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<https://doi.org/10.5109/7395720>

出版情報 : Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 11, pp.1597-1604, 2025-10-30. International Exchange and Innovation Conference on Engineering & Sciences

バージョン :

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Drainage network characterization through lineament analysis of Manoligao watershed, Dinagat Islands, Philippines using multifactorial approach

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Abstract: Manoligao watershed, located in Barangay Del Pilar, Cagdianao, Dinagat Islands, serves as the primary freshwater source for the local community. Measuring around 9.31 kilometers in length and ranging from 5 to 210 meters in elevation, the watershed features a mix of mountainous and forested terrain. To better understand its drainage network, the study used satellite imagery from Sentinel-1 and RS-GIS tools like PCI Geomatica 2018 and HEC-HMS for automated lineament extraction and watershed analysis. Findings show that the drainage pattern is strongly influenced by NE-NW trending lineaments, which were also observed in the outcrops nearby natural springs, with a majority rock unit of harzburgite. These structural features appear to guide both surface water flow and groundwater distribution. The study focuses on how geological structures play a significant role in shaping Manoligao watershed's hydrology and reinforces the importance of using modern GIS tools for more accurate analysis.

Keywords: Watershed; Lineaments; Morphometric Parameters; Cagdianao; Drainage Network Analysis.

1. INTRODUCTION

1.1 Background of the study

Researchers have explored various approaches to studying drainage basins and stream channels, investigating a wide range of areas. Strahler [17,18,19,20], building on Horton's work [6], have gathered a significant amount of data on the morphology of drainage basins and the characteristics of drainage networks. However, each of these studies only defined the morphometric parameters of a watershed, not considering the in-depth geologic aspect of a drainage basin.

In a watershed, the structural influence of a single linear feature in the area greatly affects the movement of the streams, as well as its ability to form natural springs and smaller-catchment basins [1]. Linear features found both in the surface area of rocks and or lineaments that are considered fractures in an outcrop can change the overall movement of flowing water from the head point of the basin, down to lowest point of the river [8].

1.2 Study area

The Municipality of Cagdianao, located in the province of Dinagat Islands, Philippines, is a coastal town subdivided into 14 barangays (Fig.1). With a land area of 196.57 km², it represents 24.05% of the total area of Dinagat Islands. Cagdianao lies in the southeastern part of Dinagat Island, bordered by Libjo to the north, Nonoc Island (part of Surigao City) to the south, and the municipalities of Dinagat, San Jose, and Basilisa to the west. Its approximate coordinates are 9°55' N latitude and 125°40' E longitude. The town's watershed, located in Barangay Del Pilar, is the second largest in the municipality, covering a significant area and serving as an important water resource for the local community.

MUNICIPAL BOUNDARY MAP OF DINAGAT ISLANDS

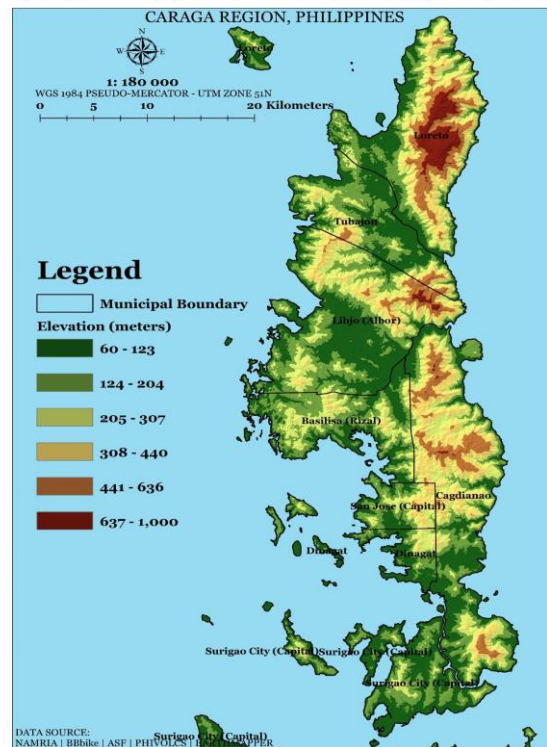


Fig. 1. Municipal Boundary Map of the Province of Dinagat Islands.

1.3 Statement of the problem

The absence of comprehensive data on the morphometric parameters of Manoligao watershed's drainage networks and the structural features of its linear systems hinders effective resource management, particularly in groundwater exploration and hazard assessment. Many of the surface lineaments in the area may or may not correspond to subsurface faults or fractures, creating uncertainties about their influence on the local geology and hydrogeology. Furthermore, the accuracy of

structural analysis in remote areas is usually limited because of inaccessibility of site and costly fieldwork, having the tendency of only relying on RS-GIS analysis of lineaments, hindering researchers to conduct on-site field validation procedures.

1.4 Objective of the Study

The primary objective of the research is to evaluate the morphometric parameters and extract surface lineaments in Manoligao watershed using Remote Sensing and Geographic Information System (GIS) techniques. This research aims to establish a more comprehensive understanding of the geological and structural characteristics of Manoligao watershed and their relationship with hydrological processes.

1.5 Significance of the Study

By characterizing the morphometric parameters of the watershed, as well as mapping lineaments and analyzing their density, orientation, and intersection patterns, the study helps to identify the fault systems and structural controls influencing the drainage movement of the Manoligao watershed.

1.6 Scope and Limitations

The scope of the research is limited to the application of PCI Geomatica 2018 for the lineament delineation, and the Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS) for the morphometric characterization of Manoligao watershed. Despite its contributions, the study is subject to several limitations such as the accuracy of the analysis influenced by the resolution of the satellite imagery and DEM data, which may limit the detection of fine-scale features, introducing subjective biases in manual lineament extraction, automated lineament extraction methods that rely on algorithms that may not accurately distinguish between true geological features and surface structures, and relies heavily on remote sensing and GIS techniques, with limited field verification of morphometric parameters and lineament features due to logistical challenges in accessing the rugged terrain.

2. REVIEW OF RELATED LITERATURE

2.1 Geology of Dinagat Islands

Almost a large area of Dinagat island is underlain by a mafic-ultramafic rock formation known as the Dinagat Ophiolite as shown in the map (Fig. 2). 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 [11]. This formation is visible in the western parts of the island and lies above the basalt and diabase dikes of the Dinagat Ophiolite. Figure 2 shows that the lithology in Cagdianao is mostly composed of igneous and metamorphic rocks. In the northern portion of the region, there is mostly a large distribution of Harzburgite and a minimal amount of dunite. Two main structural trends are present on the island; an older northeast (NE) lineament found mainly north of Loreto near Panamaon and Masdang Point, and a younger northwest (NW) lineament that cuts across the NE structures and dominates from south of Loreto to Nonoc and Rasa Islands. The NW lineaments also extend through the sedimentary layers overlying the ophiolitic complex [15].

GEOLOGIC MAP OF DINAGAT ISLANDS

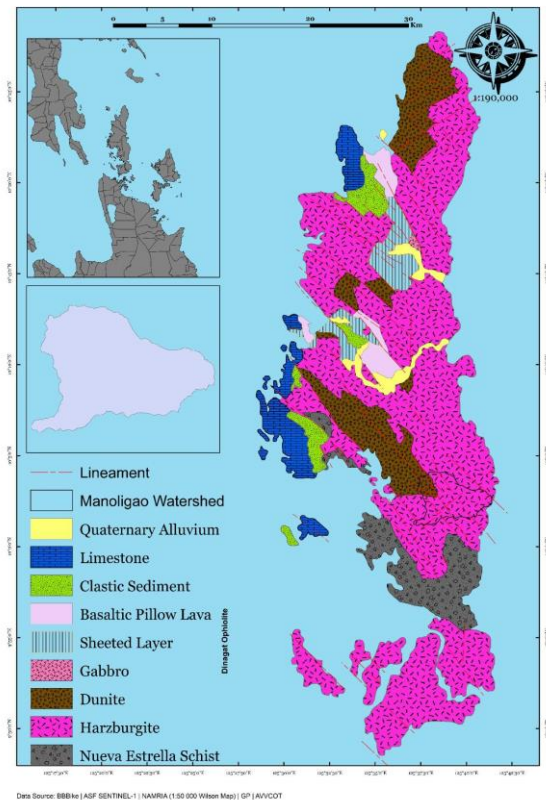


Fig. 2. Geologic Map of Dinagat Islands (Modified from RA Santos, 2014).

2.2 Drainage Network

A drainage network is an interconnected system of streams and rivers within a drainage basin that channels surface water from rainfall and other sources toward a common outlet, such as a larger river or a body of water [3]. The structure and arrangement of the drainage network are influenced by the topography, geology, and underlying lithological features of the area [10]. It is the spatial arrangement of surface watercourses within a watershed that facilitates the collection, movement, and discharge of water resulting from precipitation and surface runoff [14]. In geomorphology, it is the physical network of channels formed by erosion and sediment transport processes over time, shaped by the topography, underlying geology, and climatic conditions of an area (Fig.3).

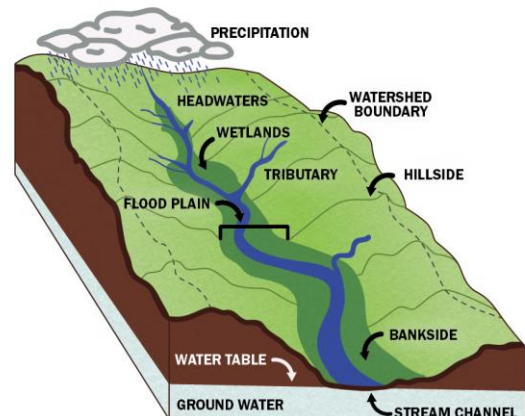


Fig. 3. Visualization of a watershed based on Daniel, 2011

2.3 Drainage Patterns

Drainage patterns in river systems form based on the landscape and the type of rocks in the area, with different patterns showing how water moves through various terrains (Fig. 4). For example, dendritic patterns look like tree branches and form in flat areas with similar rock types, while other patterns like trellis, radial, or rectangular reflect different land shapes and are mostly structurally controlled rock structures, helping researchers understand the hydrologic characteristics of the area [7].

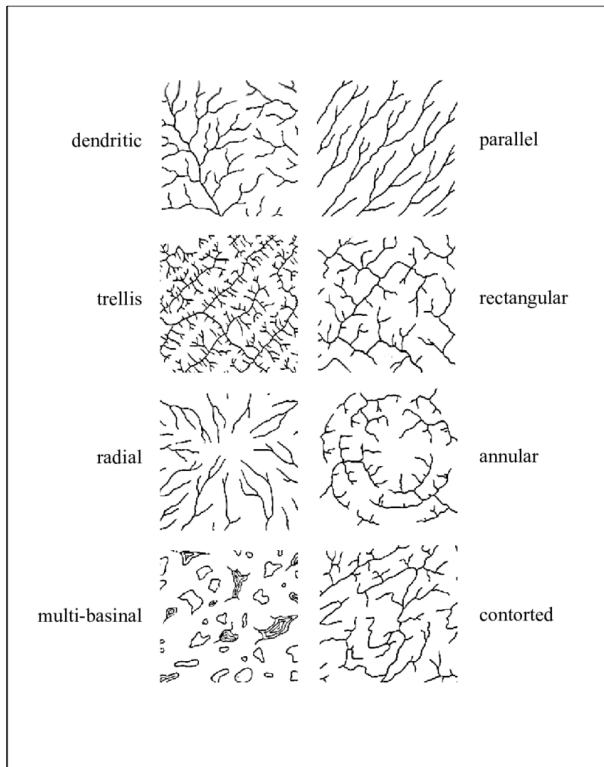


Fig. 4. Basic drainage patterns in a river system according to Horton, 1952.

2.4 Morphometric Parameters

Morphometric parameters is a quantitative framework for describing the geometry of drainage basins, enabling researchers to discern variations in initial slope, differences in rock hardness, structural influences, recent tectonic activities, and the geological and geomorphic evolution of the basin (Table 1.) [20]. The drainage patterns within a basin or sub-basin are predominantly influenced by the characteristics of the underlying rocks, soils, and structural features, making it possible to infer lithology, structural configurations, and soil types [2]. Higher-order streams tend to be shaped by rock structures, while the behavior and interactions of lower-order streams provide insights into the properties of the underlying rocks and soils [2].

Table 1. Morphometric Parameters for watershed characterization

Morphometric Parameters	Formula	Reference
No. of Stream Order	Hierarchical Rank	Strahler (1964)
Length of Stream	Length of Stream	Horton (1945)

Morphometric Parameters	Formula	Reference
Mean Stream Length	$L_{sm} = L_u / N_u$ where: $L_u =$ Total stream length of order 'u' $N_u =$ Total no. of stream of order 'u'	Strahler (1964)
Stream Length Ratio	$R_L = L_u / L_{u-1}$ where, $L_u =$ Total Stream length of order 'u' $L_{u-1} =$ Total stream length of its next lower order	Horton (1945)
Bifurcation Ratio	$R_b = N_u / N_{u+1}$ where: $N_u =$ Total no. of stream segments of order 'u' $N_{u+1} =$ Total no. of stream order of its next lower order	Schumm (1956)
Mean Bifurcation Ratio	$R_{bm} =$ Average of bifurcation ratio of all orders	Strahler (1957)
Drainage Density	$D = L_u / A$ Where: $L_u =$ Total stream length of all orders, $A =$ Area of the basin	Horton (1932)
Stream Frequency	$F_s = N_u / A$ where: $N_u =$ Total .no of stream of all orders, $A =$ Area of the basin	Horton (1932)
Drainage Texture	$D_t = N_u / p$ Where : $N_u =$ Total no. of stream of all orders, $P =$ Perimeter of the basin	Horton (1945)
Form Factor	$R_f = A / L_b^2$ Where: $A =$ Area of the basin $L_b =$ Maximum basin length	Horton (1932)
Circulatory Ratio	$R_c = 12.57 * (A / P^2)$ Where: $A =$ Area of the basin, $P =$ Perimeter of the basin	Schumm (1956)
Elongation Ratio	$R_e = 2 A / L_b$ Where: $A =$ Area of the basin $L_b =$ Maximum Basin Length, $\pi = 3.14$	Schumm (1956)
Length of OverLand Flow	$L_g = 1 / D^2$ Where : $D =$ Drainage Density	Horton (1945)
Constant Channel Maintenance	$C = 1 / D$ Where : $D =$ Drainage Density	Schumm (1956)
Basin Shape	$B_s = L_b^2 / A$ where : $L_b =$ Maximum basin length, $A =$ Area of the Basin	Horton (1932)

Morphometric Parameters	Formula	Reference
Infiltration Number	$I_f = D * F_s$: $I_f =$ infiltration number $D =$ drainage density, $F_s =$ Stream frequency.	Horton (1945)

2.5 Lineaments

Lineaments are linear or curvilinear features on the Earth's surface that reflect underlying geological structures. These features have been a subject of interest for geologists for over a century, dating back to the early 1900s [5]. Lineaments are often associated with zones of weakness or structural displacement in the Earth's crust. Defined as mappable linear or slightly curvilinear features [9], they can signify faults or other structural weaknesses.

The formation of lineaments is generally attributed to tectonic stress and strain. These features are often the surface expression of underlying structural phenomena, such as faults, joint sets, folds, cracks, or fractures. Many geological lineaments are ancient and may be buried under younger sediments. When these structures are reactivated, they often manifest as brittle surface features or arrays of smaller lineaments visible in the topography [12].

3. METHODOLOGY

3.1 Methods Used

This study utilized a quantitative descriptive approach to characterize the drainage pattern of Manoligao watershed, as well as its structural control in the stream pattern that majority governs the movement of water in Manoligao area. To perform watershed characterization, two softwares were utilized; HEC-GeoHMS and HEC-HMS. For the extraction of manual and automatic delineation of lineaments in the area, 3 different softwares were utilized; ArcMap v10.8, PCI Geomatica 2018, and Rockworks v.15. All manual and automatic lineament extractions are carried out using all the mentioned softwares.

3.2 Watershed characterization and Lineament analysis

The research involves two different methodological frameworks to assess the morphometric parameters and the comparison of lineament delineation of Manoligao watershed as shown in figures 5 & 6.

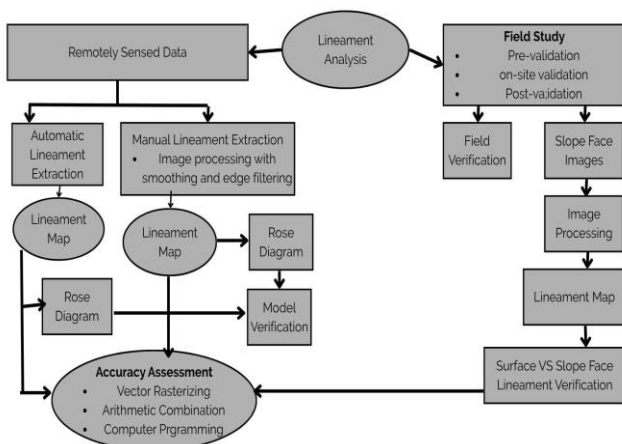


Fig. 5. Methodological Framework for lineament extraction (Modified from Hobbs, 1904)

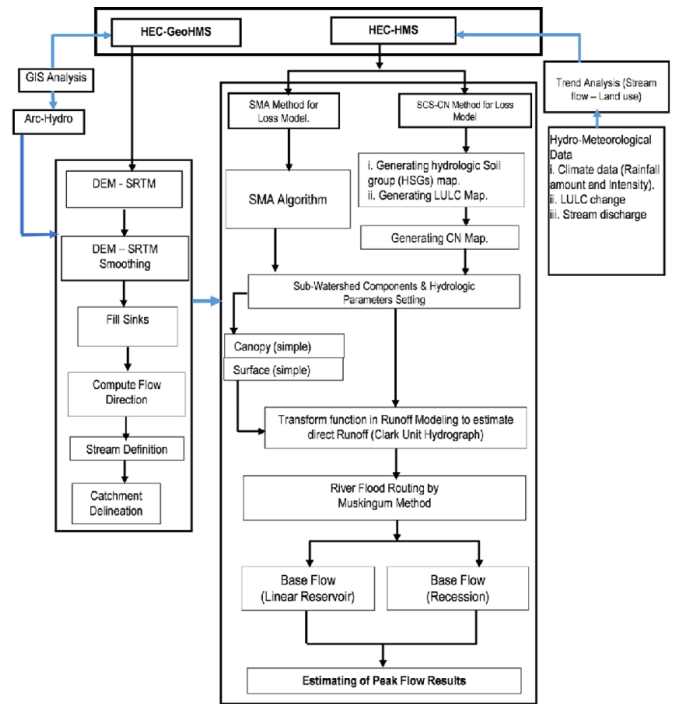


Fig. 6. Modified Methodological Framework of morphometric analysis of the watershed (Strahler, 1964).

3.3 Existing Data

A range of sources, including geological records, academic papers, satellite imagery, and topographic maps, were consulted to assess the area's lithology and structural features. These findings guided the selection of potential sampling locations.

3.4 Pre-Fieldwork Maps

ArcMap v10.8 integrated geological and topographic data to create baseline maps for both lineament and watershed characterization (Fig.7).

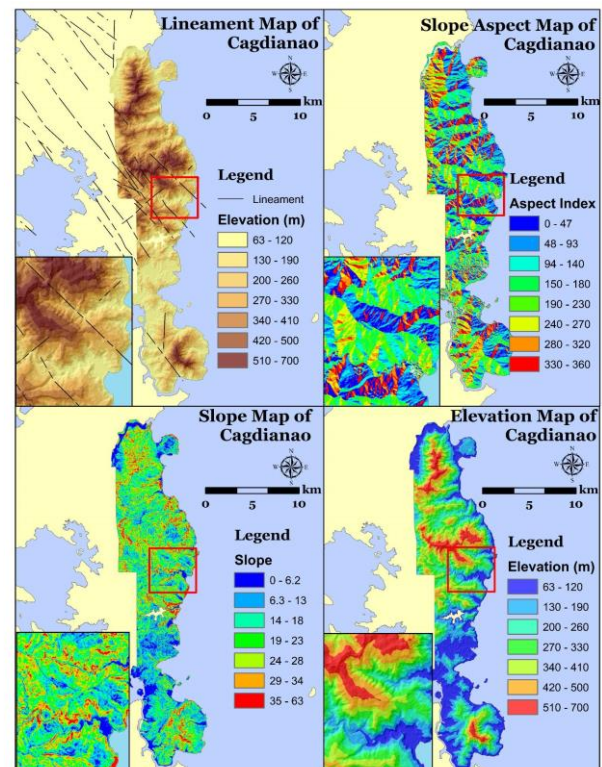


Fig. 7. Pre-processed maps for lineament extraction

3.5 Fieldwork

Lineaments observed in satellite images may represent a range of surface expressions, such as faults, joints, lithological boundaries, or even anthropogenic features like roads or pipelines. Without field validation, it is often difficult to distinguish between true geological structures and visual artifacts or non-geological linear features. This ground-truthing process confirms the geological nature of the features, refines their classification, and provides context that satellite data alone cannot offer. In this study, 14 locations near the main channel of Manoligao river were identified and validated (Fig. 8).



Fig. 8. 14 validation points of lineaments found in the river system of Manoligao watershed.

4. RESULTS AND DISCUSSIONS

4.1 Morphometric Analysis of Manoligao Watershed

Manoligao Watershed is a moderately sized basin encompassing an area of 25.05 km² with a perimeter of approximately 17.74 km. The maximum basin length extends to 42.24 km, indicating an elongated shape, which is supported by a relatively low elongation ratio of 0.56426 and a basin shape index of 0.429. The form factor of 0.593101 and a very high circularity ratio close to 1 (0.99999) suggest that while the basin is elongated, it also maintains a near-circular outline, indicating rapid runoff. The drainage density of 1.22 km/km² and stream frequency of 1.32 indicate a moderate level of dissection, with 33 total stream segments distributed across three stream orders.

The total stream length is 14.24 km, with the highest number of streams found in the 1st order (27 streams), and progressively fewer in higher orders (Fig. 9). The infiltration number (1.60) and length of overland flow (0.41 km) imply a moderate capacity for water absorption and surface flow movement. The bifurcation ratio, averaging 5.2, indicates relatively high structural control or geological influence over stream branching. Drainage texture (1.86) and constant channel maintenance (0.82) values further point to moderate surface runoff and erosion characteristics (Table 2).

Parameters	Values	Parameters	Values
Area of the basin (Km)	25.0508	Total Stream Length of all Orders	14.24276
Perimeter of the Basin (Km)	17.74254	Total No. of 1st Order	27
Maximum Basin Length (Km)	42.23694	Total No. of 2nd Order	5
Drainage Density	1.216749	Total No. of 3rd Order	1
Stream Frequency	1.31732	Total No. of all Orders	33
Drainage Texture	1.859936	Mean Stream Length of 1st Order	1.229708
Form Factor	0.593101	Mean Stream Length of 2nd Order	0.139978
Circularity Ratio	0.99999	Mean Stream Length of 3rd Order	4.3148
Elongation Ratio	0.56426	Stream Length Ratio of 1st Order	0.431695
Length of Overland Flow	0.410931	Stream Length Ratio of 2nd Order	0.265357
Constant Channel Maintenance	0.821862	Stream Length Ratio of 3rd Order	0.302946
Basin Shape	0.429012	Bifurcation Ratio of 1st Order	5.4
Infiltration Number	1.602847	Bifurcation Ratio of 2nd Order	5
Total Length of 1st Order (Km)	6.14854	Bifurcation Ratio of 3rd Order	-
Total Length of 2nd Order (Km)	4.3148	Mean Bifurcation Ratio	5.2
Total Length of 3rd Order (Km)	3.77942		

Table 2. Morphometric analysis of Manoligao watershed

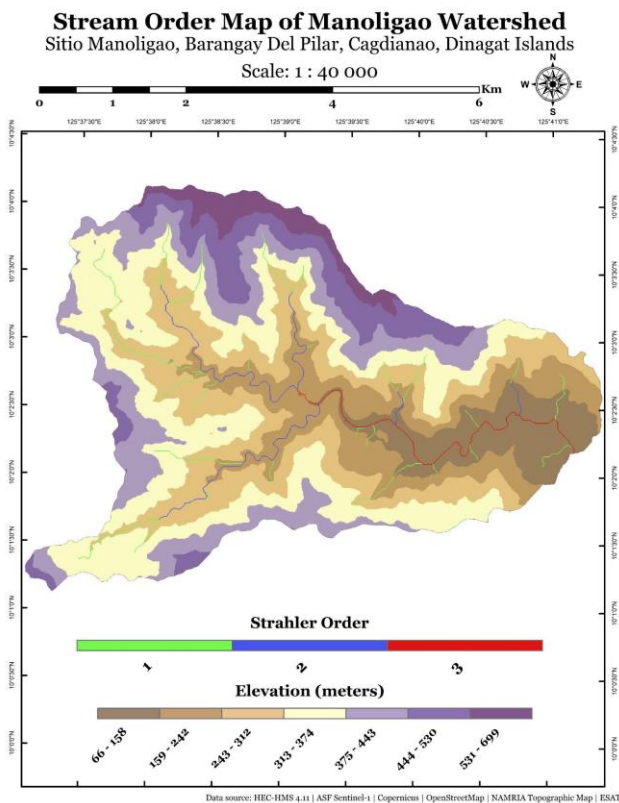


Fig. 9. Stream Order Map of Manoligao Watershed

4.2 Field observations

At Site F (Figure 7), photograph F.1 captures a rapid section of the river, while F.2 shows the river's thalweg. Fracture orientations of N62E and N43W were documented with a Brunton compass, substantiating the previously mapped NE and NW trends (Fig. 10).

Further upstream at Site I, similarly aligned joints continue to appear, along with some NW-directed breaks. The final observation point, Site N (Figure 7), lies at a midstream location and marks the end of the river transect (Fig. 10).

Photographs N.1 through N.3 documents a variety of fracture directions, including N10W and N56E (Fig. 10). The field data affirm the structural interpretation of the watershed. NE-trending fractures predominantly guide the main drainage patterns, while NW-aligned structures influence tributary development and zones of groundwater discharge.

4.3.1 Manual delineation vs Field observation

A total of 256 lineaments were manually identified from various hillshade models, revealing that many intersecting or aligned features confirm the continuity and structural importance of these linear trends (Fig. 11). The dominant NE-striking lineaments appear to be dominant in shaping the stream network, as many correspond closely with stream channel directions, indicating strong structural control over fluvial development. Field validation at multiple sites confirmed these features, with evidence suggesting that the younger NE-oriented lineaments actively influence upstream flow paths, while the older NW lineaments have less impact on surface runoff.



Fig. 10. (Site F, I, and N) Representative sampling sites of the Manoligao river, with dominant rock unit of Harzburgite

4.3.2 Automatic delineation vs Field observations

Automatic lineament extraction using PCI Geomatica generated a total of 1,925 linear features across eight distinct azimuthal directions (Fig. 12). This dataset was carefully filtered to remove anthropogenic structures, such as roads and irrigation canals, ensuring the resulting features are of geological origin. The frequent occurrence of NE-oriented features, as detected through filtered processing of Sentinel 1 SAR satellite imagery, suggests that the region's structural framework is primarily governed by these younger NE-striking fractures.

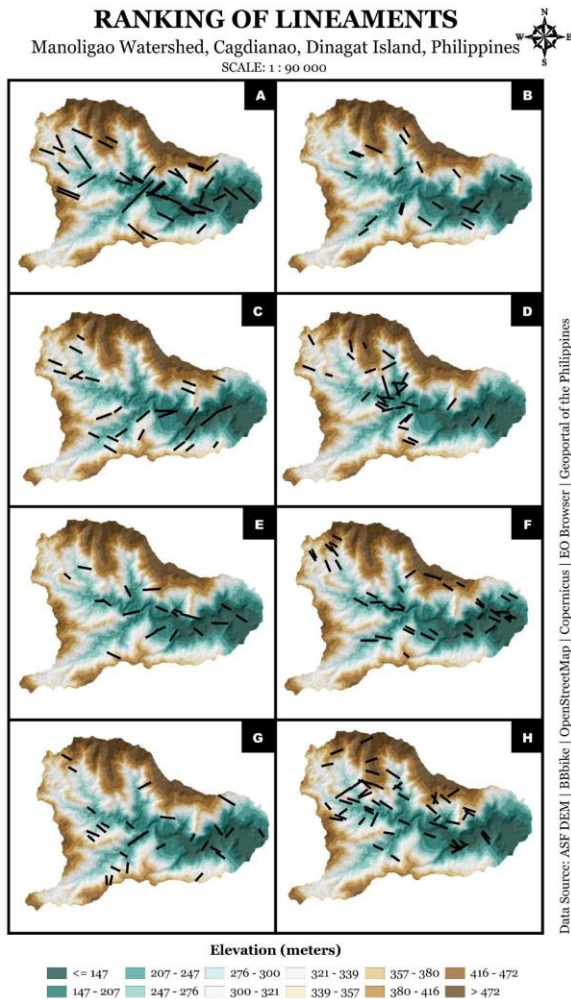


Fig. 11. Ranking of Manual delineated lineament map of Manoligao watershed.

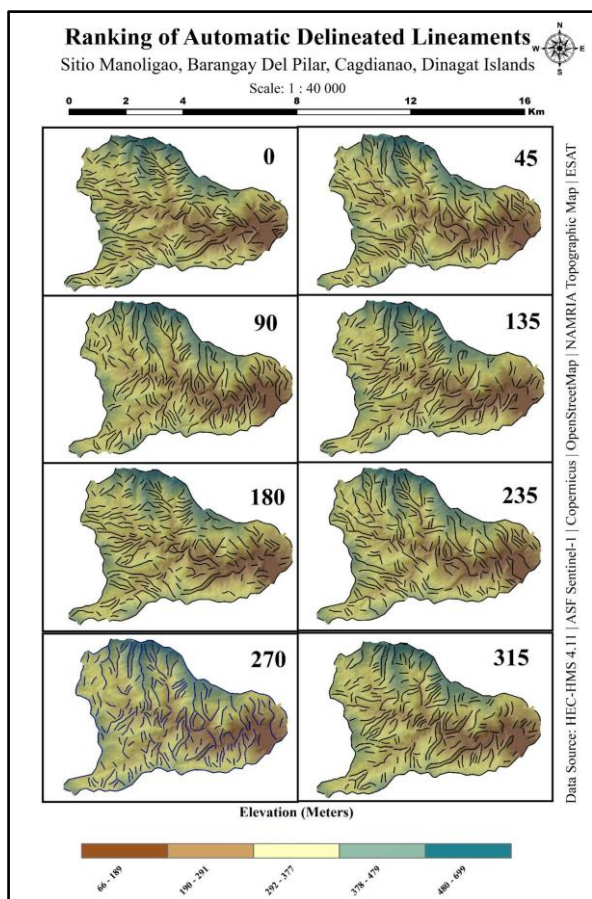


Fig. 12. Ranking of Automatic delineated lineament map of Manoligao watershed.

4.4 Geologic interpretations of lineaments

Evidence from the weighted lineament map (Fig. 13) reveals a concentrated occurrence of both NE and NW-striking features in the central portion of the watershed. This clustering, particularly where the NE-oriented lineaments intersect with the older NW-oriented lineaments in the northwestern sector of the watershed, reveals the simultaneous coexisting of multi-generational faults. This aligns with findings from R.A. Santos in 2014 [15], who noted that a more recent NE-striking lineament has overlain an older NW-striking lineament in the area. It also suggests that significant structural control can occur even in the absence of major mapped fault lines, as joints can be considered a factor for stream network flow direction, particularly in areas dominated by impermeable lithologies such as harzburgite.

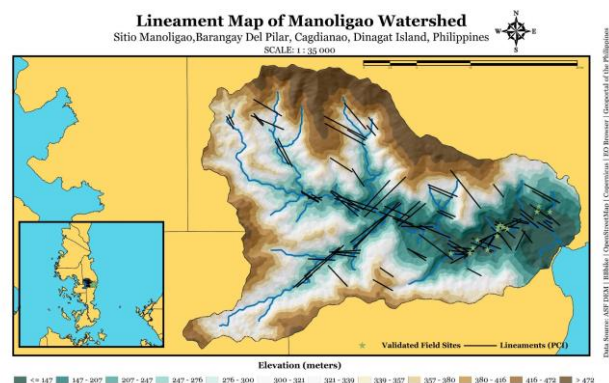


Fig. 13. True Lineament Map of Manoligao Watershed

5. CONCLUSION AND RECOMMENDATION

This study aimed to show that integrating information derived from remotely sensed satellite imagery with data from geological and topographical maps can enhance the research process by reducing cost, improving accuracy, and saving time. This is demonstrated through the compilation, registration, and analysis of these datasets within a GIS for the Manoligao watershed. From the compiled extracted lineaments of both manual and automatic lineaments, the prevalence of NE-NW striking lineaments in the area suggests that localized structures such as joints and fractures govern the movement of stream in Manoligao watershed, shaping the current formation of the basin in the area. The use of weighted average in analyzing the true lineaments found in the area also proves that the accuracy from pre-existing data are validated in the field, therefore confirming relatively exact lineaments along the river network. As a recommendation for future research endeavors, the use of different satellite images can be a factor to consider since different data may yield different results compared in this research. For local use, this paper intends to solidify the research database for Dinagat Island in studying watershed and its geological implications since there are currently a minimal number of researchers exploring and conducting hydrogeological fieldwork in the island.

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