Revista Cubana de Ciencias Forestales

Volume 13, issue 2; 2025, May-August

liberciencia
EDITORIAL CIENTÍFICA UNIVERSIDAD DE PINAR DEL RÍO
UNIVERSIDAD DE PINAR DEL RÍO
HERMANOS SAÍZ MONTES DE OCA
CFORES
REVISTA CUBANA DE CIENCIAS FORESTALES

ISSN: 2310-3469 RNPS: 2347
Revista CFORES, May-August 2025; 13(2): e877

Original article

Geomorphological characteristics and loss of vegetation cover in the Ayampe River basin

Características geomorfológicas y pérdida de cobertura vegetal en la cuenca del río Ayampe

Características geomorfológicas e perda de cobertura vegetal na bacia do rio Ayampe

Luis Fernando Lucio Villacreses[1*], *Edgar Mauro Caicedo Tapia*[1], *Mónica Virginia Tapia Zúñiga*[1]

[1] State University of Southern Manabí. Jipijapa, Manabí, Ecuador.

* Corresponding author: luis.lucio@unesum.edu.ec

Received: 01/07/2025.
Approved: 07/17/2025.
Published: 07/18/2025.

ABSTRACT

This study aimed to characterize the geomorphology and analyze changes in vegetation cover in the Ayampe River basin, Ecuador, from 1990 to 2022, in order to generate technical inputs for sustainable land management. The methodology combined morphometric relief analysis with geospatial processing of satellite images and the use of vegetation and water indices. Multitemporal analysis tools were applied to evaluate the evolution of six land cover types, and geomorphological parameters such as mean slope, compactness coefficient, time of concentration, and water retention capacity were calculated. The results showed a significant loss of forests (-78.66 km^2) and water bodies (-1.31 km^2), while agricultural land (+80.08 km^2) and anthropogenic zones (+3.80 km^2) increased considerably. Low levels of surface moisture and landscape fragmentation were also identified, especially in agricultural areas. The elongated morphology and steep average slope reflect a basin with limited water storage capacity and high susceptibility to erosion. It is concluded that urgent conservation and restoration actions are required, as well as coordinated territorial planning by the Decentralized Autonomous Governments to ensure a balance between human development and environmental sustainability.

Keywords: watershed management, planning, reforestation

RESUMEN

Este estudio tuvo como objetivo caracterizar la geomorfología y analizar los cambios en la cobertura vegetal de la cuenca del río Ayampe, Ecuador, durante el período comprendido entre 1990 y 2022, con el fin de generar insumos técnicos para la gestión sostenible del territorio. La metodología combinó el análisis morfométrico del relieve con el procesamiento geoespacial de imágenes satelitales y el uso de índices de vegetación y agua. Se aplicaron herramientas de análisis multitemporal para evaluar la evolución de seis tipos de cobertura del suelo y se calcularon parámetros geomorfológicos como pendiente media, coeficiente de compacidad, tiempo de concentración y capacidad de retención hídrica. Los resultados evidenciaron una pérdida significativa de bosques (-78,66 km^2) y cuerpos de agua (-1,31 km^2), mientras que la tierra agropecuaria (+80,08 km^2) y las zonas antrópicas (+3,80 km^2) aumentaron considerablemente. También se identificaron bajos niveles de humedad superficial y fragmentación del paisaje, especialmente en áreas agrícolas. La morfología alargada y la alta pendiente media reflejan una cuenca con escasa capacidad de almacenamiento hídrico y alta susceptibilidad a la erosión. Se concluye que se requieren acciones urgentes de conservación y restauración, así como una planificación territorial articulada por parte de los Gobiernos Autónomos Descentralizados para asegurar el equilibrio entre desarrollo humano y sostenibilidad ambiental.

Palabras clave: gestión de cuencas, ordenamiento; planificación; reforestación

RESUMO

Este estudo teve como objetivo caracterizar a geomorfologia e analisar as mudanças na cobertura vegetal da bacia do rio Ayampe, Equador, entre 1990 e 2022, a fim de gerar subsídios técnicos para a gestão sustentável do território. A metodologia combinou a análise morfométrica do relevo com o processamento geoespacial de imagens de satélite e o uso de índices de vegetação e água. Ferramentas de análise multitemporal foram aplicadas para avaliar a evolução de seis tipos de cobertura do solo, e parâmetros geomorfológicos como inclinação média, coeficiente de compacidade, tempo de concentração e capacidade de retenção hídrica foram calculados. Os resultados revelaram uma perda significativa de florestas (-78,66 km²) e corpos d'água (-1,31 km²), enquanto as terras agropecuárias (+80,08 km²) e as zonas antrópicas (+3,80 km²) aumentaram consideravelmente. Também foram identificados baixos níveis de umidade superficial e fragmentação da paisagem, especialmente em áreas agrícolas. A morfologia alongada e a alta inclinação média refletem uma bacia com baixa capacidade de armazenamento hídrico e alta suscetibilidade à erosão. Conclui-se que são necessárias ações urgentes de conservação e restauração, bem como um planejamento territorial articulado pelos Governos Autônomos Descentralizados, para garantir o equilíbrio entre o desenvolvimento humano e a sustentabilidade ambiental.

Palavras-chave: gestão de bacias hidrográficas; ordenamento; planejamento; reforestación

INTRODUCTION

From a forestry engineering perspective, understanding the geomorphological characteristics of a watershed is essential for diagnosing relief behavior, erosion processes, natural drainage, and the spatial distribution of water. This knowledge can guide concrete actions in soil conservation, watershed management, and sustainable territorial planning, especially in areas where intense human activity and active geodynamics converge.

Geomorphology, by offering a framework for understanding how the landscape is structured and transformed, has gained increasing relevance in studies applied to environmental management. In this context, tools such as morphometric analysis, the use of digital terrain models, and geospatial interpretation make it possible to characterize relief units and predict their influence on surface water flows. From an integrated perspective, these approaches have been used in various regions of Latin America to diagnose watersheds subjected to natural and anthropogenic pressures, revealing the usefulness of this information for risk reduction, land use planning, and designing mitigation strategies.

Research conducted in Mexico, Argentina, Colombia, Chile, and Peru demonstrates that geomorphological characterization allows for the identification of key relationships between relief, land use, and hydrological processes. Studies such as those by Mora *et al.* (2016), Ferreras-Munguía (2003), Asprilla-Mosquera (2020), and Alencar da Silva *et al.* (2021) have shown how morphometric and multitemporal analysis contributes to better land management in contexts with high topographic variability and increasing human pressure. In Ecuador, recent work also highlights the importance of incorporating a geomorphological approach into infrastructure planning and micro-watershed management in coastal and Amazonian regions (Brito *et al.*, 2021; Guerrero *et al.*, 2023).

In this context, the Ayampe River basin, located in the province of Manabí, represents a critical space due to its unique physiographic conditions and the increasing anthropogenic pressure associated with tourism, vegetation cover change, and climate variability. However, the terrain in this area remains poorly characterized, which hampers the implementation of technical and regulatory measures for comprehensive land management (GAD Ayampe, 2021; GAD Puerto López, 2020).

This study aims to characterize the geomorphology of the Ayampe River basin through geospatial analysis and morphometric parameters, in order to generate technical inputs that guide integrated land management and the conservation of natural resources in this coastal area of Ecuador.

MATERIALS AND METHODS

Study area

The Ayampe River basin has its centroid at coordinates 536,748.09 East and 9814,774.81 North. It covers a total area of 711.08 km², distributed between the cantons of Jipijapa (285.06 km²), Puerto López (182.32 km²), and Paján (2.37 km²) in Manabí, and the province of Santa Elena (241.33 km²). The basin has a varied topography, including plains, hills, and mountainous areas, which favors a diversity of microclimates and ecosystems. The climate is tropical, with average temperatures of 25 °C (77 °F). ° C and a rainy season that extends from January to May (Cauti, 2022). In ecological terms, it is part of a transition zone between dry forest and tropical rainforest, classified by the Ecuadorian Ministry of the Environment (2013) as a region of high biodiversity and environmental vulnerability. Figure 1 shows the geographical location of Ecuador and the Ayampe River basin.

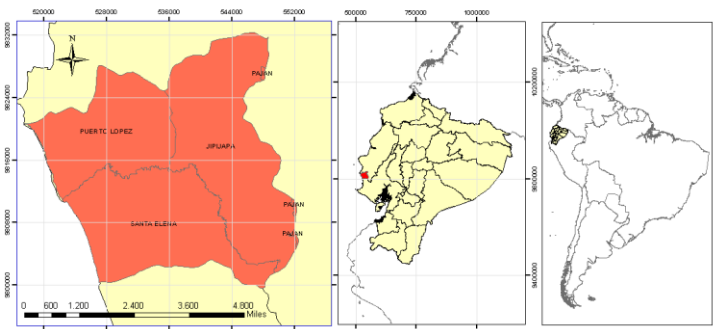


Figure 1. *- Spatial location of the Ayampe River basin*

The vegetation cover in the basin includes native species such as *Ceiba trischistandra* , *Tabebuia chrysantha* and *Bursera graveolens,* which have significant ecological, cultural and economic value for local communities (GAD Ayampe, 2011). Part of the basin has been incorporated into the National System of Protected Areas, due to its role in providing ecosystem services such as climate regulation, water purification and soil conservation (Ministry of Environment of Ecuador, 2008). However, the expansion of agricultural and anthropogenic zones has progressively altered the natural landscape and the loss of forest cover in more than 80 km² (Mora *et al*., 2016; GAD Ayampe, 2021).

The variation in temperature and precipitation over the last 40 years is shown in Figure 2. It can be seen that in 1983 the annual precipitation was extremely high and represented a climatic anomaly, while in 1985, on the contrary, very low annual precipitation was observed.

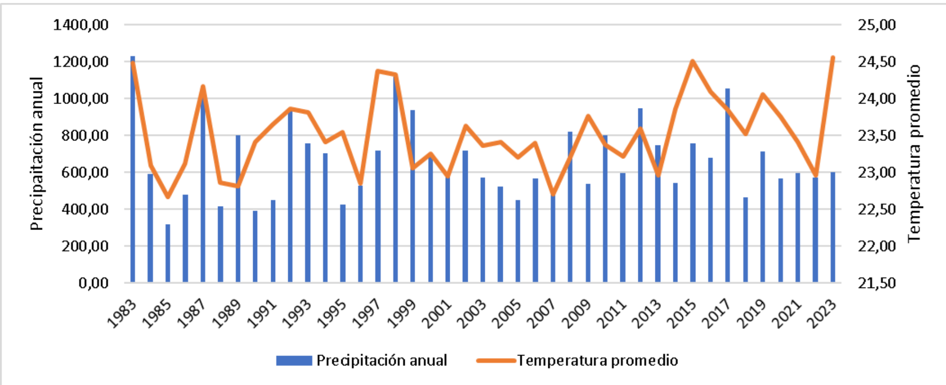


Figure 2. *- Temperature variation between 1983 – 2023*

Source: Harris, I., Osborn, TJ, Jones, P. & Lister, DH Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset. Sci Data 7, 109 (2020). *https://rdcu.be/b3nUI*

Procedure developed

The analysis of the geomorphological characteristics and land cover evolution in the Ayampe River basin was carried out using an integrated Geographic Information Systems (GIS) and multitemporal statistical analysis approach, using QGIS v3.40.3 and RStudio v4.2.2 as the primary working environments. The procedure developed is presented below:

1. Delimitation and spatial organization of the watershed: A digital elevation model (DEM) and QGIS hydrological tools were used to delimit the Ayampe River watershed. The region of interest was defined using vector clipping, integrating administrative layers of cantons, parishes, and micro-watersheds. This procedure allowed for the establishment of natural runoff limits and facilitated the generation of cartographic analysis products (Cauti, 2022; Brito *et al.*, 2021).
2. Land cover classification: To assess land use changes, Landsat images from 1990 and 2022 were used. Geometric correction, reprojection, and clipping were performed based on the watershed. In QGIS, six land cover types were classified: forest, agricultural land, shrub and herbaceous vegetation, anthropogenic zones, water bodies, and other lands, following criteria similar to those employed by Guerrero et al. (2023) and Mora *et al.* (2016). The dissolve and intersection tools were applied to unify and analyze thematic polygons, facilitating multitemporal comparison.
3. Morphometric and geomorphological analysis: The DEM was also used to derive key morphometric parameters such as mean gradient, main channel length, drainage density, sinuosity, and time of concentration, using formulas proposed by Strahler (1952), Schumm (1956), and Gravelius and Horton (1945). These calculations allowed for the interpretation of the morphodynamic evolution of the basin, as well as its susceptibility to extreme erosion and hydrological processes. The calculated parameters include:
    a. Basic parameters: surface area, perimeter, minimum and maximum elevations, length of the main channel.
    b. Shape relationships: compactness coefficient, elongation ratio, circularity ratio, shape factor.
    c. Drainage parameters: drainage density, sinuosity, number of streams, stream order, average channel length.
    d. Concentration times: applying formulas from Kirpich, USDA, Témez, Giandotti, Bransby-Williams, among others.
    e. Other indices: robustness index, massiveness index, channel gradient, orographic index.
4. Spectral indices calculation and statistical analysis: The SAVI (Soil Adjusted Vegetation Index) and NDWI (Normalized Difference Water Index) indices were

calculated using raster expressions in QGIS, using the necessary spectral bands extracted from Landsat. Subsequently, the values were exported and processed in RStudio, through exploratory data analysis with the raster, dplyr and ggplot2 packages. This procedure was based on similar methodologies applied by Alencar da Silva *et al.* (2021) and Pabón (2022) to interpret vegetation cover dynamics and water availability.

5. The NDVI (Normalized Difference Vegetation Index), EVI (Enhanced Vegetation Index), SAVI (Soil Adjusted Vegetation Index) and NDWI (Normalized Difference Water Index) indices were applied from the corresponding spectral bands of Landsat 8 images. The indices were generated using raster operations in QGIS and validated by calculations in RStudio v4.2.2, using the raster, terra, ggplot2 and factoextra packages. The procedure consisted of:
    a. Import the bands (B2, B3, B4, and B5) and construct false-color composites (B4-B3-B2 and B5-B4-B3) for preliminary visualization and interpretation. Vegetation and water indices were then calculated using rasterized algebraic expressions. Graphical analyses such as histograms, thematic maps, and comparisons between raw values and specific thresholds (e.g., NDVI < 0.4) were performed to identify levels of water stress, sparse vegetation cover, and areas of potential environmental degradation.
    b. Furthermore, the SAVI index corrected for the influence of bare soil, while the NDWI was used to assess surface moisture and potential water bodies. The combined use of NDVI, EVI, SAVI, and NDWI provided a more accurate view of the ecological status of the watershed, following methodologies similar to those employed by Alencar da Silva *et al.* (2021) and Pabón (2022).
6. Validation and synthesis of results: The results obtained were compared with previous local studies, technical reports from the Ecuadorian Ministry of the Environment (2008, 2013), and the GADs of Ayampe and Puerto López (2020, 2021). This triangulation allowed for the validation of the detected changes in land cover and morphology, strengthening inferences about degradation, risks, and restoration potential in the watershed.

RESULTS AND DISCUSSION

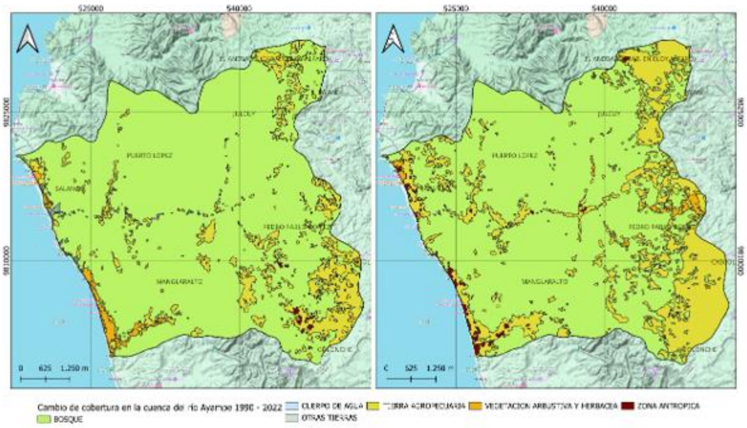
Land use change in the Ayampe River basin

Comparative analysis of land cover in the Ayampe River basin between 1990 and 2022 reveals substantial transformations in land use. According to the data presented in Table 1, there is a considerable loss of forests (-78.66 km²), water bodies (-1.31 km²), shrub and herbaceous vegetation (-2.24 km²), as well as a reduction in other lands (-1.67 km²). In contrast, there is a pronounced increase in the area used for agricultural activities (+80.08 km²) and, to a lesser extent, an increase in anthropogenic areas (+3.80 km²), which points to a process of conversion of the natural landscape to agricultural, livestock, and urban uses (Table 1).

Table 1. *- Variation in coverage between 1990 and 2022*

Coverage	Year 1990	Year 2022	Variation
Body of water	1.53	0.22	-1.31
Agricultural land	85.5	165.58	80.08
Forest	611.08	532.42	-78.66
Shrubby and herbaceous vegetation	9.84	7.6	-2.24
Other lands	1.8	0.13	-1.67
	1.33	5.13	3.8
Total	711.08	711.08	0.00

These results are consistent with those pointed out by Mora *et al.* (2016), who warn that the accelerated transformation of the landscape in the absence of effective territorial planning generates imbalances that negatively impact the quality of water resources and the geomorphological stability of the basin. Furthermore, the reduction of water bodies and the loss of shrub vegetation reinforce the argument made by the Ecuadorian Ministry of the Environment (2013), that anthropogenic pressure on riparian ecosystems affects surface water availability, reduces local biodiversity, and alters hydrological cycles. Although these dynamics are common in many basins along the Ecuadorian coast, the magnitude of forest loss in Ayampe is particularly alarming, leading us to fully agree with Pabón (2022), who argues that these processes must be addressed through urgent ecological restoration and environmental zoning policies. Figure 3 shows the increase in agricultural area in the Ayampe River basin between 1990 and 2022 and, consequently, the displacement of vegetation cover.



Cobertura del suelo año 1990. Cobertura del suelo año 2022

Figure 3. *- Changes in land cover in the Ayampe River basin*

The growth of anthropogenic areas is moderate compared to agricultural expansion and indicates an incipient process of urbanization that could intensify in the coming years. This phenomenon has been widely discussed by García (2022), who argues that Decentralized Autonomous Governments have a key responsibility in land management and controlling urban growth in environmentally fragile territories. In this sense, we agree with his argument that local planning should integrate multitemporal coverage analyses as fundamental inputs to guide development toward sustainability scenarios.

Taken together, these land cover changes confirm the need to adopt a comprehensive watershed management approach that combines the conservation of forest remnants, the restoration of strategic ecosystems, and land use regulation based on technical and ecological criteria. The evidence presented here provides a solid basis for territorial and environmental authorities to prioritize interventions that halt the loss of vegetation cover and ensure ecosystem resilience to human pressure and climate change.

Morphometric characterization of the basin

The elongated morphology of the Ayampe River basin, reflected by a compactness coefficient of 1.37 and a circularity ratio of 0.53, together with an average slope of 30.94 %, indicates high runoff capacity and limited water retention. This configuration favors rapid flow concentration and erosion, which has been documented in similar basins by Alencar da Silva *et al.* (2021) and Guerrero *et al. (2023). The hypsometric curve* (Figure 4) shows an intermediate pattern of geomorphological maturation, with evidence of significant erosion, but without yet reaching a state of morphodynamic equilibrium. This profile suggests that relief shaping processes remain active, reinforcing the need to apply soil conservation measures and control structures on medium and high slopes, as recommended by Pabón (2022) in basins with active erosive dynamics on the Ecuadorian coast.

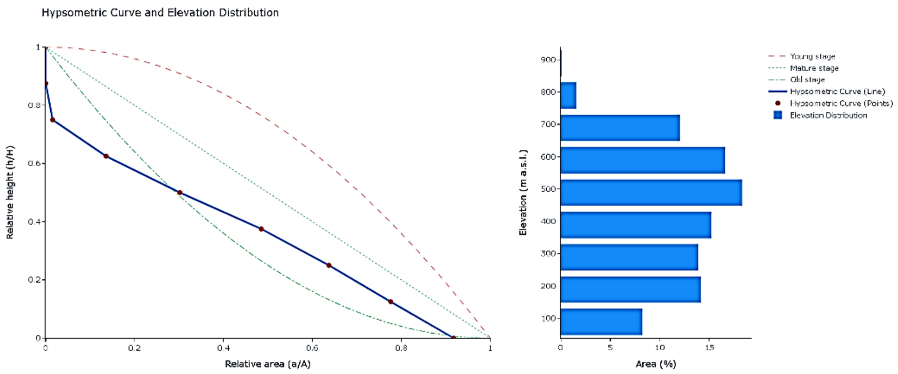


Figure 4. *- Hypsometric curve and elevations in the Ayampe River basin*

The highest concentration of watershed area is found between 400 and 600 meters above sea level, indicating a predominance of intermediate elevations characteristic of mountainous terrain with moderate slopes. This altitudinal distribution is key in the analysis of erosion and vulnerability, since these areas often present higher risks of soil instability and landslides, especially under conditions of intensive use or loss of vegetation cover. In recent studies, Guerrero *et al.* (2023) highlight that areas in this altitudinal range on the Manabí coast are highly susceptible to erosion processes and should therefore be prioritized in conservation strategies and territorial planning.

The rapid response to precipitation events is reflected in the time of concentration estimated by the Kirpich method (5.7 hours), which reinforces the hypothesis of a basin with accelerated runoff dynamics. This condition has also been documented by Asprilla (2020) in their multitemporal analysis of the Quito River basin in Colombia, and by Guerrero *et al.* (2021) in micro-basins on the Manabi coast, where they found that steep slopes and loss of vegetation cover intensify the hydrological response. Unlike these studies, where mining activities or urbanization were the main drivers of change, in Ayampe the transformation of the landscape has been dominated by agricultural expansion.

The storage coefficient (0.29) and infiltration rate (0.34) values indicate a limited water retention capacity, which is consistent with what was observed in the Salado Bajo basin in Chile (Alencar da Silva et al., 2021), where this low retention is associated with deficiencies in vegetation cover and a degraded soil structure. On this point, we partially disagree with the authors in that these conditions derive exclusively from edaphic characteristics. In the case of Ayampe, land-use patterns and the lack of conservation structures also have a significant influence, reinforcing the need to incorporate a more comprehensive approach to the territorial management of the basin.

The basin's drainage network, with a density of 0.68 km/km² and a main channel sinuosity of 1.42, suggests a moderately efficient system, but without sufficient natural buffers. In line with this, Guerrero *et al.* (2021) argue that, in Ecuadorian coastal basins with similar conditions, sparse riparian vegetation and a lack of retention infrastructure lead to concentrated runoff, which increases the risk of extreme events. On this point, we fully agree with these findings, but in the case of Ayampe, there is still a window of opportunity to implement corrective measures before reaching a critical point of degradation.

Given this scenario, the results support the urgent need to implement water management strategies adapted to the morphology of the basin. The dams in ravines with gradients greater than 30 % and infiltration trenches in agricultural areas represent viable, low-cost options that could significantly reduce runoff velocity, facilitate water recharge, and improve soil stability (MAE, 2013; Pab ó n, 2022). These actions, already recommended by various authors in similar contexts, should be integrated into local planning with an ecosystem approach.

Finally, we agree with García (2022) that decentralized autonomous governments play a key role in implementing policies based on scientific evidence. The morphometric information discussed here constitutes a valuable technical tool for guiding land-use planning processes, delimiting risk zones, and prioritizing interventions in critical areas.

Integrated watershed management, in this sense, should be understood not only as a technical action but also as an institutional commitment to sustainable development and environmental resilience.

Spectral indices of the Ayampe River basin

Figure 5 shows moderate vegetation cover in the Ayampe River basin, with SAVI values concentrated between 0.3 and 0.6 and a peak close to 0.5, indicating the presence of vegetation in an intermediate state, combining conserved areas with degraded sectors. This pattern aligns with that reported by Peña et al. (2019) and Álvarez and Ludeña (2021), who highlight the usefulness of SAVI to identify vegetation mosaics in landscapes fragmented by agricultural expansion. The spatial distribution shows that the best-conserved areas are located in the upper reaches, while the areas with the lowest index coincide with agricultural regions or those in the process of transformation. These results reflect a dynamic of increasing anthropogenic pressure, which reinforces the need to apply differentiated conservation and restoration strategies according to the state of vegetation cover.

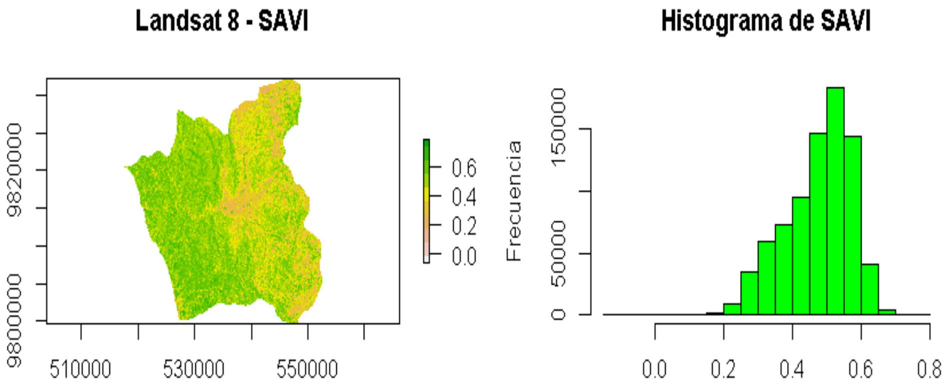


Figure 5. *- Soil Adjusted Vegetation Index (SAVI)*

Figure 6 shows the NDWI in the Ayampe River basin, with mostly negative values between -0.4 and -0.2, and a peak at -0.3, which shows low surface humidity in much of the territory. This condition suggests a scarce presence of water bodies and limited water retention, possibly due to the loss of vegetation cover and intensive land use. Similar results have been reported by Cauti (2022) in basins with anthropogenic pressure and degraded land cover. In this context, the NDWI allows identifying critical areas where actions such as rainwater harvesting, riparian restoration, and reforestation with native species adapted to dry conditions are required.

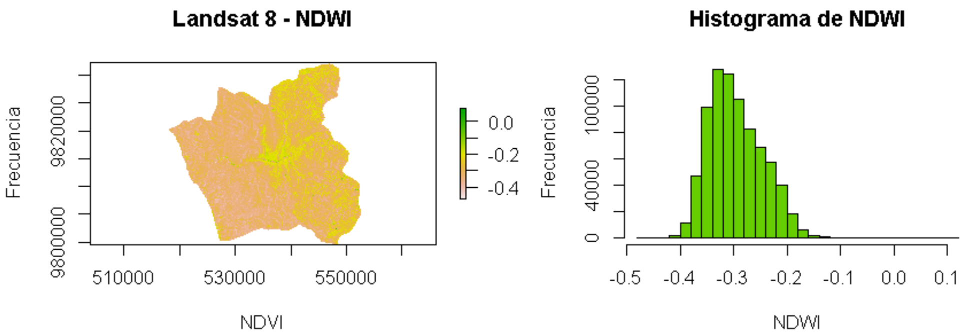


Figure 6. *- Normalized Difference Water Index (NDWI)*

CONCLUSIONS

This study demonstrated that the Ayampe River basin has a geomorphological configuration with a high average gradient, elongated morphology, and low water storage capacity, making it particularly vulnerable to intense runoff, erosion, and potential extreme events such as flooding. These parameters, together with the hypsometric curve obtained, place the basin in a phase of intermediate geomorphological maturation, where relief shaping processes are still active.

Multitemporal land cover analyses revealed a considerable loss of natural vegetation over the past three decades, accompanied by a significant increase in agricultural use. This transformation has reduced protective soil cover and negatively impacted surface moisture, as confirmed by the NDWI and SAVI spectral indices. Areas with low values for these indices coincide with agricultural and degraded areas, reinforcing the need to focus restoration efforts on these sectors.

From a management perspective, the results indicate that interventions such as levees, infiltration ditches, riparian corridor restoration, and reforestation systems with native species should be prioritized. These measures would contribute to reducing the basin's vulnerability and improving water regulation. Furthermore, the Decentralized Autonomous Governments (GAD) should integrate spatial and geomorphological analysis into their territorial planning instruments and promote joint governance, given that the basin spans several cantons and provinces.

Finally, this research demonstrates the usefulness of integrating GIS tools, morphometric analysis, and spectral evaluation as a technical basis for environmental decision-making. Future research suggests incorporating dynamic hydrological models and climate change scenario assessments to strengthen adaptation and sustainable management strategies in coastal watersheds with similar characteristics.

REFERENCES

ALENCAR DA SILVA ALVES, KM, PARODI DÁVILA, MC, ZIMMERMANN, ED, RODRIGUES DE LIRA, D., & DE ARAUJO MONTEIRO, K. 2021. Morphometric characterization of the Salado Bajo basin, Atacama Region, Chile. *Geographic Research* [online], ISSN 0719-5370. DOI 0.5354/0719-5370.2021.64574. Available at: https://www.researchgate.net/publication/357550929_Caracterizacion_morfometrica_de_la_cuenca_del_Salado_Bajo_Region_de_Atacama_Chile.

ÁLVAREZ, J., and LUDEÑA, P., 2021. Assessment of vegetation cover using spectral indices in degraded basins of the Ecuadorian coast. *Journal of Environmental Sciences* [online], vol. 45, no. 1, pp. 72-85. Available at: https://doi.org/10.1234/rca.2021.45.1.072.

Campo de Ferreras, A.M. and Munguía, S.I., 2003. Hydro-geomorphological characteristics of the Pescado Castigado Stream basin, Buenos Aires, Argentina. *Geography Papers* [online], no. 38, pp. 137–150. [Accessed July 18, 2025]. ISSN 1989-4627. Available at: https://dialnet.unirioja.es/servlet/articulo?codigo=919064.

CAUTI QUISPE, JH, 2022. *Environmental zoning through the analysis of the physical and geomorphological characteristics of the Cachi River basin, Huamanga province, Ayacucho - 2022* [online]. Sl: Universidad Continental. [accessed: 18 July 2025].

Available at: https://repositorio.continental.edu.pe/handle/20.500.12394/13383.

GAD AYAMPE, 2011. *Biodiversity and Land Use Report for the Ayampe River Basin. Puerto López, Ecuador: Decentralized Autonomous Government of Ayampe.* 2011. SL: GAD Ayampe.

GAD AYAMPE., 2021. *Report on the relief and water resources management of the Ayampe River basin.* 2021. Sl: GAD Ayampe.

GAD PUERTO LÓPEZ, 2020. *Flood Vulnerability Report. Puerto López, Ecuador: Decentralized Autonomous Government of Puerto López.* 2020. SL: GAD Puerto López.

GARCÍA MALDONADO, ME, 2022. Environmental Competencies and Territorial Planning in Ecuador's GADs. *Ecuadorian Journal of Governance* , vol. 4, no. 2, pp. 35-52.

GUERRERO, EEB, 2023. Erosion processes in coastal basins of Ecuador: Morphometric assessment and management. *Journal of Geography and Territory* , vol. 8, no. 1, pp. 45-60.

GUERRERO, EEB, HIDROVO, EXV, MATA, WJM, MENÉNDEZ, EAM and ZAMBRANO, XHV, 2021. Geomorphological and anthropic controls on differentiated extreme hydrological responses of micro-basins on the Manabi coast (Ecuador). *Journal of Hydrology* , vol. 29, no. 3, pp. 234-248.

MORA, L., BONIFAZ, R., & LÓPEZ-MARTÍNEZ, R. 2016. Geomorphological units of the Comitán River basin, Montebello Lakes, Chiapas, Mexico. *Bulletin of the Mexican Geological Society* [online], vol. 68, no. 3, pp. 377-394. [accessed: 18 July 2025]. ISSN 1405-3322, Available at: https://www.redalyc.org/articulo.oa?id=94347938001.

PEÑA, DF, ÁLVAREZ, J. and MOLINA, R., 2019. Application of spectral indices in vegetation cover monitoring in semi-arid watersheds. *GeoAmbiente* [online], vol. 11, no. 2, pp. 110-124. Available at:

https://doi.org/10.5678/geoamb.2019.11.2.110.

Conflicts of interest:

The authors declare no conflicts of interest.

Authors' contributions:

The authors have participated in the writing of the work and analysis of the documents.