

Article

Water Poverty Traps: Modeling Heterogeneous Effects of Public Investment and Household Water Expenditure in Different Natural Regions and Poverty Strata in Peru (Cohort 2017 and 2023)

Alex Rengifo Rojas ^{1,*}, Nelino Florida Rofner ^{2,*}, Barland Alfonso Huamán Bravo ¹,
Luis Abanto Morales y Chocano ¹, Miguel Angulo Cárdenas ³, Liliana Vega Jara ⁴, Segismundo Casado Álvarez ⁵
and Jorge Antonio Romero Estacio ⁶

¹ Academic Department of Economic Sciences, National Agrarian University of the Selva, Tingo María 10131, Peru

² Academic Department of Soil and Water Conservation Sciences, National Agrarian University of the Selva, Tingo María 10131, Peru

³ Academic Department of Administrative Sciences, National Agrarian University of the Selva, Tingo María 10131, Peru

⁴ Academic Department of Agrarian Sciences, Hermilio Valdizán National University, Huánuco 10001, Peru

⁵ Academic Department of Agricultural Sciences, National Agrarian University of the Selva, Tingo María 10131, Peru

⁶ Servicio Nacional de Meteorología e Hidrología del Perú (SENAMHI), Huánuco 10001, Peru

* Correspondence: alex.rengifo@unas.edu.pe (A.R.R.); nelino.florida@unas.edu.pe (N.F.R.);
Tel.: +51-949-689-577 (A.R.R.); +51-900-651-979 (N.F.R.)

Abstract

Currently, access to safe drinking water in developing countries remains a structural challenge. Despite progress, many households still lack access to clean and safe water, leading to serious consequences for health, human dignity, and the economy. This research aims to evaluate the impact of drinking water and sanitation investment projects on monetary expenditures for water consumption. Using data from the 2017 and 2023 National Household Survey (ENAH-INEI) in Peru, a longitudinal study with a retrospective cohort design was conducted. The complex, probabilistic sampling method allowed for modeling both periods using ordered multiple response logit regression. The results show that household connections to potable water positively impacted water consumption expenditures in 2017 ($n = 21,251$) and 2023 ($n = 19,482$). Similarly, connections to sanitation facilities positively influenced expenditures in 2017, although no significant evidence was found in 2023. Having access to safe water (adequate chlorine) versus unsafe water (inadequate chlorine) showed a positive effect on consumption expenditures in both years, reflecting that families must bear a double expense to access alternatives such as bottled water. A higher monthly income of the head of household, associated with greater age and years of education, increases expenditures on potable water, excluding households in monetary poverty. A differentiated design of water policies is recommended, based on natural region (coast, highlands, and rainforest) and area (urban or rural), considering the different water access alternatives according to the geographic location of the dwelling.

Keywords: bottled water; water quality; equity; water poverty; ordered logit model



Academic Editor: Fernando António Leal Pacheco

Received: 25 April 2026

Revised: 9 June 2026

Accepted: 10 June 2026

Published: 31 July 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article

distributed under the terms and

conditions of the [Creative Commons](#)

[Attribution \(CC BY\)](#) license.

1. Introduction

In Peru, the National Institute of Statistics and Informatics [1] reports that as of 2024, 93.2% of the urban population had access to drinking water, while in rural areas this figure was only 78.7%. These variations in access can have consequences, especially for children under 5 years of age living in rural areas, who are more exposed to diarrheal diseases due to fecal contamination in drinking water. Despite the efforts of local authorities to improve water quality, these actions have not been effective [2].

Peru is a country with three distinct natural regions: coast, highlands, and rainforest [3], and efforts to achieve uniform investment in drinking water and sanitation have not been very effective. This is evident in the Loreto Region, in the Peruvian rainforest, where households have less access to drinking water and sanitation, lower incomes, and an average birth weight of less than 2.5 kg. Furthermore, there is a high infant mortality rate along with a significant prevalence of diarrheal diseases, dysentery, and shigellosis [4]. In addition, in regions like Puno, poor water quality due to the presence of fecal matter negatively impacts children's health, causing cases of acute diarrhea and a high rate of anemia [5]. Similarly, in Bagua (Amazonas Region), the quality of drinking water is poor due to the presence of total coliforms and *Escherichia coli*, which compromises the health of the population [6]. In two peri-urban areas of Lima, households receive drinking water of good quality and in sufficient quantity; however, poor practices within the home have led to contamination of the water intended for consumption with *Escherichia coli* [7]. Consequently, after improving access to drinking water and sanitation through investment, it is also necessary to incorporate proper hygiene practices by mothers in every household [8].

The provision of drinking water must be planned considering the continuity and quality of service; however, climate change, pollution, the condition of treatment plants, and increased demand pose significant threats to these decisions [9]. For this reason, the supply is continuously affected, making it necessary to have sufficient funding to mitigate this impact [10]. In this context, considering that the water service operates as a natural monopoly, the state is responsible for regulating service provision, guaranteeing its continuity and availability in both rural and urban areas [11]. Drinking water users, in their pursuit of better service, face high adaptation costs due to deficient infrastructure, which can represent up to double their usual bills [12].

Given that the continuity and availability of water service is crucial for public health, as enshrined in the Sustainable Development Goals (SDGs), poor water quality can trigger gastrointestinal infections [13]. In this regard, in addition to access to the service, greater investment in hygiene education, especially for mothers, along with socio-behavioral changes, would contribute to preventing diarrheal diseases in children under five [14]. Consequently, reducing household water consumption is associated with higher school attendance and improved child health [15].

It is important to emphasize that having an adequate water supply and the best sanitation technology does not, in itself, guarantee good health; it is essential that people also have proper education in hygiene habits [16]. These habits, as part of comprehensive education, are fundamental to ensuring the success of investment projects in drinking water and sanitation [17]. The implementation of programs with infrastructure provision reduces the expenses and time spent searching for water [18]. These investments contribute to better infrastructure that ensures greater access in less time and in greater quantity, as well as better quality drinking water, generating economic (reduced consumption costs), social, and environmental benefits (decreased purchase of bottled water) [19]. Public investment policies in drinking water and sanitation are aligned with the SDGs, and due to their positive impact, people are more willing to live in urban areas where economic conditions and infrastructure allow for improved quality of life [20].

The reduction in drinking water costs and improved access to sanitation services not only strengthen the achievement of SDG 6 (Clean Water and Sanitation) but also have a positive impact on SDG 1 (No Poverty) by reducing the financial burden on low-income households. This improvement also contributes to child health by decreasing the incidence of water-related diseases, which aligns with SDG 3 (Good Health and Well-being). Finally, by focusing on rural and peri-urban communities, social equity is promoted and progress is made toward reducing inequalities, consistent with SDG 10 (Reduced Inequalities) [21].

One alternative for the efficient use and supply of drinking water is its reuse in rural areas for purposes unrelated to human consumption. This could reduce household spending on drinking water [22], allowing them to allocate the money saved to food purchases [23]. In this regard, government water policy should focus on poor households, given the impact that socioeconomic conditions have on access to this resource [24]. Another alternative is rainwater harvesting and treatment, which is technically and economically viable through public investment. This ensures a sufficient supply of water in terms of both quantity and quality, thus preventing negative impacts on the socio-environmental context and public health [25].

In this context, this research aims to evaluate the impact of drinking water and sanitation investment projects on household spending on drinking water consumption in Peruvian households between 2017 and 2023, comparing water access and quality in both periods. This manuscript contributes quantitative evidence regarding changes in household spending as a direct economic indicator of the benefits of these interventions. Furthermore, it examines the differences in expenditure variations among households, taking into account geographical heterogeneity (coast, highlands, and rainforest; urban and rural areas) and the complementary role of hygiene practices. This enhances our understanding of the economic mechanisms that link water infrastructure to family well-being, in addition to the already established effects on school attendance, health, and the reduction in inequalities (SDGs 1, 3, 6, and 10).

2. Materials and Methods

2.1. Description of the Data

The study was based on microdata from the National Household Survey on Living Conditions and Poverty (ENAHU), administered by the National Institute of Statistics and Informatics (INEI) of Peru. A longitudinal comparative analysis was conducted between 2017 and 2023 to evaluate the evolution of public investment projects in the provision of drinking water and basic sanitation, taking into account Codes from Modules 1, 3, 5, 7, and 34.

2.2. Sampling Method

The sample design was structured around independent sampling by department, including the constitutional province of Callao, in Peru. A cluster sampling approach was used, based on geographic area: urban and rural.

In urban areas, multistage sampling was applied. The primary sampling unit (stage 1) consisted of populated centers. In stage 2, six geographic strata were defined based on population size (expressed in thousands): 0.5–2, 2–20, 20–50, 50–100, 100–500, and 500 or more inhabitants. Finally, in stage 3, dwellings constituted the tertiary sampling unit.

In rural areas, two selection methods were considered. The first, corresponding to the simple rural census area, included populated centers with a population (expressed in thousands) of 0.5 to 2 inhabitants, characterized by widely dispersed dwellings. In this case, the design was two-stage: the primary sampling units (stage 1) were agricultural or livestock production units, and the secondary sampling units (stage 2) were dwellings. The

second method, specific to the composite rural census area, corresponded to clusters of grouped dwellings and followed a multi-stage design: in stage 1, hamlets or communities were selected; in stage 2, groups of streets or roads; and in stage 3, dwellings.

Overall, the sampling design is complex and probabilistic, since all dwellings had a known and non-zero probability of being selected. Additionally, the expansion factor 07 was applied to extrapolate the results obtained in the sample of homes to the total population of Peru. The sample consisted of 21,251 households in 2017 [26] and 19,482 households in 2023 [27].

Figure 1 shows the study area, which comprises the 25 departments that make up the Peruvian territory, located in South America. These departments are distributed across the three natural regions: coast, highlands, and rainforest. The Peruvian territory exhibits marked heterogeneity both at the departmental level and among natural regions with respect to access to, quality of, and cost of drinking water services.

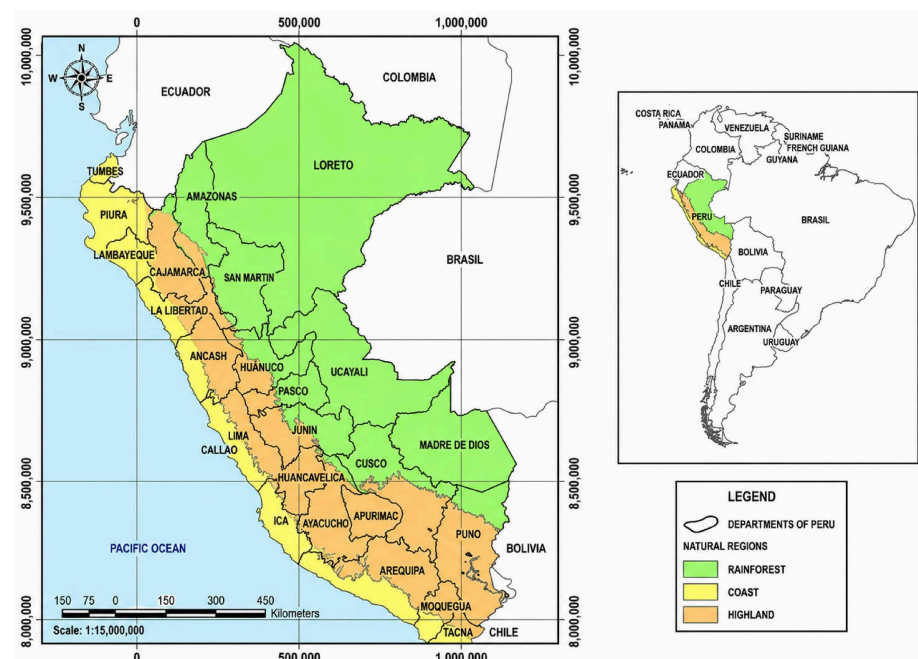


Figure 1. Study area: 25 political departments of Peru, distributed in the three natural regions (coast, highlands and rainforest).

2.3. Definition of Variables

To measure the level of monetary expenditure on drinking water consumption (Table 1), the most recent payment on the dedicated drinking water bill was used as a reference. As shown in Figure 6A,B, deflated expenditures were used. Once the values were adjusted for inflation, the corresponding real costs for 2017 and 2023 were analyzed. For this purpose, expenditure levels were classified based on a non-central tendency measure, specifically using quartiles.

Table 1. Operational definition of the study variables: Typology, indicators and description.

Variable Type	Indicator Name	Description	Module Code [26,27]
Dependent: Expenditure on drinking water consumption.	Level of monthly monetary expenditure in soles allocated to drinking water consumption per household (NG)	Characterizes the level of monthly monetary expenditure in pens allocated to drinking water consumption per household. It takes five values: No expenditure (NG = 0), low expenditure (NG = 1), medium expenditure (NG = 2), high expenditure (NG = 3) and very high expenditure (NG = 4).	Module 1: d1172_01

Table 1. Cont.

Variable Type	Indicator Name	Description	Module Code [26,27]
Independent 1: Intervention of the public investment project in drinking water and sanitation.	Potable water connection in the home (AP)	Dimension 1. Access to service. The indicator takes two values: (i) 1, if the dwelling has a drinking water connection; and (ii) 0, it does not.	Module 1: p110a1
	Connection to sanitary facilities in the home (CSH)	Dimension 1. Access to the service. The indicator takes two values: (i) 1, if the dwelling has a connection to sanitary services; and (ii) 0, it does not.	Module 1: p111a
	Availability of safe water in the home (AS)	Dimension 2. Service availability. The indicator takes two values: (i) 1, if the dwelling has access to safe water with an adequate concentration of chlorine; and (ii) 0, otherwise.	Module 1: p110a
	Availability of unsafe water in the home (AnS)	Dimension 2. Service availability. The indicator takes two values: (i) 1, if the dwelling has unsafe water available with an inadequate concentration of chlorine; and (ii) 0, otherwise.	Module 1: p110a
	Continuity of water service in the home (AC)	Dimension 2. Service availability. The indicator takes two values: (i) 1, if the dwelling has continuity of water service with daily and permanent supply (24 h); and (ii) 0, otherwise.	Module 1: p110c
Independent 2 (Control Variable): Socioeconomic-demographic factors	Monetary expenditure on bottled water (AEm)	Dimension 1. Socioeconomic factors. Monthly monetary expenditure in pens on bottled water.	Module 7: p601b1 p601b2 p601c
	Average monetary income of the head of household (IM)	Dimension 1. Socioeconomic factors. Average monthly monetary income in pens of the head of household.	Module 5: p523 p524a1
	Sex of the head of household (Sex)	Dimension 1. Socioeconomic factors. The indicator takes two values: (i) 1, if the head of the household is male; and (ii) 0, if female.	Module 3: p207
	Age of head of household (Age)	Dimension 1. Socioeconomic factors. Age in years of the head of household.	Module 3: p208a
	Years of education of the head of household (AEs)	Dimension 1. Socioeconomic factors. Years of education of the head of household.	Module 3: p301a
	Household with at least one child aged 6 to 12 (HM)	Dimension 1. Socioeconomic factors. The indicator takes two values: (i) 1, if there is at least one child between 6 and 12 years old in the household and attends school; and (ii) 0, otherwise.	Module 1: nbi4
	Adequate physical condition of the dwelling (CF)	Dimension 1. Socioeconomic factors. The indicator takes two values: (i) 1, adequate physical condition of the dwelling; and (ii) 0, otherwise.	Module 1: nbi1
	Absence of overcrowding in housing (VsH)	Dimension 1. Socioeconomic factors. The indicator takes two values: (i) 1, absence of overcrowding in the dwelling; and (ii) 0, otherwise.	Module 1: nbi2
	Economically dependent housing (VDE)	Dimension 1. Socioeconomic factors. The indicator takes two values: (i) 1, housing with economic dependence; and (ii) 0, otherwise.	Module 1: nbi5
	Household in extreme poverty (EP)	Dimension 1. Socioeconomic factors. The indicator takes two values: (i) 1, the household is in extreme poverty; and (ii) 0, otherwise.	Module 34: pobreza
	Household in non-extreme poverty (PnE)	Dimension 1. Socioeconomic factors. The indicator takes two values: (i) 1, the household is in non-extreme poverty; and (ii) 0, otherwise.	Module 34: pobreza
	Housing located on the north coast (CN)	Dimension 2. Demographic factors. The indicator takes two values: (i) 1, the dwelling is located on the north coast of the country; and (ii) 0, otherwise.	Module 1: dominio
	Housing located on the central coast (CC)	Dimension 2. Demographic factors. The indicator takes two values: (i) 1, the dwelling is located on the central coast of the country; and (ii) 0, otherwise.	Module 1: dominio
	Housing located on the south coast (CS)	Dimension 2. Demographic factors. The indicator takes two values: (i) 1, the dwelling is located on the southern coast of the country; and (ii) 0, otherwise.	Module 1: dominio
	Housing located in the northern mountains (SN)	Dimension 2. Demographic factors. The indicator takes two values: (i) 1, the dwelling is located in the northern highlands of the country; and (ii) 0, otherwise.	Module 1: dominio
	Housing located in the central highlands (SC)	Dimension 2. Demographic factors. The indicator takes two values: (i) 1, the dwelling is located in the central highlands of the country; and (ii) 0, otherwise.	Module 1: dominio
	Housing located in the southern highlands (SS)	Dimension 2. Demographic factors. The indicator takes two values: (i) 1, the dwelling is located in the southern highlands of the country; and (ii) 0, otherwise.	Module 1: dominio
	House located in the rainforest (Rainforest)	Dimension 2. Demographic factors. The indicator takes two values: (i) 1, the dwelling is located in the rainforest of the country; and (ii) 0, otherwise.	Module 1: dominio
	Housing located in an urban area (AU)	Dimension 2. Demographic factors. The indicator takes two values: (i) 1, the dwelling is located in an urban area of the country; and (ii) 0, rural area.	Module 1: estrato

2.4. Regression Model with Limited Dependent Variable

2.4.1. Specification and Marginal Effects Analysis of the Model

According to the nature of the dependent variable, which is discrete and of ordered multinomial choice, a modeling based on latent regression is chosen [28], as expressed in Equation (1):

$$NG^* = X'\beta + \varepsilon \quad (1)$$

Starting from the latent variable NG^* , not directly observable, the observable variable NG is defined by means of a censoring mechanism, described in Equation (2):

$$NG = \begin{cases} NG = 0 & \text{si } NG^* < \mu_1, \\ NG = 1 & \text{si } \mu_1 \leq NG^* < \mu_2, \\ NG = 2 & \text{si } \mu_2 \leq NG^* < \mu_3, \\ NG = 3 & \text{si } \mu_3 \leq NG^* \leq \mu_4, \\ NG = 4 & \text{si } NG^* > \mu_4 \end{cases} \quad (2)$$

In this scheme, μ_1 , μ_2 , μ_3 and μ_4 represent unknown thresholds that must be estimated jointly with the parameter vector β . Thus, the variable NG depends both on the observable independent variables X and on an unobservable stochastic component ε .

This study employs an ordered response probability model to analyze the impact of public investment projects in drinking water and sanitation on the level of monthly monetary expenditure on water consumption between 2017 and 2023. The specification incorporates control variables that capture heterogeneities in household behavior, considering both the socioeconomic characteristics of the head of household and national demographic factors. Equation (3) presents the empirical formulation corresponding to the systematic component of Equation (1):

$$\begin{aligned} X'\beta = & \beta_0 + \beta_1 AP_i + \beta_2 CSH_i + \beta_3 AS_i + \beta_4 AnS_i + \beta_5 AC_i + \beta_6 LnAEm_i + \beta_7 LnIM_i + \\ & \beta_8 Sex_i + \beta_9 LnAge_i + \beta_{10} AEs_i + \beta_{11} HM_i + \beta_{12} CF_i + \beta_{13} VsH_i + \beta_{14} VDE_i + \beta_{15} PE_i + \\ & \beta_{16} PnE_i + \beta_{17} CN_i + \beta_{18} CC_i + \beta_{19} CS_i + \beta_{20} SN_i + \beta_{21} SC_i + \beta_{22} SS_i + \beta_{23} Rainforest_i + \\ & \beta_{24} AU_i + \varepsilon_i \end{aligned} \quad (3)$$

where $i = 1, 2, \dots, n$ indexes each head of household in the sample. In order to linearize relationships and correct asymmetries in the distribution, a logarithmic transformation was applied to the variables of monetary income (IM_i), Age (Age_i) and another relevant variable (AEm_i). The β s are estimated using the maximum likelihood method (β_{MV}).

From Equations (1) and (2), the probabilities corresponding to the ordered response model are derived, using a probit or logit link function, as presented in Equation (4):

$$\begin{aligned} \text{Prob}[NG = 0/X] &= \varphi(-X'\beta), \\ \text{Prob}[NG = 1/X] &= \varphi(\mu_2 - X'\beta) - \varphi(-X'\beta), \\ \text{Prob}[NG = 2/X] &= \varphi(\mu_3 - X'\beta) - \varphi(\mu_2 - X'\beta), \\ \text{Prob}[NG = 3/X] &= \varphi(\mu_4 - X'\beta) - \varphi(\mu_3 - X'\beta), \\ \text{Prob}[NG = 4/X] &= 1 - \varphi(\mu_4 - X'\beta) \end{aligned} \quad (4)$$

where $\varphi(\cdot)$ denotes the cumulative distribution function of the standard normal or logistic distribution in the case of the probit or logit model. Furthermore, the following condition must be strictly met to guarantee that all resulting probabilities are positive: $0 < \mu_1 < \mu_2 < \mu_3 < \mu_4$.

To interpret the estimated β coefficients, the marginal effects derived from changes in the explanatory variables X are used [29], which are expressed in Equations (5) and (6):

Case of a quantitative independent variable:

$$\begin{aligned}\frac{\partial \text{Prob}[\text{NG}=0/X]}{\partial X_k} &= \varphi(-X'\beta), \\ \frac{\partial \text{Prob}[\text{NG}=1/X]}{\partial X_k} &= [\varphi(-X'\beta) - \varphi(\mu_1 - X'\beta)]\beta, \\ \frac{\partial \text{Prob}[\text{NG}=2/X]}{\partial X_k} &= [\varphi(\mu_1 - X'\beta) - \varphi(\mu_2 - X'\beta)]\beta, \\ \frac{\partial \text{Prob}[\text{NG}=3/X]}{\partial X_k} &= [\varphi(\mu_2 - X'\beta) - \varphi(\mu_3 - X'\beta)]\beta, \\ \frac{\partial \text{Prob}[\text{NG}=4/X]}{\partial X_k} &= \varphi(\mu_3 - X'\beta)\beta.\end{aligned}\quad (5)$$

Qualitative independent variable case:

$$\begin{aligned}\frac{\Delta \text{Prob}[\text{NG}=0/X]}{\Delta X_k} &= \text{Prob}[\text{NG} = 0/X_k = 1] - \text{Prob}[\text{NG} = 0/X_k = 0], \\ \frac{\Delta \text{Prob}[\text{NG}=1/X]}{\Delta X_k} &= \text{Prob}[\text{NG} = 1/X_k = 1] - \text{Prob}[\text{NG} = 1/X_k = 0], \\ \frac{\Delta \text{Prob}[\text{NG}=2/X]}{\Delta X_k} &= \text{Prob}[\text{NG} = 2/X_k = 1] - \text{Prob}[\text{NG} = 2/X_k = 0], \\ \frac{\Delta \text{Prob}[\text{NG}=3/X]}{\Delta X_k} &= \text{Prob}[\text{NG} = 3/X_k = 1] - \text{Prob}[\text{NG} = 3/X_k = 0], \\ \frac{\Delta \text{Prob}[\text{NG}=4/X]}{\Delta X_k} &= \text{Prob}[\text{NG} = 4/X_k = 1] - \text{Prob}[\text{NG} = 4/X_k = 0].\end{aligned}\quad (6)$$

2.4.2. Goodness-of-Fit Tests for Model Selection

Several goodness-of-fit tests are useful for selecting the appropriate model between Logit and Probit specifications. According to McFadden [30] and Poston et al. [31], the McFadden coefficient of determination (pseudo R^2_{McF}) is a measure of the fit of the regression model with a multiple-response dependent variable, whose expression is presented in Equation (7):

$$R^2_{\text{McF}} = 1 - \frac{\ln(L_M)}{\ln(L_0)} \quad (7)$$

where $\ln(L_M)$ represents the logarithm of the likelihood of the model estimated under the logit or probit specifications, $\ln(L_0)$ is the logarithm of the likelihood of the null model that only includes the intercept. R^2_{McF} values within the interval [0.2, 0.4] indicate an excellent fit.

To evaluate the goodness of fit of the selected model, the approach proposed by Korn and Graubard [32]. was used. They employ Wald's F-statistic with degrees of freedom in the numerator ($df_1 = k - J + 1$), where k is the total number of estimated parameters and J is the number of equations, and degrees of freedom in the denominator ($df_2 = N - k - J + 2$), where N is the total number of clusters. This test allows us to determine whether the set of independent variables exerts a statistically significant influence on the dependent variable, making it particularly suitable for surveys with complex sample designs. In this context, the cluster was considered to be the specific common area defined by department, province, and district; the strata were the geographic strata based on population size and rural area; and finally, the expansion factor was 07.

In addition, the information criteria of Akaike [33], Schwarz [34], and Hannan-Quinn [35] are used, which allow the identification of the best-fitting model by presenting the lowest value when comparing the logit and probit specifications. Their respective expressions are presented in Equations (8)–(10).

$$\text{AIC} = -2\ln(L_M) + 2k \quad (8)$$

$$\text{SIC} = -2\ln(L_M) + k\ln(n) \quad (9)$$

$$\text{HQIC} = -2\ln(L_M) + 2k\ln(\ln(n)) \quad (10)$$

2.4.3. Robustness of the Chosen Model

To ensure that the selected ordered logit model is robust, with unbiased and consistent estimates, it is necessary to compare it with a generalized ordered logit model that assumes proportional probabilities or parallel lines [36]. For this purpose, the Wald parallel lines test proposed by Brant [37] is used, which estimates a dichotomous response logit model for each level “j” of the ordinal dependent variable. The hypotheses are as follows:

Null hypothesis (H_0): $\beta_j = \beta$

Alternate hypothesis (H_a): $\beta_j \neq \beta$

The contrast is based on the Chi-square statistic with R degrees of freedom ($df = R$), where R represents the total number of restrictions derived from the parallel-line comparisons. The null hypothesis (H_0) is accepted when the p -value is greater than the established significance level ($\text{Prob}[\chi^2 > \chi^2_C / df = R] > \alpha$). This indicates that the ordered logit model maintains the informative ordinal structure; however, considering this type of model when rejecting H_0 leads to erroneous conclusions about the significance of the predictors [38].

2.5. Econometric Tools and Software

The ENAHO-INEI microdata were processed, cleaned, and analyzed, including the variable design, using the econometric software Stata 15 (64-bit) (StataCorp LLC, College Station, TX, USA). First, adjustments were made to the complex sample design using the “svyset” command, as suggested by West et al. [39]. This configuration considered clusters as the primary sampling units, specifically dwellings located in provinces and departments, followed by geographic strata, and finally, sample weights based on the expansion factor provided by INEI. These weights ensure representativeness at the departmental, national, and domain of study levels. The Stata configuration was as follows: “svyset cluster [pweight = factor07], strata(stratum)”, taking into account Kolenikov [40]. Consequently, standard errors and hypothesis tests were calculated considering stratification and clustering using the Taylor series linearization method proposed by Wolter [41]. Second, the prefix “svy” was used to estimate the ordered logit and ordered probit regression models, respecting the sample design, using the configurations: “svy: ologit [independent variables]” and “svy: oprobit [independent variables]” [42,43]. The command “gologit2” was also used to estimate the generalized ordered logit model at different levels [36]. Third, given the difficulty in directly interpreting the coefficients, marginal effects were calculated using the command “mfx compute, predict(outcome(‘i’))” [42].

2.6. Ethical Considerations and Replicability

Regarding ethics, this research is based on the analysis of secondary microdata from the National Household Survey (ENAHO), a publicly accessible and free resource provided by the National Institute of Statistics and Informatics (INEI) of Peru. The ENAHO is an official survey whose public version does not include personally identifiable information of respondents, such as names, addresses, or identification numbers, thus guaranteeing the anonymity of data at the household level and for each of its members [26,27]. Furthermore, the survey did not involve any intervention with human subjects, no primary data was collected, and review by an ethics committee of the National Agrarian University of the rainforest or any other institution was not required. Therefore, the authors declare that they have strictly complied with the terms of use established by the INEI, which has allowed for the development of this scientific research, provided that the official source is cited. Regarding reproducibility, in accordance with the principles of open science and

replicability standards, all the complete commands of the analysis performed in Stata are made available as Supplementary Material.

2.7. Methodological Limitations

The manuscript presents several methodological limitations inherent to the research design and the use of the National Household Survey (ENAH). First, measurement biases inherent to household surveys may exist, which could affect the magnitude of point estimates. This is because variables such as water consumption expenditure, income, and other factors are subject to underreporting, recall error, and social desirability bias, even despite the quality controls implemented by the National Institute of Statistics and Informatics (INEI). Second, while the ENAH is designed to be representative at the urban/rural, departmental, and national levels, it lacks representativeness at the local or district level without specific adjustments. Furthermore, the survey does not include people experiencing homelessness or those residing in collective households (such as prisons, barracks, or clinics). It also does not include Indigenous populations in contact with Indigenous peoples living in very difficult-to-access areas, which limits the generalizability of the results to these groups. Third, the comparison between 2017 and 2023 encompasses the period of the COVID-19 pandemic, which implies a likely structural disruption in the variables of monetary income, survey logistics, and household behavior. It was not possible to directly estimate the effect of these changes; however, in the Supplementary Material, we present sensitivity analyses that assess the robustness of the results to non-response bias and economic shocks. The main findings remain unchanged under prudent assumptions.

3. Results

3.1. Descriptive Analysis Between 2017 and 2023

Figure 2 shows access to and availability of drinking water services in Peruvian households between 2017 and 2023, differentiating between rural and urban areas. Regarding connections to the drinking water system (Figure 2A), it can be observed that in urban areas, 16,874 households (79.40%) had connections in 2017, while in 2023 the figure was 15,293 households (78.50%). In rural areas, the number of households with connections remained relatively stable: 928 (4.37%) in 2017 and 926 (4.75%) in 2023. These data show virtually unchanged coverage in rural areas, but a slight decrease in urban areas. At the opposite extreme, the number of homes without a connection to the service increased in urban areas from 1676 (7.89%) in 2017 to 1739 (8.93%) in 2023; while in rural areas they decreased from 1773 (8.34%) in 2017 to 1524 (7.82%) in 2023. These results reflect an increase in the lack of connection in urban areas during the analyzed period, attributable to insufficient infrastructure and the disorderly growth of these areas.

Regarding the availability of safe drinking water (Figure 2B), defined as an adequate concentration of free residual chlorine between 0.5 and 3.4 mg/L, it was observed that, in urban areas, 7981 households (37.56%) in 2017 and 7819 (40.13%) in 2023 reported having access to it. In rural areas, only 94 households (0.44%) in 2017 and 162 (0.83%) in 2023 reported this condition. These figures show a relative increase in both urban and rural areas, which could be attributed to sufficient monitoring at treatment plants and distribution networks, greater availability of chemical inputs for continuous disinfection, and adequate infrastructure. Additionally, the number of homes without access to safe drinking water decreased in urban areas from 10,569 (49.73%) in 2017 to 9213 (47.29%) in 2023, and in rural areas from 2607 (12.27%) to 2288 (11.74%) during the same period.

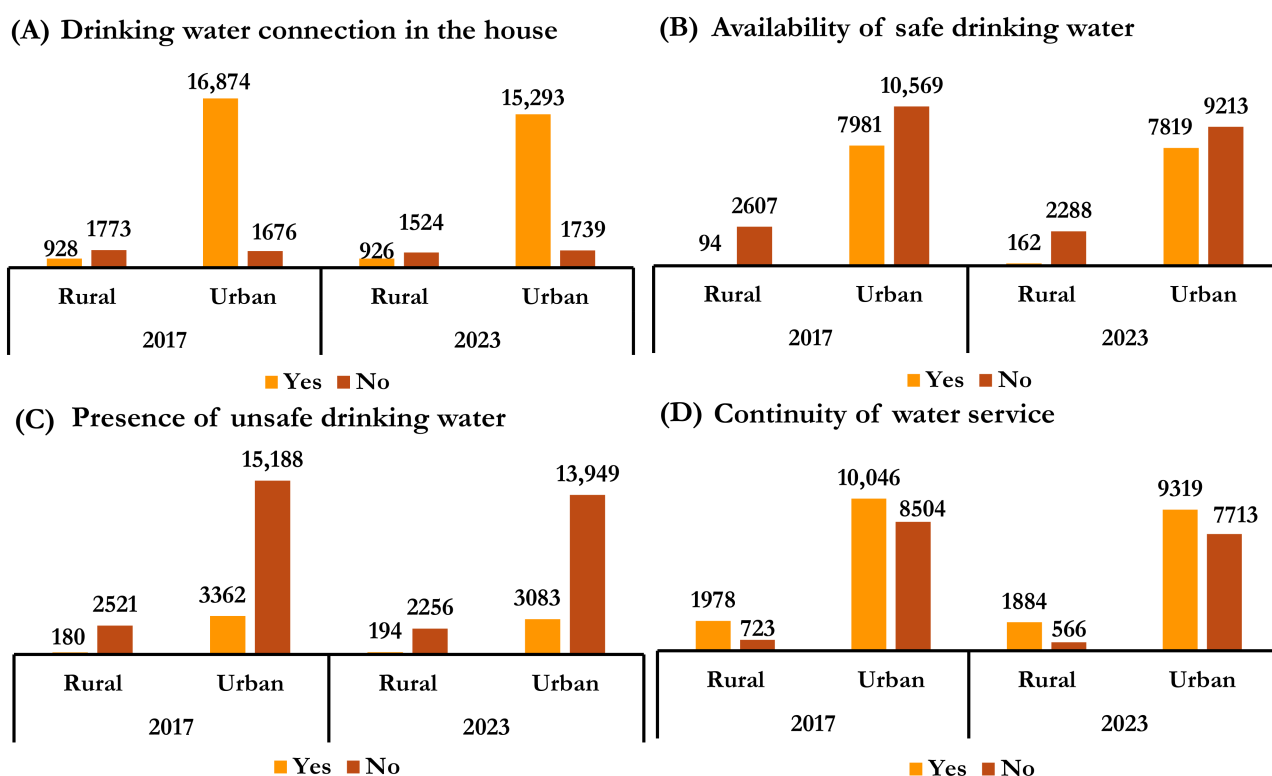


Figure 2. Access to service (A) and availability of drinking water service (B–D) in Peru for the years 2017 and 2023. Source: ENAHO-INEI [26,27].

Figure 2C shows the presence of unsafe drinking water, characterized by inadequate chlorine dosage (0.1 to 0.4 mg/L). In this context, the percentage of unsafe drinking water in urban areas remained relatively stable at 3362 households (15.82%) in 2017 and 3083 (15.82%) in 2023; while in rural areas it increased from 180 households (0.85%) in 2017 to 194 (1.00%) in 2023. This data on unsafe drinking water reflects a low level of investment that hinders the renewal of chlorination systems. This investment remains low when analyzing the situation of those homes that do not have any amount of chlorine dosage in the water, represented for the urban area of 7207 (33.91%) in 2017 and 6130 (31.46%) in 2023, and for the rural area of 2427 (11.42%) in 2017 and 2094 (10.75%) (these values are obtained by subtracting the “No” response from Figure 2C and the “Yes” response from Figure 2B).

Finally, regarding the continuity of water service (Figure 2D), defined as the supply of potable water 24 h a day, it was observed that in urban areas, 10,046 homes (47.27%) in 2017 and 9319 (47.83%) in 2023 had this benefit. In rural areas, number was 1978 (9.31%) in 2017 and 1884 (9.67%) in 2023. These values show a minimal improvement in service continuity, with an increase of less than 1% in both areas, which is associated with aging infrastructure, high water losses, and low levels of public investment in sanitation. This situation is reinforced by observing that, in the urban area, the number of non-continuous dwellings decreased slightly from 8504 (40.02%) in 2017 to 7713 (39.59%) in 2023; while in the rural area they went from 723 (3.40%) to 566 (2.91%) in the same period.

Figure 3A,B show bottled water consumption by household members, while Figure 3C,D present the average monthly monetary income of the head of household. In 2017, the average consumption $\pm$ standard deviation was 10.63 ± 37.47 L per month in rural areas and 42.10 ± 105.08 L per month in urban areas. By 2023, this consumption had increased to 14.01 ± 60.58 L per month in rural areas and 45.91 ± 125.81 L per month in urban areas. Regarding monetary income, in 2017, monthly income was recorded at 796.17 ± 718.18 pens in rural areas and 1519.26 ± 4050.51 pens in urban areas. In 2023, these numbers increased

to 1054.93 ± 944.23 pens per month in rural areas and to 1843.90 ± 4373.28 pens per month in urban areas. Comparing these average values reveals a positive correlation between increased bottled water consumption and improved income, highlighting the inadequacy of public investment in drinking water and sanitation.

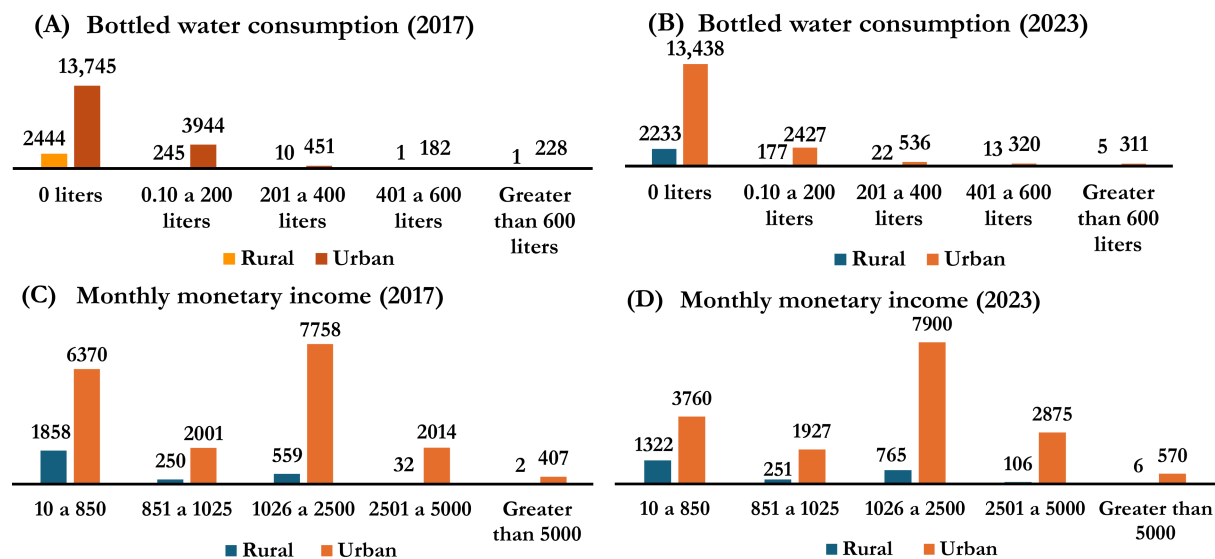


Figure 3. Bottled water consumption (in liters), 2017 (A) and 2023 (B), and monthly monetary income (in pen), 2017 (C) and 2023 (D), in Peru. Source: ENAHO-INEI [26,27].

A closer look at Figure 3A,B reveals that, in rural areas, the number of households whose members did not consume bottled water decreased from 2444 (11.50%) in 2017 to 2233 (11.46%) in 2023. In urban areas, the number of households without bottled water consumption fell from 13,745 (64.68%) in 2017 to 13,438 (68.98%) in 2023. Overall, the percentage of households not consuming bottled water increased from 76.18% to 80.44% between 2017 and 2023. Furthermore, in rural areas, the number of households consuming between 0.10 and 200 L of bottled water decreased from 245 (1.15%) in 2017 to 177 (0.91%). In 2023, this group decreased from 3944 (18.56%) to 2427 (12.46%) in urban areas during the same period. Regarding consumption exceeding 200 L, the number of households in rural areas rose from 12 (0.06%) in 2017 to 40 (0.21%) in 2023, while in urban areas it increased from 861 (4.05%) to 1167 (5.99%).

According to Figure 3C,D, the monthly monetary income of heads of household in rural areas was more homogeneous in 2017 than in 2023. In 2017, in rural areas, 1858 households (8.74%) reported monthly incomes between 10 and 850 pens, and 843 (3.97%) reported incomes exceeding 850 pens. In 2023, however, 1322 households (6.79%) received monthly incomes between 10 and 850 pens, 1016 (5.22%) had incomes between 851 and 2500 pens, and 112 (0.57%) had incomes exceeding 2500 pens per month.

In urban areas, the distribution of household head income shows a similar pattern between 2017 and 2023. The most frequent group is that with incomes between 1026 and 2500 pens per month, with 7758 households (36.51%) in 2017 and 7900 (40.55%) in 2023. The second most important group is that with incomes from 10 to 850 pens per month, with 6370 households (29.98%) in 2017 and 3760 (19.30%) in 2023. Next, incomes from 2501 to 5000 pens per month are recorded in 2014 households (9.48%) in 2017 and 2875 (14.76%) in 2023; incomes of 851 to 1025 pens in 2001 homes (9.42%) in 2017 and 1927 (9.89%) in 2023; finally, incomes above 5000 pens per month in 407 homes (1.92%) in 2017 and 570 (2.93%) in 2023.

Figure 4 summarizes the characteristics of heads of household in Peru for the years 2017 and 2023, disaggregated by age (panels A and B) and years of schooling (panels

C and D). Since the same units of analysis are used in both periods, the comparisons reflect changes within the same population cohort. In rural areas, the average age of the head of household was 34.84 ± 14.94 years in 2017, with minimal variation in 2023 (34.28 ± 14.89 years). In urban areas, the average ages were 39.75 ± 14.55 years (2017) and 40.22 ± 14.92 years (2023). Regarding years of schooling, in rural areas the average was 7.86 ± 4.16 years (2017) and 8.58 ± 3.99 years (2023); while in urban areas it was 11.62 ± 4.00 years (2017) and 11.69 ± 3.90 years (2023).

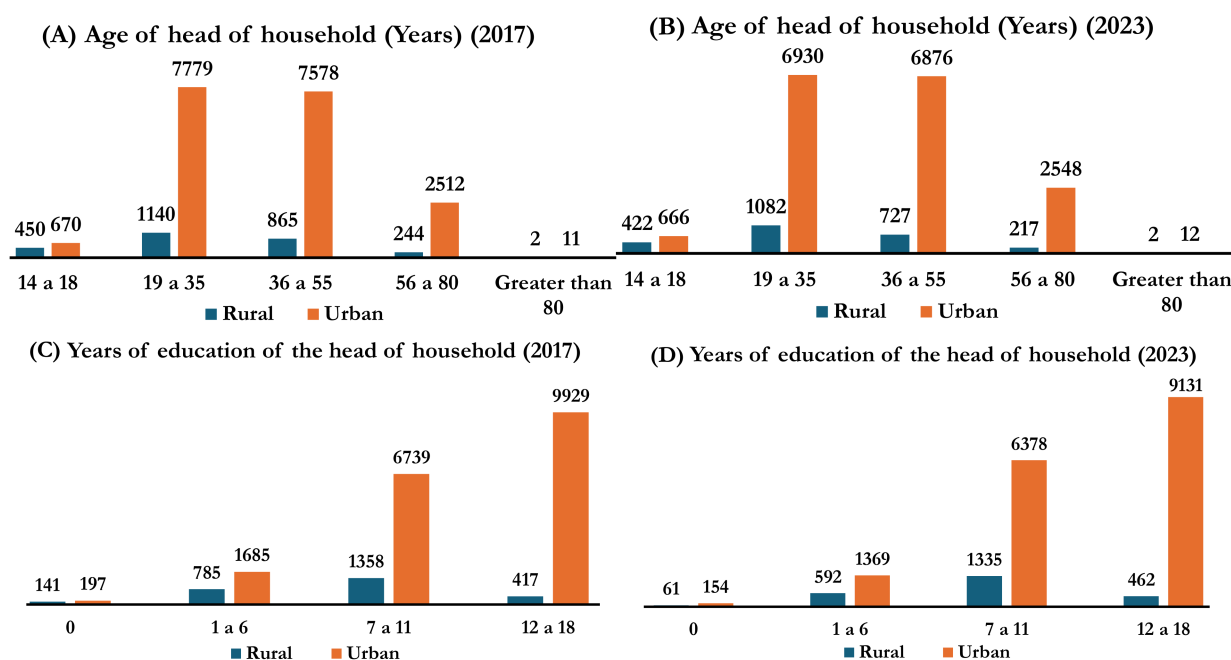


Figure 4. Characteristics of the head of household according to age group, 2017 (A) and 2023 (B), and according to years of study, 2017 (C) and 2023 (D) in Peru. Source: ENAHO-INEI [26,27].

A more detailed analysis of age (Figure 4A,B) shows that the predominant age group was 19 to 35 years, with 1140 households (5.36%) in rural areas and 7779 (36.61%) in urban areas in 2017; in 2023, these numbers were 1082 (5.55%) and 6930 (35.57%), respectively. The next largest group was the 36–55 age group: 865 rural dwellings (4.07%) and 7578 urban dwellings (35.66%) in 2017; and 727 rural dwellings (3.73%) versus 6876 urban dwellings (35.29%) in 2023. In the 56–80 age range, there were 244 rural dwellings (1.15%) and 2512 urban dwellings (11.82%) in 2017; and 217 rural dwellings (1.11%) versus 2548 urban dwellings (13.08%) in 2023. For the 14–18 age group, there were 450 rural dwellings (2.12%) and 670 urban dwellings (3.15%) in 2017; and 422 rural (2.17%) compared to 666 urban (3.42%) in 2023. Finally, heads of households over 80 years old were scarce: 2 rural and 11 urban homes in 2017; and 2 rural versus 12 urban in 2023.

Regarding years of schooling (Figure 4C,D), in urban areas, heads of household with 12 to 18 years of education stood out: 9929 households (46.72%) in 2017 and 9131 (46.87%) in 2023. They were followed by those with 7 to 11 years of schooling: 6739 households (31.71%) in 2017 and 6378 (32.74%) in 2023. In contrast, the lowest educational levels in urban areas corresponded to 1 to 6 years of schooling (1685 households, 7.93% in 2017; 1369, 7.03% in 2023) and no years of schooling (197 households, 0.93% in 2017; 154, 0.79% in 2023). In rural areas, the pattern was reversed: the highest frequencies were concentrated in the lower educational levels. Thus, for the 7–11-year age group, 1358 homes (6.39%) were recorded in 2017 and 1335 (6.85%) in 2023; for the 1–6-year age group, 785 homes (3.69%) in 2017 and 592 (3.04%) in 2023. The lowest frequencies in rural areas corresponded

to 12–18 years of schooling (417 homes, 1.96% in 2017; 462, 2.37% in 2023) and no schooling (141 homes, 0.66% in 2017; 61, 0.31% in 2023).

Figure 5 presents a comparison of housing characteristics in Peru between 2017 and 2023. In Figure 5A, which refers to sanitation service connections, it can be observed that the number of homes without this service is small. In rural areas, 354 homes (1.67%) were recorded in 2017, while that number decreased slightly to 193 (0.99%) in 2023. In urban areas, homes without connections experienced a similar trend, going from 369 (1.74%) in 2017 to 317 (1.63%) in 2023. At the opposite extreme, the number of homes with sanitation service connections increased relatively and slightly in rural areas, from 2347 (11.04%) in 2017 to 2257 (11.59%) in 2023. And in the urban area from 18,181 (85.55%) to 16,715 (85.80%) in the same period.

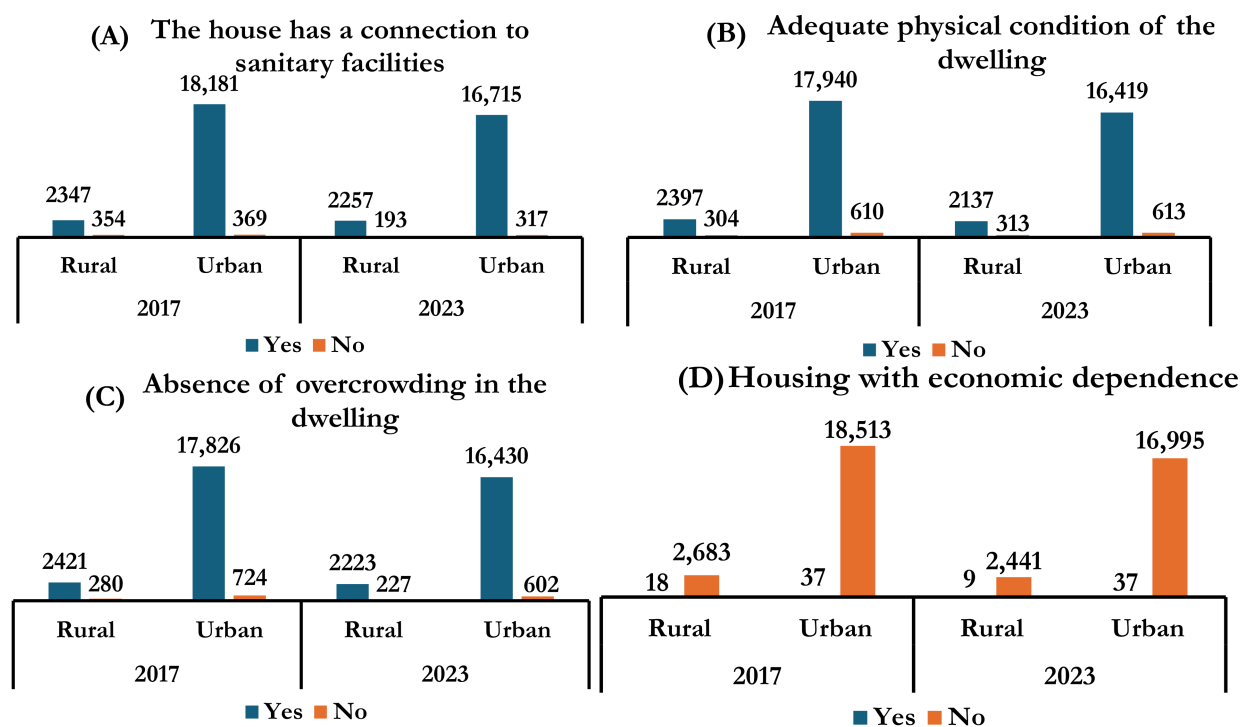


Figure 5. Housing characteristics: sanitation facilities (A), adequacy (B), overcrowding (C), and economic dependence (D) of households in Peru, 2017 and 2023. Source: ENAHO-INEI [26,27].

Regarding Figure 5B, which shows the adequate physical condition of housing (floors and walls with durable materials), an increase in the proportion of homes with inadequate conditions is identified. In rural areas, these increased from 304 (1.43%) in 2017 to 313 (1.61%) in 2023; in urban areas, from 610 (2.87%) to 613 (3.15%). However, the majority of homes have durable materials. In rural areas, the number of physically adequate homes decreased from 2397 (11.28%) in 2017 to 2137 (10.97%) in 2023; in urban areas, however, they remained relatively stable, decreasing from 17,940 (84.42%) to 16,419 (84.28%).

Figure 5C illustrates the condition of no overcrowding (fewer than 3.4 people per room). In rural areas, the number of dwellings without overcrowding remained relatively stable, at 2421 (11.39%) in 2017 and 2223 (11.41%) in 2023; in urban areas, they increased in relative terms, from 17,826 (83.88%) to 16,430 (84.33%). On the other hand, overcrowded dwellings in rural areas decreased from 280 (1.32%) in 2017 to 227 (1.17%) in 2023; likewise, in urban areas they decreased slightly from 724 (3.41%) to 602 (3.09%).

Figure 5D shows that economic dependency is infrequent in both rural and urban areas. Households with economic dependency represented 18 (0.08%) in 2017 and 9 (0.05%) in 2023 in rural areas, and 37 (0.17%) in 2017 and also 37 (0.19%) in 2023 in urban areas.

In contrast, households without economic dependency remained relatively stable in rural areas, with 2683 (12.63%) in 2017 and 2441 (12.53%) in 2023, as well as in urban areas, where they also remained practically stable in relative terms, with 18,513 (87.12%) and 16,995 (87.23%).

In 2017, the number of households that did not allocate part of their income to drinking water consumption was 1977 (9.30%) in rural areas and 2163 (10.18%) in urban areas (Figure 6A). By 2023, this number had decreased to 1721 (8.83%) in rural areas and increased to 2409 (12.37%) in urban areas (Figure 6B).

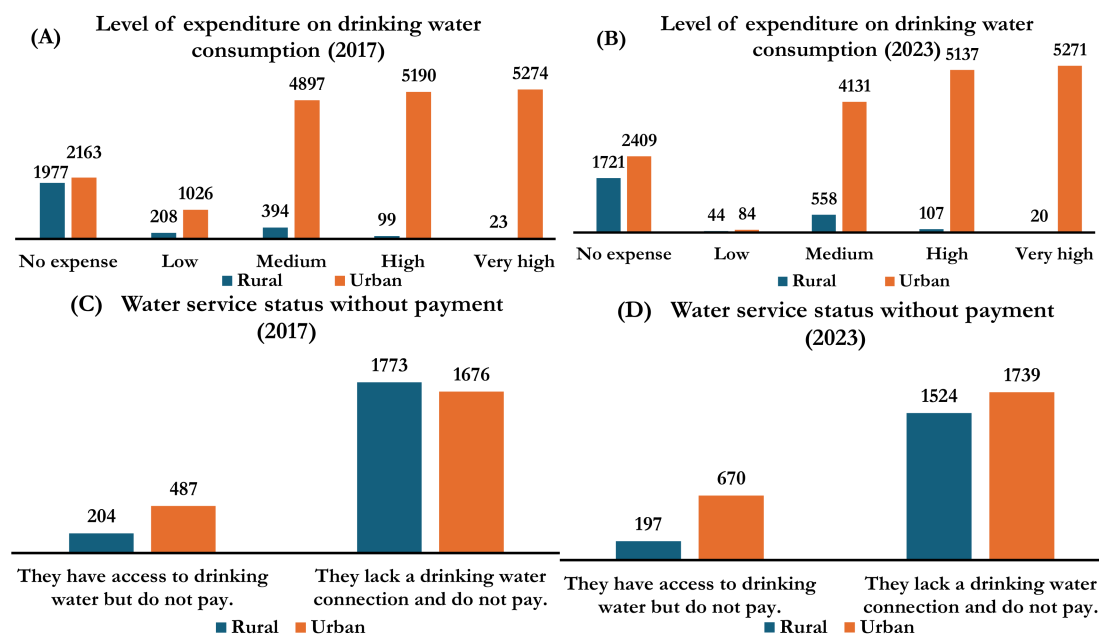


Figure 6. Distribution of the level of monetary expenditure on drinking water in Peru, 2017 (A) and 2023 (B), and situation of the drinking water service and payment for housing in Peru, 2017 (C) and 2023 (D). Note: Expenditure ranges, in pens, are defined as: No expense (0), Low (1–61 in 2017; 1–33 in 2023), Medium (62–218; 34–211), High (219–425; 212–480), and Very High (>425; >480). Source: ENAHO-INEI [26,27].

Analyzing Figure 6C,D, it is evident that among the homes lacking a water connection and making no payments, 1773 (42.83%) in rural areas were located in 2017, a number that decreased to 1524 (36.90%) in 2023. These homes obtain their water from alternative sources such as springs, rivers, or similar sources. On the other hand, as shown in Figure 6C,D, the remaining 204 homes (4.93%) in 2017, which decreased to 197 (4.77%) in 2023, correspond to homes with access to potable water but which do not make any payments, primarily because they belong to community organizations. In the urban area the 1676 homes (40.48%) that lacked a drinking water connection and did not make any payments in 2017 increased slightly to 1739 (42.11%) in 2023. Likewise, the 487 homes (11.76%) in 2017 that had drinking water and did not make any payments increased to 670 (16.22%) in 2023, mainly supplied by tanker trucks, wells, springs or bottled water.

Regarding households with drinking water expenditure (Figure 6A,B), the low expenditure level included 208 rural dwellings (0.98%) in 2017, a number that decreased to 44 (0.23%) in 2023; in urban areas, it fell from 1026 (4.83%) to 84 (0.43%) during the same period. At the medium expenditure level, rural dwellings increased from 394 (1.85%) in 2017 to 558 (2.86%) in 2023, while in urban areas they decreased from 4897 (23.04%) to 4131 (21.20%). For the high expenditure level, in rural areas it increased from 99 (0.47%) to 107 (0.55%); in contrast, in urban areas, the number increased in relative terms, rising from 5190 (24.42%) to 5137 (26.37%). Finally, at the very high expenditure level, rural

households remained practically stable, with 23 (0.11%) in 2017 and 20 (0.10%) in 2023, while in urban areas they increased relatively, from 5274 (24.82%) to 5271 (27.06%). The increase at certain levels reflects a greater proportion of expenditure due to the limited availability of alternative services, while the decrease at others reflects a growing adoption of alternative consumption options, such as bottled water, albeit to a lesser extent.

3.2. Statistical and Microeconomic Inference

Table 2 shows the estimates of the Logit and Probit models using data from 2017 and 2023, according to the goodness-of-fit tests. For both years, when comparing the two models (Logit versus Probit), the Logit model shows a better fit to the data, with higher Pseudo R^2_{McF} values: 22.56% for 2017 and 37.20% for 2023. This indicates an excellent fit in explaining the variation in the independent variables on the probability of drinking water expenditure, compared to the values of the Probit model (21.93% for 2017 and 36.66% for 2023). Additionally, the Wald F-statistic confirms that the coefficients of the Logit model are jointly significant ($F_w = 98.64$, p -value < 0.01 for 2017; $F_w = 68.56$, p -value < 0.01 for 2023). Similarly, the Probit model also shows statistical relevance ($F_w = 108.03$, p -value < 0.01 for 2017; $F_w = 78.21$, p -value < 0.01 for 2023). To reinforce the choice of the Logit model, the values of the logarithm of the maximum likelihood function (ML) are compared, being higher in the Logit model ($ML = -25.41$ for 2017 and $ML = -22.26$ for 2023) compared to the Probit model ($ML = -25.52$ for 2017 and $ML = -22.45$ for 2023). Similarly, the information criteria of Akaike, Schwarz, and Hannan-Quinn ultimately determine that the Logit model is superior to the Probit model. This is evidenced by the lower values of 50.88, 51.1073, and 50.9570 compared to the 2017 values of 51.3027, 51.5257, and 51.3754, respectively. Likewise, the Logit model is considered superior to Probit because it has lower values in the Akaike, Schwarz, and Hannan-Quinn criteria of 44.5764, 44.7970, and 44.6486, compared to the 2023 values of 44.9619, 45.1825, and 45.0342.

Table 2. Goodness of fit tests for the choice of the drinking water expenditure model (ordered level) in Peru, 2017 and 2023.

Goodness-of-Fit Tests	Logit Model		Probit Model	
	2017	2023	2017	2023
McFadden coeff. of determination (Pseudo R^2_{McF})	0.2256	0.3720	0.2193	0.3666
Calculated Wald F statistic: F_w	98.64	68.56	108.03	78.21
Prob[$F \geq F_w/df_1 = k - J + 1$ and $df_2 = N - k - J + 2$]	0.0000 ***	0.0000 ***	0.0000 ***	0.0000 ***
Maximum likelihood logarithm (MLL) (in thousands)	−25.4141	−22.2602	−25.6233	−22.4530
Information criteria				
Akaike (in thousands)	50.8843	44.5764	51.3027	44.9619
Schwarz (in thousands)	51.1073	44.7970	51.5257	45.1825
Hannan-Quinn (in thousands)	50.9570	44.6486	51.3754	45.0342

*** $p < 0.01$.

According to the results in Table 3, the Wald test for the parallel lines assumption yielded a calculated Chi-square statistic of 14.34 for the ordered logit model corresponding to 2017, and 3.19 for the 2023 model. The associated probability values (p -value = 0.1109 for 2017 and p -value = 0.3627 for 2023) exceed the significance level $\alpha = 0.05$, leading to the failure to reject the null hypothesis (H_0) of proportionality of the odds. Consequently, the parallel lines assumption is confirmed for both years, thus validating the robustness of the ordered logit model compared to more flexible specifications such as the generalized ordered logit. These findings support the conclusion that the ordinal structure of the dependent variable remains informationally adequate, and that the estimates of the multiple-response ordered logit model are predictively reliable.

Table 3. Wald test on the parallel lines assumption for the ordered logit model of drinking water expenditure in Peru, 2017 and 2023.

Test	2017	2023
Calculated Chi-square statistic [χ^2_C]	14.34	3.19
Prob[$\chi^2 > \chi^2_C / df = R$]	0.1109	0.3627

The results presented in Table 4 show the effect of the coefficients associated with independent variable 1 (Intervention of the public investment project in drinking water and sanitation) and independent variable 2 (Socioeconomic and demographic factors) on the probability of monetary expenditure on drinking water consumption by households in Peru.

Table 4. Ordered logit model of drinking water expenditure in Peru, 2017 and 2023.

Independent Variable	Spending Level	
	2017	2023
Variable 1: Intervention of the public investment project in drinking water and sanitation		
Dimension 1: Access to the service		
Drinking water connection in the dwelling (Yes = 1 and No = 0)	1.6471 ***	1.3656 ***
Connection of sanitary services in the dwelling (Yes = 1 and No = 0)	0.6686 ***	−0.0133
Dimension 2: Service Availability		
Availability of safe water (Yes = 1 and No = 0)	0.6375 ***	0.7251 ***
Presence of unsafe water (Yes = 1 and No = 0)	0.4365 ***	0.4017 ***
Continuity of water service (Yes = 1 and No = 0)	0.0491	0.0229
Variable 2: Socioeconomic-demographic factors		
Dimension 1: Socioeconomic factors		
Monthly expenditure on bottled water (pens)	0.0802 ***	0.0432 **
Monthly monetary income of the head of household (pens)	0.2056 ***	0.1107 ***
Sex of the head of household (Male = 1 and Female = 0)	−0.1284 ***	−0.0676
Age of the head of household (Years)	0.1883 ***	0.3616 ***
Education of the head of household (Years)	0.0724 ***	0.0828 ***
Child aged 6 to 12 attending school (Yes = 1 and No = 0)	0.6302 *	−0.2148
Adequate physical condition of the dwelling (Yes = 1 and No = 0)	0.3113 **	0.1237
Absence of overcrowding in the dwelling (Yes = 1 and No = 0)	0.4029 ***	0.1873
Dwelling with economic dependence (Yes = 1 and No = 0)	0.2303	1.1772 ***
Extreme poverty (Yes = 1 and No = 0)	−0.5029	−0.5092 ***
Non-extreme poverty (Yes = 1 and No = 0)	−0.3296 ***	−0.1841 **
Dimension 2: Demographic factors		
North Coast (Yes = 1 and No = 0)	−0.8646 ***	−0.7391 ***
Central Coast (Yes = 1 and No = 0)	−1.2591 ***	−1.1679 ***
South Coast (Yes = 1 and No = 0)	−1.7250 ***	−1.2213 ***
North Highlands (Yes = 1 and No = 0)	−2.2107 ***	−1.6099 ***
Central Highlands (Yes = 1 and No = 0)	−2.4663 ***	−2.0922 ***
South Highlands (Yes = 1 and No = 0)	−2.1338 ***	−1.8912 ***
Rainforest (Yes = 1 and No = 0)	−1.3007 ***	−1.0879 ***
Urban Area (Yes = 1 and No = 0)	1.5863 ***	1.5586 ***
Cutting point		
Cut 1	4.7249 ***	3.2690 ***
Cut 2	5.2509 ***	3.3140 ***
Cut 3	6.9623 ***	4.8521 ***
Cut 4	8.5225 ***	6.4661 ***
Number of geographic strata (S)	8	8
Number of clusters per department (N)	4375	4303
Sample size (n)	21,251	19,482
McFadden coefficient of determination (Pseudo R^2_{McF})	0.2256	0.3720
Calculated F-Fisher statistic: F_C	98.64	68.56
Prob[$F \geq F_C / df_1 = k - (J - 1)$ and $df_2 = N - k - (J - 2)$]	0.0000 ***	0.0000 ***

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Regarding independent variable 1, within Dimension 1 (access to the service), consider the year 2017. In that year, the connection to drinking water and sanitation facilities in the home had a positive impact on the category with the highest probability of spending on drinking water. This impact was statistically significant (p -value < 0.01). By 2023, the connection to drinking water maintained a positive and significant impact at the 1% level (p -value < 0.01), while the connection to sanitation facilities did not reach statistical significance at the conventional level (p -value > 0.10). This does not allow us to reject the null hypothesis of no effect, but neither does it establish evidence of inefficiency or diminishing returns.

Regarding Dimension 2 (service availability), the coefficients for safe water availability and the presence of unsafe water have a positive impact, placing homes in the highest expenditure category with a significance of 1% (p -value < 0.01) for 2017 and 2023. In contrast, the water service continuity coefficient is not statistically significant (p -value > 0.10) in either 2017 or 2023.

Turning to the second independent variable, in Dimension 1 (socioeconomic factors), monthly expenditure on bottled water for 2017 and 2023 is statistically significant at the 1% and 5% levels (p -value < 0.01 and p -value < 0.05 , respectively), positively impacting and placing the probability in the highest expenditure category for drinking water. Monthly monetary income, age, and years of education of the head of household show similar behavior, with positive and significant impacts at the 1% level (p -value < 0.01) in both years.

Regarding the sex of the head of household (male = 1), a negative impact is observed, placing the probability in the lowest spending category for 2017 (significant at the 1% level), while for 2023, no statistical significance is evident (p -value > 0.10). The indicators of children aged 6 to 12 attending school, adequate physical condition of the dwelling, and absence of overcrowding show a positive impact for 2017, with significance levels of 10%, 5%, and 1% (p -value < 0.10 , p -value < 0.05 , and p -value < 0.01), respectively; however, for 2023, these effects lack statistical significance (p -value > 0.10). The indicators for housing with economic dependency and extreme poverty show no significance for 2017 (p -value > 0.10); however, for 2023, housing with economic dependency shows a positive impact (probability in the highest category) and extreme poverty a negative impact (probability in the lowest category), both with a significance level of 1% (p -value < 0.01). Meanwhile, the non-extreme poverty indicator shows a negative and statistically significant impact at the 1% level for 2017 and at the 5% level for 2023 (p -value < 0.01 and p -value < 0.05 , respectively), placing the probability in the lowest expenditure category.

In Dimension 2 (demographic factors), housing located in coastal, highland, and rainforest regions has a negative impact, with a significance level of 1% (p -value < 0.01), on the probability of the lowest expenditure category for 2017 and 2023. In contrast, urban location has a positive impact, also at a 1% significance level, on the probability of the highest expenditure category.

The model of drinking water consumption expenditure includes five categories, implying four cutoff points, which are presented in Table 4 for 2017 and 2023, all statistically significant at the 1% level (p -value < 0.01). Additionally, the model fit is excellent according to the criteria of McFadden [28] and Poston et al. [29], with pseudo R^2 values of 0.2256 for 2017 and 0.3720 for 2023. Likewise, the model is relevant, as evidenced by Fisher's F -statistic values: 98.64 (2017) and 68.56 (2023), which confirm that the variables significantly explain the probability of drinking water consumption expenditure at the 1% level (p -value < 0.01).

3.3. Impact Effect Analysis Using Elasticities

Table 5 presents two types of findings. The first corresponds to the probability of a household falling into a specific drinking water consumption expenditure category. The second refers to the quantification of the impact of each indicator belonging to a dimension and independent variable on the probability of belonging to each expenditure category. The following results were obtained:

Table 5. Impact effect through elasticities of the level of expenditure on drinking water in Peru, 2017.

Variable Independiente	No Expenditure	Low	Medium	High	Very High
	Prob[NG = j/X]				
	0.0681	0.0419	0.2964	0.3588	0.2348
Variable 1: Intervention of the public investment project in drinking water and sanitation					
Dimension 1: Access to the service					
Drinking water connection in the dwelling (Yes = 1 and No = 0)	−0.1839 ***	−0.0724 ***	−0.1277 ***	0.1822 ***	0.2018 ***
Sanitary service connection in the dwelling (Yes = 1 and No = 0)	−0.0560 ***	−0.0274 ***	−0.0820 ***	0.0656 ***	0.0999 ***
Dimension 2: Service Availability					
Availability of safe water (Yes = 1 and No = 0)	−0.0397 ***	−0.0215 ***	−0.0904 ***	0.0352 ***	0.1164 ***
Presence of unsafe water (Yes = 1 and No = 0)	−0.0246 ***	−0.0137 ***	−0.0634 ***	0.0176 ***	0.0841 ***
Continuity of water service (Yes = 1 and No = 0)	−0.0031	−0.0017	−0.0070	0.0031	0.0088
Variable 2: Socioeconomic-demographic factors					
Dimension 1: Socioeconomic factors					
Monthly expenditure on bottled water (pens)	−0.0051 ***	−0.0028 ***	−0.0115 ***	0.0049 ***	0.0144 ***
Monthly monetary income of the head of household (pens)	−0.0130 ***	−0.0071 ***	−0.0295 ***	0.0127 ***	0.0369 ***
Sex of the head of household (Male = 1 and Female = 0)	0.0081 ***	0.0044 ***	0.0184 ***	−0.0077 ***	−0.0232 ***
Age of the head of household (Years)	−0.0120 ***	−0.0065 ***	−0.0270 ***	0.0116 ***	0.0338 ***
Education of the head of household (Years)	−0.0046 ***	−0.0025 ***	−0.0104 ***	0.0045 ***	0.0130 ***
Child aged 6 to 12 attending school (Yes = 1 and No = 0)	−0.0525	−0.0258	−0.0778 **	0.0616	0.0945 **
Adequate physical condition of the dwelling (Yes = 1 and No = 0)	−0.0224 **	−0.0117 **	−0.0425 ***	0.0250 **	0.0516 ***
Absence of overcrowding in the dwelling (Yes = 1 and No = 0)	−0.0300 ***	−0.0154 ***	−0.0540 ***	0.0341 **	0.0653 ***
Dwelling with economic dependence (Yes = 1 and No = 0)	−0.0132	−0.0074	−0.0335	0.0103	0.0438
Extreme poverty (Yes = 1 and No = 0)	0.0396	0.0200	0.0650	−0.0461	−0.0784
Non-extreme poverty (Yes = 1 and No = 0)	0.0235 ***	0.0123 ***	0.0452 ***	−0.0260 ***	−0.0550 ***
Dimension 2: Demographic factors					
North Coast (Yes = 1 and No = 0)	0.0726 ***	0.0353 ***	0.1047 ***	−0.0830 ***	−0.1297 ***
Central Coast (Yes = 1 and No = 0)	0.1282 ***	0.0554 ***	0.1193 ***	−0.1390 ***	−0.1639 ***
South Coast (Yes = 1 and No = 0)	0.2169 ***	0.0768 ***	0.0965 ***	−0.2018 ***	−0.1884 ***
North Highlands (Yes = 1 and No = 0)	0.3201 ***	0.0897 ***	0.0536 **	−0.2512 ***	−0.2123 ***
Central Highlands (Yes = 1 and No = 0)	0.3545 ***	0.0953 ***	0.0610 ***	−0.2668 ***	−0.2440 ***
South Highlands (Yes = 1 and No = 0)	0.2712 ***	0.0899 ***	0.1092 ***	−0.2326 ***	−0.2377 ***
Rainforest (Yes = 1 and No = 0)	0.1323 ***	0.0571 ***	0.1230 ***	−0.1425 ***	−0.1699 ***
Urban Area (Yes = 1 and No = 0)	−0.1817 ***	−0.0706 ***	−0.1170 ***	0.1805 ***	0.1888 ***

*** $p < 0.01$, ** $p < 0.05$

In Peru, during 2017, the average household had a 6.81% probability of not incurring any drinking water consumption expenditure. Likewise, the probabilities of incurring low, medium, high, and very high expenditure were 4.19%, 29.64%, 35.88%, and 23.48%, respectively.

Regarding the impact of access to the service, all indicators were statistically significant at the 1% level (p -value < 0.01). Regarding access to potable water in the home, compared to those without the service, the probability of not spending on potable water decreases by 18.39%. This decrease is further reduced by 7.24% for the low level and by 12.77% for the

medium level. Conversely, this probability increases by 18.22% for the high level and by 20.18% for the very high level. Similarly, having access to sanitary facilities in the home, compared to other situations, reduces the probability of not spending on potable water by 5.60%, of having low spending by 2.74%, and of medium spending by 8.20%. Meanwhile, it increases the probability of high spending by 6.56% and of very high spending by 9.99%.

Regarding the impact of service availability, the indicator of safe water availability compared to those without it shows statistical significance at the 1% level (p -value < 0.01). Thus, the probability of not spending on drinking water decreases by 3.97%; the probability of low spending decreases by 2.15%; and the probability of medium spending decreases by 9.04%. Conversely, the probability of high spending increases by 3.52% and the probability of very high spending by 11.64%. In the case of unsafe water, the probability of not spending on drinking water decreases by 2.46%; the probability of low spending decreases by 1.37%; and the probability of medium spending decreases by 6.34%. Meanwhile, the probability of high spending increases by 1.76% and the probability of very high spending increases by 8.41%. Both indicators are statistically significant at the 1% level (p -value < 0.01). However, for the water service continuity indicator, no statistically significant evidence was found at the 10% level (p -value > 0.10) to support an impact on drinking water consumption levels.

Regarding socioeconomic factors, several indicators comprise this dimension. The first is monthly spending on bottled water: a 1% increase in this category has an impact effect that reduces the probability of not spending on drinking water by 0.51%, low spending by 0.28%, and medium spending by 1.15%; conversely, it increases the probability of high spending by 0.49% and very high spending by 1.44%. Next, analyzing the monthly monetary income of the head of household, a 1% increase decreases the probability of not spending on drinking water by 1.30%, low spending by 0.71%, and medium spending by 2.95%; while increasing the probability of high spending by 1.27% and very high spending by 3.69%. Regarding the sex of the head of household (male versus female), an impact effect is observed that increases the probability of not allocating funds to drinking water by 0.81%, low spending by 0.44%, and medium spending by 1.84%; conversely, it reduces the probability of high spending by 0.77% and very high spending by 2.32%. All these analyses show statistical significance at the 1% level (p -value < 0.01).

Other indicators, such as the age and years of education of the head of household, exhibit similar behavior with statistical significance at the 1% level. Thus, a 1% increase in age leads to a decrease in the probability of not spending on drinking water by 1.20%, of low spending by 0.65%, and of medium spending by 2.70%; while it increases the probability of high spending by 1.16% and that of very high spending by 3.38%. Similarly, a 1% increase in years of education reduces the probability of not spending on drinking water by 0.46%, of low spending by 0.25%, and of medium spending by 1.04%; and increases the probability of high spending by 0.45% and that of very high spending by 1.30%.

Regarding the presence in the household of a child aged 6 to 12 who attends school, this variable is statistically significant at the 5% level (p -value < 0.05). Specifically, it achieves an effect that reduces the probability of medium drinking water expenditure by 7.78% and increases the probability of very high expenditure by 9.45%. However, no statistical evidence (p -value > 0.10) is found for an effect on the remaining expenditure categories.

Indicators such as adequate physical condition of the dwelling and the absence of overcrowding show statistical significance at the 1% (p -value < 0.01) and 5% (p -value < 0.05) levels, with similar relationships. Consequently, for dwellings in adequate physical condition, the impact effect reduces the probability of not spending on drinking water by 2.24%, the probability of low expenditure by 1.17%, and the probability of medium expenditure

by 4.25%. The probability of high spending increases by 2.50%, and the probability of very high spending by 5.16%. Similarly, the absence of overcrowding in the home reduces the probability of not spending on drinking water by 3.00%, of low spending by 1.54%, and of medium spending by 5.40%; and increases the probability of high spending by 3.41% and of very high spending by 6.53%.

The condition of not being in extreme poverty has a statistically significant influence at the 1% level (p -value < 0.01) in all spending categories. Thus, the probability of not spending on drinking water increases by 2.35%, the probability of low spending by 1.23%, and the probability of medium spending by 4.52%; while the probability of high spending decreases by 2.60% and the probability of very high spending by 5.50%. Conversely, indicators of housing with economic dependency and extreme poverty do not show a statistically significant impact at the 10% level (p -value > 0.10) on the probability of the drinking water consumption expenditure categories.

Regarding demographic factors, all indicators comprising this dimension show a statistically significant impact at the 1% level (p -value) on the probability of the drinking water consumption expenditure categories. Thus, households located on the coast, in the highlands, and in the rainforest show a directly proportional relationship with the categories of no expenditure, low expenditure, and medium expenditure, and an inverse relationship with the categories of high and very high expenditure. Households in the northern and central highlands register the highest probabilities of not allocating any expenditure to drinking water (32.01% and 35.45%, respectively), compared to the other natural regions. In contrast, homes on the northern coast have a 7.26% probability, those on the central coast a 12.82% probability, and those in the rainforest a 13.23% probability—lower values compared to other regions regarding the non-allocation of funds to drinking water.

In the low expenditure category, homes on the northern coast have a lower probability (3.53%) of allocating funds to drinking water, while those in the Central Highlands have a higher probability (9.53%). In the medium expenditure category, homes in the northern highlands have the lowest probability (5.36%) and those in the rainforest the highest (12.30%). Considering the negative correlation, homes on the northern coast have a lower probability of allocating funds in the high (8.30%) and very high (12.97%) categories to drinking water; meanwhile, homes in the central highlands exhibit the highest probabilities in the high (26.68%) and very high (24.40%) expenditure categories.

The urban area where the dwelling is located has a significant influence (p -value < 0.01) across the different categories of drinking water expenditure. Thus, the probability of no drinking water expenditure is 18.17% lower; low expenditure, 7.06% lower; and medium expenditure, 11.70% lower. Conversely, the probability is 18.05% higher for high expenditure and 18.88% higher for very high expenditure.

Table 6 presents the estimated impact effects of each independent variable on the probability of belonging to the different drinking water consumption expenditure categories in Peru in 2023, along with the estimated average probabilities for each expenditure level. According to the results, an average household in 2023 has a 10.92% probability of not incurring any drinking water expenditure, while the probabilities of incurring low, medium, high, and very high expenditure are 0.45%, 26.02%, 37.61%, and 25.00%, respectively.

Regarding Variable 1, specifically Dimension 1 (access to the service), with respect to the indicator of drinking water connection in the household, it is observed that this reduces the probability (p -value < 0.01) of not incurring any drinking water expenditure by 19.32%. Furthermore, the effect is statistically significant (p -value < 0.01) for the different spending categories, reducing spending in the low and medium levels with probabilities of 0.54% and 13.01%, respectively, while increasing spending in the high and very high categories with probabilities of 13.56% and 19.31%. However, the connection of sanitary facilities in

the dwelling does not show statistical significance (p -value > 0.10) in explaining the impact effect on the probability of the spending categories.

Table 6. Estimated impact on the level of expenditure on drinking water in Peru, 2023.

Variable Independiente	No Expenditure	Low	Medium	High	Very High
	Prob[NG = j/X]				
	0.1092	0.0045	0.2602	0.3761	0.2500
Variable 1: Intervention of the public investment project in drinking water and sanitation					
Dimension 1: Access to the service					
Drinking water connection in the dwelling (Yes = 1 and No = 0)	−0.1932 ***	−0.0054 ***	−0.1301 ***	0.1356 ***	0.1931 ***
Sanitary service connection in the dwelling (Yes = 1 and No = 0)	0.0013	0.0001	0.0018	−0.0006	−0.0025
Dimension 2: Service Availability					
Availability of safe water (Yes = 1 and No = 0)	−0.0700 ***	−0.0025 ***	−0.0949 ***	0.0303 ***	0.1370 ***
Presence of unsafe water (Yes = 1 and No = 0)	−0.0352 ***	−0.0013 ***	−0.0538 ***	0.0101 ***	0.0802 ***
Continuity of water service (Yes = 1 and No = 0)	−0.0022	−0.0001	−0.0030	0.0011	0.0043
Variable 2: Socioeconomic-demographic factors					
Dimension 1: Socioeconomic factors					
Monthly expenditure on bottled water (pens)	−0.0042 **	−0.0001 **	−0.0058 **	0.0020 **	0.0081 **
Monthly monetary income of the head of household (pens)	−0.0108 ***	−0.0004 ***	−0.0148 ***	0.0052 ***	0.0208 ***
Sex of the head of household (Male = 1 and Female = 0)	0.005 *	0.0002	0.009	−0.0031 *	−0.0127
Age of the head of household (Years)	−0.0352 ***	−0.0013 ***	−0.0482 ***	0.0168 ***	0.0678 ***
Education of the head of household (Years)	−0.0081 ***	−0.0003 ***	−0.0110 ***	0.0039 ***	0.0155 ***
Child aged 6 to 12 attending school (Yes = 1 and No = 0)	0.0192	0.0007	0.0289	−0.0064	−0.0424
Adequate physical condition of the dwelling (Yes = 1 and No = 0)	−0.0126	−0.0004	−0.0163	0.0068	0.0225
Absence of overcrowding in the dwelling (Yes = 1 and No = 0)	−0.0195	−0.0007	−0.0245	0.0111	0.0336
Dwelling with economic dependence (Yes = 1 and No = 0)	−0.0730 ***	−0.0028 ***	−0.1429 ***	−0.0507	0.2695 ***
Extreme poverty (Yes = 1 and No = 0)	0.0598 **	0.0020 **	0.0626 ***	−0.0407 **	−0.0836 ***
Non-extreme poverty (Yes = 1 and No = 0)	0.0188 **	0.0007 **	0.0243 **	−0.0102 *	−0.0335 **
Dimension 2: Demographic factors					
North Coast (Yes = 1 and No = 0)	0.0888 ***	0.0029 ***	0.0884 ***	−0.0607 ***	−0.1195 ***
Central Coast (Yes = 1 and No = 0)	0.1656 ***	0.0047 ***	0.1137 ***	−0.1200 ***	−0.1639 ***
South Coast (Yes = 1 and No = 0)	0.1811 ***	0.0050 ***	0.1098 ***	−0.1321 ***	−0.1638 ***
North Highlands (Yes = 1 and No = 0)	0.2628 ***	0.0062 ***	0.1087 ***	−0.1826 ***	−0.1952 ***
Central Highlands (Yes = 1 and No = 0)	0.3579 ***	0.0073 ***	0.1046 ***	−0.2289 ***	−0.2409 ***
South Highlands (Yes = 1 and No = 0)	0.3076 ***	0.0070 ***	0.1214 ***	−0.2038 ***	−0.2322 ***
Rainforest (Yes = 1 and No = 0)	0.1476 ***	0.0044 ***	0.1132 ***	−0.1060 ***	−0.1591 ***
Urban Area (Yes = 1 and No = 0)	−0.2437 ***	−0.0061 ***	−0.1194 ***	0.1703 ***	0.1989 ***

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Regarding Dimension 2 (service availability), the indicators for the availability of safe water and the presence of unsafe water are statistically significant at the 1% level (p -value < 0.01). Specifically, having access to safe water reduces the probability of not spending on drinking water by 7.00%, while the presence of unsafe water reduces it by 3.52%. As for the different spending categories, the availability of safe water decreases low and medium spending by 0.25% and 9.49%, respectively; conversely, it increases high and very high spending by 3.03% and 13.70%, respectively. Regarding the presence of unsafe water, it reduces low and medium spending by 0.13% and 5.38%, respectively; however, it increases high and very high spending by 1.01% and 8.02%, respectively. Conversely, the water service continuity indicator does not show statistical significance (p -value > 0.10); therefore, it is not possible to attribute an impact effect on the probability of the drinking water expenditure categories.

Regarding socioeconomic factors, it was found that a 1% increase in monthly bottled water expenditure reduces the probability of not allocating any expenditure to drinking water by 0.42%, an effect significant at the 5% level (p -value < 0.05). In this same (negative) relationship, and with statistical significance (p -value < 0.05), monthly bottled water expenditure reduces drinking water expenditure in the low and middle socioeconomic levels with probabilities of 0.01% and 0.58%, respectively; conversely, drinking water expenditure increases in the high and very high socioeconomic levels with probabilities of 0.20% and 0.81%, respectively.

A 1% increase in the monthly monetary income of the head of household decreases the probability of not spending by 1.08% (p -value < 0.01). It also reduces the probability in the low and medium spending categories by 0.04% and 1.48%, respectively, and increases the probability in the high and very high spending categories by 0.52% and 2.08%. The fact that the head of household is male, compared to female, increases the probability of not spending on drinking water by 0.50% and decreases the probability in the high drinking water spending category by 0.31%, although these effects only reach significance at the 10% level (p -value < 0.10). Conversely, no statistically significant effects are observed in the other spending categories (p -value > 0.10).

Meanwhile, a 1% increase in the age of the head of household reduces the probability of not spending on drinking water by 3.52% (p -value < 0.01). Regarding the other categories of drinking water expenditures, the effects are also statistically significant (p -value < 0.01): they reduce the probability at the low level by 0.13% and at the medium level by 4.82%, and increase the probability at the high level by 1.68% and at the very high level by 6.78%. As for years of education, with statistical relevance (p -value < 0.01), a 1% increase in years of education reduces the probability of not spending on drinking water by 0.81%; the same occurs with a probability of 0.03% at the low expenditure level and 1.10% at the medium level. While it incentivizes an increase in probability of 0.39% for the high level and 1.55% for the very high level.

The indicator related to the presence of a child aged 6 to 12 attending school is not statistically significant (p -value > 0.10); therefore, an impact effect on the probability of the drinking water expenditure categories cannot be established. Similarly, adequate housing conditions and the absence of overcrowding do not reach statistical significance (p -value > 0.10). In contrast, households with economic dependency show a significant effect at the 1% level (p -value < 0.01), reducing the probability of not spending on drinking water by 7.30%; likewise, it decreases the probability in the low water expenditure category by 0.28% and in the medium category by 14.29%, and increases the probability in the very high expenditure category by 26.95%. No evidence of a significant effect at the 10% level (p -value > 0.10) was found in the high spending category.

Regarding poverty conditions, both extreme and non-extreme poverty are statistically significant at different levels. Specifically, being in extreme poverty increases the probability (p -value < 0.05) of not spending on drinking water by 5.98% and increases the probability (p -value < 0.05 for low spending; p -value < 0.01 for medium spending) of spending on water in the low category by 0.20% and in the medium category by 6.26%; while it reduces the probability (p -value < 0.05 for high spending; p -value < 0.01 for very high spending) of spending on drinking water in the high category by 4.07% and in the very high category by 8.36%. According to the non-extreme poverty status, this increases the probability (p -value < 0.05) of not allocating funds to drinking water by 1.88%, as well as in the very low expenditure category by 0.07% and in the medium expenditure category by 2.43%. However, it reduces the probability (p -value < 0.10 for high expenditure; p -value < 0.05 for very high expenditure) in the high expenditure category by 1.02% and in the very high expenditure category by 3.35%.

In Dimension 2 of demographic factors, all regional indicators and the area of residence are statistically significant at the 1% level (p -value < 0.01). Households located on the north coast, central coast, south coast, northern highlands, central highlands, southern highlands, and in the rainforest show positive effects on the probability of not spending on drinking water, with magnitudes of 8.88%, 16.56%, 18.11%, 26.28%, 35.79%, 30.76%, and 14.76%, respectively. These results indicate that, compared to the reference region, residing in any of these geographic areas increases the probability that the household will not spend money on drinking water. Conversely, urban areas show a negative and significant effect at the 1% level: residing in urban areas reduces the probability of not spending on drinking water by 24.37% compared to rural areas.

At the 1% significance level (p -value < 0.01), housing in the regions of the north coast, central coast, south coast, north highlands, central highlands, south highlands and rainforest shows positive effects on the probability of spending on drinking water in the very low category: 0.29%, 0.47%, 0.50%, 0.62%, 0.73%, 0.70% and 0.44%, respectively; as well as in the medium category: 8.84%, 11.37%, 10.98%, 10.87%, 10.46%, 12.14% and 11.32%. On the other hand, they show negative effects on the probability of drinking water expenditure in the high category: 6.07%, 12.00%, 13.21%, 18.26%, 22.89%, 20.38%, and 10.60%; and in the very high category: 11.95%, 16.39%, 16.38%, 19.52%, 24.09%, 23.22%, and 15.91%. Conversely, the urban residential area has negative effects on the probability of drinking water expenditure in the very low and medium categories, with values of 0.61% and 11.94%, respectively; while the positive effects on the probability of drinking water expenditure in the high and very high categories are 17.03% and 19.89%, respectively.

4. Discussion

When analyzing drinking water expenditure after combining both samples (Table S1, Supplementary Material), no significant interaction influence was found at the 5% level (p -value > 0.05). According to the results of the modified Wald test (Table S2, Supplementary Material), this interaction reveals that expenditure on drinking water consumption did not change drastically between 2017 and 2023. Likewise, the interaction coefficients between 2023 and the following variables—connection to the drinking water service, availability of safe water, presence of unsafe water, continuity of water service, monthly expenditure on bottled water, and monthly monetary income of the head of household—were not statistically significant (p -value > 0.05) (Tables S1 and S2). These findings indicate that these variables did not change systematically between the two years, despite the external shocks that occurred, thus validating the comparison of the separately estimated models presented in Table 4.

The evidence reveals a critical paradox: although infrastructure coverage remained relatively stable, particularly in rural areas (4.37% in 2017 and 4.75% in 2023), while households without coverage increased in urban areas (from 7.89% in 2017 to 8.93% in 2023) and decreased in rural areas (from 8.34% in 2017 to 7.82% in 2023) (Figure 2A), spending on drinking water in pens has increased relatively (in percentage, but not significantly), while in total numbers decreased according to Figure 6 in the high and very high categories in urban areas, as has the consumption of bottled water (Figure 3A,B). This finding suggests that greater access to the service was not accompanied by a corresponding improvement in the quality, reliability, or continuity of supply, leading households to adopt costly adaptation strategies.

4.1. The Double Burden of Drinking Water: Infrastructure and Perceived Quality

The econometric results in Table 4 show that having a potable water connection increases the probability of falling into the highest expenditure categories (high and very

high) by 18.22% and 20.18% for 2017 (Table 5), and by 13.56% and 19.31% for 2023 (Table 6), respectively. This result could be interpreted as a success of the public investment policy: connected households value the service, which aligns with the market mechanisms described in the tariff literature, as argued by Vera et al. [44]. This finding also suggests greater demand elasticity among households with potable water, demonstrating their willingness to adjust spending based on tariffs. Therefore, this tariff should be set at low levels for low and moderate consumption, while it would be high for high consumption; in addition, tariff adjustments are needed during periods of high seasonal demand and in summer.

However, the persistence and increase in spending on bottled water—a 1% increase in this category is associated with a 1.44% increase in the probability of very high spending on drinking water in 2017 (Table 5)—demonstrates a duality in spending patterns. This behavior is consistent with the research of Oyelami et al. [45]. Their study shows that, in contexts of inadequate or alternative water supply, households facing deficiencies in the public system resort to more dependable sources, including groundwater from hand-dug wells and deep wells.

Specialized literature, such as that by Mudiyansele et al. [46], has documented that when the public supply is perceived as unreliable, households tend to seek private alternatives for water supply, generating significant additional expenses.

The work of Pattanayak et al. [12] shows that households in Kathmandu, Nepal, incur hidden costs because they assume double expenses as an adaptation strategy (pumping, collection, treatment, purchase, and storage) in the face of insufficient water service and inadequate infrastructure. Our findings indicate that the availability of unsafe water with inadequate chlorine further increases the likelihood of expenditure in the high category (Tables 5 and 6). This suggests that users not only pay for access but also for poor quality through corrective mechanisms such as purchasing filters, boiling water, or buying bottled water.

The systematic review by Majuru et al. [47] in developed countries shows that households experience continuous water supply interruptions, leading them to store water or seek alternative sources. This situation is more critical for poor households, who must dedicate more time and effort to water collection. These findings reinforce the results of this manuscript, indicating that low-income households bear an excessive burden. Consequently, these households resort to labor- and time-intensive strategies, while those with higher incomes access market solutions, such as purchasing bottled water. In this regard, the results in Tables 5 and 6 consistently reveal that both extreme and non-extreme poverty reduce the likelihood of high or very high expenditure on drinking water, which is consistent with this heterogeneous distribution of the adaptive burden.

4.2. Heterogeneity and the Water Poverty Trap

A key contribution of this research is the identification of stark geographic and socioeconomic disparities. The results show that residing in the highlands (south and central regions), compared to the coast, increases the likelihood of not spending money on drinking water (Tables 5 and 6). This situation does not reflect well-being, but rather exclusion from the state-provided supply or a formal service so scarce that it has been completely replaced by informal sources (rivers, streams, cisterns, and wells). This finding, as noted by Fagundes et al. [48] and Liu et al. [49], is crucial and aligns with the global concern for monitoring inequalities in access to drinking water beyond national averages.

The link with socioeconomic strata exacerbates this problem. Non-extreme poverty showed a solid negative impact on the high and very high spending categories, both in 2017 (p -value < 0.01, Table 5) and in 2023 (p -value < 0.10 and p -value < 0.05, respectively, Table 6); while it showed a positive impact on the low and medium spending categories in

both 2017 (p -value < 0.01, Table 5) and 2023 (p -value < 0.05, Table 6). In contrast, extreme poverty, statistically relevant only in 2023, increased the probability of not spending by 5.98% (Table 6). This suggests that households in extreme poverty are being excluded from the formal water market due to infrastructure or economic constraints. This finding is corroborated by Borgomeo et al. [50], who found that water risks have economic effects and that improving the management and maintenance of infrastructure allows overcoming the poverty trap towards an economic improvement of households.

Heads of households with higher monetary income, years of education, and urban locations are more likely to incur high spending. This behavior reveals a structure in which drinking water expenditure is regressive: the poorest households without access to the service are forced to spend nothing, while those with access must allocate a disproportionate share of their income to ensure a minimum safe supply (dual expenditure on bottled water). This phenomenon is known as the water poverty trap. The work of Fagundes et al. [48] demonstrates that inequality in access to drinking water and sanitation increases the costs of these services, affecting households' ability to pay for other essential services and contributing to the cycle of poverty. Similarly, the paper by Fagundes et al. [51] indicates that disparities in drinking water coverage and affordability perpetuate poverty and inequality.

4.3. *The Mediating Role of Human Capital and the Failure of Passive Interventions*

A notable result is the loss of statistical significance in 2023 for the indicators of physical condition of housing, absence of overcrowding and, surprisingly, connection to sanitary services (Table 4). This finding reflects less variability in the sample, likely due to sanitation programs that are not captured by the ENAHO survey.

While in 2017 these indicators mitigated the likelihood of water expenditure in the low and medium categories (Table 5), in 2023 their effect disappeared (Table 6). This is because, in 2017, households with overcrowding or poor physical infrastructure may have exhibited more restricted consumption patterns due to their reliance on free public water taps and water trucks; whereas by 2023, the pandemic stabilized water consumption as an inelastic biological, sanitary necessity, regardless of overcrowding, housing physical condition, and connection to sanitation services. Thus, handwashing and disinfection became mandatory, leading to households having water connections or collective water meters.

In contrast, indicators such as the age and years of education of the head of household maintained their significant and positive effect on spending in both 2017 and 2023 (Table 4). This indicates that human capital is a more robust determinant of households' capacity to manage water resources, whether by investing in storage technologies, navigating the tariff system, or implementing effective hygiene practices. This finding aligns with the results of Agustin et al. [52], who emphasize that socio-behavioral changes and water resource management are essential complements to the success of infrastructure investment projects. This demonstrates that public investment alone is insufficient if it is not accompanied by capacity-building programs at the local level.

4.4. *Policy Commitments and Progress Towards the SDGs*

The results have direct implications for the effectiveness of public policies in the context of SDGs 1, 3, 6, and 10. The data show that investment has improved access to drinking water and sanitation (SDG 6) but has not closed the affordability (SDG 1) or quality gaps. The statistically significant values for 2017 (p -value < 0.01) and 2023 (p -value < 0.05) in the elasticity of expenditure on bottled water (Tables 5 and 6) reveals a market failure: the State is not guaranteeing the human right to water, forcing households to pay twice for the same service (one public service of low quality and another private service of dubious

quality, but perceived as safe). In this regard, the work of Gómez-Lobo et al. [53] shows that the tariff reform in Peru, aimed at focusing subsidies, is insufficient to alleviate this burden on the most vulnerable sectors, particularly in the rainforest and highlands.

Discussing this evidence in light of international scientific literature allows us to understand that the Peruvian problem is not isolated. The research of Fagundes et al. [51] and Fagundes et al. [54] documents, from Brazil, how loss minimization targets and social tariffs are indispensable tools but difficult to implement without generating inequities. Similarly, Gómez-Lobo et al. [53] demonstrate, based on the Chilean experience with subsidies, the importance of refined policy design to prevent benefits from being captured by the non-poor. Our research provides evidence that, in a country as diverse and spatially fragmented as Peru, one-size-fits-all responses are ineffective. Territorially differentiated interventions are needed to address connectivity, quality, continuity, and affordability, incorporating hygiene education as a fundamental component of the public investment project. Specifically, we propose:

1. Differentiated tariffs: In urban coastal areas, higher tariffs should be charged to those who consume more water, adjusting the price by district so that higher-income families pay for their actual consumption and do not receive subsidies from middle-income households. In rural highlands, on the other hand, a fixed monthly fee should be charged according to housing conditions and district, supplemented by community meters due to the lack of infrastructure for individual metering.
2. Implementation of two types of subsidies: In peri-urban areas, direct cash transfers should be provided to households through social programs such as Juntos or Pensión 65, allocating these resources to finance the installation of household water pipes and the purchase of water filters. In rural rainforest areas, on the other hand, the money should be given directly to community organizations, provided their members are trained in maintenance and chlorine application.
3. Community management in isolated and impoverished areas: In the high Andean regions, the State should provide supplies (pipes and chlorine) and technical assistance, while the community operates the system and charges subsistence-level social tariffs. In areas of extreme poverty where the water market excludes households, priority should be given to managing small-scale water collection and storage systems. These systems should rely on community reservoirs, financed with mining and/or gas royalties, and be operated by the residents themselves.

4.5. Limitations and Future Research

This manuscript is based on cohort data, in which most households were studied in 2017 [26] and 2023 [27], but without longitudinal follow-up of the same households. Therefore, future research should use the ENAHO panel structure to control for the unobserved heterogeneity at the household level. The study has another limitation: the available data are restricted to chlorine concentration (0.5–3.4 mg/L) and inadequate chlorine concentration (0.1–0.4 mg/L). The absence of microbiological, chemical, and physical parameters hinders a more complete assessment of safe drinking water. Therefore, research including this additional data is needed. Furthermore, qualitative research is necessary to understand the perceptions of quality and risk that lead households to choose bottled water even when they have a piped water connection. Finally, assessing the impact of specific programs, such as micro-metering or point-of-use chlorination, could offer more cost-effective solutions than large infrastructure projects to improve perceived water quality.

5. Conclusions

Analysis of microdata from the ENAHO-INEI survey (2017 and 2023) reveals three main findings that qualify the impact of public investment projects in drinking water and sanitation on household spending on this service in Peru.

First, a paradox emerges: Despite the increase in household water connection coverage in rural areas (from 4.37% to 4.75%), monetary expenditure on drinking water and bottled water consumption increased significantly. This suggests that infrastructure expansion has not been accompanied by equivalent improvements in service continuity or quality, transferring unforeseen adaptation costs to households.

Second, a regressive spending pattern is observed: In 2023, households in extreme poverty were 5.98% more likely to spend no money on drinking water, revealing exclusion rather than well-being. In contrast, heads of households with higher levels of education and income were more likely to incur high or very high expenses. This pattern, consistent with a potential water poverty trap, appears to be more pronounced in the highlands, where residing in these regions increases the probability of spending no money on water by up to 35.79%.

Third, the lack of statistical significance in 2023 for access to sanitation services—which was significant in 2017—did not reveal a statistically relevant effect. This discrepancy between years could be due to various factors, such as the sample composition or contextual situations, so it cannot be inferred that the provision of physical infrastructure has entered a phase of diminishing returns. On the contrary, years of education and the age of the head of household maintained a positive and robust effect, which underscores that human capital is more fundamental than passive infrastructure.

In terms of public policy, homogeneous state interventions are ineffective in a country with high geographic segmentation like Peru. Territorially differentiated strategies are required that integrate improvements in affordability, continuity and microbiological quality of service, along with hygiene education programs.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/su18157743/s1>. Table S1: Ordered joint logit model of drinking water expenditure in Peru, 2017–2023; Table S2: Adjusted Wald Test of the Ordered Joint Logit Model of Drinking Water Expenditure in Peru, 2017–2023.

Author Contributions: Conceptualization, A.R.R. and N.F.R.; methodology, A.R.R. and B.A.H.B.; software, A.R.R. and L.A.M.y.C.; validation, A.R.R. and N.F.R.; formal analysis, A.R.R.; investigation, M.A.C., L.V.J. and S.C.Á.; resources, S.C.Á. and J.A.R.E.; data curation, L.V.J. and S.C.Á. and J.A.R.E.; writing—original draft preparation, A.R.R.; writing—review and editing, N.F.R.; visualization, A.R.R.; supervision, L.A.M.y.C.; project administration, A.R.R.; funding acquisition, L.V.J., S.C.Á. and J.A.R.E. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets generated and analyzed during this study are available at 832 the following permanent web link: <https://github.com/AlexRengifo20/dryad-app/blob/main/Supplementary%20material.docx> (accessed on 9 June 2026).

Acknowledgments: The authors have reviewed and edited the output and take full responsibility for the content of this publication.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

ENAH	National Household Survey
INEI	National Institute of Statistics and Informatics
SGD	Sustainable Development Goals

References

1. INEI. Peru: Formas de Acceso al Agua y Saneamiento Básico al 2024. Instituto Nacional de Estadística e Informática, 2026. Available online: https://www.inei.gob.pe/media/MenuRecursivo/boletines/boletin_agua_2024.pdf (accessed on 9 June 2026).
2. Loyola, S.; Sanchez, J.F.; Maguiña, E.; Canal, E.; Castillo, R.; Bernal, M.; Meza, Y.; Tilley, D.H.; Oswald, W.E.; Heitzinger, K.; et al. Fecal contamination of drinking water was associated with diarrheal pathogen carriage among children younger than 5 years in three peruvian rural communities. *Am. J. Trop. Med. Hyg.* **2020**, *102*, 1279–1285. [\[CrossRef\]](#) [\[PubMed\]](#)
3. Pulgar, V. Las ocho regiones naturales del Perú. *Terra Bras. Rev. Rede Bras. História Geogr. Geogr. Histórica* **2014**, *3*, 238. [\[CrossRef\]](#)
4. Villanueva, K.M.; Vasquez, T.P.; Yori, P.P.; Cacique, L.R.; Garcia Bardales, P.F.; Shapiama Lopez, W.V.; Paredes, F.Z.; Perez, K.F.; Pinedo, S.R.; Delgado, H.S.; et al. The Enterics for Global Health (EFGH) Shigella Surveillance Study in Peru. *Open Forum Infect. Dis.* **2024**, *11*, S121–S128. [\[CrossRef\]](#) [\[PubMed\]](#)
5. Ferro, P.; Rossel-Bernedo, L.J.; Ferró-González, A.L.; Vaz-Moreira, I. Quality Control of Drinking Water in the City of Ilave, Region of Puno, Peru. *Int. J. Environ. Res. Public Health* **2022**, *19*, 10779. [\[CrossRef\]](#) [\[PubMed\]](#)
6. Ferro, P.; Morales, E.; Ticona, E.; Ferró-Gonzales, P.; Oblitas, A.; Ferró-González, A.L. Water quality and phenotypic antimicrobial resistance in isolated of *E. coli* from water for human consumption in Bagua, under One Health approach. *Heliyon* **2024**, *10*, e23961. [\[CrossRef\]](#) [\[PubMed\]](#)
7. Oswald, W.E.; Lescano, A.G.; Bern, C.; Calderon, M.M.; Cabrera, L.; Gilman, R.H. Fecal Contamination of Drinking Water within Peri-Urban Households, Lima, Peru. *Am. J. Trop. Med. Hyg.* **2007**, *77*, 699–704. [\[CrossRef\]](#)
8. Oswald, W.E.; Hunter, G.C.; Kramer, M.R.; Leontsini, E.; Cabrera, L.; Lescano, A.G.; Gilman, R.H. Provision of private, piped water and sewerage connections and directly observed handwashing of mothers in a peri-urban community of Lima, Peru. *Trop. Med. Int. Health* **2014**, *19*, 388–397. [\[CrossRef\]](#) [\[PubMed\]](#)
9. Mortazavi-Naeini, M.; Bussi, G.; Elliott, J.A.; Hall, J.W.; Whitehead, P.G. Assessment of Risks to Public Water Supply from Low Flows and Harmful Water Quality in a Changing Climate. *Water Resour. Res.* **2019**, *55*, 10386–10404. [\[CrossRef\]](#)
10. Becher, O.; Smilovic, M.; Verschuur, J.; Pant, R.; Tramberend, S.; Hall, J. The challenge of closing the climate adaptation gap for water supply utilities. *Commun. Earth Environ.* **2024**, *5*, 356. [\[CrossRef\]](#)
11. Bai, X.Y.; Muhammad, I.H.; Li, F.S.; Muhammad, S.H.; Gu, Y.H. An empirical study on application and efficiency of gridded management in public service supply of Chinese Government. *J. Sci. Technol. Policy Manag.* **2017**, *8*, 2–15. [\[CrossRef\]](#)
12. Pattanayak, S.K.; Yang, J.C.; Whittington, D.; Bal Kumar, K.C. Coping with unreliable public water supplies: Averting expenditures by households in Kathmandu, Nepal. *Water Resour. Res.* **2005**, *41*, W02012. [\[CrossRef\]](#)
13. Hyllestad, S.; Lyngstad, T.M.; Lindstrøm, J.C.; White, R.A.; Andreassen, M.; Svendsen, C. Estimating the risk of gastrointestinal illness associated with drinking tap water in Norway: A prospective cohort study. *BMC Public Health* **2024**, *24*, 2107. [\[CrossRef\]](#) [\[PubMed\]](#)
14. Aydamo, A.A.; Gari, S.R.; Mereta, S.T. The nexus between household water insecurity, mother's handwashing practices, and diarrheal diseases among under-five children. *J. Water Health* **2024**, *22*, 1357–1371. [\[CrossRef\]](#) [\[PubMed\]](#)
15. Komarulzaman, A.; De Jong, E.; Smits, J. Effects of water and health on primary school enrolment and absenteeism in Indonesia. *J. Water Health* **2019**, *17*, 633–646. [\[CrossRef\]](#) [\[PubMed\]](#)
16. Vass, A. Water and sanitation: The targets and challenges. *BMJ* **2003**, *326*, 30494. [\[CrossRef\]](#)
17. Levan, M.; Khatuna, K.; Luiza, G.; Levan, B.; Lia, G. The Impact of a School-Based Water, Sanitation and Hygiene Intervention on Knowledge, Practices, and Diarrhoea Rates in the Philippines. *Int. J. Environ. Res. Public Health* **2019**, *16*, 118–130. [\[CrossRef\]](#)
18. Liu, Y.; Tan, Y.; Zhang, X. The long-term economic impact of water quality: Evidence from rural drinking water program in China. *J. Asian Econ.* **2024**, *94*, 101796. [\[CrossRef\]](#)
19. Tosun, J.; Scherer, U.; Schaub, S.; Horn, H. Making Europe go from bottles to the tap: Political and societal attempts to induce behavioral change. *Wiley Interdiscip. Rev. Water* **2020**, *7*, e1435. [\[CrossRef\]](#)
20. Wang, W.-K.; Tsai, M.-C. Effects of Public Investment on Sustainable Urban Development. *J. Urban Plan. Dev.* **2024**, *150*, 4024040. [\[CrossRef\]](#)
21. United Nations. The Sustainable Development Goals Report. 2024. Available online: <https://unstats.un.org/sdgs/report/2024/The-Sustainable-Development-Goals-Report-2024.pdf> (accessed on 21 September 2025).

22. Angelova, I.; Alitchkov, D.; Radovanov, V. Technical and economic impact of water reuse as an integrated water resource management measure in rural water supply systems. *Water Supply* **2024**, *24*, 1974–1984. [\[CrossRef\]](#)
23. Bisung, E.; Elliott, S.J. Improvement in access to safe water, household water insecurity, and time savings: A cross-sectional retrospective study in Kenya. *Soc. Sci. Med.* **2018**, *200*, 1–8. [\[CrossRef\]](#) [\[PubMed\]](#)
24. Adams, E.A. Intra-urban inequalities in water access among households in Malawi’s informal settlements: Toward pro-poor urban water policies in Africa. *Environ. Dev.* **2018**, *26*, 34–42. [\[CrossRef\]](#)
25. Morales Rojas, E.; Díaz Ortiz, E.A.; Medina Tafur, C.A.; García, L.; Oliva, M.; Rojas Briceño, N.B. A Rainwater Harvesting and Treatment System for Domestic Use and Human Consumption in Native Communities in Amazonas (NW Peru): Technical and Economic Validation. *Scientifica* **2021**, *2021*, 4136379. [\[CrossRef\]](#) [\[PubMed\]](#)
26. INEI. Condiciones de Vida y Pobreza—ENAH0 2017, Instituto Nacional de Estadística e Informática Periodo 55: Microdatos (Código de Encuesta 603) [Conjunto de Datos]. Proyectos INEI—Microdatos. 2018. Available online: <https://proyectos.inei.gob.pe/microdatos/> (accessed on 31 May 2025).
27. INEI. Condiciones de Vida y Pobreza—ENAH0 2023, Instituto Nacional de Estadística e Informática. Periodo 55: Microdatos (Código de Encuesta 906) [Conjunto de Datos]. Proyectos INEI—Microdatos. 2024. Available online: <https://proyectos.inei.gob.pe/microdatos/> (accessed on 10 June 2025).
28. Greene, W.H. *Econometric Analysis*; Prentice Hall: Upper Saddle River, NJ, USA, 2003.
29. Beltrán, A.; Casto, J.F. *Modelos de Datos de Panel y Variables Dependientes Limitadas: Teoría y Práctica*; Universidad del Pacífico: Lima, Peru, 2010.
30. McFadden, D. *Conditional Logit Analysis of Qualitative Choice Behavior*; Institute of Urban and Regional Development: Berkeley, CA, USA, 1972; Volume 199, pp. 1–48. Available online: <https://escholarship.org/uc/item/61s3q2xr%0A> (accessed on 26 March 2026).
31. Poston, D.L.; Conde, E.; Field, L.M. (Eds.) Binomial Logistic Regression. In *Applied Regression Models in the Social Sciences*; Cambridge University Press: Cambridge, UK, 2023; pp. 282–338. [\[CrossRef\]](#)
32. Korn, E.L.; Graubard, B.I. Simultaneous testing of regression coefficients with complex survey data: Use of bonferroni *t* statistics. *Am. Stat.* **1990**, *44*, 270–276. [\[CrossRef\]](#)
33. Akaike, H. Information Theory and an Extension of the Maximum Likelihood Principle. In *Proceedings of the 2nd International Symposium on Information Theory*; Akadémiai Kiadó: Budapest, Hungary, 1973; pp. 267–281.
34. Schwarz, G. Estimating the Dimension of a Model. *Ann. Stat.* **1978**, *6*, 461–464. [\[CrossRef\]](#)
35. Hannan, E.J.; Quinn, B.G. The Determination of the Order of an Autoregression. *J. R. Stat. Soc. Ser. B Stat. Methodol.* **1979**, *41*, 190–195. [\[CrossRef\]](#)
36. Williams, R. Generalized ordered logit/partial proportional odds models for ordinal dependent variables. *Stata J. Promot. Commun. Stat. Stata* **2006**, *6*, 58–82. [\[CrossRef\]](#)
37. Brant, R. Assessing Proportionality in the Proportional Odds Model for Ordinal Logistic Regression. *Biometrics* **1990**, *46*, 1171–1178. [\[CrossRef\]](#)
38. Liu, A.; He, H.; Tu, X.M.; Tang, W. On testing proportional odds assumptions for proportional odds models. *Gen. Psychiatry* **2023**, *36*, e101048. [\[CrossRef\]](#) [\[PubMed\]](#)
39. West, B.T.; Sakshaug, J.W.; Aurelien, G.A.S. Accounting for Complex Sampling in Survey Estimation: A Review of Current Software Tools. *J. Off. Stat.* **2018**, *34*, 721–752. [\[CrossRef\]](#)
40. Kolenikov, S. Resampling variance estimation for complex survey data. *Stata J. Promot. Commun. Stat. Stata* **2010**, *10*, 165–199. [\[CrossRef\]](#)
41. Wolter, K.M. Introduction to Variance Estimation. *J. Am. Stat. Assoc.* **2008**, *103*, 1324–1325. [\[CrossRef\]](#)
42. Carlin, J.B.; Galati, J.C.; Royston, P. A new framework for managing and analyzing multiply imputed data in Stata. *Stata J. Promot. Commun. Stat. Stata* **2008**, *8*, 49–67. [\[CrossRef\]](#)
43. Liu, X.; Koirala, H. Fitting proportional odds models to educational data with complex sampling designs in ordinal logistic regression. *J. Mod. Appl. Stat. Methods* **2013**, *12*, 235–248. [\[CrossRef\]](#)
44. Vera, A.M.C.; Vásquez-Lavín, F.A.; Oliva, R.P. Estimating Residential Water Demand Under Systematic Shifts Between Uniform Price (UP) and Increasing Block Tariffs (IBT). *Water Resour. Res.* **2024**, *60*, e2022WR033508. [\[CrossRef\]](#)
45. Oyelami, A.A.; Ogunbode, T.O.; Owoeye, M.O. Dynamics of household water use determinants in selected Local Government Areas in Oyo Zone of Oyo State Nigeria. *Sci. Rep.* **2026**, *16*, 9613. [\[CrossRef\]](#) [\[PubMed\]](#)
46. Konara, K.M.G.K.; Tokai, A. Exploring behaviour of socio-economic metabolic flows to promote environmentally sustainable consumption patterns in Sri Lankan households. *Environ. Dev. Sustain.* **2024**, 1–28. [\[CrossRef\]](#)
47. Majuru, B.; Suhrcke, M.; Hunter, P.R. How do households respond to unreliable water supplies? A systematic review. *Int. J. Environ. Res. Public Health* **2016**, *13*, 1222. [\[CrossRef\]](#) [\[PubMed\]](#)
48. Fagundes, T.S.; Marques, R.C.; da Cunha Ferreira, D.F.; Malheiros, T.F. Exploring water affordability through subsidy policies. *Water Res.* **2025**, *286*, 124251. [\[CrossRef\]](#) [\[PubMed\]](#)

49. Liu, M.; Fang, C.; Bai, Y.; Liu, Z. Unraveling patterns and drivers of urban-rural gap in water consumption sufficiency and efficiency: Evidence from city-level China during 1990–2022. *Water Res.* **2025**, *282*, 123737. [[CrossRef](#)] [[PubMed](#)]
50. Borgomeo, E.; Hall, J.W.; Salehin, M. Avoiding the water-poverty trap: Insights from a conceptual human-water dynamical model for coastal Bangladesh. *Int. J. Water Resour. Dev.* **2018**, *34*, 900–922. [[CrossRef](#)]
51. Fagundes, T.S.; Marques, R.C.; Malheiros, T.F. Impact of efficiency on affordability: A study of the Brazilian new water loss goals. *Water Supply* **2024**, *24*, 1645–1657. [[CrossRef](#)]
52. Agustin, M.; Moengin, P.; Sari, E.; Rinanti, A.; Goni, F.A.; Abu, M.Y. Sustainable performance indicators in improving sustainable performance in urban drinking water services. *Indones. J. Urban Environ. Technol.* **2025**, *8*, 346–360. [[CrossRef](#)]
53. Gómez-Lobo, A.; Serebrisky, T.; Sosa, B.S.; Cárdenas, H.; Martínez, M.O.G.; Antonio, S.A.H. Reducing Leakage: Subsidies and Tariff Reform in Water and Sanitation Services in Metropolitan Lima, Peru. *Water Econ. Policy* **2023**, *9*, 2350004. [[CrossRef](#)]
54. Fagundes, T.S.; Marques, R.C.; Malheiros, T.F. Are Brazilian water auction prices affordable for vulnerable families? *Util. Policy* **2024**, *88*, 101749. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.