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Analyzing household water consumption under water quality degradation and economic burden: A comparative evidence from Indonesia

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Abstract: Water quality degradation forces households to rely on multiple water sources and incur higher costs. This study analyses household adaptation strategies and economic burdens under water quality degradation in Jabon and Krian districts, Sidoarjo Regency. Data were collected from 100 households using stratified cluster random sampling and analyzed using Replacement Cost (RC), Cost of Illness (COI) and regression. The results show that 83% of respondents still rely on groundwater despite pollution. Average household water consumption ranges from 18.63 m^3 (low-income) to 23.85 m^3/month (high-income). Environmental degradation imposes a highly regressive financial burden, total negative externalities consume 10.63% of monthly income for low-income households in Krian and 9.37% in Jabon. In Krian, low-income groups bear the highest health burden (2.84%) due to behavior shift toward private healthcare over public insurance. Econometric analysis confirms that absolute externality costs are significantly driven by regional attributes and clean water expenditures, while absolute income is statistically insignificant. Therefore, policy interventions must shift from basic infrastructure expansion toward spatially differentiated water tariffs and regional Pigouvian taxes.

Key words: Water pollution; household water consumption; economic burden; cost of illness; negative externality.

1. INTRODUCTION

Water is a vital resource for human life. The availability of clean water is increasingly threatened by rapid population growth, which simultaneously drives the expansion of human economic activities. This rapid demographic surge is recognised as a major catalyst for environmental degradation and poses a challenge to sustainable natural resource management (Elmadani et al., 2024). Domestic water demand is projected to increase by 50–80% over the next two decades (He et al., 2021). However, as demand increases, water quality is deteriorating due to land-use conversion and the discharge of untreated wastewater from the industrial, domestic, and agricultural sectors. In developing countries, this pressure is exacerbated by a lack of public infrastructure and weak wastewater management systems. As a result, there is unequal access to clean water and increased vulnerability among households.

Indonesia reflects many of these challenges. River pollution has become a persistent environmental issue, particularly on Java Island. Major rivers on Java Island are polluted, primarily due to domestic, agricultural, and industrial waste (Sudalma et al., 2015). Previous studies report that major rivers such as the Brantas, Surabaya, and Porong Rivers have experienced significant declines in water quality, with Biological Oxygen Demand (BOD) levels exceeding environmental quality standards (Sudalma et al., 2015). At the same time, piped water supply coverage remains limited. National piped water supply service coverage reached only 21.8% in 2022. This has forced many households to rely on alternative water sources such as groundwater, refillable drinking water, mobile water vendors and bottled water.

These conditions are particularly evident in Sidoarjo Regency. Sidoarjo Regency is characterized by rapid industrial growth and high population density make the water quality issues are complex. Piped water service, also known as PDAM, coverage only about 32%, while the raw water supply from the Umbulan spring continues to decline (Statistic Sidoarjo, 2024). Consequently, households often rely on multiple water sources to secure adequate water for daily consumption. The adaptation strategies impose an additional financial burden, including the cost of purchasing alternative clean water and healthcare costs associated with waterborne diseases.

These impacts can be understood as negative externalities. These external costs arise when economic activities (such as industrial or domestic waste) impose harmful impacts on third parties, in this case, households. Previous studies have generally used the replacement cost (RC) approach to estimate the expenses incurred in securing an alternative water source, while the cost of illness (COI) approach has been used to estimate health related economic losses resulting from water contaminated (Driver et al., 2020). Although both approaches have been widely discussed, previous research tends to apply separately or focuses primarily on overall environmental costs. Attention to how households adjust their water consumption behavior while simultaneously bearing economic and health burdens remains limited. This is particularly evident at the local household level in developing countries facing various environmental pressures.

This study addresses that gap by examining household water consumption behavior and economic burdens under water quality degradation in two contrasting districts in Sidoarjo, Jabon and Krian Districts. The two districts were selected because they represent different geographic characteristics and pollution sources. Jabon, located in the coastal lowlands, faces structural challenges due to the impacts of the Lapindo mudflow, seawater intrusion, and landfill leachate. Research in the downstream areas of Jabon indicates moderate-to-high pollution, with BOD levels reaching 38.06 mg/L (Hapsari et al., 2021). According to the Environment and Forestry Agency (2025), the water quality at the downstream level of the Krian River is polluted (Class II), with BOD levels reaching 25 mg/L. Water pollution in Krian, caused by industrial wastewater, is known to be discharged directly into water bodies without adequate wastewater treatment facilities (Fauzi, 2023).

By comparing differences in pollution factors and adaptation patterns between the two districts, this study aims to analyze how differences in environmental pressures influence household water consumption patterns, strategies, and economic burdens. This research addresses the following questions: (1) how does water quality degradation affect household water consumption behavior in Jabon and Krian districts and (2) what economic burdens are borne by households through replacement costs and health costs. This study contributes by applying the replacement cost and cost of illness approaches simultaneously within comparative household level analysis. These findings are expected to provide empirical evidence for more equitable and sustainable water management policies in water stressed regions facing similar environmental and institutional challenges.

2. MATERIAL AND METHODS

2.1 Study area and sampling

The research was conducted between August and September 2025 in Sidoarjo Regency, East Java, a region known for its strategic role as a metropolitan buffer for Surabaya. This period was chosen to capture environmental conditions during the late dry season transition, when water quantity and quality problems tend to become more pronounced. Two districts with contrasting ecological and socio-economic characteristics were selected as primary study locations. Jabon District, located in the southern coastal lowlands, experiences significant environmental pressures from the Lapindo mudflow, seawater intrusion, and leachate from local landfills. The district has a population density of 680.95 people/km^2. In contrast, Krian District represents an urban-suburban area characterized by intensive industrial activity and higher population density around 4,013 people/km^2. It is characterized by high industrial activity, with approximately 70 large-scale industrial firms.

The study employed a stratified cluster random sampling approach to obtain household level data from 100 respondents. The respondents were selected from households in Jabon and Krian. From these two districts, several villages were randomly selected in each. In the next stage, respondents were selected from the chosen villages and then categorized based on income. The distribution of respondents included 50 respondents from Jabon and 50 respondents from Krian. This approach allows for balanced representation of each subgroup, while also being efficient in terms of cost and data collection time (Kamalu et al., 2024). The use of stratified random sampling allows the study to capture the spatial diversity of regional characteristics (Putra & Tjahjono, 2018).

Although the sample size is relatively limited when divided into subgroups, this study was designed as a comparative analysis at the household level that prioritizes depth of information over broad population generalization. The use of stratified random sampling enhances representativeness by ensuring that the major socio-economic groups from both districts were included in the analysis proportionally. Furthermore, the sample size is considered adequate for exploratory statistical comparisons typically applied in household level studies with similar scope and resource constraints.

2.2 Analytical framework

2.2.1 Replacement cost (RC)

The Replacement Cost (RC) approach identifies household expenditures incurred to obtain clean water from alternative sources resulting from environmental quality losses. This reflects the direct financial effort to restore the function of a degraded resource. In this study, RC is calculated based on the type of alternative sources (piped water service, bottled water, refill stations, or water trucks), the volume consumed, and the purchase frequency (Rustiadi et al., 2009). The mathematical model for total monthly replacement cost (TBA) is as follows:

$$TBA = \sum_{i=1}^{n} (BA_i \times a_i) \tag{1}$$

where:

TBA: Total monthly cost of clean water purchase (IDR)
BA : Cost of purchasing clean water per household (IDR)
a : Intensity of water purchase per month
n : Number of respondents
i : The i^{th} respondent

2.2.2 Cost of Illness (COI)

The Cost of Illness (COI) approach measures the economic consequences of health-related losses resulting from water pollution. This method estimates the value of lost well-being from a decline in physical health. COI is divided into two main categories, direct costs and indirect costs (Das et al., 2025). The total COI is formulated as:

$$C = P + MC \tag{2}$$

where:

C : Total Cost of Illness (IDR)
P : Lost income due to productivity loss (IDR)
MC : Medical costs for treatment (IDR)

Lost earnings are calculated using the time-cost approach, which represents the income an individual loses when unable to work due to illness. This is calculated by multiplying the number of days absent from work by the respondent's daily income:

$$P = \sum_{i=1}^{n} H_i \times W_i \tag{3}$$

where:
P : Direct Medical Costs
H : Number of days the i^{th} respondent was unable to work
W : Daily income level of the i^{th} respondent (IDR)
n : Number of respondents
i : The i^{th} respondent

Medical costs represent the actual household expenditures for care, including doctor visits, medications, and hospitalization. The estimation for medical costs is as follows:

$$MC = \sum_{i=1}^{n} (J \times BK_i) + BO_i + BP_i \tag{4}$$

where:
MC : Medical costs
J : Number of medical visits per month
BK : Cost per medical visit (IDR)
BO : Cost of purchasing medicine (IDR)
BP : Hospitalization or treatment costs (IDR)

The integration of Replacement Cost and Cost of Illness in this study enables a more comprehensive assessment of household vulnerability under water quality degradation. RC captures preventive and adaptive expenditures related to securing clean water access, while COI reflects the economic consequences of health impacts associated with unsafe water consumption. These measures provide an estimate of the overall financial burden borne by households in different environmental settings.

This study evaluates the proportional burden of water expenditures relative to household income to assess affordability pressures. The proportional burden is calculated by comparing total water related expenditures to monthly household income. Several studies have shown that the proportional burden is maintained below the threshold of 4.6% threshold.

To validate the factors driving the economic burden by households due to water quality degradation, this study also used multiple linear regression analysis. Although combining RC and COI gives a comprehensive estimate of total external costs (Y) and additional analysis is needed to examine how preventive expenditures, structural economic factors, and spatial dynamics collectively influence this financial burden. Therefore, the model is formulated as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \epsilon \tag{5}$$

where:
Y = household externality cost (IDR)
X_1 = total clean water expenditure (IDR)
X_2 = income group (dummy variable: 1 = low income; 2 = high income)
X_3 = regional (dummy variable: 1 = Jabon; 2 = Krian)

Following model estimation, diagnostic tests for multicollinearity were conducted using the Variance Inflation Factor (VIF) to ensure the stability and reliability of the ordinary least squares (OLS) estimates. This framework effectively links the conceptual framework of household vulnerability with the empirical findings discussed.

3. RESULTS AND DISCUSSION

3.1 Water consumption patterns

The household water consumption patterns in Jabon and Krian rely on five primary sources namely groundwater, regional water company (PDAM), water stations refilled, mobile water vendors, and branded bottled water. Water consumption patterns in Jabon mostly rely on groundwater, water stations refilling, and mobile water vendors. In Krian, water consumption relies on groundwater and water stations refilled. Groundwater remains the most pervasive source, used by 83% of respondents, while only 17% have transitioned to piped water services from regional water company (PDAM).

The study found a significant difference in the accessibility and nature of water services between the two districts. Access to clean water through piped systems in the Jabon district is essentially non-existent. Regional water services in Jabon refer to distribution via water trucks/tanks with a capacity of 5,000-10,000 liters per delivery, delivered directly to households. This indicates a strong dependence on non-piped water service distribution as a primary solution for water scarcity (Ito et al., 2021). The Sidoarjo Delta Tirta Regional Water Company (PDAM) pipeline network does not yet reach all areas, particularly those far from the city center. While access to PDAM in Krian refers to standard household connections with water meters, indicating more established urban infrastructure. Those are caused by rapidly developing areas in Krian, both industrial and residential. Respondents who use PDAM as a primary source still rely on other water sources to meet their needs such as refilled water or branded bottled water for consumption purposes (Zikrina et al., 2024).

Households frequently substitute primary water sources with alternatives to ensure its safety and quality (Majuru et al., 2016). The dominant pattern in Jabon is a combination of groundwater, refill water, and mobile vendors, whereas in Krian it is dominated by groundwater and refill water. In terms of volumetric quantification, the total cumulative water consumption across all sampled respondents reached 994.46 m^3/month in Jabon. Total cumulative consumption for the entire sample in Krian was higher at 1,155.15 m^3/month. At the individual household level, average monthly water consumption was significantly lower. High income households consumed an average of 23.85 m^3 per household per month, while low-income households consumed an average of 18.63 m^3 per household per month.

An Independent-Samples t-Test indicates a statistically significant difference ($p < 0.001$) in average monthly household water consumption between high- and low-income groups. High-income households consume an average of 23.85 m^3 per month, compared to 18.63 m^3 for low-income households. The difference in usage by income level strongly supports the idea that higher purchasing power correlates with a higher intensity of domestic water use. In addition, higher income is associated with larger homes and more intensive consumption patterns, which contribute to higher household water demand (Fang et al., 2014).

3.2 Cost of illness (COI)

Health issues caused by water degradation were significantly more common among households that primarily used groundwater. Skin diseases are the most common among groundwater users in both districts. This result aligns with a previous study that chronic exposure to contaminated groundwater commonly leads to dermatological disorders (Monteiro et al., 2021). Diarrhea was found at high rates among groundwater users, while rates dropped to zero among respondents in Krian who used non-groundwater sources.

Analyzing the economic impact of illness needs an approach that goes beyond the nominal cost. It is crucial to assess the actual impact of medical expenses on household financial capabilities. Applying the Cost of Illness framework enables this study to measure the actual economic burden on households during illness. To provide more detailed perspective, the sample was grouped by income level (low and high) in two different subdistricts, namely Jabon and Krian. This structural grouping helped identify potential spatial and socioeconomic disparities in healthcare costs. A comprehensive dataset detailing these financial variations is presented in Table 1.

Table 1. Cost of Illness based on group income.

Group Income	Income Group Average (IDR)	Average COI (IDR)	Proportional Burden (%)
Low-income Jabon	2,091,304	36,014	1.72
Low-income Krian	1,779,545	50,530	2.84
High-income Jabon	4,207,037	21,111	0.50
High-income Krian	4,494,643	69,524	1.55

Based on Table 1, there is a marked gap in health expenditures between the two study areas. Households in Krian consistently incur significantly higher medical costs than households in Jabon across all income categories. This spatial difference is driven by the higher number of healthcare providers in Krian, which expands options for the community. Field observations indicate a clear shift in behavior, where the population consciously chooses self-funded health services rather than utilizing national health insurance (BPJS). In health economics, this phenomenon aligns with the provider choice theory by Wohlin et al., (2021) and Breckert & Kelly (2021), which argues that the availability of multiple healthcare service options often leads households to ignore subsidized public healthcare services if private alternatives offer quality, flexibility, and shorter waiting times that are preferred.

The most significant finding concerns low-income households in Krian, which allocate approximately 2.84% of their monthly income to healthcare. This figure represents the highest proportional burden of all the groups observed. This high burden is a direct consequence of their preference for self-funded private health services. Although more financially secure groups can easily cover these costs, this behavior makes households in Krian more vulnerable to financial hardship due to health expenditures. According to Xu et al. (2003) and Fattah et al. (2023), when low-income households choose or force themselves to ignore the national health insurance, their exposure to financial hardship and extremely high health expenditures increases significantly. This can potentially push low-income households into temporary poverty in order to maintain access to health services.

Ultimately, this phenomenon shows that the availability of more healthcare options does not automatically guarantee economic efficiency for all segments of society. While high-income groups in Krian bear a manageable financial burden of just 1.55%, low-income groups must pay high financial costs to choose self-funded private healthcare services. This dynamic reflects a trade-off between perceptions of service quality and household financial sustainability. To prevent this behavior from causing long-term financial distress among the low-income household, local health authorities in Krian must find a way to bridge this gap. Rather than pushing for public insurance, policies should focus on improving service quality and responsiveness at local facilities that partner with BPJS, to make public healthcare an equally attractive and financially safer option for vulnerable households.

3.3 Replacement cost (RC)

The shortage of clean water caused by pollution forces households to seek alternative sources to meet their daily needs. When the main water sources are contaminated, families must buy bottled water by the gallon, refill water containers, or mobile water delivery services. Comparing the group by income levels with these forced water expenditures can identify the household groups most severely affected. The final figures reveal a clear disparity between water expenditures and the actual economic burden felt by families. Specific details regarding income levels, average water costs, and the resulting financial burden are outlined in detail in Table 2.

Table 2. Replacement Cost based on group income.

Group Income	Income Group Average (IDR)	Average RC (IDR)	Proportional Burden (%)
Low-income Jabon	2,091,304	159,870	7.64
Low-income Krian	1,779,545	138,651	7.79
High-income Jabon	4,207,037	276,426	6.57
High-income Krian	4,494,643	198,548	4.42

Table 2 highlights a notable economic pattern, known as the regressive financial burden of basic living needs. Low-income households earn less than half of what their high-income households earn, but they have to bear a heavy financial burden just to drink and cook. In both Jabon and Krian, low-income households must sacrifice nearly eight percent of their monthly income to buy clean water. Meanwhile, high-income group face a far smaller percentage impact for the exact same basic needs. Although high-income household purchase bottled water and spend more cash, these expenses barely affect their overall monthly budget. These findings reflect the concept of environmental vulnerability, where environmental degradation disproportionately affects economically low-income households. Similar findings were reported by Ali et al., (2021), who showed that households facing water insecurity and unsafe drinking water conditions can increase economic pressure due to higher water expenditures and associated health costs.

A further examination of these regions reveals a strong contrast in how income affects this water burden. In Krian, high-income households face the lowest impact by spending only 4.42% of their income for daily use of water. On the other hand, low-income households in Krian face the relatively worst pressure at 7.79% because their base income is low. Jabon shows a slightly smaller gap between the haves and have-nots. These differences demonstrate that local geographic conditions and pollution pressures and household income significantly influence household resilience. A similar pattern was also observed in Indonesia by Komarulzaman et al., (2017), where declining trust in water quality encouraged households to rely on bottled water and alternative water vendors despite having to bear additional financial burdens.

If the water disparity is ignored, it could make local poverty worse and deepen public health disparities over time. When a low-income family loses eight percent of its small income to water vendors, they must sacrifice other basic needs. They may reduce consumption of healthy food, skip medical checkups, or use groundwater that may be contaminated by pollution. This constant pressure makes it extremely difficult for low-income families to save money or get out of poverty. Water pollution causes significant economic losses and health burdens for affected households through increased medical expenses and reduced environmental quality (Andesgur et al., 2025). Therefore, local governments must intervene through equitable clean water infrastructure, groundwater protection and targeted subsidies to reduce the unequal economic burden caused by water pollution.

3.4 Negative externality

The socioeconomic impact of environmental degradation on household welfare was quantified using the negative externality valuation approach. To provide macro level perspective on the economic burden, average monthly household externalities were aggregated across the entire household population in each district. The number of households is lower in Jabon (18,167) than in Krian (41,659). These externalities in both regions are presented in Table 3.

Table 3 reveals an interesting pattern between the environmental externality burden at the household level. Low-income households in Krian and Jabon allocate 10.63% and 9.37% of their monthly income, accordingly, to cover these externalities. In contrast, high-income households sacrifice only 5.96% and 7.07% of their income to address the same environmental degradation. This symmetrical distribution indicates that the economic burden functions as an implicit regressive tariff, disproportionately affecting the lowest income groups. Similar findings were identified by

Nauges and Whittington (2010), who explained that water related expenditures in developing countries tend to consume a larger proportion of income among poorer households, thereby worsening economic inequality. Studies by Ali et al. (2021) also demonstrated that defensive household expenditures on clean water and illness treatment create a disproportionate burden for low-income communities exposed to unsafe environmental conditions.

Table 3. Negative externality cost.

Group Income	Income Group Average (IDR)	Average Externality (IDR)	Proportional Burden (%)
Low-income Jabon	2,091,304	195,884	9.37
Low-income Krian	1,779,545	189,181	10.63
High-income Jabon	4,207,037	297,537	7.07
High-income Krian	4,494,643	268,071	5.96

From a theoretical view, this regressive burden reflects a market failure that significantly reduces consumer surplus within society. This defensive expenditure represents a form of compensatory variation within the welfare economics framework. This variation constitutes the minimum monetary adjustment required to restore an individual to their original level of well-being following environmental degradation. Because these financial resources are reallocated to compensatory expenditures such as medical care and water replacement costs, this results in significant welfare losses. This reallocation forces low-income families to sacrifice their optimal consumption bundles. Consequently, this undermines disposable income that should fund long-term investments that enhance well-being, such as education, nutrition, and household savings. This reality strongly supports the defensive expenditure framework, which explains that households exposed to environmental degradation are forced to spend private resources to maintain minimum living standards and protect their health. These expenditures represent hidden welfare losses because household income that could otherwise support productive investments must instead be diverted toward pollution adaptation costs (Alzahrani et al., 2023).

To validate the findings, a statistical test using regression was conducted. The validation was performed to verify whether the observed descriptive findings into a framework for targeted environmental economic policy (Table 4). The regression model is as follows:

$$Y = -13{,}249{,}59 + 0.648(X1) + 11{,}050.74(X2) + 56{,}199.53(X3) \tag{6}$$

Table 4. Regression results for factors influencing household externality costs.

Variable	Coefficient	T-statistic	Sig.	VIF
(Constant)	-13294.92	-0.283	0.778	
Total clean water expenditure (X_1)	0.648	9.150	<0.001*	1.346
Income group (X_2)	11050.748	0.503	0.616	1.185
Regional (X_3)	56199.530	2.589	0.011*	1.169
R-Square				52.1%
Adj R-Square				50.6%

This model assigns a positive coefficient of 56,199.53 to the regional dummy variable (X3), which is statistically significant. This significant positive parameter explicitly indicates that living in Krian structurally increases a household's absolute externality costs when other variables are held constant. Although Jabon exhibits a higher average local intensity per household, the systemic spatial attributes and massive demographic density in Krian result in a statistically larger and far more severe macroeconomic burden across the entire regional landscape.

Furthermore, this framework provides insight into distributional justice through other explanatory variables. The coefficient for the income group is positive but does not reach statistical significance. This statistically insignificant result supports the income distribution paradox discussed in the welfare analysis. Although high-income households bear slightly higher nominal expenditures in absolute terms, their relative financial sacrifice is minimal. The proportional burden borne exclusively by low-income groups cancels out the linear significance of absolute income in the model. Meanwhile, total expenditure on clean water emerges as the dominant driver of the model with a coefficient of 0.648. This model is statistically strong, resulting in an Adjusted R-square of 50.6% and showing no signs of multicollinearity, as the Variance Inflation Factors for all variables fall strictly within the range of 1.1 to 1.3.

Government intervention must implement highly specific and actionable mechanisms directly linked to these findings. Since the regression demonstrates that Krian bears a significant aggregate scale burden and low-income groups face a regressive proportional burden exceeding 10%, local authorities must implement a spatially differentiated increasingly progressive rate structure. Low-income households in Krian and Jabon could benefit from a basic allocation of subsidized water funded directly through crossover subsidies applied to high-volume industrial water users in the region. Furthermore, given the highest micro-intensity in Jabon indicating acute local degradation, policies must prioritize direct mitigation at the point of use. Local environmental agencies should distribute decentralized, community managed communal water systems to targeted low-income clusters in Jabon, which would directly reduce their individual replacement costs.

Ultimately, market failures must be addressed at the institutional level by using existing externalities to adjust local industrial pollution taxes. Environmental enforcement agencies can utilize monthly fees as a benchmark in Krian to legally justify and calculate appropriate regional Pigouvian taxes on polluting factories. The revenue generated must be legally allocated to dedicated regional water welfare fund. This fund will be used exclusively to restore local groundwater levels and directly finance the physical expansion of the public pipeline network to low-income residential zones. This targeted financial mechanism will effectively transform defensive private costs back into public utility investments, reducing the welfare loss from deadweight costs to society.

4. CONCLUSION

The conclusion of this study is that local environmental degradation imposes a heavy and highly regressive economic burden on households in suburban areas. Households in Jabon face higher household financial burdens for mitigation due to severe exposure to the Lapindo mudflow and seawater intrusion. The unique contribution of this study rests on the empirical integration of descriptive welfare metrics with econometric models. This approach reveals a paradox in income distribution where absolute income levels hold no linear significance, as water degradation operates as an involuntary tax that inflicts substantial relative welfare losses disproportionately on the utility of low-income households. Consequently, local government policies that focus only on expanding public infrastructure are fundamentally inadequate to address this issue. The implementation of actionable mechanisms driven by this empirical data ensures that the “polluter pays” principle directly mitigates the unproductive welfare losses suffered by vulnerable communities.

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