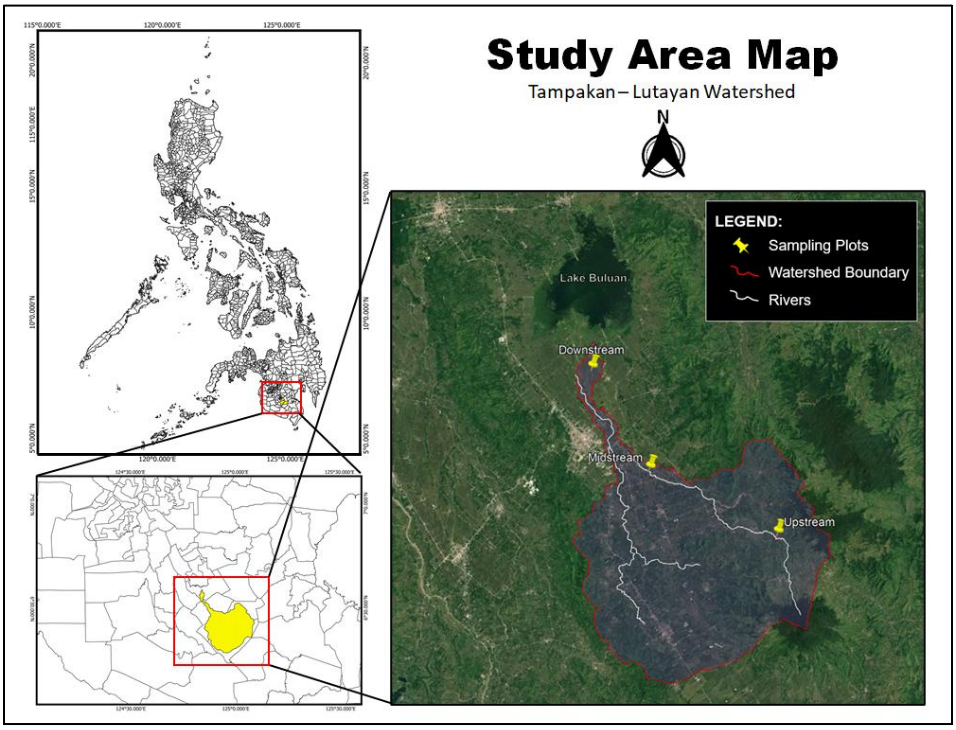

Figure 1. Study Area of Tampakan-Lutayan Watershed

Watershed Delineation and Spatial Analysis

The delineation of the watershed was carried out using a Digital Elevation Model (DEM) processed by ArcSWAT. The DEM was used as a source of data for the derivation of watershed boundaries, drainage networks, elevation classes, and slope classes. Spatial analysis was carried out using GIS, resulting in thematic maps for elevation, slope, rainfall, temperature, groundwater, soil types, land capability, and land use/land cover. The delineation and characterization of the watershed were carried out following the guidelines of the Department of Environment and Natural Resources Memorandum Circular 2008-05 for integrated watershed management planning.

Geology, Soil, and Land Capability Data

Geologic, soil, and land capability maps were also compiled and interpreted with the use of secondary spatial datasets. These thematic layers were utilized in describing the distribution of rock formations, soil types, and land capability classes within the watershed. These maps were utilized as supporting inputs for watershed characterization and interpretation of environmental conditions.

Rainfall, Temperature, and Groundwater Mapping

Rainfall and temperature maps were created through the classification of spatial data related to climate in the watershed. Groundwater maps were generated through the analysis of existing spatial data and classified based on groundwater permeability. These maps were analyzed to understand the climatic and groundwater variations in the upstream, midstream, and downstream areas of the watershed.

Soil Erosion Assessment

Soil erosion was estimated through the Revised Universal Soil Loss Equation (RUSLE), and the RUSLE model is expressed as follows:

$$A = R \times K \times LS \times C \times P$$

where A = computed soil loss, R = rainfall-runoff erosivity factor, K = soil erodibility factor, LS = slope length and slope steepness factor, C = cover management factor, and P = support practice factor.

The RUSLE factors were estimated through spatial and field data analysis and then processed through a GIS to create the soil erosion map of the watershed. Field validation of the data was also performed.

Land Use and Land Cover Analysis

The different land use and land cover (LULC) classes were analyzed for the years 2017 and 2023 to understand the spatial changes in the watershed. The LULC maps were classified into different classes, including annual crops, perennial crops, grassland, brush/shrubs, built-up areas, closed forests, open forests, open/barren lands, and inland water. Area statistics were computed and changes were observed in the distribution of the land cover.

Data Presentation and Analysis

Descriptive spatial analysis techniques were used to describe watershed characteristics based on thematic maps, areal distribution, and site observations. Tables and figures were used to present geographic coordinates, soil erosion estimates, and LULC change values, while thematic maps were used to describe watershed conditions.

Results and Discussion

Elevation and Slope Characteristics

The elevation map in Figure 2 indicates that the total area of the Tampakan-Lutayan Watershed is approximately 46,913.82 ha, distributed across five elevation classes. The majority of the watershed is composed of the elevation class 0-300 m, covering an area of 20,372.84 ha or 43.43%. The elevation class covering an area of 300-600 m is slightly smaller at 14,851.30 ha or 31.65%. The combined area in the higher elevation classes above 600 m is approximately 11,689.68 ha or 24.92%. Lower elevation classes are predominantly located in Lutayan, Koronadal City, and surrounding low-lying areas. On the other hand, higher elevation classes are predominantly located in Tampakan and surrounding upland areas.

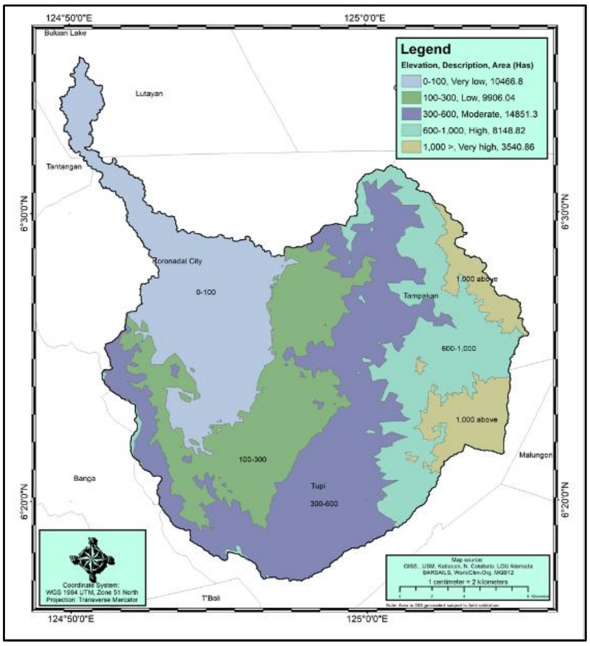

Figure 2. Elevation Map of Tampakan-Lutayan Watershed

Elevation affects land use and environmental conditions in the Tampakan-Lutayan Watershed. Lower elevation classes are generally accessible and thus suitable for land use. Similarly, higher elevation classes are characterized by steeper terrain, low accessibility, and high erosion susceptibility. This is consistent with the characteristics of watersheds in previous studies, where elevation is an important factor in the suitability of land use and vegetation in watersheds (Prashanth et al., 2023; Alejo et al., 2024).

The slope map in Figure 3 indicates that flat to level terrain is predominantly located in the western and central parts of the Tampakan-Lutayan Watershed in Lutayan and Koronadal City. On the other hand, moderately steep to very steep terrain is predominantly located in the eastern and southern upland parts of Tampakan. Slope is an important factor in assessing the suitability of land for specific land use due to the increased rate of runoff in steeper terrain. This is consistent with previous studies where steeper terrain is characterized by high erosion susceptibility and thus requires effective land management approaches such as contouring, vegetative cover, and reforestation (Fombe & Tossa, 2015; Bamutaze, 2019).

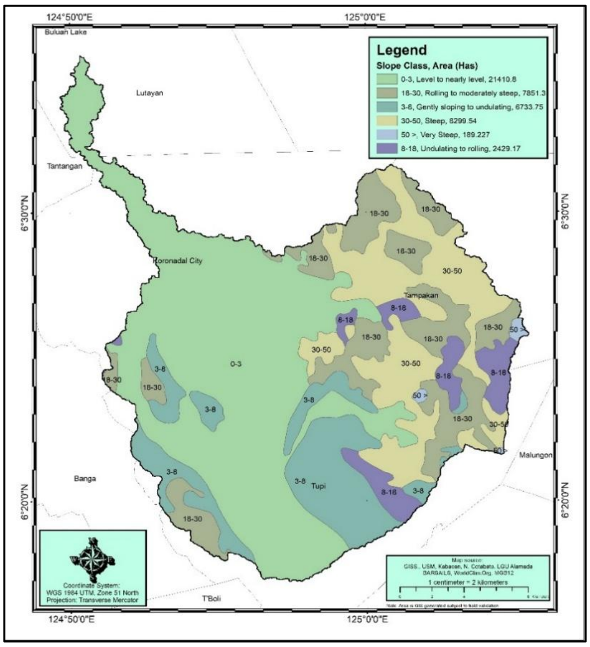

Figure 3. Slope Map of Tampakan-Lutayan Watershed

Geologic, Soil, and Land Capability Characteristics

The geologic map in Figure 4 shows the spatial distribution of major geologic units in the Tampakan-Lutayan Watershed. The central part of the watershed, especially in Lutayan, is composed mainly of Oligocene-Miocene (IN1) sedimentary rocks. This indicates that the area was once subjected to marine and terrestrial depositional environments. This is the reason for the formation of relatively fertile soils that support agricultural activities in the area, especially in rice and corn cultivation (Dizon et al., 2017; Torres et al., 2019). Moreover, the presence of alluvial deposits in the valleys and low-lying areas also contributes to the fertility of the soils in these parts.

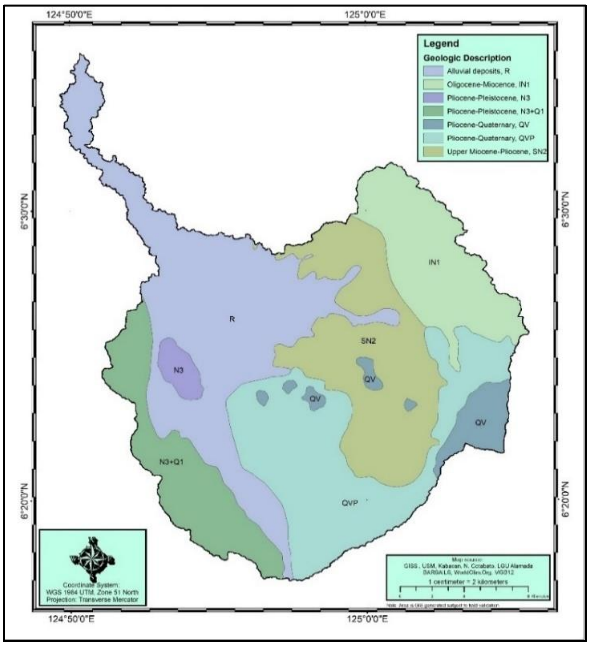

Figure 4. Geologic Map of Tampakan-Lutayan Watershed

In the western area of the watershed, the formation in the Koronadal area is composed of Upper Miocene-Pliocene (SN2) and Pliocene-Quaternary (QVP) volcanic deposits. These formations have a geological history characterized by tectonic and volcanic activity. This may have an impact on the properties of the soils and the hydrological characteristics. The properties of soils formed from volcanic deposits are porous and have good drainage properties. This affects water retention and land productivity (Bautista et al., 2018). On the other hand, in the eastern upland part of Tampakan, the formation is composed of Pliocene-Pleistocene (N3) deposits containing conglomerates, sandstones, and volcanic deposits. Although these formations have good properties for soil fertility, they are also prone to soil erosion and instability, especially in areas with vegetation disturbance or high land use intensity (Lim et al., 2021).

The soil map (Figure 5) indicates that the western and central part of the watershed, including the areas in Lutayan and Koronadal City, is predominantly composed of Tupi Fine Sandy Loam, covering an area of about 30,117 ha. This type of soil is generally well-drained and is applicable for crops that need moderate drainage conditions. In contrast, the eastern part of the watershed, particularly in Tampakan, is dominated by Nupol Sandy Loam, covering an area of about 5,989.63 ha. This type of soil is generally associated with good drainage and is applicable for a range of crops, including high-value crops grown under upland conditions (Wang et al., 2022; Santiago et al., 2020).

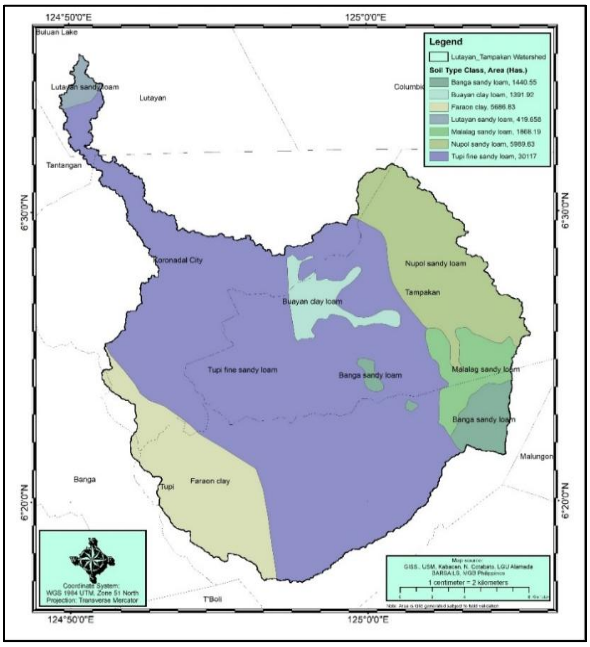

Figure 5. Soil Types Map of Tampakan-Lutayan Watershed

From the land capability map in Figure 6, the watershed area shows a range of classes in terms of land capability, which means that there are varying degrees of suitability for agricultural development as well as for conservation purposes. The highly suitable areas, such as Class 1, are mostly in the low-lying areas with minimal risk of erosion, while the moderately suitable areas, such as Classes 2 and 3, may require certain management interventions, such as terracing, contour farming, etc. The areas with Classes 4-8 are less suitable for cultivation, while they are more suitable for permanent vegetation, pasture, forestry, and conservation purposes, with the majority of these classes in the southeastern part of the watershed, including the upland areas, which are more prone to erosion (Rajani, 2019; Yadav, 2023).

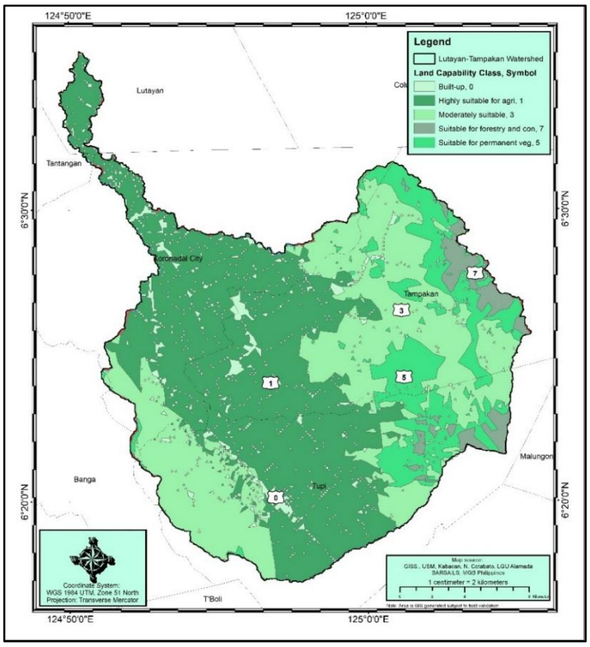

Figure 6. Land Capability Classification of Tampakan-Lutayan Watershed

The land capability classification gives valuable information about the relationship between topography, soil erosion, and land use in the watershed. Areas with Class 1 and Class 2 land capability are mainly in low elevation and gentle slope areas in Lutayan and Koronadal City, which is consistent with the flatter topography as depicted in Figures 2 and 3. These areas are good for farming and settlement due to low erosion hazard and accessibility. Areas with high land capability classes (Classes 4 to 8) are in the upland areas of Tampakan, where topography is rugged due to high elevation and slope steepness. These areas are consistent with the high soil erosion hazard as depicted in Figure 10, thus less suitable for cultivation but good for conservation-oriented land use.

Additionally, the land capability classification assists in the explanation of the observed land use and land cover changes. For instance, the reduction in the amount of natural vegetation such as brush/shrubs and forest cover, especially in areas with higher land capability limitations, may imply increasing pressure on the land. This may result in the conversion of such lands into other uses such as agriculture, thus increasing the rate of land degradation, especially in areas with steeper topography and higher erosion potential. This demonstrates the relationship between topography and land capability and the impact of human use of land. In conclusion, the integration of the geology, soils, land capability classification, and topography demonstrates the impact of physical landscape characteristics on land use and the contribution of land degradation in the watershed.

Rainfall and Temperature Variability

Figure 7 shows that the eastern and upland sections of the watershed receive higher rainfall than the western and southwestern lowland areas. This may be due to topographical features because highlands usually have higher rainfall amounts compared to lowlands. This is also seen in mountainous watersheds where moist air ascends to higher ground and cools, resulting in rain formation (Ntwali et al., 2016; Kozak et al., 2019).

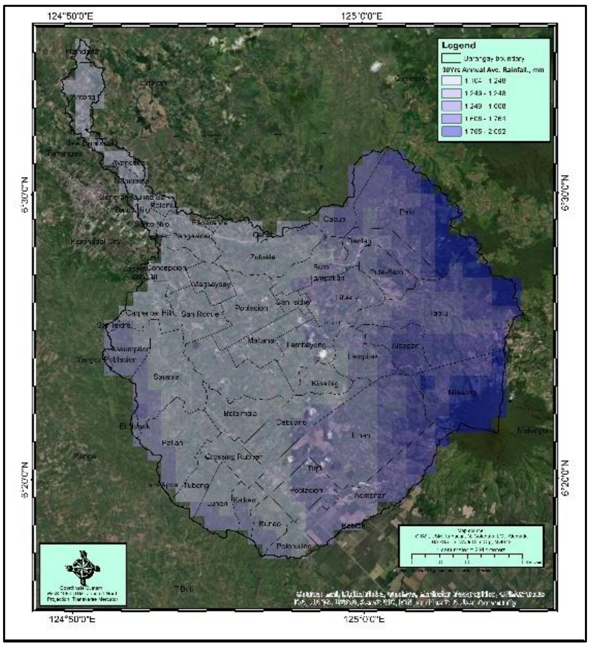

Figure 7. Rainfall Map of Tampakan-Lutayan Watershed

Figure 8 shows that cooler temperatures are concentrated in the highland areas of Tampakan and around Mt. Matutum, whereas warmer temperatures occur in the lowland areas of Lutayan and Koronadal. This is also consistent with the general weather patterns in the country where temperature is inversely proportional to elevation. As elevation increases, temperature decreases (Tai et al., 2020; Guan et al., 2024). Moreover, this may also be due to the presence of vegetation in the highlands and the presence of agricultural and built-up lands in the lowlands.

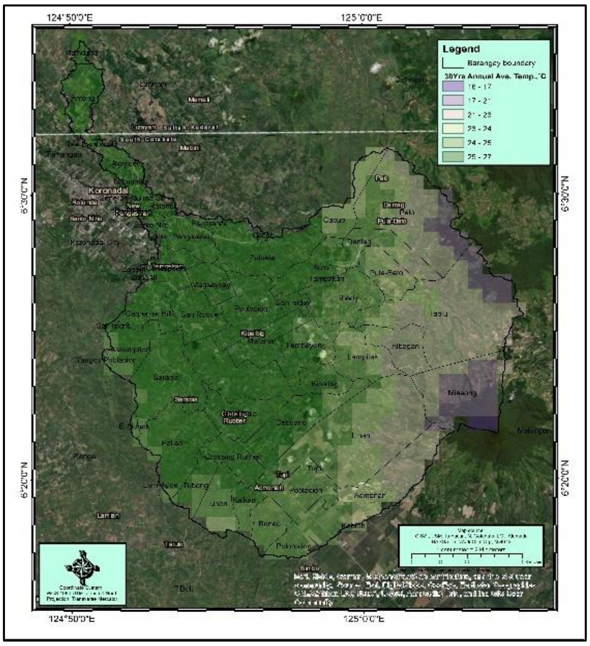

Figure 8. Temperature Map of Tampakan-Lutayan Watershed

Groundwater Characteristics

The groundwater map in Figure 9 indicates that the watershed has three major classes of groundwater based on its permeability and other characteristics. These are low permeability (III-A), localized intergranular flow (I-C), and fairly extensive intergranular flow (I-B). The low permeability areas are small compared to the areas with localized and fairly extensive intergranular flow. The latter are more common in the central, southern, and southeastern sections of the watershed.

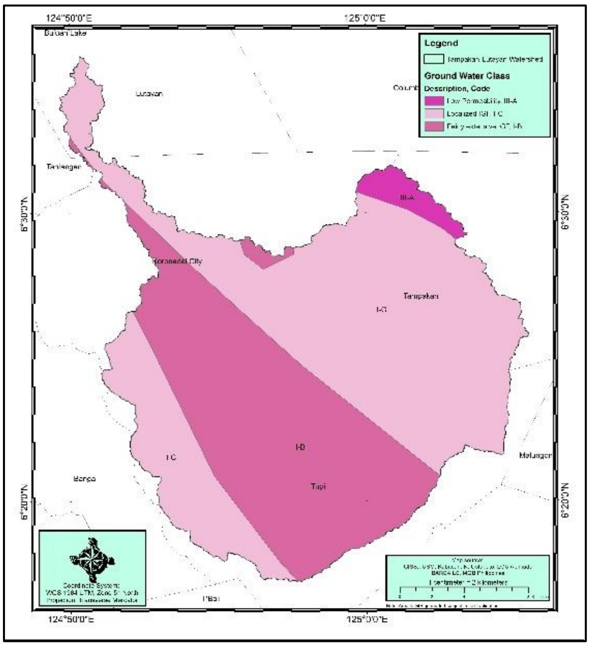

Figure 9. Groundwater Map of Tampakan-Lutayan Watershed

The differences in the areas with low permeability and intergranular flow may imply differences in the potential for groundwater recharge and storage. The areas with more promising intergranular flow may have more promising groundwater for use in different productive activities. However, it is important to remember that the potential for groundwater use should also consider the geology, soil type, and land cover because they may also affect the potential for infiltration and recharge.

Soil Erosion Assessment

The soil erosion map (Figure 10) shows clear spatial variation in erosion intensity across the Tampakan-Lutayan Watershed. Lower erosion rates are primarily concentrated in the central and western sections, where terrain is relatively gentle and vegetation or land cover may help reduce soil loss. In contrast, higher erosion rates are observed in the eastern upland areas, particularly in Tampakan, where steeper slopes, higher rainfall, and more exposed land surfaces contribute to increased erosion risk.

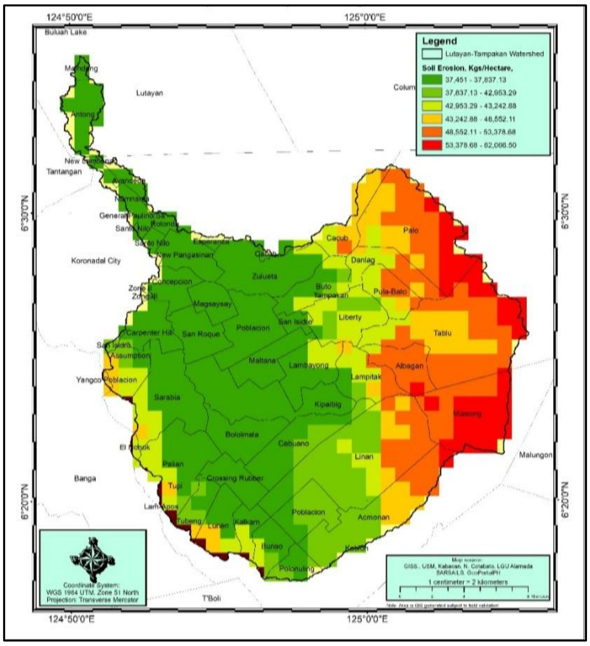

Figure 10. Soil Erosion Map of Tampakan-Lutayan Watershed

The soil loss values presented in Table 2 support this spatial pattern. Site 5 in Tablu, Tampakan recorded the highest annual soil loss at 230,400.00 kg/ha/year, whereas Site 4 in New Pangasinan, Koronadal City recorded the lowest value at 118.80 kg/ha/year. These findings indicate that slope, rainfall, vegetation cover, and conservation practices strongly influence soil erosion within the watershed. Similar studies in tropical environments have shown that steep slopes and inadequate vegetation or support practices significantly increase erosion rates (Ganasri & Ramesh, 2016; Fayas et al., 2019; Alejo et al., 2024).

Table 2: The Annual Soil Loss Rate of the Tampakan-Lutayan Watershed

Study points	Location	Actual assessment (kg/ha/year)
Site 1	Maindang, Lutayan	460.80
Site 2	Antong, Lutayan	2,304.00
Site 3	Rotonda, Koronadal City	6,180.00
Site 4	New Pangasinan, Koronadal City	118.80
Site 5	Tablu, Tampakan	230,400.00
Site 6	Poblacion, Tampakan	2,280.00

The observed erosion patterns are also consistent with the land capability classification (Figure 6). Areas classified under higher land capability classes (Classes 4 to 8), which are associated with steeper slopes and greater limitations for cultivation, correspond to zones with higher erosion rates. This further emphasizes that topographic constraints and land suitability play a critical role in shaping erosion dynamics within the watershed. Improper use of these marginal lands for agriculture may exacerbate soil loss and contribute to long-term land degradation.

Land Use and Land Cover Change

Land use and land cover analysis revealed that there were significant changes in Tampakan-Lutayan Watershed from 2017 to 2023, as shown in Table 3 below. The annual crop area decreased from 9,724.66 ha to 8,034.89 ha, resulting in a decrease of 1,689.77 ha.

Similarly, closed forest, grassland, and open forest areas decreased from 2017 to 2023. On the other hand, a significant decrease in brush/shrub area was noted in the watershed area. Inland water area also decreased from 226.85 ha to 107.67 ha from 2017 to 2023. The overall trend in Table 3 suggests that Tampakan-Lutayan Watershed has continued to undergo significant changes in its land cover from 2017 to 2023.

Table 3: Land Use and Land Cover (LULC) Data from 2017 to 2023 of the Tampakan-Lutayan Watershed.

Class	LULC 2017 (Area, Ha)	LULC 2023 (Area, Ha)	LULC Distribution	LULC Change (Hectares)	LULC Change (%)
1. Annual Crop	9,724.66	8,034.89	Annual Crop	8,034.89	82.65
			Brush/Shrubs	629.92	6.48
			Built-up	415.92	4.28
			Grassland	6.04	0.06
			Inland Water	50.70	0.52
			Open Forest	2.70	0.03
			Open/Barren	21.22	0.22
			Perennial Crop	559.51	5.76
			Closed Forest	0.13	0.00
2. Closed Forest	679.83	671.16	Annual Crop	2.02	0.30
			Closed Forest	671.16	98.87
			Brush/Shrubs	3.47	0.51
			Open Forest	2.17	0.32
3. Grassland	489.03	389.23	Annual Crop	3.89	0.80
			Brush/Shrubs	74.00	15.14
			Built-up	1.78	0.36
			Grassland	389.23	79.62
			Open Forest	19.32	3.95
			Perennial Crop	0.62	0.13
4. Open Forest	1,639.98	1,388.27	Annual Crop	15.96	0.97
			Brush/Shrubs	181.14	11.05
			Built-up	0.90	0.06
			Closed Forest	51.75	3.16
			Grassland	0.64	0.04
			Open Forest	1,388.27	84.70
			Open/Barren	0.12	0.01
			Perennial Crop	0.33	0.02
			Inland Water	0.01	0.00
5. Open Barren	12.81	9.21	Annual Crop	0.02	0.16
			Brush/Shrubs	1.62	12.66
			Open Forest	0.18	1.43
			Open/Barren	9.21	71.91
			Inland Water	1.77	13.84

Table 3: *Continued…*

6. Perennial Crop	15,982.88	14,586.12	Annual Crop	554.72	3.47
			Brush/Shrubs	37.19	0.23
			Built-up	750.56	4.70
			Grassland	0.28	0.00
			Inland Water	52.54	0.33
			Open Forest	0.20	0.00
			Open/Barren	1.60	0.01
			Perennial Crop	14,586.12	91.26
7. Brush/ Shrubs	16,783.89	14,211.61	Annual Crop	869.50	5.18
			Brush/Shrubs	14,211.61	84.69
			Built-up	210.27	1.25
			Closed Forest	1.45	0.01
			Grassland	274.45	1.64
			Inland Water	15.33	0.09
			Open Forest	372.86	2.22
			Open/Barren	0.67	0.00
			Perennial Crop	825.44	4.92
8. Built-up	1,356.47	1,092.21	Annual Crop	50.89	3.75
			Brush/Shrubs	122.81	9.06
			Built-up	1,092.21	80.59
			Inland Water	1.47	0.11
			Perennial Crop	87.90	6.49
9. Inland Water	226.85	107.67	Annual Crop	30.83	13.60
			Brush/Shrubs	40.37	17.80
			Built-up	4.30	1.90
			Inland Water	107.67	47.48
			Open/Barren	5.89	2.60
			Perennial Crop	37.41	16.50
			Grassland	0.30	0.13

The decrease in forest area, grassland area, and brush/shrub area in Tampakan-Lutayan Watershed from 2017 to 2023 is significant in that natural and semi-natural vegetation plays a central role in infiltration control and surface runoff reduction. A review in tropical regions revealed that forest loss due to expansion in agricultural and settlement areas often results in increased streamflow and surface runoff and decreased evapotranspiration and groundwater recharge in such regions. In most cases in tropical regions, forest loss in such regions often results in hydro-morphologic alterations due to increased sediment transport and channel instability in such regions. These observations suggest that continued forest loss in Tampakan-Lutayan Watershed may result in increased surface runoff and increased susceptibility to landslides in such regions, especially in areas that are already prone to landslides and erosion in such regions (Daramola et al., 2022; Kayitesi et al., 2022).

The reduction in the amount of vegetated land cover can be attributed to the changes in erosion patterns observed in the watershed. In topographically constrained areas, changes in LULC can increase soil erosion risk as they tend to expose the ground surface, reduce the amount of intercepted rainfall, and weaken the strength of the root systems of plants. In the Himalayan region, changes in LULC were observed to have significantly affected the soil erosion process in the region, indicating the significance of vegetation in soil erosion control. In the Philippines, changes in LULC in the Calumpang Watershed were modeled to increase surface runoff by 5%, sediment yield by 6%, and baseflow by -11%. These changes in LULC are significant in the Tampakan-Lutayan Watershed, as the upland areas are prone to erosion risk, with the reduction in land cover contributing to increased surface runoff in the region (Boongaling et al., 2018; Prashanth et al., 2023).

The reduction in the amount of inland water can be attributed to changes in the hydrology of the region, which may be linked to changes in the drainage condition, land encroachment, changes in the amount of runoff, and sediment deposition in the region. In the Philippines, changes in LULC in the Calumpang Watershed were modeled to increase surface runoff, sediment yield, and reduce baseflow in the region, indicating the significance of LULC changes in the hydrology of the region. In the Himalayan region, changes in LULC were observed to be significantly linked with water quality degradation in the region, indicating the significance of LULC changes in the hydrology of the region (Hua, 2017; Kayitesi et al., 2022).

Conclusion

This study employed GIS and remote sensing technologies, as well as DEM-based approaches, in the mapping and analysis of the Tampakan-Lutayan Watershed. The results of the analysis showed significant variations in the environment of the Tampakan-Lutayan Watershed in terms of elevation, slope, rainfall, temperature, groundwater, soil erosion, and land use/land cover. The upstream section in Tampakan was associated with steeper terrain, higher rainfall, cooler temperatures, and greater soil erosion risk, while the midstream and downstream sections in Koronadal and Lutayan were characterized by lower elevation, gentler slopes, warmer temperatures, and relatively lower erosion risk. Land use and land cover analysis further indicated substantial landscape change between 2017 and 2023. These findings provide baseline information for integrated watershed management and highlight the need for sustainable land-use planning, erosion control, vegetation restoration, and community-based conservation to improve long-term watershed resilience.

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Conflict of Interest

The authors state that there is no conflict of interest.

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