Spatio-temporal variations of the soil moisture and drainage network of Barangay Valencia, Cagdianao, Dinagat Islands, Philippines through lineament analysis and remote sensing techniques

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Spatio-temporal variations of the soil moisture and drainage network of Barangay Valencia, Cagdianao, Dinagat Islands, Philippines through lineament analysis and remote sensing techniques

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Abstract: *This study examines the hydrology of the Maraguing stream in Brgy. Valencia, Cagdianao, Dinagat Islands, Philippines, focusing on drainage patterns and lineament features from 2008 to 2020. Using ASTER GDEM and ALOS PALSAR data, the research identifies significant changes in drainage boundaries driven by natural erosion and land conversion for residential use. A consistent northeast trend in lineament features reflects ongoing geomorphological processes and erosion susceptibility. Soil moisture levels during the dry season dropped from 0.081% in 2010 to 0.047% in 2020, likely due to increased groundwater extraction and rising temperatures. Despite stable wet-season moisture, the findings highlight the impact of human activities on local hydrology. This study emphasizes the importance of sustainable water management and demonstrates how remote sensing and hydrological modeling can offer valuable insights into the relationship between geological structures and hydrological dynamics in the Dinagat Islands.*

Keywords: Spatio-temporal variation; Lineaments; Watershed; Dinagat Islands; Drainage Network

1. INTRODUCTION

Understanding the spatial and temporal behavior of streams is essential in assessing water resources. This study focuses on analyzing drainage patterns, geological features, and streamflow dynamics to support effective water resource management in Brgy. Valencia, Cagdianao, Dinagat Islands.

1.1 Project area description

Dinagat Islands is an island province situated in the Caraga region of the Philippines. It lies to the south of Leyte Gulf, with the island of Leyte to the west across Surigao Strait and mainland Mindanao to the south. The four outermost points of Dinagat Islands are geographically defined as follows: to the north, beginning at Desolation Point, it is bordered by Surigao Strait; to the east by the Philippine Sea; to the southeast by Dinagat Sound; to the south by Gaboc Channel and Nonoc Island; to the southwest by Awasan Bay, Hanigad Island, and Hikdop Island; and to the west again by Surigao Strait.

The provincial capital is the Municipality of San Jose (see Fig. 1). The province covers an area of 817.47 square kilometers, or 315.63 square miles. According to the 2020 Census, the population of Dinagat Islands was around 128,117. This figure accounted for 4.57% of Caraga region's total population, 0.49% of Mindanao Island group's total population, and 0.12% of the entire population of the Philippines.

1.2 Geology

Almost a large area of Dinagat Island is underlain by a mafic-ultramafic rock formation known as the Dinagat Ophiolite. This ophiolite is primarily composed of harzburgites, with dunite and chromite lenses at the base. It also includes layered and isotropic gabbro, a sheeted dike complex, and pillow basalts toward the upper sections. The arrangement of these ophiolitic units, from bottom to top, indicates a westward inclination of the ophiolite. The most recent geological unit in the province is the Late Miocene Loreto Formation, which features conglomerates, sandstone-mudstone layers, and shale. The oldest clastic sedimentary formation in the island is the Late Eocene Madanlog Formation, distinguished by layers of conglomerate, calcareous sandstone, and mudstone [15]. This formation is visible in the western parts of the island and lies above the basalt and diabase dikes of the Dinagat Ophiolite.

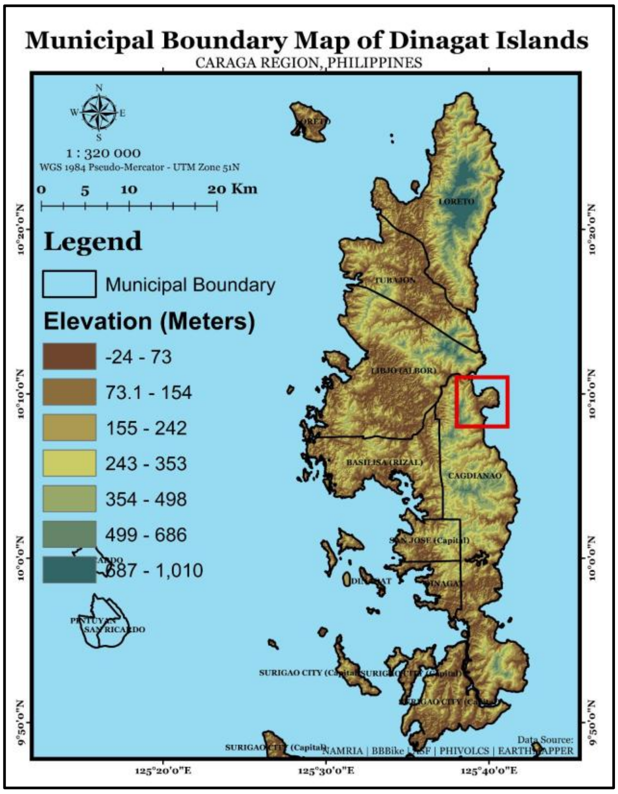

Fig. 1. Political boundary of the province of Dinagat Islands

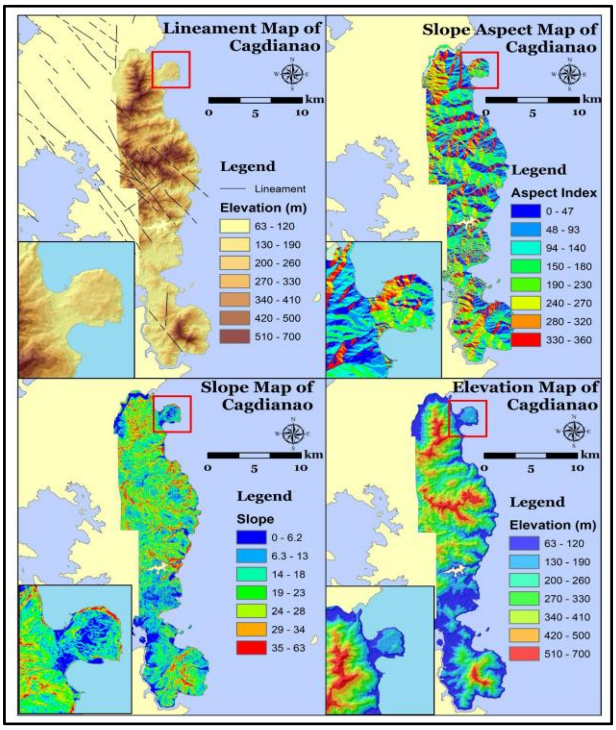

Fig. 2. Project area Lineament Map of Dinagat Islands (top left) and Thematic Map for analysis: Slope Aspect, Slope, Elevation Map of Cagdianao municipality.

1.3 Statement of the Problem

Identifying and managing water resources can be a major constraint for most companies especially to the mining sector since different behavior of streams responds differently to the complex relationship between the physiographic and hydrogeologic characteristics of a watershed or basin boundary [5]. In the course of characterizing a potential source of water for the consumers, morphometric analysis (i.e., calculation of linear, relief, and aerial aspects) must be considered in order to extract a convincing drainage pattern that can be delineated and can be verified in the field (see Fig. 2). Streamflow also exhibits different patterns depending on the characteristics of the area (i.e., lithology, elevation, geomorphology, geology) that are useful for spatio-temporal variations, especially when looking for a sign of major changes in stream direction and streamflow path that affects the totality of a stream [3].

1.4 Objectives of the study

The study aims to assess Maraguing Stream, Barangay Valencia, through hydrologic modeling, lineament extraction, and drainage mapping, using multi-year DEMs (2008–2020) to analyze spatio-temporal changes in streamflow, drainage patterns, and topographic lineament features.

2. METHODOLOGY

2.1 Data Set

The data needed for the lineament analysis includes Advanced Spaceborne Thermal Emission Radiometer Global Digital Elevation Map (ASTER GDEM) with 10-meter spatial resolution dating 2015-2024, Advanced Land Observing Satellite Phased Array type L-band Synthetic Aperture Radar (ALOS PALSAR) 12.5-meter high resolution terrain corrected images from 2007-2010, Landsat 7 image with a projection of World Geodetic System 1984 (WGS84) Universal Transverse Mercator (UTM) zone 52 in year 2010 and Landsat 8 image with the same projection in 2022 for soil moisture analysis.

2.2 Lineament extraction

Lineament is a single or multiple composite linear features of a surface where there is a relationship to the rectilinear pattern of different features that reflects the surface of an area [14]. One of the basic elements in characterizing a stream pattern is to look for a linear or curvilinear feature that can either be expressed as a displacement in the surface, or probably a zone of weakness that is usually accompanied by the stream flow path of water that forms the different basins, tributaries, and outlets of the drainage network in an area [Arreza2]. Most lineaments extracted through remote sensing data are a good indicator for underlying geologic structures [9].

The lineaments extracted from Digital Elevation Model can not only be in a specific time range but can also be analyzed in different time frames, supporting a spatio-temporal analysis of lineament in the area throughout the years. Various automatic extraction has been used to analyze and trace a lineament, some of which are methods based on edge filtering techniques [12], linear characterization with 4 azimuths (e.g., 0, 45, 90, 135), linear delineation with 8 azimuths (e.g., 0, 45, 90, 135, 180, 225, 270, 315) [1], and factorial analysis of lineaments [11].

In this project, since the area of interest doesn't have any major changes in topography and lithology, the method used in delineating lineament is manual extraction with 4 and 8 azimuth analysis. The ranking of lineament is based on different azimuth that contributes the overall linear features found both in the ASTER GDEM and ALOS PALSAR data. The more frequent the lineament found in the same area in different azimuths, the more it is considered as a true linear feature of the data. The equation for the factorial analysis (Eq. 1) is based on the line segment feature found in Geomatica software, but due to minimal lineaments delineated in the field, manual computation and turn-bias analysis was performed;

$$Fi = b_1y_{1j} + b_2y_{2j} + b_3y_{3j} \dots + b_my_m \quad \text{Equation.(1).}$$

Eq. 1. Manual delineation formula derived from PCI Geomatica Line Module

Where F represents the principal factor, b is the loading of factor, y for the measured variable, i is the factorial number, j is the number of samples, and m is the sum of all variables [18].

2.3 Drainage network delineation

The softwares used to delineate the drainage line of the area are ArcMap V10.4 and the ArcHydroTool plugin. The different DEM's (e.g., 2007, 2008, 2010, 2024) are calibrated first by fill sinking [23]. This identifies and fills surface depressions and the downward slope along the path of most digital elevation models. After filling the sinks in the DEM, the next procedure is to identify its flow direction and flow accumulates by indicating the direction of flow from different cell bands to its downslope cells (Eq. 2). Next would be to calculate the flow accumulation by weighing the cells of the input raster, and distribute it to the relative cell band corresponding to the actual cell number. The calculated band in the area is less than 500 with Equation.(2), which is the formula for drainage line according to directional method of ArcMap

$$"Fac" > 500, \quad \text{Equation.(2).}$$

Where "Fac" is the flow accumulation of the input raster and 500 is the maximum cell number of the raster to be generated and form the drainage line. The stream order is based on Strahler [20] in 1952, where the stream order increases when streams of the same order intersect. If two first-order streams collide, it forms a second-order stream, and the classification of order continues as the tributaries grow away from the source point of the channel.

2.4 Drainage boundary characterization

The drainage area of a stream at a specific location is the region measured on a horizontal plane, bounded by a topographic divide, from which precipitation typically flows by gravity directly into the stream [10].

To characterize the drainage boundary, both ASTER GDEM and ALOS PALSAR datasets were preprocessed by means of DEM manipulation, specifically filling of sinks [23], and DEM reconditioning and leveling. After which, flow direction and flow accumulates where computed to categorize the basins found in every stream network that has already been processed by means of DEM leveling [16].

2.5 Soil Moisture Content

Soil Moisture is a ground factor that influences how soil energy is divided depending on the area of interest, affecting crop water stress, ground water, and interaction between the land surface and atmosphere [24]. In hydrogeology, soil moisture is a parameter to drive weather conditions, plant growth, and groundwater usage that is defined as an essential climate variable [7] that affects the global climate and hydrologic cycle [22]. Conventional methods such as ground surveying and field validation can be hard on labor, expensive, and may only be available on a limited number of stations depending on the area. Thus, remote sensing provides a much easier, effective, and convenient data analysis to determine soil moisture on the surface by interpreting bands of images from satellites [8]. Equation.(3), Composite bands equation for moisture content classification in ArcMap

$$\frac{\boldsymbol{Band}\ 5 - \boldsymbol{Band}\ 6}{\boldsymbol{Band}\ 5 + \boldsymbol{band}\ 6} \quad \text{Equation.(3).}$$

In this project, the satellite images used for soil moisture analysis are derived from Landsat 8 OLI using Normalized Difference Moisture Index (NDMI). NDMI uses near infrared and short-wave infrared bands to display differences in moisture [24]. SWIR are usually reflected bands of vegetation canopies, and vegetation water content that changes depending on the season. NIR on the other hand are commonly affected by the internal structure of dry matter content but are not concentrated in water content [6]. The classification of soil moisture content is determined by the values ranging from -1 to 1 based on the combination of bands as shown in Equation 3 and Table 1 to interpret Landsat images into moisture content values.

Table 1. Classification of NDMI Values according to [24].

NDMI RANGE VALUES	DESCRIPTIVE CLASSIFICATION
>0.8	Very Wet
0.24-0.032	Moderately Wet
0.032-0	Slightly Wet
0 - (-0.24)	Dry
0.208	Slightly Dry
7.76	Moderately Dry
>-8	Very Dry

3. RESULTS & DISCUSSIONS

3.1 Lineament Analysis

Lineaments were based on the shaded relief of 4 azimuths (e.g., 0, 45, 90, 135), and 8 azimuths (e.g., 0, 45, 90, 135, 180, 225, 270, 315) from the reclassified terrain models from ASTER GDEM and ALOS PALSAR. The result was summed into one classified lineament with Factorial Analysis. The elevation may have slightly changed over the past years due to continuous weathering, erosion, climate change, and other factors that may affect the ground surface (see Fig. 4).

The topography of the area, on the other hand, doesn't have any major changes in lithology, nor its geomorphology. The linear features delineated based on the shaded relief coincides with the drainage pattern of the Maraguing stream way back 2008, 2010, 2015, and 2020 (see Fig. 4). A total of 92 linear features from 4 azimuths were delineated and a total 184 linear features found in 8 azimuth reliefs.

With the integration of Factorial Analysis method, the two azimuthal analysis was factorized and reduced into 13 linear features and are now considered as the true lineament both from ASTER GDEM and ALOS-PALSAR spatial datasets (see Fig. 5). The lineaments found in the central portion of the Maraguing stream has a NE trend, indicating that most of the features of the geomorphology of the area originated from a pattern of erosional process (Fig. 5). This coincides with the sudden change of drainage line of Maraguing from 2008, 2010, and 2020 (see Fig. 6).

The general temporal pattern of deformation prior to any changes in elevation showed that the lineament found through GIS extraction relates to the sudden change of drainage network because of the NE trending lineaments extracted from the different year of spatial datasets (Figs. 5 & 6). Four validated lineaments were found in the area with the same NE trend from the GIS extracted (Fig. 5). The first lineament found measured N47E | 59SE, with the next lineament- with a N49E | 51SE, just 3 meters northward of the first lineament. The third lineament is located near the headwaters, measuring N68E | 73SE and N55E | 57SE. The strike trend of each lineament coincides with the lineament extracted from the DEM of 2008, 2010, 2015, and 2020 (Fig. 5). Any small to medium changes of land cover has been affected by the nearby linear features in the area as evidenced by the succession of the NE trending lineaments. In the study of Santos [17] in 2014, lineaments can also be a manifestation of much erodible soil and rock such as harzburgite for bedrock, and a lateritic surface that are common in Barangay Valencia.

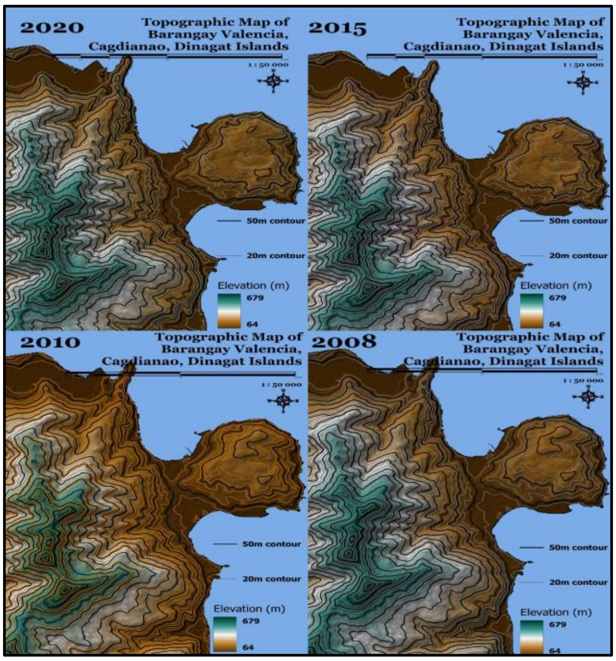

Fig. 4. Spatio-temporal variation of topography from 2008, 2010, 2015, and 2020 in barangay Valencia, Cagdianao, Dinagat Islands.

3.2 Drainage network analysis

The basin boundary of Maraguing stream has been moving and changing since 2007 according to the spatial distribution visualized in 2008, 2010, and 2020 (see Fig. 6). In 2008, the Maraguing stream had two different basins at the north and south portion of the drainage line (Fig. 6d). There is a different limiting boundary between two sub-basins responsible for collecting and managing its own runoff. There is no sign of a steep topographic boundary in the area to conclude that there is a visible line of different runoff streams.

In 2010, the boundary of Maraguing stream was moving northward in the nearest coastal area of Barangay Valencia. There are no significant changes in the topography, but the boundary of the basin seems to push northward of its previous boundary limit (Fig. 6c). The only time that a basin moves its boundary to another place is due to the flow of water that previously directed to two different systems are now combined into one. This coincides with the idea of Sondergaard & Jeppesen [19] in 2007 where a natural drainage boundary is actively moving due to stress difference, water flow rate, and the difference in volumetric discharge of water. This leads to a change of stream flow, stream order, and stream accumulation and may change the water designation to nearby areas that are previously being collected. The presence of residential areas for the public, and conversion of natural land into agricultural areas is also a possible cause for the boundary to be merged or moved somewhere else because of unbalanced use of water rather than its collection from nearby sub-basins [13].

In 2015, the drainage boundary of Maraguing stream was moved from the southern part of Barangay Valencia to the southeastern portion. The outlet of the drainage line also moved based on the drainage boundary itself (Fig. 6b). There are numerous explanations for this phenomenon and one possible explanation is the possibility of natural processes such as erosion, sediment deposition, and or tectonic activities that can alter the course of the drainage line [21]. But in some aspects, the major factor of the shifting of the drainage line from its original course are human activities (e.g., residential building, agriculture) that affects the flow of the water. After 2015, there is no difference in basin boundaries as of 2020 (Fig. 6a).

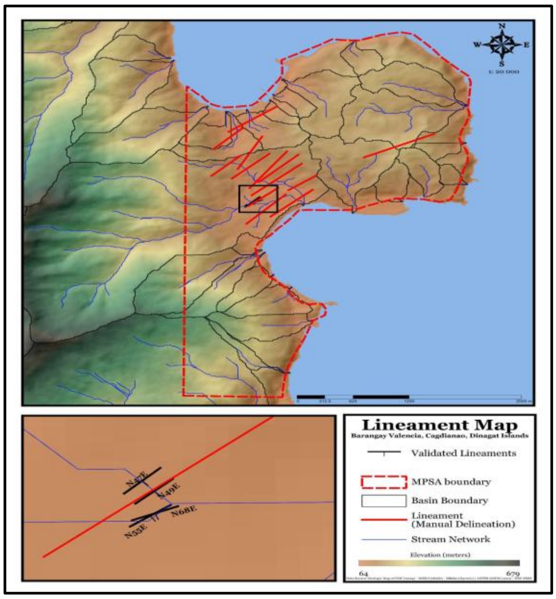

Fig 5. Lineament map of barangay Valencia, Cagdianao, Dinagat Islands.

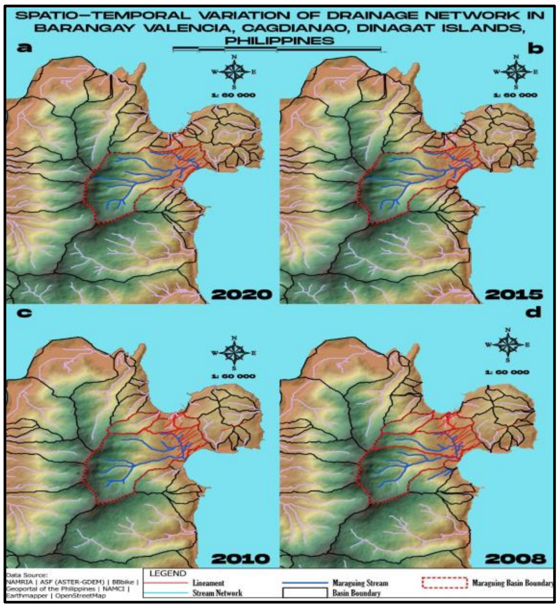

Fig. 6. Spatio-temporal variation of drainage network in barangay Valencia, Cagdianao, Dinagat Islands from year a.2020, b.2015, c.2010, d.2008.

3.3 Soil Moisture Analysis

Soil moisture is crucial in understanding the hydrology of an area, as it directly influences water distribution within the soil. This plays a key role in drainage network analysis, essential for accurately extracting lineaments; linear features that often indicate significant geological structures like faults or fractures (Saidi et al., 2020). Dinagat Islands, classified under the modified Coronas Classification as Type II, experiences no dry season with a pronounced maximum temperature from December to February [4] (Fig. 7). To minimize bias, soil analysis was conducted during periods of maximum rainfall (December to February) and minimum rainfall (March to

May) (Fig. 8).

Between 2010 and 2020, soil moisture during the dry season dropped significantly from 0.081% to 0.047%, a 0.034% decrease (Table 2). This trend could suggest drier conditions, potentially due to increased groundwater extraction and water usage, driven by population growth and conversion of natural forests into residential sites (Fig. 9). These activities may have placed additional stress on both groundwater and surface water supplies, contributing to the reduced soil moisture levels.

The wet season showed a slight decrease in soil moisture, from 0.047% to 0.042%, a minimal 0.005% drop. This indicates that the soil's water retention capacity has remained relatively stable over the years, likely due to consistent soil structure, even though external factors such as temperature and rainfall may have varied.

Between 2010 and 2020, a notable drop in soil moisture was observed during the dry season, from 0.081% to 0.047%, indicating a 0.034% decrease. This trend, coupled with a rise in maximum annual temperature from 24.12°C to 25.22°C, suggests that increased evaporation is playing a role in the soil's diminished water retention capacity.

Despite an increase in maximum annual rainfall (from 55 mm/year to 70 mm/year), the soil's ability to hold moisture appears compromised, especially in the dry season. This could be due to factors like groundwater over-extraction, increased land use, and temperature rise. In the wet season, soil moisture showed only a minimal decrease (0.047% to 0.042%), implying that while external climate factors are changing, the soil's retention capacity during the wet season remains relatively stable, likely due to its inherent structure. However, rising temperatures and increased water use from residential consumers and increase of agricultural areas, growth may stress the local hydrological cycle, leading to further soil moisture depletion.

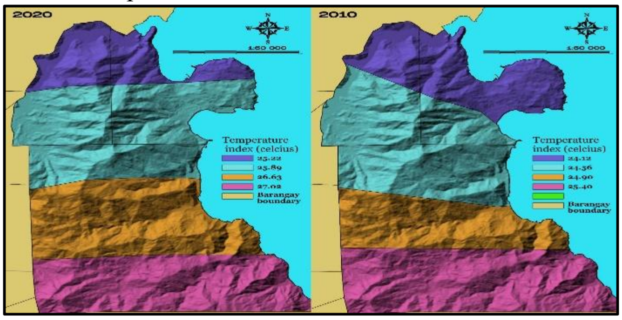

Fig. 7. Temperature Map of Barangay Valencia: year 2010 (right) and year 2020 (left).

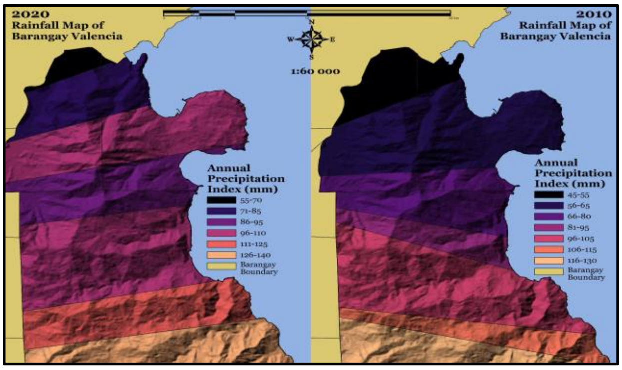

Fig. 8. Rainfall Map of Barangay Valencia: year 2010 (right) and year 2020 (left).

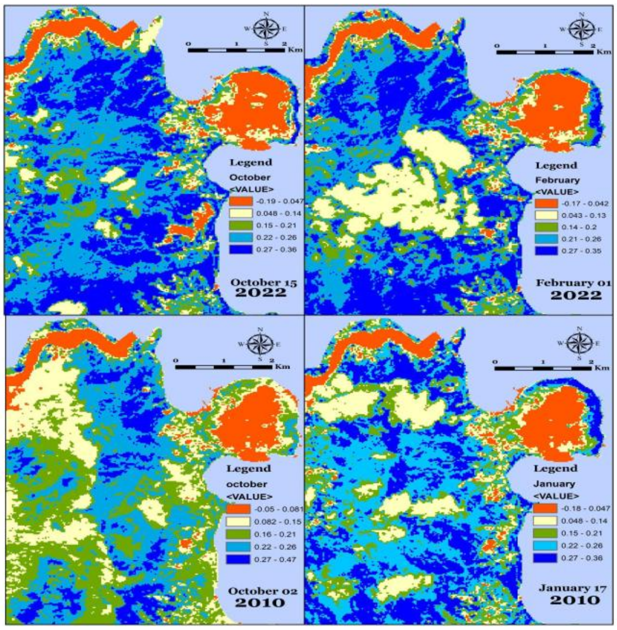

Fig. 9. Soil Moisture Analysis of Barangay Valencia: year 2022 (top) and year 2010 (bottom).

Table 2. Maximum Values of parameters from NDMI classification from 2010 and 2020.

Year	2010	2020	Difference
Soil Moisture (Dry Season) Maximum %	0.081	0.047	-0.034
Soil Moisture (Wet Season) Maximum %	0.047	0.042	-0.005
Temperature (Maximum °C/year)	24.12	25.22	1.1
Rainfall (Maximum mm/year)	55	70	15

4. CONCLUSIONS

From the results obtained in this study, remote sensing has been the major contributor for analyzing data, including lineament delineation, and watershed boundary analysis and characterization. The processed and extracted data from different sources including Landsat images, ASTER GDEM, ALOS PALSAR, and Sentinel 1 data has been thoroughly analyzed and performed based on the standard calculations from various references.

The study of lineaments in the Maraguing stream area, utilizing shaded relief from different azimuths and Factorial Analysis, has identified and confirmed 13 true lineament features within the tenement. These features primarily show a northeast trend of linear characteristics, emphasizing the role of erosional processes in shaping the region's geomorphology and indicating significant changes in the drainage network from 2008 to 2020.

The relationship between the identified lineaments and historical drainage patterns brings out the impact of geological and climate conditions on the area, suggesting that lineaments may point to areas with erodible materials, such as the lateritic surfaces in the area. The basin boundary of the Maraguing stream has shifted northward since 2007 due to both natural processes and human activities, resulting in the merging of two sub-basins and changes in stream flow and water management. By 2020, the basin boundary appeared to stabilize, indicating that while human influences are significant, natural processes may have adapted to these changes.

In soil moisture analysis, the moisture content of Barangay Valencia has notably declined during the dry season from 2010 to 2020, likely due to increased groundwater extraction and land use changes driven by population growth and conversion of many natural lands into farmlands and or built-ups. Although there was a slight decrease in soil moisture during the wet season and because human interventions usually don't carry out during the wet season, the soil's ability to retain moisture has remained relatively stable, suggesting resilience in its structure amidst changing climate conditions. However, the combination of rising temperatures and heightened human activities such as land conversion into residential, industrial and farms presents ongoing challenges to the local hydrological cycle, underscoring the importance of implementing sustainable water management practices.

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