

Hydrometeorological anomalies and impacts on the infrastructure of Huánuco: analysis of the first quarter, 2025

Anomalías hidrometeorológicas e impactos en la infraestructura de Huánuco: análisis del primer trimestre, 2025

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Received: 15-10-25

Approved: 18-12-25

Published: 15-01-26

ABSTRACT

During the first quarter of 2025 and their impact on the infrastructure of Huánuco. Daily precipitation series (2015–2025) and flow series (2020–2025) from SENAMHI and ANA were used, applying the Standardized Precipitation Index (SPI) and the Z-score method to detect anomalies. The results show an atypical hydrological behavior characterized by significant positive anomalies in flow, with values exceeding 2.5 standard deviations in March 2025, while precipitation exhibited high interseasonal variability, with intense events mainly concentrated in February. The hydrological stations Higuera, San Rafael, and Taruca recorded flow increases of up to 80% compared to their historical averages. This decoupling between accumulated precipitation and the hydrological response suggests the influence of factors such as prior soil saturation, accumulated runoff, and contributions from the upper zones. These conditions generated overflows, mudslides, and floods that affected road infrastructure, housing, and agricultural areas in Huánuco, Ambo, and Santa María del Valle. It is concluded that the 2025 event responds to a non-stationary hydrological regime, which highlights the need to update hydraulic design criteria and incorporate risk management packages based on the changing climatic conditions of the Huánuco region. This research constitutes a fundamental technical basis for disaster risk management in the region.

Keywords: hydrometeorological anomalies, flow, SPI index, climatic variability, risk management.

RESUMEN

Este estudio analiza las anomalías de caudal y de precipitación en la cuenca media del río Huallaga durante el primer trimestre de 2025 y su impacto en la infraestructura de Huánuco. Se utilizaron series diarias de precipitación (2015-2025) y de caudal (2020-2025) provenientes del SENAMHI y de la ANA, aplicando el índice de precipitación estandarizado (SPI) y el método de Z-score para detectar anomalías. Los resultados evidencian un comportamiento hidrológico atípico caracterizado por anomalías positivas significativas en el caudal, con valores superiores a 2.5 desviaciones estándar en marzo de 2025, mientras que la precipitación presentó alta variabilidad interestacional, con eventos intensos concentrados principalmente en febrero. Las estaciones hidrológicas Higuera, San Rafael y Taruca registraron incrementos de caudal de hasta un 80 % respecto a sus promedios históricos. Este desacople entre la precipitación acumulada y la respuesta hidrológica sugiere la influencia de factores como la saturación previa del suelo, la escorrentía acumulada y los aportes de las zonas altas. Estas condiciones generaron desbordes, huacos e inundaciones que afectaron la infraestructura vial, las viviendas y las áreas agrícolas en Huánuco, Ambo y Santa María del Valle. Se concluye que el evento de 2025 responde a un régimen hidrológico no estacionario, lo que evidencia la necesidad de actualizar los criterios de diseño hidráulico e incorporar paquetes de gestión de riesgos basados en las condiciones climáticas cambiantes de la región de Huánuco. Esta investigación constituye una base técnica fundamental para la gestión del riesgo de desastres en la región.

Palabras clave: anomalías hidrometeorológicas, caudal, índice SPI, variabilidad climática, gestión del riesgo.

Cite as: Aguirre-Quispe, K., Díaz-Quispe, N., De la Cruz-Guillén, A., Villaran-Rojas, V., and Romero-Estacio, J. (2026). Hydrometeorological anomalies and impacts on the infrastructure of Huánuco: analysis of the first quarter, 2025. *Revista Peruana de Ingeniería, Arquitectura y Medio Ambiente*, 3(1), 23-36. <https://doi.org/10.37711/repiama.2026.3.1.3>



Introduction

At a global scale, studies indicate that increasing extreme precipitation associated with climate change is intensifying the risk of urban flooding, affecting infrastructure and human settlements (Dharmarathne et al., 2024). Furthermore, in areas such as the Andes, urban expansion toward riverbanks and low-lying areas increases the risk of extreme hydrological events due to the lack of urban planning, which aggravates this vulnerability by reducing soil infiltration and obstructing drainage systems, intensifying the impact of rainfall and flooding in cities (Fan et al., 2025). In view of this, analyses such as the identification of anomalies in the hydrological regime acquire particular relevance. Likewise, climate change and urbanization alter rainfall and, consequently, the increase in river discharge, which causes hydrological anomalies when historical ranges are exceeded (Sui et al., 2024).

Hydrological anomalies are deviations from historical climatic and hydrological patterns detected through statistical analyses that make it possible to identify events such as flooding or prolonged droughts (Alvarez-Garretón et al., 2021). In regions such as the Andes, seasonal variations in precipitation have been evaluated to understand how extreme rainfall events alter the soil water balance and affect aquifer recharge (Nasta et al., 2020). According to Grimm and Tedeschi (2009), abrupt variations in the rainfall regime, influenced by anomalies, can cause flooding with direct consequences for urban infrastructure, such as buildings, roads, bridges, and other human constructions. Such events generate direct impacts on urban infrastructure and on land adjacent to riverbanks (Lopardo et al., 2023).

Anomalies in precipitation and river discharge have been shown to have critical effects on urban infrastructure in multiple contexts worldwide. Afroz et al. (2021) demonstrated that intense and concentrated rainfall causes sudden flooding, since monthly averages do not reflect the runoff peaks that affect drainage systems and infrastructure. In another study, Yang et al. (2024) analyzed how compact urban development intensifies precipitation anomalies, causing extreme rainfall to occur more frequently than in nearby rural areas. In addition, Walczykiewicz and Skonieczna (2020) demonstrated that intense rainfall causes urban flooding, aggravated by soil sealing and topography, which increases the vulnerability of infrastructure and housing. These studies provide solid evidence that hydrological anomalies are not only unpredictable but can also cause considerable structural damage.

The city of Huánuco has historically presented a high vulnerability to river flooding, which causes recurrent overflows, according to media reports (Tu Diario Huánuco, 2025). According to hydrological warnings issued by the National Meteorology and Hydrology Service of Peru (SENAMHI) and the National Institute of Civil Defense (INDECI), during February and March 2025, the Huallaga River recorded significant increases in its discharge, which caused overflows in various areas (León, 2025). Likewise, the Regional Emergency Operations Center (COER) reported that, due to the intense rainfall recorded for approximately eight hours on the night of March 5, six districts were affected by the overflow of the Huallaga River: San Rafael, Ambo, Tomayquichua, Conchamarca, Pillco Marca, and Amarilis (Espinoza, 2025). In addition, the overflow caused damage to at least four hundred hectares of crops and nineteen educational institutions, demonstrating the magnitude of the impact on both the productive and educational infrastructure of the region (Redacción RPP, 2025). The recurrence of these phenomena highlights the need to analyze these climatic phenomena and the effects of increases in the Huallaga River's discharge, with the aim of generating technical information that contributes to better risk management and sustainable development in the region.

The present study aims to analyze discharge and precipitation anomalies in the Huallaga River, focusing on their impacts on infrastructure and land adjacent to the city of Huánuco during the first quarter of 2025. Likewise, critical points where the increase in discharge has caused damage to buildings and roads will be identified, in order to determine the relationship between climatic conditions and the behavior of the river. In this way, the study seeks to identify the irregularities of this particular event that caused landslides and soil displacement in vulnerable areas. Through this work, the study is expected to provide key information for water risk management,

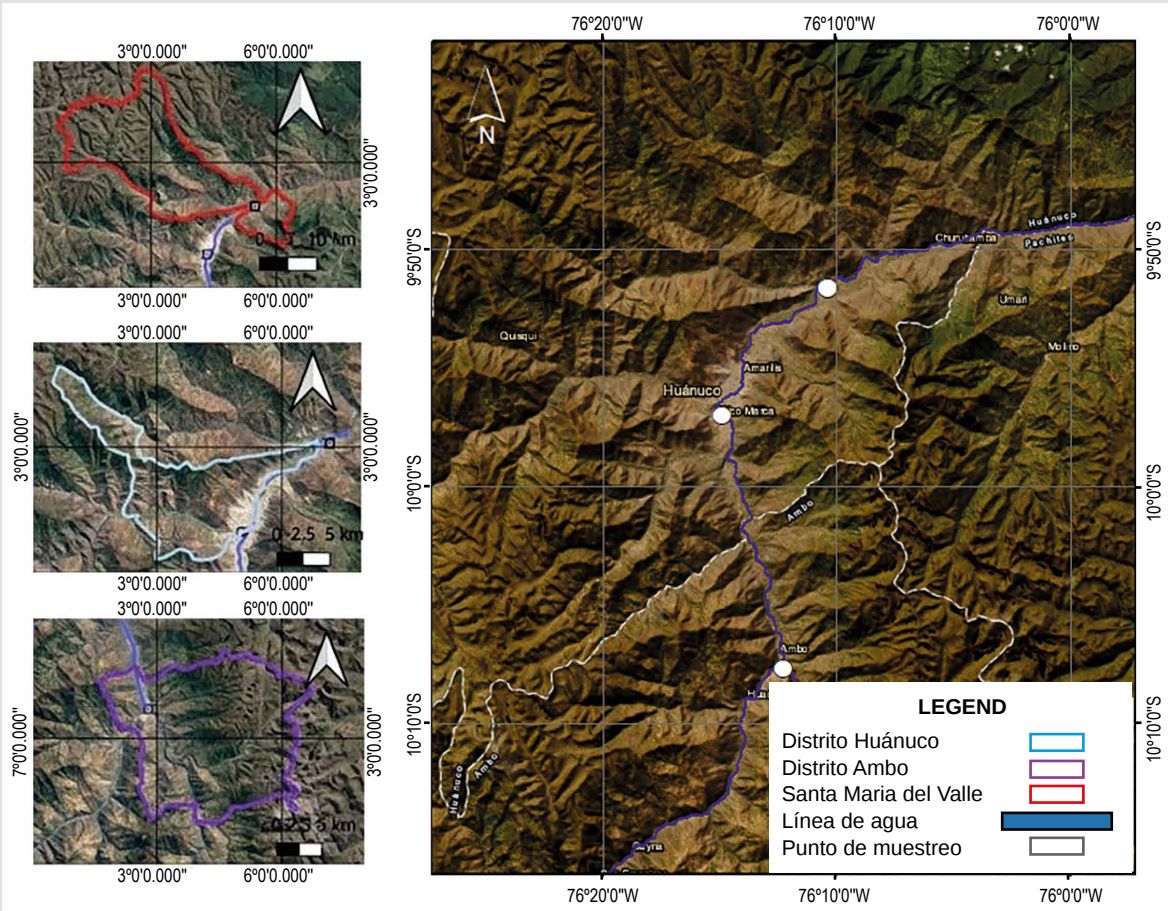
sustainable urban planning, and flood prevention. Finally, the study seeks to strengthen local authorities' decision-making and promote mitigation strategies in response to future extreme events.

Metodos

Study area

The present study was conducted in the vicinity of the city and the valley, encompassing three geographic areas of particular interest: the city of Huánuco, the district of Santa María del Valle, and the province of Ambo, located south of the city of Huánuco. These areas were selected due to their direct exposure to precipitation variability and its hydrological impacts on urban infrastructure and adjacent agricultural land. The Huánuco Valley constitutes an inter-Andean area of transition between the highlands and the high jungle of the country, with an average elevation of 1,890 m a.s.l., crossed by the Huallaga River and its tributaries, among which the Higuera and Huertas rivers stand out (see Figure 1). Its strategic location, together with population concentration and urban expansion toward the riverbanks, generates high vulnerability to intense rainfall events and river overflows (Info Perú, n.d.).

Figure 1
Location map of the study area. The map presents three study areas corresponding to the districts of Huánuco, Ambo, and Santa María del Valle, indicated with different colors. The valleys and the main channel of the Huallaga River, as well as the study points, can be observed.



Data source

Hydrometeorological data from stations operated by the National Meteorology and Hydrology Service of Peru (SENAMHI) and the National Water Authority (ANA) were used. For the precipitation analysis, records from pluviometric stations located in the Huánuco area were used, namely:

- Huánuco station (Lat: 09° 57' 7.24"; Lon: 76° 14' 54.80")
- Ambo station (Lat: 10° 19' 45.27"; Lon: 76° 10' 35.47")

For the discharge analysis, the following hydrometric stations were used:

- Higuera station (Lat: 09° 55' 19.92"; Lon: 76° 18' 33.76")
- San Rafael station (Lat: 10° 20' 23.65"; Lon: 76° 10' 56.65")
- Taruca station (Lat: 09° 51' 01"; Lon: 76° 09' 07")

The data were obtained through the official SENAMHI platforms (<https://www.senamhi.gob.pe>) and ANA platforms (National Water Resources Information System) (<https://snirh.ana.gob.pe>). All records were previously validated, ensuring consistency, temporal continuity, and quality control.

Data collection and anomaly detection procedure

The data collection and processing were developed based on daily precipitation and discharge records corresponding to the period from 2015 to 2025 for precipitation and from 2020 to 2025 for discharge, with emphasis on the first quarter of 2025. The information was collected from the operational stations closest to the city of Huánuco and its immediate surroundings.

To identify anomalies in the variables analyzed, standardized statistical methods were applied to quantify the magnitude and frequency of anomalous events, which are expressed through the following formulas:

a) Calculation of the standardized anomaly (Z-score)

For the analysis of discharge anomalies, the *Z-score* method was used to evaluate the deviation of the observed value from the historical mean, normalized by the variability of the series. The following expression was used:

$$Z = (X - \mu) / \sigma$$

Where:

The standardized anomaly (*Z-score*) is calculated by applying the formula described above, in which the difference between an individual value (X) and the population mean (μ) is divided by the population standard deviation (σ). The result (Z) indicates how many standard deviations a data point represents with respect to the mean, either above or below it.

Standardized precipitation index (SPI)

$$SPI = \frac{P_t - P^-}{\sigma}$$

In the case of precipitation anomalies, the standardized precipitation index (SPI) was used. This is calculated by transforming accumulated precipitation data into a standard probability distribution, where P_i is the observed precipitation, P^- is the historical mean precipitation, and σ is the standard deviation of the

dataset. It is used to compare current precipitation with historical precipitation and to classify drought events as mild, moderate, severe, or extreme, thereby enabling decision-making in agriculture, water resource management, and planning.

Once the anomalies were calculated, time series and monthly trend graphs were generated in Microsoft Excel. Finally, a cross-correlation was performed between the detected anomalies and the physical impact events reported by Civil Defense and the ANA, such as floods, overflows, bank erosion, and landslides. This made it possible to analyze the impacts on urban infrastructure and on the land surrounding the city of Huánuco caused by extreme hydrometeorological events during the first quarter of 2025.

Information processing

The information was processed in several stages. First, precipitation and discharge data corresponding to the 2000–2025 period were cleaned, which involved removing inconsistent records, completing the time series when necessary, and verifying the presence of outliers following statistical criteria and recommendations from the specialized literature. Subsequently, the cleaned data were structured in spreadsheets for organization and analysis, applying standard statistical tools to identify anomalies expressed as percentages and determine deviations from the average values of the 2000–2025 reference period. Finally, this processing made it possible to characterize anomalous hydrometeorological events and relate them to the impacts observed on infrastructure and on the land adjacent to the city of Huánuco.

Statistical analysis

The statistical analysis applied made it possible to evaluate the hydrological anomalies recorded during the first quarter of 2025 in the middle basin of the Huallaga River. This procedure was based on descriptive and inferential statistical methods that made it possible to identify anomalous patterns, compare monthly values with historical averages, and analyze the magnitude of the hydrometeorological variables of discharge and precipitation.

Results

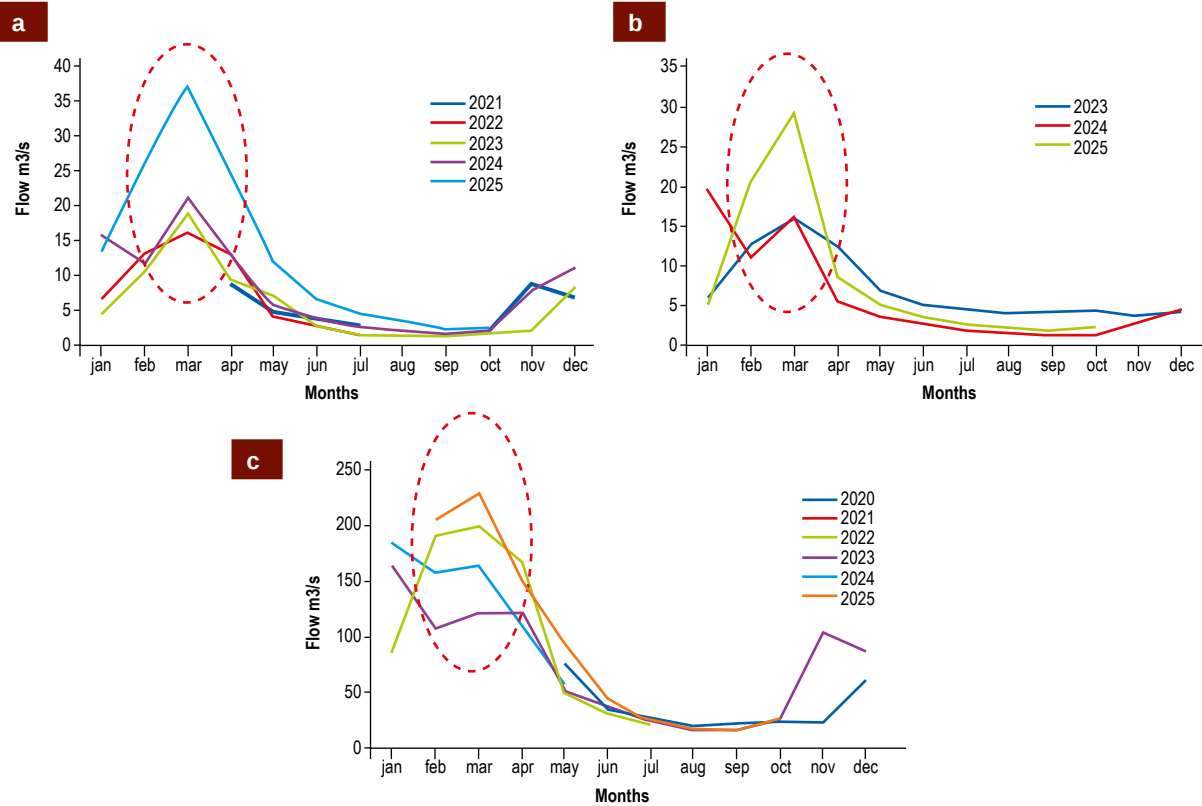
Flow rate analysis

Figure 2 presents the flow rate analysis for the Higuerras, San Rafael, and Taruca stations, showing a stable pattern in the years prior to 2025. In general terms, flow rates show progressive increases beginning in January, reach their maximum in March, and decline rapidly toward April. The minimum values are recorded between June and September, with flow rates remaining below 5 m³/s at Higuerras and San Rafael, and below 20 m³/s at Taruca. At the Higuerras station, the flow rates in February and March 2025 show unprecedented increases in the historical series: in February, the flow rate reaches approximately 27 m³/s, exceeding typical values (10–20 m³/s) by 40–60 % while in March, the highest value in the entire series is recorded: 37 m³/s, almost twice the historical average (15–21 m³/s). At the San Rafael station, the detected anomalies are consistent with those observed at the Higuerras station. In February 2025, approximately 20 m³/s, are recorded, exceeding the historical average by 40–60 % In March 2025, the flow rate rises to 30 m³/s, an increase of approximately 80 % compared with the expected value (≈ 16 m³/s). Likewise, at the Taruca station, characterized by naturally higher flow rates, anomalies are recorded: in February 2025, the flow rate reaches 210 m³/s, ligeramente superior al rango normal (150–200 m³/s), and in March, it rises to 225 m³/s, exceeding the expected behavior (160–180 m³/s) by between 20 % and 30 %.

Annual temporal analysis of precipitation

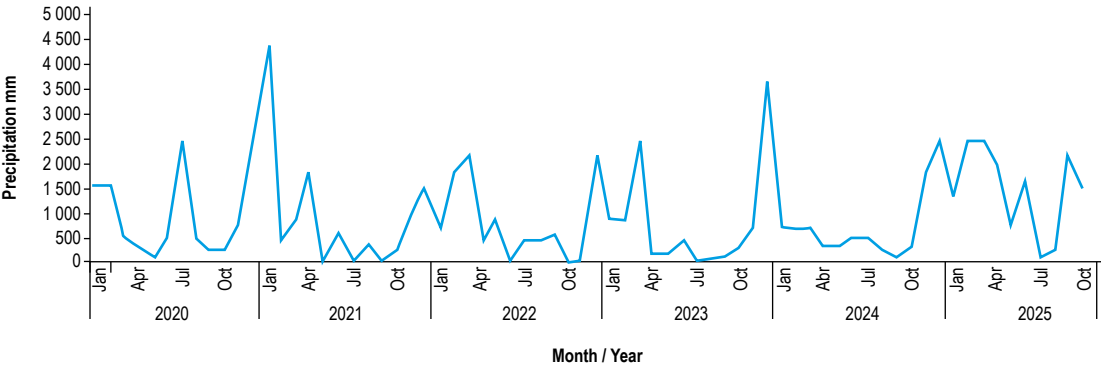
Figure 3 shows that, between 2020 and 2021, precipitation levels progressively decreased and remained below the historical average. However, starting in 2025, a considerable increase in total annual precipitation was recorded, constituting a positive anomaly compared with previous years. This abrupt increase in rainfall

Figure 2
Annual and monthly flow rate records for each station: (a) Higuera station, (b) San Rafael station, and (c) Taruca station



during 2025 reflects a notable change in recent climatic behavior, generating high-intensity events that caused overflows, floods, and impacts on the infrastructure of the city of Huánuco. Likewise, a marked monthly variation in precipitation is evident during the first quarter of 2025. February recorded the highest precipitation level, significantly exceeding those of January and March. This anomalous increase in rainfall evidences an atypical situation compared with historical monthly averages, generating excess surface runoff that contributed to soil saturation and the overflow of the Huallaga River. This behavior reflects the influence of extreme weather events, which directly affected the city of Huánuco during this period.

Figure 3
Annual and monthly precipitation analysis

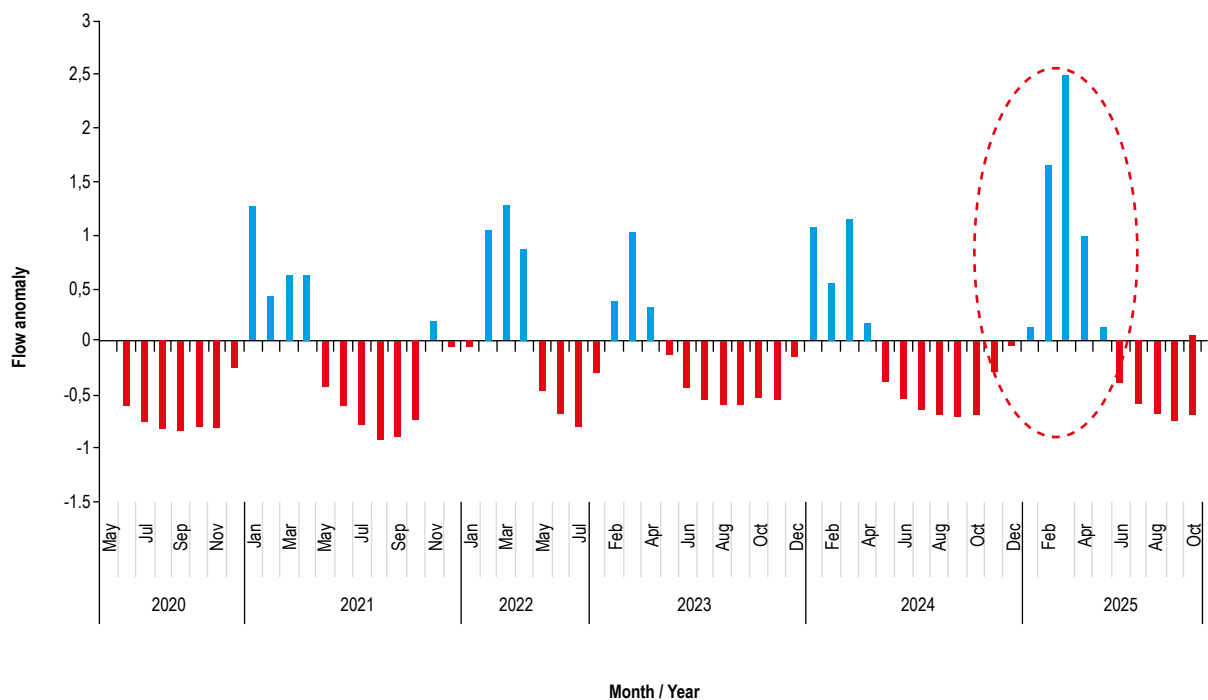


Flow rate anomalies

Figure 4 shows the monthly average flow rate and precipitation anomalies between 2020 and 2025. It shows red bars representing negative values (deficits) and blue bars reflecting positive anomalies (excesses) relative to the historical averages. During the 2020–2024 period, anomalies with average values ranging from -0 to -1.5, predominate, indicating normal anomalies in flow rates. However, in the first quarter of 2025 (January–March), an abrupt change occurs, with significant positive anomalies, highlighting values above 1.5 anomalies in February and close to 2.5 in March. This behavior suggests the occurrence of an extreme precipitation event, with a notable increase in flow rates in the rivers and streams crossing the city of Huánuco, associated with exceptional precipitation during the period.

Figure 4

Flow rate anomalies over the last five years

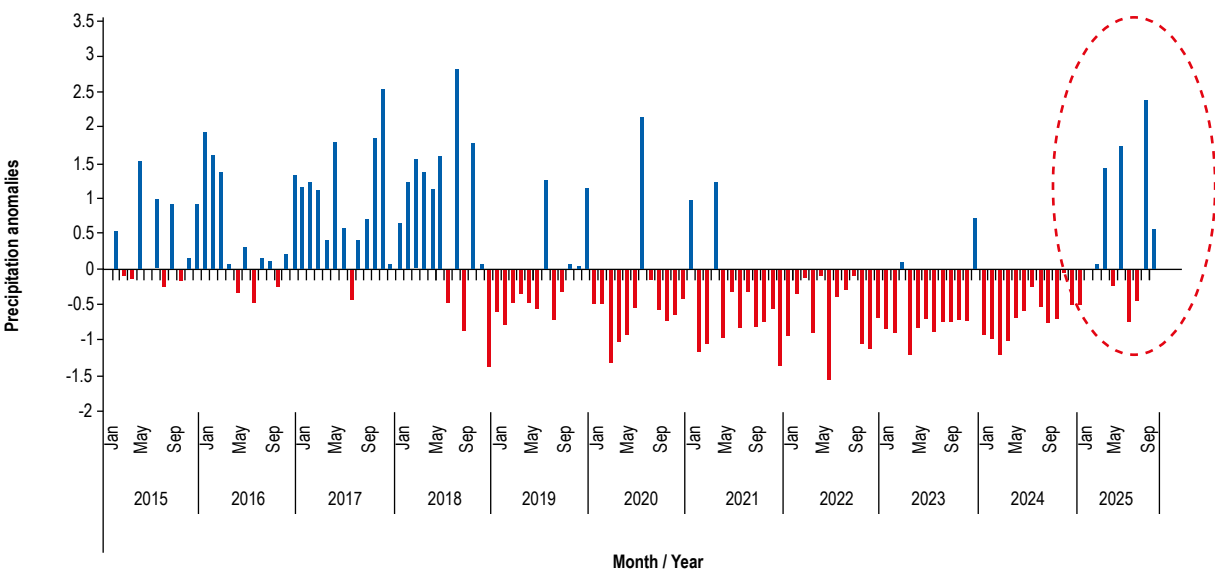


Precipitation anomaly

Figure 5 shows the temporal evolution of monthly precipitation anomalies during the 2015–2025 period. Positive values (blue bars) indicate months in which precipitation exceeded historical averages; negative values (red bars) represent a rainfall deficit relative to those averages. High peaks are identified, particularly between 2015 and 2017, during which several months exceed anomaly values of 2.5 above normal levels; from 2019 to 2025, a marked pattern of repeated and pronounced negative anomalies is observed, with values ranging from 0 to 1.5 anomaly values.

The values recorded for January, February, and March 2025 show high variability in precipitation, with intense events concentrated mainly in February, although the monthly accumulated values do not consistently exceed the historical average. This behavior demonstrates that short-duration extreme events can generate significant hydrological responses without requiring sustained positive anomalies in monthly precipitation.

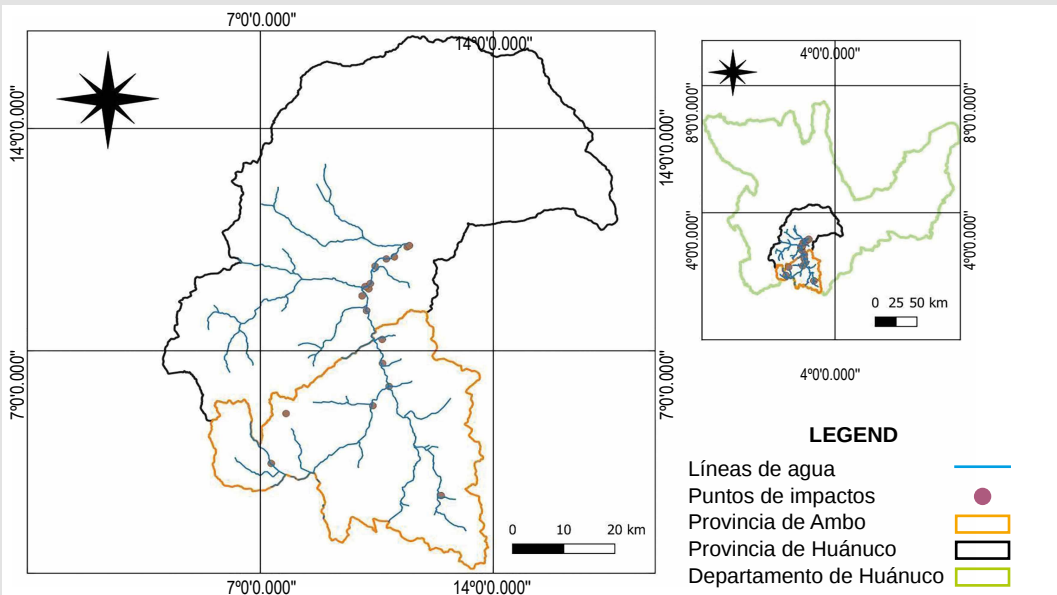
Figure 5
Precipitation anomalies over the last ten years



Material, environmental, and social impacts

Figure 6 presents the spatial distribution of the material, environmental, and social impacts associated with the hydrometeorological events during the first quarter of 2025 in the middle basin of the Huallaga River. These impacts are mainly concentrated in areas near the main river channel and in areas with steep slopes, evidencing the influence of geomorphological factors on the occurrence of floods and debris flows.

Figure 6
Map of the material, environmental, and social impacts



Coordinates, type of damage, and aspects of the impacts caused by the increase in discharge and precipitation

Table 1 complements this analysis by detailing the geographical location, type of event, and nature of the impact recorded at each affected point. It can be observed that flood events predominate in low-lying areas near the Huallaga River, such as Colpa Baja, Huácar, and the Calicanto Bridge, indicating a direct relationship with the overflow of the main river channel. In contrast, debris flows occur mainly in areas with steeper slopes, such as San Rafael, Cayna, and Conchamarca, associated with mass movement processes induced by soil saturation.

Table 1

Table of coordinates, type of damage, and aspects of the impacts caused by the increase in discharge and precipitation

Place	Coordinates		Type of damage	Aspect
	Latitude	Longitude		
Colpa Baja	9°58'56.70"S	76°14'34.74"O	FLOODING	Environmental
Calicanto Bridge (Huánuco)	9°55'56.17"S	76°14'12.45"O	FLOODING	Infrastructural
San Rafael	10°19'42.26"S	76°6'33.39"O	DEBRIS FLOW	Infrastructural
Pillco Marca	9°57'17.73"S	76°15'6.23"O	DEBRIS FLOW	Social
Tomayquichua	10°4'53.54"S	76°12'54.35"O	FLOODING	Infrastructural
Amarilis	9°56'31.10"S	76°14'19.70"O	DEBRIS FLOW	Social
San Sebastián Brigde (Huánuco)	9°56'15.96"S	76°14'45.34"O	FLOODING	Infrastructural
Conchamarca	10°2'11.58"S	76°12'54.74"O	DEBRIS FLOW	Environmental
Colpa Baja (aeropuerto)	9°53'59.50"S	76°13'43.87"O	FLOODING	Environmental
Huachog	9°53'10.64"S	76°12'33.25"O	FLOODING	Social
District of Huácar	10°9'37.75"S	76°14'2.36"O	FLOODING	Infrastructural
Colpas (Ambo)	10°16'7.28"S	76°24'48.38"O	DEBRIS FLOW	Social
Cayna	10°10'28.74"S	76°23'11.75"O	DEBRIS FLOW	Social
Limón Pampa	9°50'00. 9"S	76°45'00.76"O	FLOODING	Social
Cullcuy	9°52'58.20"S	76°11'34.88"O	DEBRIS FLOW	Social

Environmental impacts

Figure 7 illustrates the direct consequences on the environment resulting from hydrological phenomena and landslides. In Figure 7a), the overflow of the Huallaga River causes flooding in agricultural areas, resulting in waterlogging, vegetation loss, and a decrease in soil fertility. In Figure 7b), mud and rock landslides in Conchamarca damage the land by covering crops and removing the nutrient-rich soil layer. In Figure 7c), another overflow in Colpa Baja increases sediment accumulation and alters the composition of the soil. Overall, these impacts reduce agricultural productive capacity, alter the physicochemical characteristics of the land, and increase the risk of future extreme events.

Figure 7

Evidence of environmental impacts: (a) overflow of the Huallaga River affecting crops; (b) impact on the agricultural area of Conchamarca due to the displacement of mud and rocks; and (c) impact on the agricultural area of Colpa Baja due to the overflow of the Huallaga River.

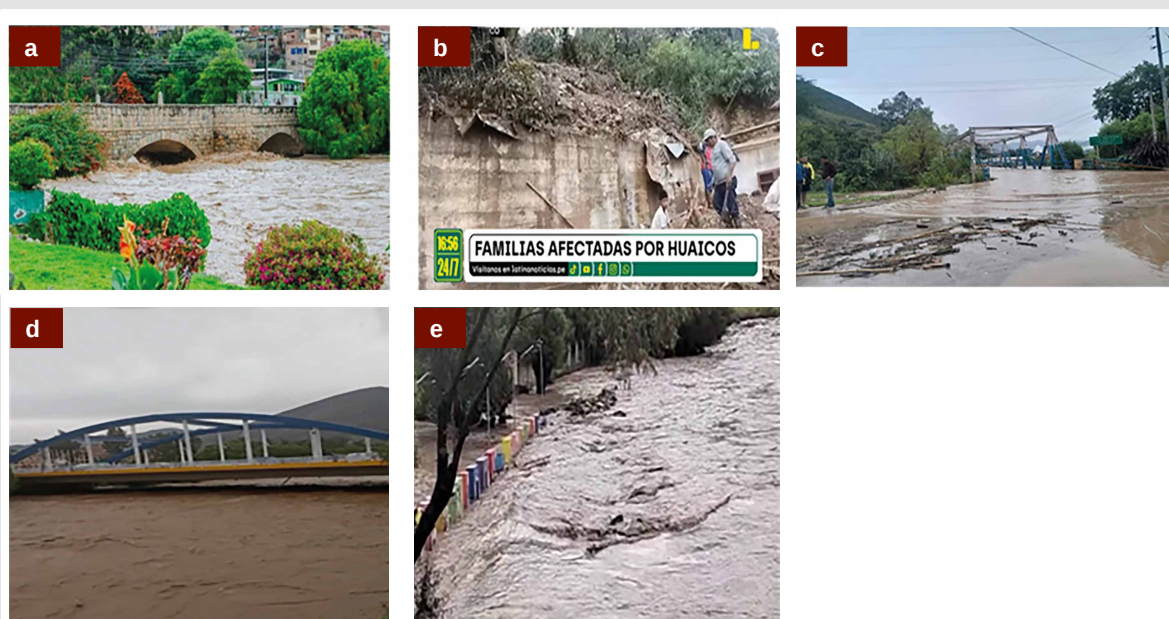


Impacts on infrastructure

According to Figure 8, direct impacts on infrastructure associated with the increase in the Huallaga River's discharge and mass movement processes can be observed. In Figures 8a), 8b), and 8c), the rise in river levels at the Calicanto, Tomayquichua, and San Sebastián bridges generates risks of scouring, erosion, and loss of road functionality. In Figure 8d), the displacement of mud and rocks in San Rafael evidences ground instability and affects homes. In Figure 8e), the overflow in Huácar causes flooding and structural deterioration in nearby buildings. Overall, these events indicate a high vulnerability of local infrastructure to river rises and landslides, affecting both connectivity and housing safety.

Figure 8

Evidence of impacts on infrastructure: (a) increase in the Huallaga River level at the Calicanto Bridge; (b) displacement of mud and rocks in San Rafael, affecting several nearby family homes; (c) increase in the Huallaga River level at the bridge at the entrance to Tomayquichua; (d) increase in the Huallaga River level at the San Sebastián Bridge; and (e) overflow caused by increased discharge in the district of Huácar toward nearby homes.



Source: fieldwork records.

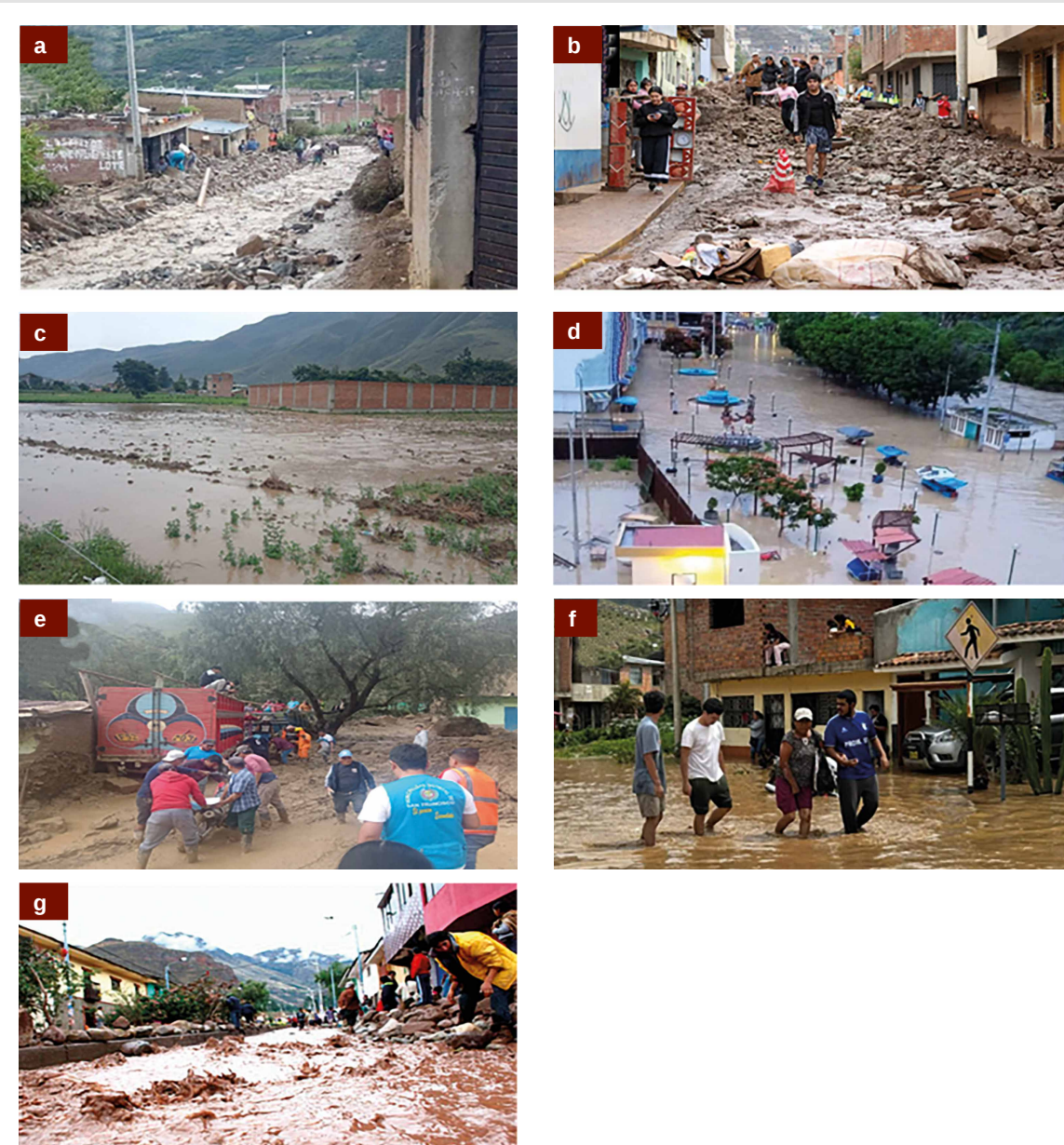
Social impacts

Figure 9 shows the social repercussions resulting from the overflows and landslides associated with the increase in the Huallaga River's discharge. In Figures 9a), 9b), 9c), and 9d), local mobility is disrupted by the displacement of rocks and mud in the populated center of Culcuy and in the districts of Cayna, Amarilis, and Pillco Marca, posing an immediate risk to residents and resulting in the loss of vital roads. Flooding of homes and community areas in Huachog, Colpas (Ambo), and Limón Pampa, caused by rising river levels, results in material losses, the temporary relocation of families, and disruption of essential services.

In general, these events demonstrate significant social vulnerability to extreme hydrometeorological phenomena. This is manifested through people's exposure to physical hazards, disruption of their daily activities, and an increased need for assistance and immediate response.

Figure 9

Evidence of social impacts: (a) displacement of mud and rocks in the district of Pillco Marca, (b) displacement of mud and rocks in the district of Amarilis, (c) overflow of the Huallaga River in the district of Huachong, (d) overflow in Colpas-Ambo due to the increase in discharge, (e) large-scale mud and rock landslide in the district of Cayna, (f) river overflow due to the increase in discharge in Limón Pampa, and (g) displacement of mud and rocks in the district of Cullcuy.



Source: fieldwork records.

Discussions

The presence of a monthly peak exceeding $225 \text{ m}^3/\text{s}$ in March 2025 confirms the abrupt hydrological response to intense rainfall. This behavior is consistent with the SENAMHI report on overflows in the basins of Loreto and Ucayali due to extreme precipitation (Ramos, 2025). Likewise, the National Center for the Estimation, Prevention, and Reduction of Disaster Risk (CENEPRED, 2023) indicates that intense rainfall can cause an increase in river discharge, in some cases exceeding the maximum threshold of river channels and generating floods that cause considerable damage to basic service infrastructure.

The irregular trend in discharge closely coincides with the precipitation behavior observed during the same period. Although in previous years (2020–2024) precipitation remained below the historical average, 2025 recorded an abrupt increase in rainfall, with February being the most critical month, which caused excess surface runoff and soil saturation. Sardon et al. (2022) indicate in their inventory of flood events that episodes of intense rainfall with flood potential are not completely exceptional, but may exhibit some recurrence. In this regard, multiple events were documented between 1981 and 2021, suggesting that overflows are part of the national hydrological variability, but with varying levels of risk. The discharge response observed at the Taruca, Higuera, and San Rafael stations reflects the same phenomenon documented in urban and rural mountain basins, where rapid soil saturation and the pronounced morphology of the terrain cause rapid and significant increases in discharge during extreme rainfall events (Valencia and Nájera, 2018).

The data obtained in March 2025 (up to 225 m³/s at Taruca) are quantitatively higher than those recorded in related studies in Andean basins, where increases commonly range between 20 % and 50 % relative to the mean (Valencia and Nájera, 2018). In this case, the increases exceeded 80 %, evidencing a stronger-than-expected hydrological response. This disparity could be associated with local conditions, such as prior soil saturation and the geomorphology of the Huánuco Valley, which enhance surface runoff.

The results obtained suggest that the hydrological behavior in 2025 evidences a non-stationary regime, implying that historical hydraulic design parameters (channels, bridges, riverbank defenses, drainage systems) may be insufficient in the face of future extreme events. Jiménez-U et al. (2022) indicate that changing climatic conditions alter the magnitude and frequency of hydrological maxima; therefore, designs based solely on historical records no longer provide an adequate level of safety, reinforcing the need to incorporate non-stationary approaches into the planning and assessment of hydraulic works. Therefore, analyzing anomalous hydrological events and non-stationary regimes is crucial for understanding how extreme floods and droughts can exceed traditional design parameters. Historical patterns no longer guarantee infrastructure safety or enable effective planning, since climate change and recent variations in precipitation alter the frequency and intensity of extreme events. Analyzing these anomalies makes it possible to identify existing vulnerabilities and design adaptive measures that reduce risks and increase the resilience of hydraulic systems and the safety of the population in the face of future phenomena (Milly et al., 2008). Therefore, it is important to understand anomalous hydrological events in order to strengthen risk management and reduce the exposure of communities and infrastructure to potential disasters. This approach contributes to planning more effective preventive measures and ensuring greater safety in the face of river rises and floods (INDECI, 2023).

The interpretation of the results is constrained by the temporal availability of the historical series, which cover a relatively short period from a hydrological perspective (2020–2025), preventing robust frequency analyses associated with return periods. Likewise, the data analyzed come exclusively from specific hydrometric stations, which may limit spatial extrapolation to other sub-basins in Huánuco due to differences in elevation, geomorphology, and land-use characteristics. Another limitation is the lack of detailed information on anthropogenic interventions (deforestation, urban expansion, soil imperviousness), which also influence the discharge response. Likewise, hydraulic modeling was not considered to quantify the structural impact on infrastructure; therefore, the results describe the hydrological hazard but do not quantify potential damage or risk levels.

Conclusions

The hydrological behavior observed in the middle basin of the Huallaga River during the first quarter of 2025 evidences a significant anomaly, characterized by extreme increases in discharge that do not have a direct proportional relationship with monthly accumulated precipitation. The records show that, in March 2025, discharge reached maximum values of approximately 37 m³/s at the Higuera station, 30 m³/s at the San Rafael station, and 225 m³/s en la estación Taruca, at the Taruca station, exceeding historical means by up to 80 % which confirms the occurrence of an extreme hydrological event. This decoupling between precipitation and

discharge demonstrates that the basin's hydrological response is strongly influenced by nonlinear processes, such as soil saturation, the temporal concentration of intense rainfall, and contributions from high-Andean areas. Consequently, it is evident that an analysis based solely on monthly averages is insufficient to explain extreme events.

The results confirm the presence of a non-stationary hydrological regime in the region, implying that traditional hydraulic design practices based on stable historical conditions could lose validity under current climate variability. This finding has direct implications for hydraulic engineering and territorial planning, as it increases the probability of failures in infrastructure designed according to conventional criteria. Likewise, the observed impacts, such as floods, debris flows, and damage to road infrastructure, housing, and agricultural areas, evidence high exposure and vulnerability of the territory to extreme hydrometeorological events, particularly in urban areas expanding toward risk-prone areas. In this context, it is concluded that risk management in the Huallaga River basin requires a transition toward integrated approaches that incorporate the analysis of extreme events, non-stationary conditions, and real-time monitoring. It is recommended to prioritize the updating of hydraulic design criteria, the implementation of more robust early warning systems, and restrictions on urban expansion in high-risk flood-prone areas as key measures to reduce future vulnerability.

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Author contributions

The authors development the research in its entirety.

Funding sources

The funding was conducted with the author's own resources.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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