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Cost analysis of climate change and prevention measures in the Chancay-Lambayeque Valley, Perú

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Abstract
This study analyzes the economic costs associated with climate change and the implementation of preventive measures in the Chancay-Lambayeque Valley, Peru. Through a cost-benefit analysis, the study quantifies the impact of extreme flood events on agriculture and hydraulic infrastructure, considering scenarios with and without mitigation measures. The results show that adopting structural and non-structural strategies significantly reduces economic losses and enhances the resilience of the region's water and productive systems. The findings emphasize that strengthening investments in resilient infrastructure and adaptation strategies is crucial for the economic and environmental sustainability of the watershed.

Keywords: climate change; economic costs; cost-benefit analysis; extreme flooding; mitigation measures.

Análisis de costos de cambio climático y medidas de prevención en el valle de Chancay-Lambayeque, Perú

Resumen
El estudio analiza los costos económicos asociados al cambio climático y la implementación de medidas preventivas en el Valle de Chancay-Lambayeque, Perú. A través de un análisis costo-beneficio, se cuantifica el impacto de eventos de inundaciones extremas sobre la agricultura y la infraestructura hidráulica, considerando escenarios con y sin medidas de mitigación. Los resultados evidencian que la adopción de estrategias estructurales y no estructurales reduce significativamente las pérdidas económicas y mejora la resiliencia del sistema hídrico y productivo de la región. Se concluye que fortalecer la inversión en infraestructura resiliente y estrategias de adaptación es clave para la sostenibilidad económica y ambiental de la cuenca.

Palabras clave: cambio climático; costos económicos; análisis costo-beneficio; inundaciones extremas; medidas de mitigación.

1 Introduction

Human interventions have decreased the frequency of minor floods, but extraordinary floods have increased. The inclusion of historical data is crucial to improve accuracy in estimating future flows and risks. Extreme floods are on the rise due to climate change and the increased vulnerability of urban areas [12].

Peru is one of the 10 megadiverse countries in the world; it has the second-largest Amazonian Forest after Brazil, the

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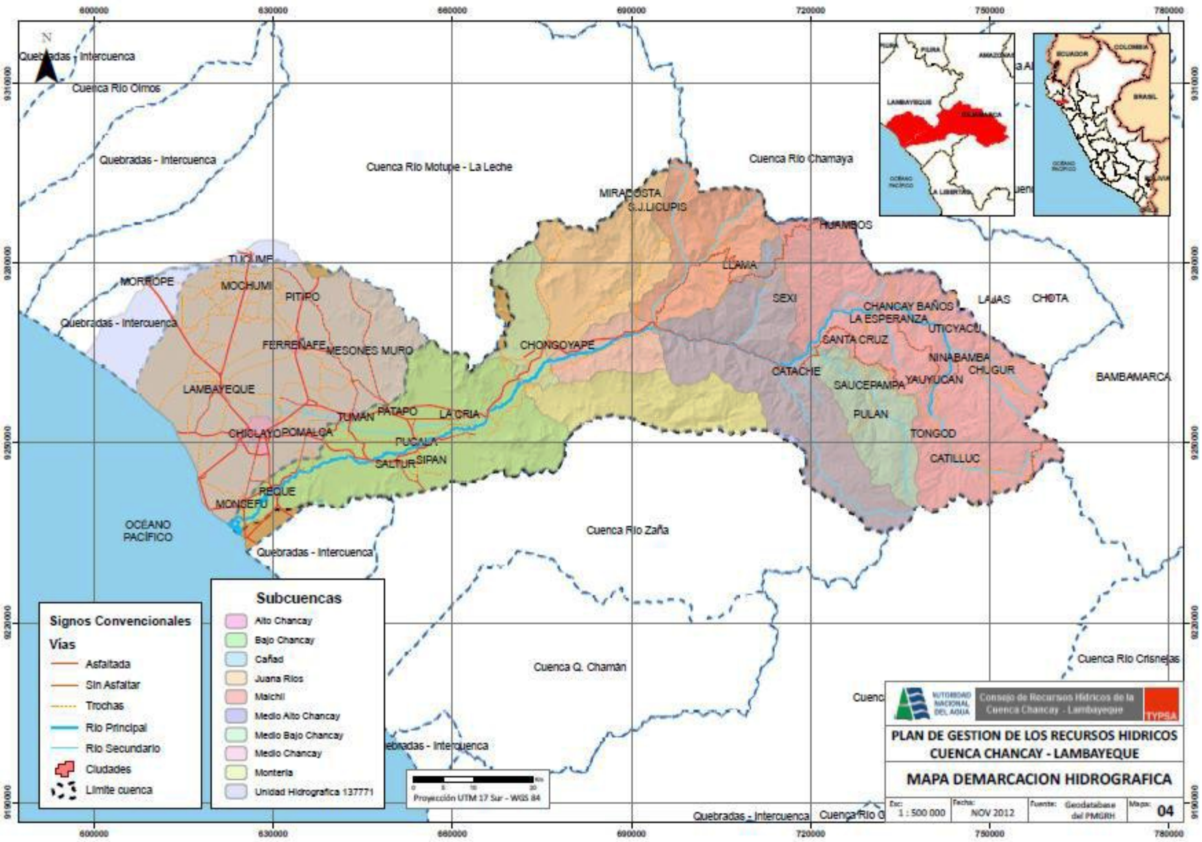

Figure 1. Location of the Chancay-Lambayeque basin.
Source: ANA, 2015.

largest tropical mountain range, 71% of tropical glaciers, 84 of the 104 life zones identified on the planet, and 27 of the 32 climates in the world. This diversity is seriously threatened by climate change and explains much of the country's high vulnerability [8]. In addition, 21.77% of the population lives in poverty, while 4.07% experiences extreme poverty [5], increasing their vulnerability to the effects of climate change due to their dependence on agriculture.

The Chancay-Lambayeque Valley is undergoing a process of socioeconomic development with a clear upward trend, as new public and private investments are improving the productive, urban, and social services infrastructure, allowing production to grow and improving the quality of social services, which has been accompanied by a process of sustainable economic development. Fig. 1, shows the location of the Chancay- Lambayeque watershed [1].

Globally, climate change has intensified the frequency and magnitude of extreme hydrometeorological events, particularly affecting vulnerable agricultural regions [6]. In Peru, recurrent floods impact food security and water infrastructure, generating high socioeconomic costs [7]. In the Chancay-Lambayeque Valley, millions of dollars in losses have been recorded due to events such as El Niño [10]. However, there is little empirical evidence on the economic effectiveness of long-term mitigation strategies. This study employs a cost-benefit analysis to assess the effectiveness and impact of adaptation measures in this context.

2 Methodology

The study employs a cost-benefit analysis model to assess the economic feasibility of various climate change mitigation interventions. The methodology includes:

- Evaluation of direct and indirect costs of extreme weather events in the Chancay-Lambayeque Valley.
- Estimate of avoided costs through the implementation of preventive measures such as infrastructure reinforcement, reforestation, and land use management.
- Comparison of scenarios with and without a project, with 10, 100, and 500-year return periods.
- Incorporation of measures of the Integral Plan for flood control and disaster risk reduction in the Chancay-Lambayeque River basin [10].
- Adaptation of the avoided cost approach based on previous studies in the Chincha Valley [2] and Ghana [3].

This methodology allows quantifying the economic impact of climate change and determining the benefits of adaptation strategies. A cost-benefit analysis was performed using hydrometeorological data from the National Water Authority [1] and [10]. Return periods of 10, 100, and 500 years were determined using hydrological modeling based on historical series [2]. Avoided costs were estimated by comparing scenarios with and without adaptation measures, considering damage to crops, infrastructure, and agricultural production, following the methodology of Azumah [6].

2.1 Cost-benefit analysis

Risk reduction refers to the implementation of physical investments aimed at transforming economic assets and/or the environment in vulnerable areas, to prevent or reduce the negative impact of disasters associated with climate change. Examples of risk reduction include strengthening and adapting infrastructure, integrating risk into initial investments, building resilient infrastructure, improving housing, and other measures aimed at strengthening the response and adaptive capacity of communities.

In public administration, loss sharing refers to a joint and several agreements among the participants to distribute any losses incurred if one or more of the participants is unable to meet their obligations.

2.2 Benefits or costs avoided

The avoided cost approach was implemented using two types of approaches. The first method was to use information on the potential loss of assets that would result in the loss of environmental services provided by natural resources to estimate the costs that society would face. In this case, the researcher would estimate the potential damage to assets if the resources were not restored or conserved. Determining whether society or resource owners have invested funds to protect resource features is a second approach. In this way, expenditures to prevent the loss of ecosystem services provide an estimate of the value of those services [9].

The investment project measures aim to protect irrigated agricultural areas or land, hydraulic infrastructure (intakes and canals), protective infrastructure (levees and river defenses), public facilities (roads, bridges, electrical networks, drinking water supply infrastructure, irrigation infrastructure, etc.) from possible flooding of the Chancay Lambayeque River.

These measures help prevent or mitigate both direct and indirect damages resulting from a discharge with a return period of up to 500 years. Consequently, the avoided costs or damages represent the benefits attributed to the project when compared to the scenario without its implementation.

3 Results and discussion

3.1 Avoided costs

The summary of damages or avoided costs for the Chancay-Lambayeque Valley is presented at private prices in the "without" and "with" project situations, the difference or net benefit of which will be used for the economic evaluation of each project.

Tables 1, 2, and 3 show a summary of damages in the Chancay Lambayeque Valley in terms of sectors and types of damages for the without-project scenario. These damages will be caused by the extraordinary floods of the Chancay Lambayeque River, according to the return time and flood level.

Table 1.
Summary of Damages to Affected Sectors in the Chancay-Lambayeque Valley without Project for TR 10 years (Expressed in thousands of soles at private prices as of August 2024).

Sector	Description	Soles
Agriculture	Production Lost Flood	41985.43
	Erosion of Agricultural Areas	3862.64
	Unrealized production	41985.43
	Crop replenishment	47306.23
	Unrealized production (Hydraulic Inf.)	29758.10
Hydraulic Infrastructure	Intakes	273.25
	Channels	18413.61
	Riverine defenses	4263.14
	Wells	22949.99
	TOTAL	162,778.23

Source: The authors.

Table 2.
Summary of Damages to Affected Sectors in the Chancay-Lambayeque Valley without Project for TR 100years (Expressed in thousands of soles at private prices as of August 2024).

Sector	Description	Soles
Agriculture	Production Lost Flood	68533.60
	Erosion of Agricultural Areas	6297.78
	Unrealized production	68533.60
	Crop replenishment	76993.95
	Unrealized production (Hydraulic Inf.)	58131.73
Hydraulic Infrastructure	Intakes	2744.11
	Channels	65906.44
	Riverine defenses	8778.81
	Wells	77558.85
	TOTAL	345,132.71

Source: The authors.

Table 3.
Summary of Damages to Affected Sectors in the Chancay-Lambayeque Valley without Project for TR 500years (Expressed in thousands of soles at private prices as of August 2024).

Sector	Description	Soles
Agriculture	Production Lost Flood	82343.92
	Erosion of Agricultural Areas	7599.32
	Unrealized production	82343.92
	Crop replenishment	92977.05
	Unrealized production (Hydraulic Inf.)	70690.90
Hydraulic Infrastructure	Intakes	13725.71
	Channels	177789.26
	Riverine defenses	26632.97
	Wells	237663.58
	TOTAL	210797.81

Source: The authors.

Tables 4, 5, and 6 show a summary of damages in the Chancay-Lambayeque valley by sector and type of damage for the situation with the Project, which will be affected by the extraordinary floods of the Chancay- Lambayeque River, according to the return period and flood level. The amount of damages or avoided costs at private prices during the 10-year, 100-year, and 500-year return periods.

Table 4.
Summary of Damages to Affected Sectors in the Chancay-Lambayeque Valley with 10-Year TR Project (Expressed in thousands of soles at private prices as of August 2024).

Sector	Description	Soles
Agriculture	Production Lost Flood	909.08
	Erosion of Agricultural Areas	1889.34
	Unrealized production	909.08
	Crop replenishment	0.00
Hydraulic Infrastructure	Unrealized production (Hydraulic Inf.)	47.66
	Intakes	0.00
	Channels	0.00
	Riverine defenses	852.64
	Wells	852.64
	TOTAL	5460.43

Source: The authors.

Table 5.
Summary of Damages to Affected Sectors in the Chancay-Lambayeque Valley with Project for TR 100 years (Expressed in thousands of soles at private prices as of August 2024)

Sector	Description	Soles
Agriculture	Production Lost Flood	1483.90
	Erosion of Agricultural Areas	3148.88
	Unrealized production	1483.90
	Crop replenishment	0.00
Hydraulic Infrastructure	Unrealized production (Hydraulic Inf.)	165.22
	Intakes	0.00
	Channels	13207.71
	Riverine defenses	1755.83
	Wells	14963.53
	TOTAL	36208.96

Source: The authors.

Table 6.
Summary of Damages to Affected Sectors in the Chancay-Lambayeque Valley with Project for TR 500 years (Expressed in thousands of soles at private prices as of August 2024)

Sector	Description	Soles
Agriculture	Production Lost Flood	1781.78
	Erosion of Agricultural Areas	3778.67
	Unrealized production	1781.78
	Crop replenishment	0.00
Hydraulic Infrastructure	Unrealized production (Hydraulic Inf.)	445.35
	Intakes	0.00
	Channels	35558.11
	Riverine defenses	9095.12
	Wells	44717.98
	TOTAL	97158.79

Source: The authors.

The comparison between scenarios with and without prevention measures shows that the avoided costs are substantial in all the sectors analyzed. In particular, it was identified that:

- Losses in the agricultural sector can be reduced by up to 96.64% for a 10-year payback period.
- Water infrastructure shows a damage reduction of up to 89.50% over a 100-year return period.
- In a 500-year return period, damage mitigation reaches 53.90%, demonstrating the effectiveness of the structural measures implemented.

The implementation of adaptation measures reduced economic losses by 96.64% for 10-year return events and by 53.90% for 500-year extreme events. These results are consistent with studies in Chincha [2], where damage reduction reached 64%. However, in the case of Chancay-Lambayeque, mitigation effectiveness decreases with larger magnitude events, suggesting the need to strengthen resilient infrastructure and financial mechanisms for climate insurance. Comparison with previous studies in the Chincha Valley [2] and Ghana [3] demonstrates the effectiveness of cost-benefit analysis in planning climate adaptation investments.

3.2 Comparison with previous studies

The results obtained are consistent with previous research. In the Chincha Valley, flood prevention measures were able to reduce economic damages by up to 64%, demonstrating the economic viability of mitigation strategies [2]. Similarly, in Ghana, the adoption of sustainable agricultural practices significantly reduced climate impacts [3].

These findings are consistent with the study by Haer et al. [4], where cost-benefit analysis was used to identify economically efficient adaptation strategies. In this sense, the application of similar approaches in the Chancay-Lambayeque Valley could optimize investment in water infrastructure and strengthen agricultural resilience in the face of extreme climate events.

3.3 Green infrastructure and its role in climate mitigation

Beyond traditional structural measures, green infrastructure is emerging as a key strategy for risk reduction in urban areas. However, its implementation still faces limitations due to the lack of detailed cost and effectiveness studies. Evaluating its hydrological performance under different climate scenarios would allow optimizing resources and fostering more resilient solutions to mitigate flood impacts [11].

3.4 Implications for risk management and climate adaptation

The results of this study support the importance of integrating cost-benefit analysis into investment planning for climate adaptation. In particular, in the case of the Chancay-Lambayeque Valley, there is a need to strengthen water infrastructure and promote sustainable agricultural strategies to reduce the vulnerability of the productive sector.

In addition, the combination of traditional infrastructure with innovative approaches, such as green infrastructure, could provide more sustainable and cost-effective solutions for climate change mitigation. Therefore, future research should focus on evaluating their effectiveness in different climate scenarios, facilitating their incorporation into territorial planning and public risk management policies.).

4 Conclusions

This study confirms that climate change mitigation strategies generate substantial economic benefits in the Chancay-Lambayeque Valley. The reduction of damages to water infrastructure and agricultural production highlights the relevance of investments in adaptation measures. To strengthen the resilience of the system, it is recommended to evaluate emerging technologies such as green infrastructure and to model higher resolution climate change scenarios. In addition, it is necessary to develop financial mechanisms to facilitate the implementation of these strategies at the regional level.

Future studies should refine climate models by incorporating localized data and improving hydrological accuracy. Long-term economic assessments of climate change impacts on water resources, agriculture, and infrastructure are necessary. The integration of geospatial AI and remote sensing can enhance monitoring and prediction. Research should explore cost-effective adaptation strategies, evaluate policies, and engage stakeholders for effective decision-making. Additionally, socioeconomic vulnerability studies and comparative analyses with similar basins can provide insights into sustainable water resource management and climate adaptation.

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