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Geomorphological Analysis of the Right Bank Area of Bulango Ulu Dam, Gorontalo Province Using Geological and DEM-Based Terrain Evaluation

Muhamad Danial Suma[1], Yayu Indriati Arifin[1], Noviar Akase[1]

[1] *Geological Engineering, Universitas Negeri Gorontalo, Jl.Prof. Dr. Ing. B. J. Habibie, Bone Bolango, 96119, Indonesia*

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Corresponding author:
Yayu Indriati Arifin
Email: yayu_arifin@ung.ac.id

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ABSTRACT

This study investigates the geomorphological characteristics of the right bank area of the Bulango Ulu Dam in Gorontalo Province to support infrastructure planning, risk assessment, and sustainable land use. Employing integrated methods involving field observations and Digital Elevation Model (DEM) analysis, the research identifies two principal geomorphological units: Structural Low Hills (S1) and Fluvial Plains (F1). These units are shaped by the combined influence of endogenic processes, such as tectonic uplift and structural deformation, and exogenic processes, including fluvial erosion, sedimentation, and weathering. Lithological analysis revealed the presence of three main rock units diorite, granodiorite, and alluvial deposits each contributing to the area's terrain diversity and physical stability. Morphometric classification indicates that steep (30–70%) and very steep (70–140%) slopes dominate more than half of the study area, highlighting a high susceptibility to landslides and erosion hazards, particularly during peak rainfall seasons. The identification of a sub-dendritic drainage pattern suggests that geological structures play a vital role in directing surface runoff and sediment transport. The novelty of this research lies in its localized and detailed geomorphological assessment, which had not been previously conducted on the dam's right bank. The findings have practical implications for dam safety, slope reinforcement strategies, and regional spatial planning under dynamic geological conditions.

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1. INTRODUCTION

Geomorphology is fundamental to understanding the Earth's surface processes and forms, especially in regions undergoing dynamic environmental and geological changes. The application of geomorphological knowledge in infrastructure planning, particularly dam development, is critical for identifying landform characteristics, assessing hazard potential, and ensuring the structural stability of the dam. The integration of geomorphological data such as morphometry, landform classification, and lithological distribution is essential during the initial phases of engineering planning, where terrain plays a central role in determining design feasibility and long-term functionality (Isdianto et al., 2022; Mamonto et al., 2024; Petrone et al., 2023). In the case of Gorontalo Province, the presence of complex geological conditions further justifies the necessity of geomorphological studies to inform technical decisions and mitigate the risks associated with dam infrastructure (Sutriyono et al., 2021).

The lack of localised geomorphological analysis in specific segments of dam structures, particularly the right bank area of the Bulango Ulu Dam, represents a critical gap in regional infrastructure research. This omission poses significant risks because undetected variations in slope gradient, lithological composition, or drainage patterns can undermine dam stability and effectiveness. A general solution lies in applying comprehensive terrain analysis through field studies and remote sensing techniques, which enable the delineation of geomorphological units and detection of physical features relevant to engineering and environmental planning (Liao et al., 2022; Sutriyono et al., 2021).

A combination of field surveys and Digital Elevation Model (DEM) analysis has been widely recognised as an effective approach in recent geomorphological studies. This integration enhances spatial accuracy and allows for the extraction of detailed morphometric parameters such as slope distribution, elevation variation, and drainage patterns (Hamim et al., 2023; Mamonto et al., 2024). Furthermore, the application of morphographic interpretation aids in the identification of landform types, while morphogenetic analysis provides insight into the processes driving their formation, including tectonic and climatic influences (Bishta & Qudsi, 2023). These methodological frameworks have proven effective in tectonically active regions similar to the study site and offer a strong foundation for evaluating the terrain characteristics of the right bank of the Bulango Ulu Dam.

Despite numerous regional geomorphological investigations in the Gorontalo area, studies with a localised focus on dam infrastructure zones, particularly the right bank of the Bulango Ulu Dam, remain notably absent. This gap is especially relevant considering that this segment includes critical structural components, such as the water gate and spillway. Previous studies have predominantly addressed regional morphostructure without conducting targeted slope classification or flow pattern analysis specific to the right bank (Melo et al., 2024; Mohd et al., 2023). The lack of detailed data on geomorphological units and their lithological compositions necessitates a focused study to bridge this deficiency and support the resilience of the infrastructure.

This study aimed to evaluate the geomorphological characteristics of the right bank of the Bulango Ulu Dam through a combination of field observations and DEM-based terrain analysis. The novelty of this study lies in its focus on a neglected yet crucial segment of dam infrastructure, offering new insights into the geomorphological composition and lithological variation of the area. The scope is confined to a 0.145 km² area and includes classification of geomorphological units, lithological identification, and hazard potential analysis, with direct implications for construction planning, land use, and environmental risk mitigation (Ranganai et al., 2017; Zingaro et al., 2022).

2. METHOD

2.1. Materials

The study was conducted in Tuloa Village, North Bulango District, Bone Bolango Regency, Gorontalo Province, covering an area of 0.145 km² with elevations ranging from 40 to 160 m above sea level. The location of the study area is shown in Figure 1. The main materials used include Digital Elevation Model (DEM) imagery for morphometric analysis, topographic maps, and the Kotamobagu geological map sheet (Apandi & S. Bachri., 1997) for stratigraphy and lithological identification. Field tools such as a geological compass, GPS device, digital camera, and geological hammer were employed to conduct direct observations of the lithological and geological structural conditions at the study site.

2.2. Sample Preparation

Sample preparation involved direct field observation to identify lithological units and collect morphological data of the land surface, including rock conditions, colour, structure, texture, and mineral content. Observation points were determined based on morphological differences detected from the preliminary DEM analysis and topographic maps. The field data were systematically recorded and converted into descriptive and tabulated formats as part of the geomorphology and lithology characterisation of each landform unit.

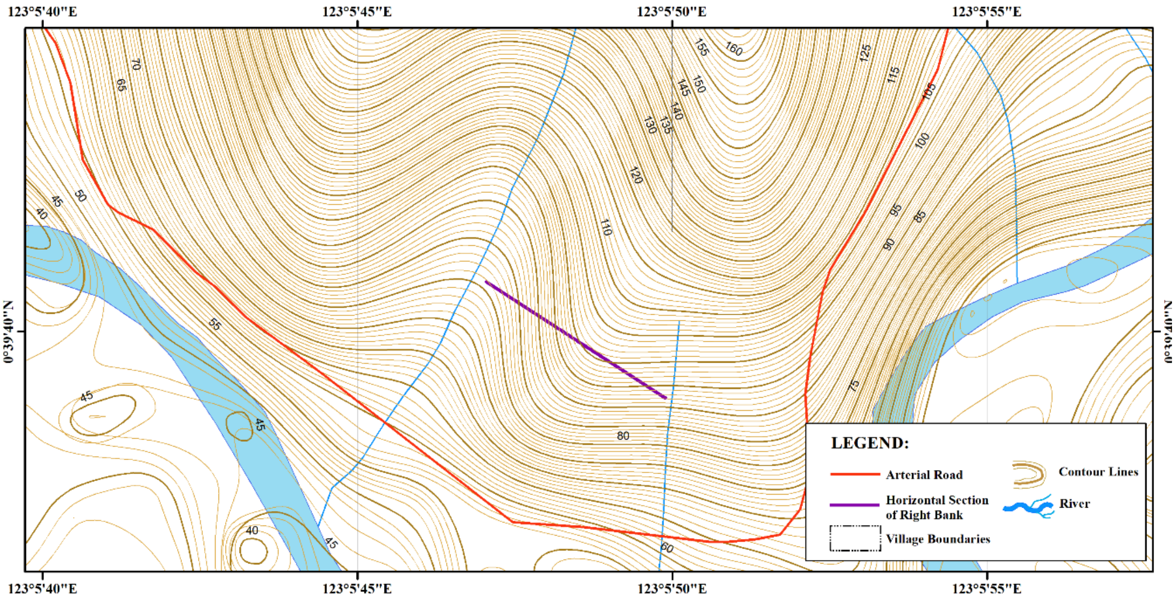

Figure 1. Map of the research location.

2.3. Experimental Set-up

The experimental setup integrated field observations and DEM image interpretation. DEM interpretation was conducted to obtain information on morphometric parameters, such as elevation, slope gradients, and valley forms. The data were processed using spatial analysis software to generate slope class, drainage pattern, and landform classification maps. Although no explicit mathematical formulas were used, the morphometric classification followed Van Zuidam's system (1985) for slope and terrain form classification (Nurwihastuti et al., 2014). Geological structure interpretation, such as discontinuity planes, was performed through field measurements of strike and dip and identification of principal stress orientations ($\sigma 1$, $\sigma 2$, $\sigma 3$).

2.4. Parameters

The parameters measured in this study included key geomorphological elements: morphographic (shape and distribution of landforms), morphometric (elevation, slope gradient, and valley shapes), and morphogenetic (formation processes of landforms). Morphographic data were gathered through visual observations of the surface features and contour patterns. Morphometric data were derived from the DEM and topographic data, classifying slope gradients into seven categories: flat, very gentle, gentle, moderately steep, steep, very steep, and extremely steep. Morphogenetic parameters were interpreted based on endogenous (tectonic activity) and exogenous (erosion, weathering, and sedimentation) processes.

2.5. Statistical Analysis

Statistical analysis was conducted using descriptive quantitative methods based on the spatial classification. Data from the DEM interpretation and field observations were categorised, and the area percentage for each slope class and geomorphological unit was calculated. The results are presented in the form of distribution graphs, thematic maps, and a geomorphological unit column. Inferential statistical tests were not applied because this study was exploratory and qualitative in nature, focusing on spatial geomorphological evaluation. Validation was performed through cross-referencing between remote sensing interpretations and field data to ensure the accuracy and consistency of landform classifications.

3. RESULTS AND DISCUSSION

3.1. Results

Field observations in the right bank area of the Bulango Ulu Dam identified three main lithological units arranged chronologically: diorite, granodiorite, and alluvial deposits. Diorite is the oldest unit, characterised by a phaneritic texture and felsic composition. Granodiorite, which is slightly younger, intrudes into the diorite and features mineralogical compositions such as plagioclase, quartz, and biotite. The youngest lithology, alluvial deposits, consists of unconsolidated sediments from fluvial processes, comprising materials such as rounded boulders, sand, and clay.

Table 1. Characteristics of Lithological Units

Lithology	Texture	Composition	Relative Age	Formation
Diorite	Phaneritic	Plagioclase, quartz, K-feldspar, amphibole	Oldest	Tmb (Bone Diorite)
Granodiorite	Phaneritic	Plagioclase, quartz, K-feldspar, biotite	Younger than diorite	Tmb (Bone Diorite)
Alluvial Deposits	Unconsolidated	Mixed sediments (sand, clay, boulders)	Youngest	Qal (Holocene)

According to Van Zuidam's classification, the study area comprises two morphographic landforms: lowlands and low hills. The lowlands are situated at an elevation of 0–50 m above sea level, whereas the low hills occupy an elevation range of 50–200 m. Low hills dominate the landscape, characterised by a dense contour pattern and sharply incised V-shaped valleys, indicative of significant fluvial incision and tectonic influence. This morphological configuration highlights the geomorphic complexity and terrain variation present within the right bank area of the Bulango Ulu Dam.

The river network analysis revealed a sub-dendritic flow pattern, indicating moderate structural control and variation in the underlying lithology. This pattern emerges when geological structures moderately influence drainage, leading to a more organised yet branching river system. In the right bank zone of the Bulango Ulu Dam, this pattern manifests along the primary river course, reflecting the influence of both geological heterogeneity and slope conditions in directing water flow, as shown in Figure 2.

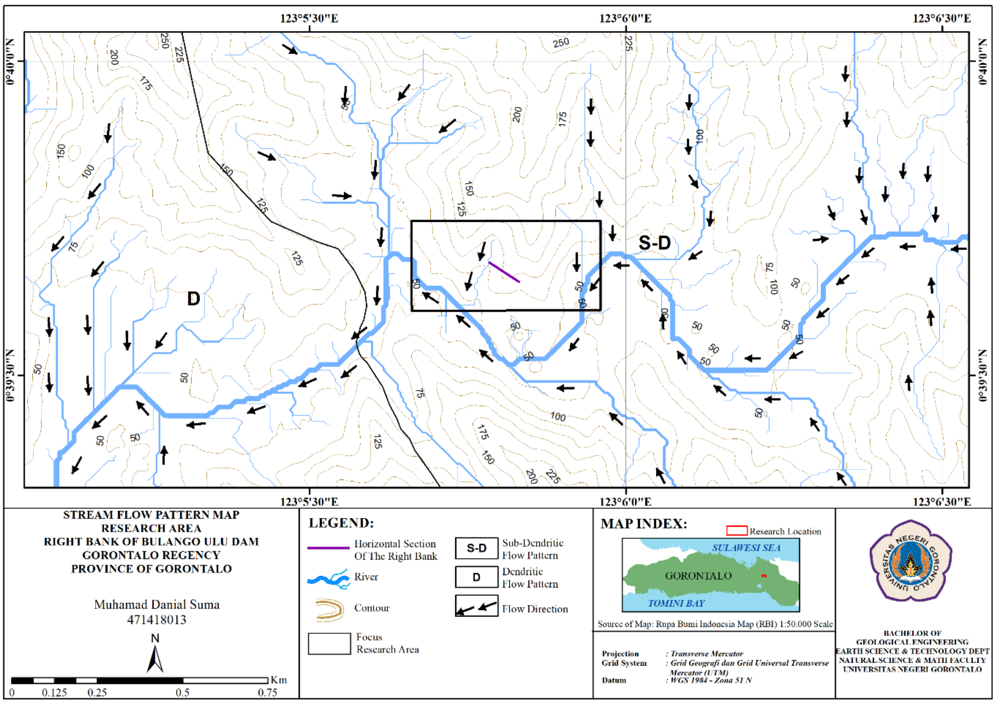

Figure 2. Map of the river flow patterns in the study area.

Slope analysis revealed that the area is dominated by steep slopes (30–70%) and moderately steep slopes (15–30%), which account for 42% and 22% of the area, respectively. Very steep slopes

(70–140%) occupy 14% of the terrain, primarily in the northern region. In contrast, flatter terrains, including flat (0–2%), very gentle (2–7%), and gentle (7–15%) slopes, are only marginally present and scattered across the southeastern and southwestern parts of the area. These variations in slope

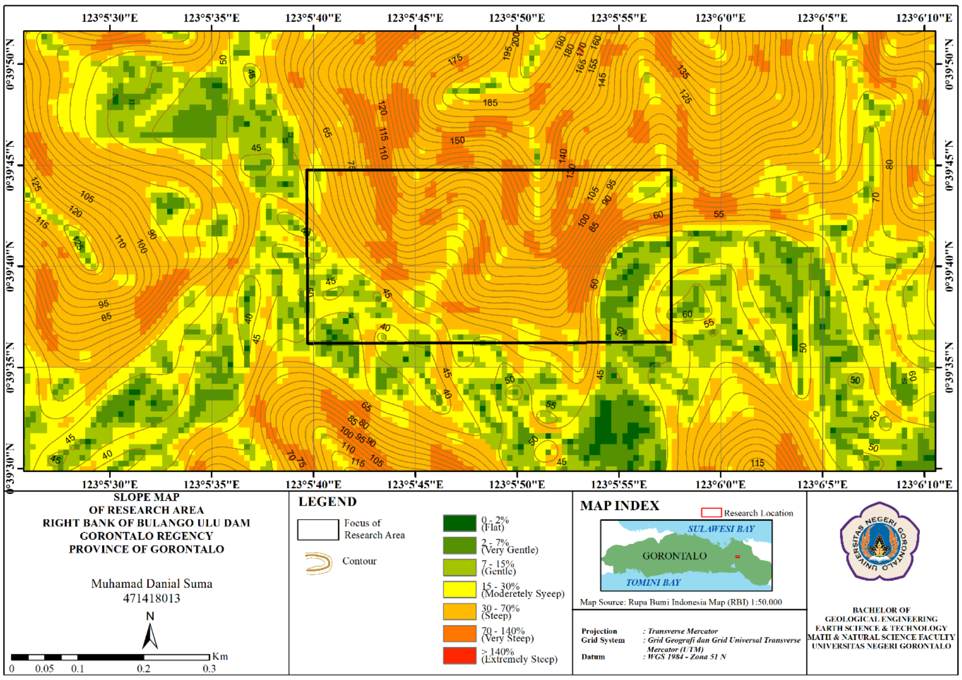

Figure 3. Slope class map of the research area.

gradient significantly influenced both surface runoff and geomorphological stability in the study area, as shown in Figure 3.

The geological structures identified in the study area are primarily characterised by discontinuity planes, including shear and extension fractures, which are predominantly developed within diorite units. These structural features reflect the tectonic deformation history of the area. Stress orientation analysis revealed principal stress directions of σ1 = N292°E, σ2 = N195°E, and σ3 = N027°E, indicating a dominant tectonic stress regime trending in a northwest–southeast direction. This pattern suggests that the region has been subjected to significant tectonic forces, influencing the development and orientation of fractures and contributing to the current structural configuration of the Diorite body.

Two geomorphological units were identified: Structural Low Hills (S1) and Fluvial Plains (F1). S1 covers 78.81% of the area, with elevations ranging from 50 to 200 masl, and is dominated by tectonic and erosional processes. This unit is depicted in Figure 4, which combines two frames: Figure 6a and 4b. Figure 4a shows the visual characteristics of rolling hill relief, whereas Figure 4b presents the slope distribution within the structural low hill unit, illustrating variations influenced by geological structures.

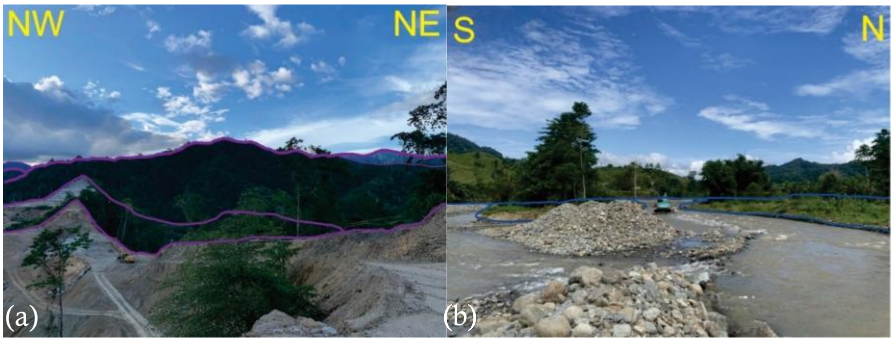

Figure 4. a) Structural Low Hills unit showing hilly relief; b) Slope variation within the unit

F1 accounts for 21.19% of the area and is characterised by flat terrain and sediment deposition from fluvial dynamics. Figure 5 shows the spatial extent of these fluvial plains, highlighting areas shaped by alluvial processes and the presence of loose sedimentary materials. Figure 6 presents a geomorphological column that summarises the composition and relative positioning of the geomorphological units in the study area.

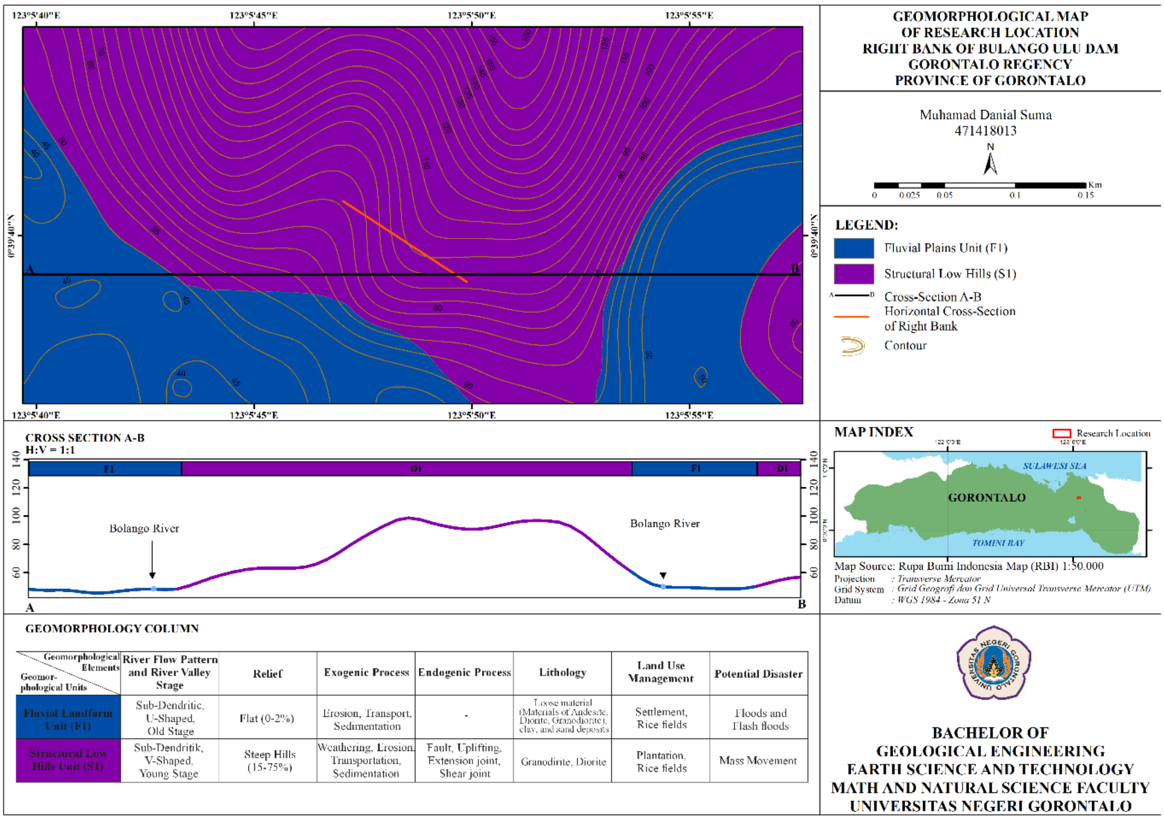

Figure 5. Geomorphological map of the research area.

Geomorphological Elements / Geomorphological Units	River Flow Pattern and River Valley Stage	Relief	Exogenic Process	Endogenic Process	Lithology	Land Use Management	Potential Disaster
Fluvial Landform Unit (F1)	Sub-Dendritic, U-Shaped, Old Stage	Flat (0-2%)	Erosion, Transport, Sedimentation	-	Loose material (Materials of Andesite, Diorite, Granodiorite), clay, and sand deposits	Settlement, Rice fields	Floods and Flash floods
Structural Low Hills Unit (S1)	Sub-Dendritik, V-Shaped, Young Stage	Steep Hills (15-75%)	Weathering, Erosion, Transportation, Sedimentation	Fault, Uplifting, Extension joint, Shear joint	Granodirite, Diorite	Plantation, Rice fields	Mass Movement

Figure 6. a) Structural Low Hills unit showing hilly relief; b) Slope variation within the unit influenced by geological structures..

3.2. Discussion

The geomorphological analysis of the right bank area of the Bulango Ulu Dam revealed a complex interaction between geological formations and surface processes. The identification of three lithological units diorite, granodiorite, and alluvial deposits aligns with the regional stratigraphic framework of the Bone Diorite Formation and confirms prior geological mapping in the area (Vincent et al., 2022; Yang et al., 2023). However, the detailed lithological characterisation performed in this study offers a more refined understanding of the rock composition and weathering profiles specific to the dam's right bank, which is a critical zone for hydrological control infrastructure.

The delineation of morphographic units into lowlands and low hills corresponds well with the geomorphological evolution observed in similar tectonic regions, where uplift and erosion processes shape a gradient of elevation and landform complexity (Hamim et al., 2023). The identified sub-dendritic flow pattern provides key insights into the control exerted by the underlying geological structures, reinforcing the interpretations of stress orientation and discontinuity alignment. This is significant because such structural guidance on hydrological pathways directly affects erosion patterns and sediment transport, particularly in dam catchment areas (Coblentz et al., 2014).

The slope classification revealed a terrain dominated by steep (30–70%) and very steep (70–140%) gradients, which together accounted for approximately 56% of the total area. This geomorphic condition poses a significant challenge in the context of dam engineering because of the increased susceptibility to mass movements, soil creep, and landslides, particularly under the intense rainfall conditions common in Gorontalo Province. These findings reaffirm prior assessments that identified the Bone Bolango region as geologically unstable and susceptible to slope-related hazards (Delgado-Reivan et al., 2023; Sutriyono et al., 2021). Incorporating detailed slope classification into the design and maintenance of dam infrastructure is essential for ensuring long-term operational safety, particularly for spillways, retaining structures, and road access. Moreover, aligning this analysis with morphometric parameters enhances predictive modeling of slope failure risk in tectonically active terrains (Mamonto et al., 2024).

The morphogenetic interpretation further supports the influence of both endogenic and exogenic processes, which together sculpt the present-day landforms. The prevalence of tectonic fractures and high-stress orientations in the diorite unit validate that endogenous forces, particularly tectonic uplift and structural deformation, have actively contributed to terrain elevation and morphological steepness in the region (Jiang et al., 2024; Zaccagnino & Doglioni, 2022). These structural features not only shape the landscape but also influence the hydrological behaviour of the terrain by guiding surface runoff and subsurface water movement. Exogenous factors such as fluvial erosion, high rainfall-induced surface runoff, and sediment deposition were especially pronounced in the fluvial plain unit. These processes have created lithologically diverse, loosely consolidated, and hydrologically active sediment zones, which exhibit higher susceptibility to flooding and material displacement, particularly in lowland agricultural and residential areas (Isdianto et al., 2022; Mamonto et al., 2024). The interaction between geomorphic dynamics and climatic variables underscores the critical importance of integrating geomorphological and meteorological data into regional hazard management and infrastructure design.

The integration of these geomorphological insights reinforces the practical importance of localised terrain analyses in dam planning. Unlike previous studies which addressed general geomorphological patterns, this study provides a precise evaluation of geomorphic units and lithological variability, supporting a more robust infrastructure design, especially for spillway placement and slope reinforcement strategies. In comparison with the geomorphological conditions in similar volcanic and tectonic regions, the findings offer a transferable framework for risk assessment and landscape management in hydro-infrastructure development.

4. CONCLUSIONS

This study concludes that the geomorphology of the right bank area of the Bulango Ulu Dam comprises two primary landform units: Structural Low Hills (S1) and Fluvial Plains (F1), which are shaped by both endogenic tectonic forces and exogenic processes such as erosion and sedimentation. The lithological configuration is dominated by diorite, granodiorite, and unconsolidated alluvial deposits, each contributing distinct physical and mechanical properties to the terrain. Morphometric analysis revealed that steep and very steep slopes cover over half of the area, indicating high susceptibility to slope instability and hydrological hazards.

The presence of sub-dendritic river flow patterns and the alignment of stress fractures support the influence of tectonic activity in controlling geomorphic evolution, whereas climatic data emphasise the role of surface runoff in modifying landforms. These findings underscore the importance of localised geomorphological assessments in the design, risk evaluation, and operational sustainability of dam infrastructure. Future research should incorporate higher-resolution terrain models and long-term hydrometeorological monitoring to refine hazard mitigation strategies and improve the resilience of water infrastructure systems in tectonically active regions.

5. REFERENCES

Apandi, T., & S. Bachri. (1997). *Peta Geologi Lembar Kotamobagu, Sulawesi, Skala 1:250.000*.

Bishta, A. Z., & Qudsi, E. Z. (2023). Implementation of space imageries, remote sensing and GIS techniques in the geological and geomorphological analysis of Wadi Fatima drainage basin, Saudi Arabia. *The Egyptian Journal of Remote Sensing and Space Sciences*, *26*(3), 563–579. https://doi.org/10.1016/J.EJRS.2023.06.006.

Coblentz, D., Pabian, F., Prasad, L., Coblentz, D., Pabian, F., & Prasad, L. (2014). Quantitative Geomorphometrics for Terrain Characterization. *International Journal of Geosciences*, *5*(3), 247–266. https://doi.org/10.4236/IJG.2014.53026.

Delgado-Reivan, X., Paredes-Miranda, C., Loaiza, S., Echeverria, M. D. P. V., Mulas, M., & Jordá-Bordehore, L. (2023). Stability Analysis of Rocky Slopes on the Cuenca–Girón–Pasaje Road, Combining Limit Equilibrium Methods, Kinematics, Empirical Methods, and Photogrammetry. *Remote Sensing 2023, Vol. 15, Page 862*, *15*(3), 862. https://doi.org/10.3390/RS15030862.

Hamim, R. H. P., Arifin, Y. I., & Manyoe, I. N. (2023). Geomorphological Study of the Talumopatu Geothermal Area Gorontalo Regency Gorontalo Province. *E3S Web of Conferences*, *400*, 01005. https://doi.org/10.1051/E3SCONF/202340001005.

Isdianto, A., Adibah, F., Haykal, M. F., Irsyad, M. J., Asyari, I. M., & Supriyadi, S. (2022). Indeks Kerentanan Pesisir Ditinjau Dari Geomorfologi, Elevasi, Dan Ancaman Gelombang Untuk Mewujudkan Ketahanan Ekosistem Pesisir. *Jukung (Jurnal Teknik Lingkungan)*, *8*(2). https://doi.org/10.20527/JUKUNG.V8I2.14912.

Jiang, L., Liu, Y., Li, W., Yuan, S., Yuan, J., Li, S., & Liu, B. (2024). Mesozoic—Cenozoic uplift of Qiman Tagh Range in northern Tibet Plateau, western China. *GSA Bulletin*, *136*(3–4), 1050–1066. https://doi.org/10.1130/B36943.1.

Liao, H. mei, Yang, X. guo, Lu, G. da, Tao, J., & Zhou, J. wen. (2022). A geotechnical index for landslide dam stability assessment. *Geomatics, Natural Hazards and Risk*, *13*(1), 854–876. https://doi.org/10.1080/19475705.2022.2048906.

Mamonto, F. K., Arifin, Y. I., Akase, N., & Manyoe, I. N. (2024). Karakteristik Geomorfologi Daerah Ayuhulalo Dan Sekitarnya Kecamatan Tilamuta, Kabupaten Boalemo. *Journal of Applied Geoscience and Engineering*, *3*(1), 51–61. https://doi.org/10.37905/JAGE.V3I1.26918.

Melo, R. H., Pambudi, M. R., & Niode, A. (2024). Socioeconomic status, lake knowledge, and community participation in the sustainable Lake Limboto management, Gorontalo Regency. *Journal of Water and Land Development*, *60*, 177–182. https://doi.org/10.24425/JWLD.2024.149119.

Mohd, R., Zawawi, M. H., Abas, M. A., Ahmad Mazlan, A. Z., Mohd Arif Zainol, M. R. R., Hassan, N. H., Che Wan Zanial, W. N., Dullah, H., & Kamaruddin, M. A. (2023). Structure Integrity Analysis Using Fluid–Structure Interaction at Hydropower Bottom Outlet Discharge. *Water 2023, Vol. 15, Page 1039*, *15*(6), 1039. https://doi.org/10.3390/W15061039.

Nurwihastuti, D. W., Sartohadi, J., Mardiatno, D., Nehren, U., , R., Nurwihastuti, D. W., Sartohadi, J., Mardiatno, D., Nehren, U., & , R. (2014). Understanding of Earthquake Damage Pattern through Geomorphological Approach: A Case Study of 2006 Earthquake in Bantul, Yogyakarta, Indonesia. *World Journal of Engineering and Technology*, *2*(3), 61–70. https://doi.org/10.4236/WJET.2014.23B010.

Petrone, P., Allocca, V., Fusco, F., Incontri, P., & De Vita, P. (2023). Engineering geological 3D modeling and geotechnical characterization in the framework of technical rules for geotechnical design: the case study of the Nola's logistic plant (southern Italy). *Bulletin of Engineering Geology and the Environment*, *82*(1), https://doi.org/10.1007/s10064-022-03017-y

Ranganai, R. T., Moidaki, M. D., King, J. G., & Bagai, Z. B. (2017). Geophysical and Hydrogeological Groundwater Prospectivity Mapping in the Kraaipan Granite-Greenstone Terrain, Southeast Botswana. *Journal of Water Resource and Protection*, *09*(11), 1270–1298. https://doi.org/10.4236/JWARP.2017.911082.

Sutriyono, Zainuri, A., & Kasim, M. (2021). Identification of Land Movement Safety Factors on the Slope of Lolak Dam. *Journal of Earth Energy Science, Engineering, and Technology*, *4*(3), 2021. https://doi.org/10.25105/JEESET.V4I3.10713.

Vincent, L. T., Eaton, B. C., Leenman, A. S., & Jakob, M. (2022). Secondary Geomorphic Processes and Their Influence on Alluvial Fan Morphology, Channel Behavior and Flood Hazards. *Journal of Geophysical Research: Earth Surface*, *127*(2), e2021JF006371. https://doi.org/10.1029/2021JF006371.

Yang, X., Becker, F., Nykamp, M., Ludwig, B., Doğan, M., & Schütt, B. (2023). Holocene geomorphodynamics of a rural catchment in the Pergamon micro-region (eastern Mediterranean). *Holocene*, *33*(11), 1407–1421. https://doi.org/10.1177/09596836231185837.

Zaccagnino, D., & Doglioni, C. (2022). Earth's gradients as the engine of plate tectonics and earthquakes. *La Rivista Del Nuovo Cimento 2022 45:12*, *45*(12), 801–881. https://doi.org/10.1007/S40766-022-00038-X.

Zingaro, M., La Salandra, M., & Capolongo, D. (2022). New Perspectives of Earth Surface Remote Detection for Hydro-Geomorphological Monitoring of Rivers. *Sustainability 2022, Vol. 14, Page 14093*, *14*(21), 14093. https://doi.org/10.3390/SU142114093.