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Drivers of Water Quality and Water Resource Management Perceptions: Evidence from the Ouémé Delta, Benin

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Abstract

This study investigates the determinants of economic agents' perceptions of water quality and water resource management in the Oueme delta, Benin, using primary survey data collected in April 2021 from 3,075 economic agents aged 16 and above, spanning fishing, agriculture, livestock rearing, water transport and household users. Because a formal test rejects the proportional-odds assumption underlying the standard ordered probit model conventionally used in this literature, and further diagnostics reveal significant heteroskedasticity, the perception model is estimated as a heteroskedastic ordered probit with standard errors clustered by commune. The results show that a recent health shock, the colour of the water, educational attainment and housing tenure are the most robust correlates of dissatisfaction, while age, sex, marital status and religious affiliation contribute comparatively little once these methodological refinements are applied. Residual variance is also significantly higher among rural and more educated respondents, indicating that perceptions are less predictable, not only less favourable, in these groups. The study contributes to the literature by jointly modelling perception across the full range of economic activities dependent on the delta's water resources and by testing, rather than assuming, the statistical adequacy of the ordered probit framework routinely applied in this literature. The findings support water governance responses differentiated by locality and socio-economic profile rather than broad demographic targeting and confirm the practical value of subjective perception data in a context where scientific water-quality monitoring remains limited.

Keywords: Water quality perception; Heteroskedastic ordered probit; Water resource governance; Oueme delta; Benin

JEL Classification: C25, **I15**, **O13**, **Q25**, **Q53**

1. Introduction

Water pollution now ranks among the most pervasive environmental pressures worldwide, driven by industrial discharge, agricultural runoff and inadequate waste disposal, and its economic and environmental costs are increasingly well documented (Sahoo and Goswami 2024). These pressures fall disproportionately on developing countries, where limited access to safe water compounds threats to public health and constrains ecosystem services such as fisheries, water supply and recreation, on which local economies depend. Because the incidence of pollution depends on the location of the emission source relative to the user, its effects and the perceptions it generates are not uniformly distributed across space but are instead sharply heterogeneous, varying markedly from one community, and one water body, to the next (Brockwell et al. 2021).

This spatial heterogeneity gives stakeholder perception a distinct evidentiary role in water governance. Because an economic agent's judgement of water quality reflects that agent's own characteristics and direct exposure to the resource, it constitutes information that no centralised monitoring network can fully replicate, which is why active public participation is enshrined as a governance principle for identifying problems and designing regulatory measures in frameworks such as that of the European Union (Artell et al. 2013). Integrating these perceptions into an inclusive governance approach is accordingly considered a precondition for effective water resource management, and assessments of public risk perception are increasingly treated as complements to, rather than substitutes for, technical expert assessment (Renn 1998; Marlon et al. 2018). In practice, however, water resource management programmes continue to give limited weight to stakeholder opinion, particularly that of local communities, at either the design or the implementation stage (Withanachchi et al. 2018). Policymakers tend, for reasons of technical convenience, to ratify management principles based on environmental risk assessments alone, leaving the concerns of direct resource users only partially examined, in part because local populations are themselves diverse in values, norms and knowledge (Raymond et al. 2010; Mostert 2003).

This gap is compounded by a practical constraint specific to resource-limited settings. In the absence of dense scientific monitoring networks, the subjective judgements of local economic agents constitute a source of information on water resource conditions that is not merely a second-best substitute but is frequently easier and considerably less costly to obtain than biophysical and chemical measurement (Artell et al. 2013), making it a particularly relevant evidentiary basis for developing countries facing binding financial constraints on environmental monitoring.

These general considerations acquire force in the Oueme delta, one of the richest zones of the Oueme river basin and a setting in which water resources simultaneously sustain agriculture, fishing, tourism, spiritual practices, water transport and livestock farming, among other high-value activities central to Benin's economy. Rising population density, shifting fishing techniques and intensifying agricultural practices have combined to make water pollution one of the delta's most pressing environmental problems (Agonkpahoun 2006), and the deltaic zone has in practice become the receiving basin for waste generated throughout the exploitation and management of the wider Oueme catchment (Direction Générale de l'Eau 2013). Harmful and toxic odours are commonly reported in several villages and neighbourhoods of the delta, and the transport of hydrocarbons on its waterways has been associated with the death of marine mammals, fish, birds and plants, disrupting the ecological balance on which these communities depend.

Against this background, the perceptions that economic agents hold of water quality and water resource management in the Oueme delta remain empirically unexamined, notwithstanding

their evident relevance to the design of effective governance responses. The present study addresses this gap by analysing, within a single econometric framework, the organoleptic, socio-demographic, socio-cultural and occupational determinants of these perceptions among a large sample of economic agents in the Oueme delta. Its contribution to the literature is twofold. First, unlike prior work, which has generally examined single occupational groups in isolation, this study adopts a holistic perspective that spans the full diversity of activities dependent on the delta's water resources, including fishing, farming, livestock rearing, water transport, sand quarrying, spiritual practice, water vending, tourism and ordinary household use, allowing the determinants of perception to be compared across occupational groups within a single, internally consistent sample rather than inferred by contrasting separate, methodologically heterogeneous studies. Second, the study extends the applied methodology itself by jointly testing, and where warranted relaxing, the proportional-odds and homoscedasticity assumptions that are routinely, and in our view too readily, imposed by the ordered probit models conventionally used in this literature, a methodological contribution detailed in Section 3.

The remainder of this article is organised as follows. Section 2 reviews the literature on the determinants of water quality perception. Section 3 presents the study area, the survey data and the econometric methodology. Section 4 reports and discusses the empirical results, and Section 5 concludes with implications for water resource governance in the Oueme delta.

2. Literature review

Research on public perceptions of water quality and water resource management converges on an organoleptic heuristic, a set of socio-demographic and experiential correlates, and a socio-cultural and economic-valuation dimension, all of which the present study draws upon.

A substantial literature identifies the sensory attributes of water, namely colour, clarity, odour and taste, as the primary heuristic through which lay users judge its quality where formal testing is unavailable (de França Doria 2010). Colour and turbidity have repeatedly been shown to condition perceived suitability for recreational and domestic use alike (Smith and Davies-Colley 1992; Smith et al. 1995). Steinwender et al. (2008) similarly find systematic divergence between residents' subjective assessments and instrumentally measured water quality in urban surface waters. More recent evidence confirms the persistence of this pattern: in an urban hill town in Darjeeling, India, Tamang and Jana (2020) find that the perceived odour and colour of water remain significant drivers of risk perception even after controlling for education, treatment behaviour and expenditure, while Nik Hassan et al. (2022), surveying a small island community in Malaysia whose gravity-fed supply tested positive for Escherichia coli in over 90 per cent of samples, show that it was a positive perception of water odour, rather than any objective indicator, that led residents to judge their untreated water safe to drink. Yet the reliability of this heuristic remains contested: Dinius (1981) and Kirk (1988) caution that organoleptic quality correlates only weakly with objective microbiological indicators, and Dogaru et al. (2009), studying a mining-affected catchment in Romania, show that community judgements track visible pollution episodes rather than the underlying, often more persistent, contamination load. This divergence between perceived and measured risk illustrates the broader gap between organoleptic assessment and objectively verified water quality.

Socio-demographic and experiential characteristics add a second, less uniform layer of explanation. Okumah and Yeboah (2019) show that age interacts with, rather than independently determines, organoleptic judgement in Ghana, while Abraham et al. (2016), also in Ghana, find that more educated respondents form more critical judgements of urban surface water quality. Direct experiential exposure appears, across several recent studies, to matter more than demographic profile per se. Jones et al. (2006) show that private-supply users' perceptions are shaped by first-hand experience of supply reliability; Javidi and Pierce (2018)

find that United States households who perceive tap water as unsafe adjust their consumption regardless of objectively measured risk; and Gachango et al. (2015), studying Danish farmers, extend the argument to occupational exposure, showing that agents whose livelihood depends directly on a water body form perceptions that diverge systematically from those of the general public. This experiential channel is corroborated in East Africa by Anthonj et al. (2019), who show that local knowledge of water-related infectious disease exposure among Kenyan wetland communities is shaped by first-hand illness experience rather than by formal health information, and by Gebremichael et al. (2021), who find that water-source choice and quality perception among urban households in north-west Ethiopia are jointly determined by socio-economic status and sanitation conditions rather than by either factor alone.

A closely related strand treats health-risk perception itself as an economically consequential outcome, typically within an averting-behaviour or willingness-to-pay framework, and has grown substantially in South Asia and West Africa over the past five years. Amoah et al. (2021), analysing household-survey data from Ghana, model the probability that a household engages in domestic water-improvement behaviour and find that age, environmental knowledge and household wealth are the principal drivers. In Pakistan, Mehmood et al. (2022) apply an ordered probit model to households' risk perceptions near a heavily polluted sewer in Rawalpindi, and find that education, income, proximity to the pollution source and prior health effects are the strongest predictors; in a companion study published in this journal, Mehmood and Arshad (2024) show that the experience of childhood diarrhoea significantly raises households' willingness to pay for safe drinking water in Pakistani urban slums. Khalil et al. (2023), surveying Karachi, similarly link household water insecurity directly to willingness to pay, reinforcing the broader finding that perceived, rather than only objectively measured, risk is what ultimately drives economic behaviour around water.

Perception is, finally, embedded in socio-cultural and institutional context: Pidgeon (1998) argues that risk perception cannot be reduced to a cognitive residual of imperfect information but is constitutively shaped by trust in the institutions responsible for the resource, while Dupont and Jahan (2012) show that households' defensive spending on substitutes for tap water reveals the implicit value they place on perceived, rather than measured, safety. This establishes that subjective perception data constitute a legitimate and economically consequential object of study in their own right, rather than a mere proxy for water quality that a chemical test could equally well provide.

Two gaps in this literature motivate the present analysis. First, notwithstanding the recent surge of comparable econometric studies in Ghana, Pakistan and Ethiopia, empirical evidence from West African deltaic settings, where water simultaneously supports domestic consumption, fishing, agriculture, transport and trade, remains scarce. Second, few of the studies reviewed above combine the organoleptic, socio-demographic and occupational-exposure channels within a single multivariate framework capable of isolating the independent contribution of each once the others are held constant. The present study addresses both gaps by jointly estimating these determinants among a large sample of economic agents in the Oueme delta, using an econometric framework, detailed in Section 3, that is explicitly designed to accommodate the ordinal nature of the perception variable and the clustered structure of the underlying survey design.

3. Study methodology

3.1. Study area

The study is set in the Oueme delta and its adjoining coastal zone, an administrative area comprising 22 communes across five departments of southern Benin, namely Atlantique, Littoral, Oueme, Plateau and Zou (Figure 1). This area corresponds to the lower course and

delta of the Oueme River, Benin's longest watercourse, which rises in the Atakora range in the northwest of the country and, after a course of several hundred kilometres, discharges into Lake Nokoue and the Porto-Novo lagoon near Cotonou. This deltaic and lagoon system supports a markedly diverse set of water-dependent livelihoods, spanning fishing, agriculture, livestock rearing, water transport, sand quarrying, small-scale water vending and tourism, in addition to the spiritual practices tied to the resource documented in Section 1, which together motivate treating the delta as a single, coherent study area rather than a collection of unrelated localities.

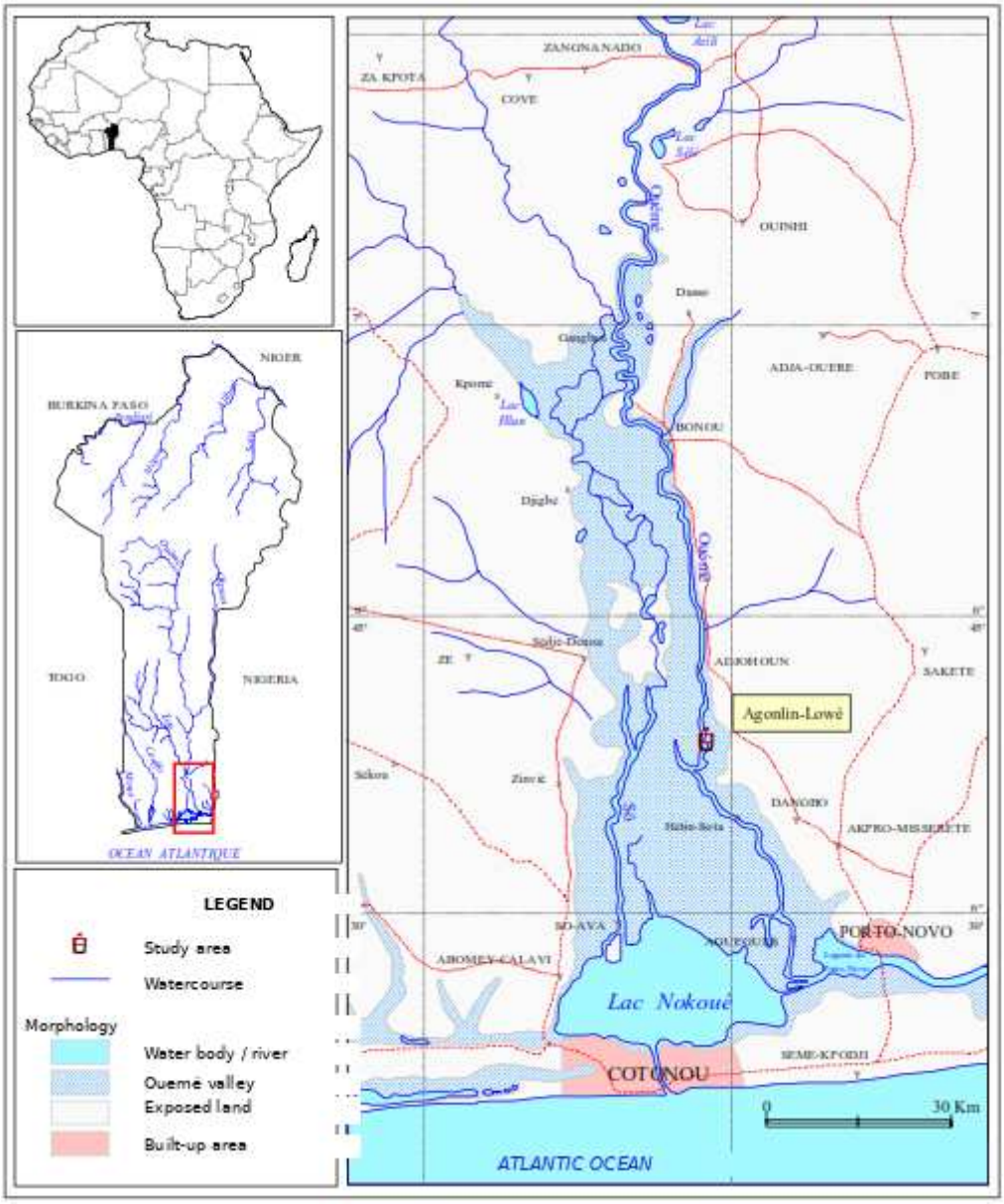


Figure 1: Administrative location of the Oueme Delta (Bouchardeau and Baudin, 1964)

According to the fourth General Population and Housing Census (INSAE 2013), the 22 communes of the Oueme delta and coastal zone were home to 3,560,089 inhabitants at the time of enumeration, more than a third of Benin's national population, with a marginally female-majority sex ratio (51.4 per cent women against 48.6 per cent men). Population is highly concentrated (Figure2). Tthe communes of Cotonou and Abomey-Calavi alone account for 19.1 per cent and 18.4 per cent of the delta's population respectively, followed at a distance by Porto-Novo and Semè-Kpodji, reflecting Cotonou's function as the country's principal economic centre and Abomey-Calavi's as its main peri-urban settlement area. This demographic

concentration, combined with a still-rising population and increasingly intensive fishing and agricultural practices, exerts sustained pressure on the delta's water resources, a pressure that is not, however, evenly distributed across the 22 constituent communes. It is this economic and demographic heterogeneity that the sampling strategy described in Section 3.2 is designed to reflect.

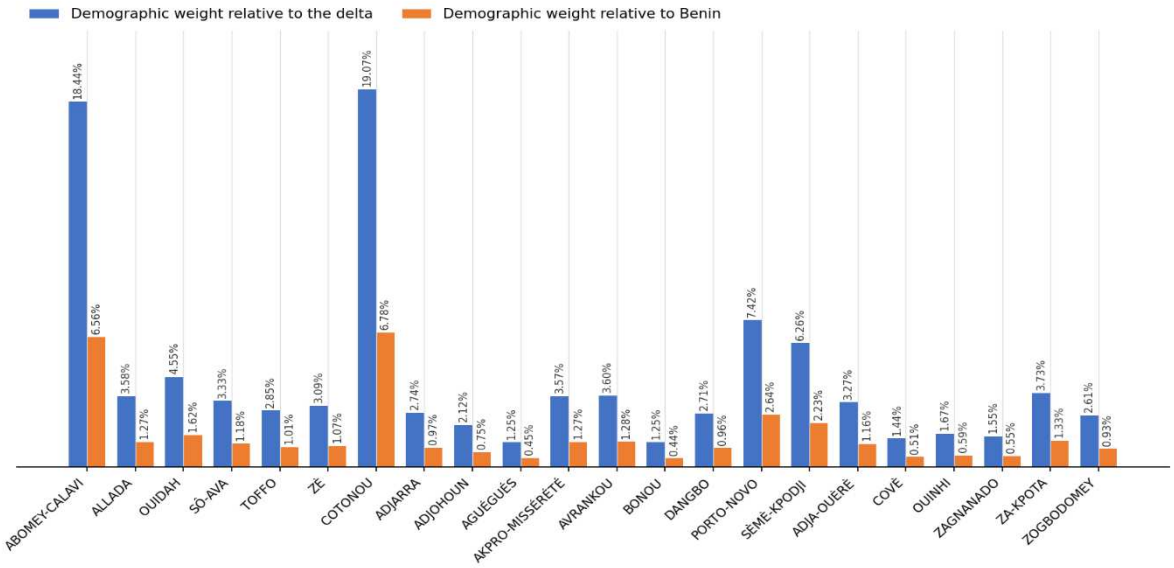


Figure 2: Demographic weight of the communes of the Oueme Delta (RGPH4, 2013).

3.2.Sample design and sample size

Data were collected through a structured, face-to-face questionnaire survey of economic agents aged 16 years and above, conducted in April 2021 under the OmiDelta research programme. Primary data collection was necessitated by the absence of any existing dataset on the economic goods and services associated with water resources in the Oueme delta, a gap that this survey was explicitly designed to fill.

Sample size was determined using the standard formula for simple random sampling from a finite population (Cochran 1977):

$$\mathrm{n} = \frac{t_p^2 \times P(1-P) \times \mathrm{N}}{t_p^2 \times P(1-P) + (\mathrm{N}-1)y^2}$$

where n is the required sample size, N is the target population, P is the expected proportion of a given response in that population, t_p is the value of the standard normal variate associated with the chosen confidence level, and y is the tolerated margin of sampling error. Assuming a 95% confidence level ($t_p = 1.96$), a 5% margin of error, and ($P = 0.5$) due to the absence of prior estimates, the minimum sample size was 384 respondents. Given the clustered survey design and the need to ensure sufficient representation across different categories of water-resource users and locations, this figure was inflated by a design effect of 8, resulting in a target sample of 3,072 respondents. The final survey covered 3,075 economic agents.

Because no comprehensive sampling frame listing individual economic agents active in the delta's water-dependent activities was available, probability sampling could not be implemented at the level of the individual respondent; the formula above was therefore used only to establish the overall target sample size, a standard practice when a sampling frame exists at the level of the population but not at the level of individual units. Respondent selection itself proceeded by quota sampling. The 22 communes of the study area were first stratified into three zones

reflecting the delta's principal settlement and production systems: an urban zone (Abomey-Calavi, Cotonou, Porto-Novo and Semè-Kpodji), a rural zone (Adjohoun, Bonou, Dangbo, Ouinhi and Zagnanado) and a lake zone (Sô-Ava and Aguegues). Within this typology, six communes (Abomey-Calavi, Cotonou, Semè-Kpodji, Dangbo, Ouinhi and Sô-Ava) were purposively retained for enumeration on the basis of their demographic weight (Section 3.1) and logistical accessibility, and enumeration quotas were allocated across communes accordingly.

Prior to administration, respondents were informed, in accordance with the introductory statement read at the start of each interview, that the survey was conducted as part of a doctoral research programme assessing the economic potential of water in the Oueme delta, that participation was voluntary and anonymous, and that individual responses would remain confidential and be reported only in aggregate form, in accordance with Article 25 of Beninese Law No. 99-014 of 12 April 2000 establishing the National Statistical Council. Under this procedure, a final sample of 3,075 economic agents aged 16 years or above was enumerated across the six selected communes in April 2021.

Because quota sampling is a non-probability method, the formal confidence intervals implied by the sample-size formula above do not strictly apply to the resulting estimates, and generalisation of the results beyond the sampled communes should be made with this limitation in mind.

3.3.Method of analysis and model specification

Data analysis proceeded in two stages. First, a descriptive analysis was carried out to summarise and identify the main patterns in the data (Tables 1 and 2). Second, an econometric analysis was conducted to identify the factors associated with economic agents' perception of current water resource management in the Oueme delta.

Prior to estimation, non-response codes on age, household composition, and monthly income were treated as missing values rather than recoded to zero, in order to avoid conflating non-response with a genuine absence of the underlying quantity. The two respondents with a missing age value were assigned the sample mean age; monthly incomes below 1,000 FCFA ($n = 27$), most of which reflected data-entry noise rather than a plausible income level, were set to zero. Household size was computed from the non-missing age-bracket components only.

The ordered probit model was chosen given the ordinal nature of the dependent variable, whose five categories are derived from a Likert-type scale. The dependent variable is the perception of economic agents regarding current water resource management in the Oueme delta, coded from 0 (very dissatisfied) to 4 (very satisfied). The model is specified as:

$$y_i^* = \beta' X_i + \mu_i \quad (1)$$

y_i^* is the latent variable underlying perception, β is the vector of parameters to be estimated, X_i is the vector of explanatory variables, and μ_i is an error term assumed to be normally distributed with mean zero. The observed ordinal outcome y_i relates to the latent variable through four threshold parameters $\kappa_1 < \kappa_2 < \kappa_3 < \kappa_4$:

$$y_i = m \text{ if } \kappa_m < y_i^* \leq \kappa_{m+1}, \ m = 0,1,2,3,4 \quad (2)$$

with the convention $\kappa_0 = -\infty$ and $\kappa_5 = +\infty$. The associated response probabilities are:

$$Prob(y_i = m|X_i) = \Phi(\kappa_{m+1} - \beta' X_i) - \Phi(\kappa_m - \beta' X_i), \ m = 0, \ldots, 4 \quad (3)$$

Marginal effects of X_i on the probability of each response category are computed as:

$$\frac{\partial Prob(y_i = m|X_i)}{\partial X} = [\varphi(\kappa_m - \beta' X_i) - \varphi(\kappa_{m+1} - \beta' X_i)]\,\beta, \;\; m = 0, \ldots, 4 \qquad (4)$$

We estimate five nested specifications (Models 1–5, Table 4) that sequentially introduce blocks of covariates: (i) organoleptic assessment criteria, disease shock, running-water connection, and core demographic and economic controls (age, age², sex, log income, household size); (ii) marital status and religion; (iii) educational attainment; (iv) place of residence; and (v) housing-tenure status. This sequential procedure allows the stability of the core coefficients to be assessed as additional covariates are introduced, and each added block is tested jointly using a Wald test. Because the survey was stratified across six communes with distinct environmental exposure profiles (Section 3.2), standard errors are clustered at the commune level throughout, rather than relying on heteroscedasticity-robust standard errors alone, since the perceptions of respondents drawn from the same commune are likely correlated.

Multicollinearity among covariates is assessed using variance inflation factors (VIF); all VIFs remain below the conventional threshold of 10, with the exception of the mechanical collinearity between age and age² ($VIF \approx 36 - 39$), which does not affect the stability of the other coefficients. The proportional-odds (parallel-lines) assumption underlying the standard ordered probit model is tested using the approximate likelihood-ratio test of Wolfe and Gould (1998); the test rejects the null hypothesis of equal coefficients across response categories ($\chi^2(66) = 428.11,\ p < 0.001$), indicating that the effect of covariates is not constant across the perception scale. A complementary test further reveals heteroscedasticity related to place of residence and educational attainment.

Because both diagnostics point to a violation of the assumptions underlying the standard ordered probit model, our preferred specification is a heteroskedastic ordered probit model, also known as a heterogeneous-choice or location-scale model (Williams, 2009), which relaxes the assumption of constant residual variance by allowing the scale of the latent variable to depend on a subset of covariates:

$$Prob(y_i = m|X_i, Z_i) = \Phi[\frac{(\kappa_{m+1} - \beta' X_i)}{\sigma_i}] - \Phi[\frac{(\kappa_m - \beta' X_i)}{\sigma_i}], \qquad ln(\sigma_i) = \gamma' Z_i \qquad (5)$$

where Z_i denotes place of residence and educational attainment, hypothesised to affect residual variability, and γ is the corresponding vector of parameters. The standard ordered probit model is nested within this specification as the special case $\sigma_i = 1\ \forall i$, and is reported alongside the preferred specification (Table 3) as a robustness comparison (Table 4).

4. Result and discussion

4.1.Sample characteristics

The estimation sample comprises 3,075 economic agents surveyed across six communes of the Oueme delta (Table 1; Table 2). Respondents are predominantly male (70.8 per cent) and married (82.9 per cent), reside mostly in rural settings (60.9 per cent), and report a mean age of 37.0 years ($SD = 12.0$). More than half (51.4 per cent) have received no formal education, a proportion consistent with the delta's largely agrarian economy, in which agriculture and fishing together account for two-thirds of respondents' principal economic activity (46.0 per cent and 20.6 per cent, respectively). Only a third of the sample (34.5 per cent) reports being connected to a piped water network, and the overwhelming majority (93.7 per cent) fetch water daily, underscoring the centrality of water collection to the everyday economic life of the delta's population.

Table 1 : Descriptive statistics, continuous variables

Variable	N	Mean	SD	Min / Max
Age (years)	3,075	37.03	11.95	17 / 90
Monthly income (FCFA)	3,073	69,552.55	163,862.10	0 / 7,500,000
Log(monthly income)	3,073	10.62	1.36	0 / 15.83
Household size (persons)	3,058	5.34	3.34	0 / 46

Notes: total sample N = 3,075. Counts below 3,075 reflect missing values (non-response) for income (2 observations) and household composition (17 observations).

Regarding perceptions of current water resource management, the distribution is markedly left-of-centre: 40.4 per cent of respondents report some degree of dissatisfaction (11.9 per cent "very dissatisfied", 28.5 per cent "rather dissatisfied"), against 36.5 per cent expressing satisfaction, and 23.2 per cent remaining indifferent. When asked to identify the basis of their judgement, 68.9 per cent of respondents cite the visual appearance of the water (colour) and 14.7 per cent its odour; the residual 16.4 per cent selected an unspecified "other" criterion which, on inspection of the accompanying open-ended responses, corresponds only loosely to concerns about solid waste and is better understood as a heterogeneous residual category than as a clean proxy for perceived contamination by refuse. We return to this point below, as it qualifies the interpretation of the "assessment criterion" variable throughout the analysis.

Table 2: Descriptive statistics, categorical variables

Variable	N	Distribution (%)
Perception of water resource management	3,075	Very dissatisfied 11.9; Rather dissatisfied 28.5; Indifferent 23.2; Rather satisfied 30.3; Very satisfied 6.2
Disease shock (respondent)	3,075	Yes 31.0
Assessment criterion (ref.: other/unspecified)	3,075	Colour/appearance 68.9; Odour 14.7; Other/unspecified 16.4
Connected to piped water network	3,075	Yes 34.5
Sex	3,075	Male 70.8
Place of residence	3,075	Rural 60.9
Marital status (ref.: divorced/widowed)	3,075	Divorced/widowed 3.1; Single 14.0; Married 82.9
Religion (ref.: Celestial)	3,075	Celestial 1.2; Endogenous 10.0; Atheist 3.2; Muslim 4.1; Christian 81.5
Educational attainment (ref.: none)	3,075	None 51.4; Primary 23.5; Lower secondary 10.8; Upper secondary 7.4; Higher 7.0
Housing tenure (ref.: tenant)	3,075	Tenant 25.3; Family home 31.1; Owner 43.6
Water-fetching frequency	3,075	Daily 93.7
Principal economic sector (ref.: none listed)	3,075	Agriculture 46.0; Fishing 20.6; Livestock 3.4; Commerce 11.2; Water transport 4.0; Other water-related 3.6; None listed 11.3

Commune	3,071	Abomey-Calavi 16.6; Cotonou 12.8; Dangbo 18.9; Ouinhi 18.6; Sèmè-Kpodji 16.6; Sô-Ava 16.4

Notes: total sample N = 3,075, except for commune (N = 3,071; 4 observations with no department reported). For binary variables, only the percentage of the category shown is reported; the complement is obtained by subtraction from 100%. The reference category used in Tables 3 and 4 is the first category listed for each variable.

4.2.4.2. Determinants of perceived water resource management

Table 3 reports our preferred specification, a heteroskedastic ordered probit model in which the scale of the latent perception variable is allowed to vary with place of residence and educational attainment, while Table 4 presents, for comparison, the sequence of standard ordered probit models (Models 1-5) that progressively introduce blocks of covariates under commune-clustered standard errors. The two sets of estimates tell a consistent, and instructive, story.

Organoleptic and health-related factors. Across both specifications, respondents who base their judgement on the colour of the water are significantly more dissatisfied than those in the residual reference category ($\beta = -0.436, p < 0.01$ in Table 3; $\beta = -0.384, p < 0.1$ in Table 4, Model 5), a result that is both quantitatively large and highly stable. By contrast, the odour-based assessment coefficient is never statistically distinguishable from zero ($p = 0.107$ and $p = 0.608$, respectively), a null result that, read together with the ambiguity of the reference category noted above, cautions against over-interpreting the organoleptic contrast as a clean colour-versus-waste comparison; we discuss this limitation further in Section 5. The experience of a recent disease shock is, on the other hand, unambiguously and robustly associated with lower satisfaction ($\beta = -0.440, p < 0.01$ in the preferred model; $\beta = -0.393, p < 0.05$ in Model 5), and remains the single most consistent predictor of perception across every specification we estimate, including the sector- and water-burden-augmented model discussed below.

Socio-demographic and economic factors. Once commune-level clustering and the corrected treatment of missing values are properly accounted for, several associations that appeared strongly significant in a naïvely specified model are considerably weaker, or disappear altogether. Age, age squared, and sex retain only marginal significance in the preferred heteroskedastic specification ($p = 0.029$, $p = 0.059$ and $p = 0.052$, respectively) and lose significance entirely under the standard clustered probit (Table 4, Model 5), while household size and connection to the piped network are only weakly, if at all, associated with perception once the full set of controls is included. This pattern is not a weakness of the analysis; it is, on the contrary, precisely what a more rigorous treatment of the sampling design and of residual heteroskedasticity should reveal, and it tempers the stronger demographic claims that a more permissive specification might otherwise have supported. Monthly income, expressed in logarithms, is negatively and robustly associated with satisfaction ($\beta = -0.047, p < 0.01$), a pattern we interpret, consistent with the wider literature on subjective wellbeing, as reflecting the higher expectations and heightened sensitivity to service shortfalls typically exhibited by better-off households rather than any objective deterioration in the resource itself.

Table 3: Heteroskedastic ordered probit estimates of the determinants of perceived water resource management (preferred specification)

Variable	**Choice equation ($\boldsymbol{\beta}$)**	**Variance equation ($\boldsymbol{ln\sigma}$)**
Disease shock	-0.440***	-
	(0.049)	
Assessment criterion (ref.:		

other/unspecified)		
Colour/appearance	-0.436***	-
	(0.061)	
Odour	0.121	-
	(0.075)	
Connected to piped water network	-0.108**	-
	(0.047)	
Age	0.024**	-
	(0.011)	
Age squared	-0.0002*	-
	(0.0001)	
Male	0.099*	-
	(0.051)	
Log(monthly income)	-0.047***	-
	(0.017)	
Household size	-0.013*	-
	(0.007)	
Marital status (ref.: divorced/widowed)		
Single	-0.028	-
	(0.148)	
Married	-0.123	-
	(0.127)	
Religion (ref.: Celestial)		
Endogenous	0.037	-
	(0.200)	
Atheist	-0.064	-
	(0.221)	
Muslim	-0.071	-
	(0.215)	
Christian	0.056	-
	(0.189)	
Educational attainment (ref.: none)		
Primary	-0.131**	0.095**
	(0.056)	(0.040)
Lower secondary	0.019	0.072
	(0.075)	(0.053)
Upper secondary	-0.220**	0.094
	(0.091)	(0.063)
Higher	-0.486***	0.173***
	(0.103)	(0.066)
Rural (ref.: urban)	-0.292***	0.079**
	(0.048)	(0.034)
Housing tenure (ref.: tenant)		
Family home	-0.308***	-
	(0.061)	
Owner	-0.075	-
	(0.060)	
Threshold 1 (/cut1)	-2.247	-
	(0.349)	
Threshold 2 (/cut2)	-1.131	-
	(0.346)	
Threshold 3 (/cut3)	-0.423	-
	(0.346)	
Threshold 4 (/cut4)	0.942	-

	(0.353)
Observations (N)	*3,056*
LR chi²(27)	*361.91*
Log-likelihood	*-4,355.47*
Pseudo R²	*0.0399*

*Notes: standard errors in parentheses. * p < 0.10; ** p < 0.05; *** p < 0.01. Dependent variable: perception of water resource management (0 = very dissatisfied to 4 = very satisfied). Reference categories: assessment criterion = other/unspecified; marital status = divorced/widowed; religion = Celestial; educational attainment = none; place of residence = urban; housing tenure = tenant. The variance equation ($\ln\sigma$) reports the determinants of heteroskedasticity; a positive coefficient indicates higher residual variance (less predictable perceptions) for the category concerned.*

Education. Educational attainment displays a strikingly monotonic gradient: relative to respondents with no formal education, satisfaction declines with primary education ($\beta = -0.131$, $p < 0.05$), declines further with completed secondary education ($\beta = -0.220$, $p < 0.05$), and is lowest among respondents with tertiary education ($\beta = -0.486$, $p < 0.01$). This gradient, which survives every robustness check reported below, echoes the theoretical proposition that education raises the informational and normative standards against which respondents evaluate public goods, so that more educated agents are more likely to perceive shortcomings that less educated agents do not register or do not weight as heavily.

Housing tenure and place of residence. Respondents living in a family home report significantly lower satisfaction than tenants ($\beta = -0.308$, $p < 0.01$), a result we interpret as capturing an attachment effect: long-settled households, often the original occupants of a locality, may hold a comparison standard rooted in the historical, undegraded state of the resource, against which present conditions compare unfavourably. Rural residence carries no significant coefficient in the choice equation of the preferred model, but, as discussed immediately below, is a highly significant driver of the variance of perceptions, a distinction that a conventional homoskedastic probit is definitionally unable to draw.

4.3.Model diagnostics, heterogeneity, and robustness

The variance equation of the preferred specification indicates that residual heterogeneity in perception is significantly greater among rural residents ($\gamma = 0.079$, $p < 0.05$) and among respondents with primary or tertiary education ($\gamma = 0.095$ and $\gamma = 0.173$, respectively, both $p < 0.05$), relative to their urban and uneducated counterparts. Substantively, this means that place of residence and education shape not only the average level of satisfaction but also its predictability: perceptions among rural and highly educated respondents are more dispersed and less well summarised by a single average effect than those of urban or uneducated respondents. This finding, which to our knowledge has not previously been documented in the water-perception literature, is itself a contribution of the heteroskedastic specification and offers a substantive, testable explanation for why the standard ordered probit, which forces a common variance on all respondents, systematically understates the precision of some coefficients (notably disease shock and the colour criterion, whose magnitude increases once heteroskedasticity is modelled) while overstating that of others.

This choice of specification is not made on convenience grounds. An approximate likelihood-ratio test of the proportional-odds assumption underlying the standard ordered probit model rejects the null hypothesis of coefficient equality across response categories ($\chi^2(66) = 428.11$, $p < 0.001$), and variance inflation factors computed on the full set of covariates reveal no material multicollinearity beyond the mechanical association between age and its square. Taken together, these diagnostics indicate that the constant-variance ordered probit – while retained in Table 4 for comparability with the wider empirical literature that relies on this workhorse specification – is a statistically dominated description of the data-generating process.

Three further checks corroborate the stability of these findings. First, replacing the urban/rural dichotomy with a full set of commune fixed effects sharpens the precision of every coefficient (the standard errors on disease shock and the colour criterion roughly halve) and reveals substantial geographic heterogeneity that the coarser rural indicator masks entirely: relative to Abomey-Calavi, satisfaction is significantly lower in Dangbo ($\beta = -0.403$, $p < 0.01$) and significantly higher in Ouinhi and Sèmè-Kpodji ($\beta = 0.362$ and $\beta = 0.671$, respectively, both $p < 0.01$). This spatial gradient, considerably sharper than any urban–rural contrast, suggests that locality-specific environmental and infrastructural conditions – rather than urbanity per se – are the more proximate drivers of perceived water quality, a hypothesis that future work combining these survey data with physicochemical measurements at the commune level could usefully test. Second, augmenting the preferred model with the frequency of the domestic water-fetching chore and the respondent's principal economic sector – two dimensions of direct resource exposure emphasised in Section 2.5 but omitted from the original specification – leaves the core results unchanged while adding two economically meaningful findings of their own: respondents who fetch water daily are significantly less satisfied than those who do so less frequently ($\beta = -0.293$, $p < 0.05$), consistent with a burden-of-collection channel, and satisfaction varies significantly across occupational sectors, being notably lower among those engaged in commerce ($\beta = -0.216$, $p < 0.05$) and, at a weaker level of confidence, among livestock keepers ($\beta = -0.241$, $p < 0.1$) and higher among fishers ($\beta = 0.209$, $p < 0.1$) – a pattern broadly consistent with the intensity and immediacy of each occupation's reliance on the water resource. Third, re-estimating the preferred model after excluding the small number of observations affected by data-quality concerns (two respondents with originally missing age values and twenty-seven implausibly low income entries) leaves every substantive conclusion intact.

4.4.Discussion

The pattern of results that emerges once the model is correctly specified is more selective, and arguably more informative, than a first pass at these data would suggest. The experience of a health shock, the colour of the water, educational attainment, and housing tenure emerge as robust, quantitatively important correlates of dissatisfaction with water resource management, while several socio-demographic characteristics conventionally treated as central to the perception literature, namely age, sex, marital status and religious affiliation, display, at best, weak and specification-dependent associations in this setting.

The negative association between disease shock and satisfaction corroborates the broader proposition that health and material wellbeing are interdependent but conceptually distinct constructs (Nanor et al. 2018; Allin and Hand 2014; Deaton 2013; World Health Organization 1986). Agents who have recently experienced illness appear to project their diminished physical wellbeing onto their evaluation of a public resource plausibly implicated in that illness, independently of any objective change in water quality. The educational gradient we document is consistent with the view that education operates primarily by raising the evaluative standard against which a public good is judged, rather than by improving objective access to it (Veenhoven 1996); on this reading, better-educated respondents are not experiencing worse water, but judging the same water more critically. This interpretation is reinforced by the housing-tenure result: family-home occupants, who by construction have the longest-standing exposure to the locality, appear to judge current conditions against a historical baseline unavailable to more recently settled tenants.

The comparatively muted role of age and sex in our preferred specification departs from a strand of the literature reporting that younger respondents are more likely to be dissatisfied with water services and to perceive tap water as riskier (Stevens 1996; MORI 2002; Grondin et al. 1995;

AWWA 1993; Parkin et al. 2001; Syme and Williams 1993), and from evidence of weak sex differences in subjective satisfaction more generally (Haring-Hidore et al. 1985; Botha and Booysen 2013; Blaauw and Pretorius 2013; Mahadea and Ramroop 2015). It also sits alongside more recent econometric evidence from other developing-country settings that continues to find age a significant driver of water-related risk perception and averting behaviour (Amoah et al. 2021; Mehmood et al. 2022). We do not read this divergence as a contradiction so much as a caution: many of the associations reported elsewhere are estimated without accounting for either the clustered structure of the underlying sample or the possibility that residual variance itself differs systematically across subgroups. Our results suggest that, at least in the Oueme delta, once these two features of the data are addressed, age and sex carry considerably less independent explanatory weight than a cross-sectional comparison of means would imply. Similarly, while the psychological literature on organoleptic perception documents systematic interactions between colour, odour and prior familiarity in shaping sensory judgement (Noble 1996; Strang 2001; Pliner and Pelchat 1991; Prescott 1998), and recent applied work continues to confirm the salience of odour and colour to risk judgement in other developing-country settings (Tamang and Jana 2020; Nik Hassan et al. 2022), the absence of a significant odour effect in our data should be interpreted in light of the ambiguity of the “other” reference category discussed in Section 4.1. We flag the construction of a cleaner, text-validated measure of the "waste" criterion as a priority for future survey rounds in the delta.

Finally, as with all ordered-response models, the coefficients reported in Table 3 index the effect of each covariate on the underlying latent propensity to be satisfied, and their sign, though generally informative, does not map mechanically onto the sign of the effect on any single observed category of the dependent variable (Greene 2003). The marginal effects reported in Table 4 of the earlier working results, and reproducible in full for every response category from the estimates underlying Table 3, should be consulted wherever a claim about a specific satisfaction category, rather than about the latent propensity as a whole, is intended.

5. Conclusion and Implications for Economic Policies

This study examined the determinants of economic agents’ perceptions of water quality and resource management in the Oueme delta using a heteroskedastic ordered probit model, adopted after formal tests rejected the assumptions underlying the standard specification. Health shocks, water colour, education and housing tenure emerge as the most robust correlates of dissatisfaction, whereas age, sex, marital status and religion contribute comparatively little, a pattern that qualifies much of the existing literature. Perceptions are also significantly more heterogeneous among rural and educated respondents. These results support governance responses differentiated by locality and socio-economic profile rather than broad demographic targeting, and confirm the value of subjective perception data where scientific water-quality monitoring remains scarce.

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The authors declare that there are no known financial or personal relationships that could have appeared to influence the work reported in this article.

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Annex 1: ***Nested models (Mod1 to Mod5)***

Tableau 4. Results of the standard ordered probit with standard errors clustered by commune

	(1)	(2)	(3)	(4)	(5)
Variables	**Mod1**	**Mod2**	**Mod3**	**Mod4**	**Mod5**
Disease shock (respondent)	-0.361*	-0.361*	-0.378*	-0.404**	-0.393**
	(0.192)	(0.191)	(0.195)	(0.188)	(0.182)
Assessment criterion = colour/appearance (ref.: other/unspecified)	-0.419*	-0.420*	-0.427*	-0.407*	-0.384*
	(0.229)	(0.229)	(0.226)	(0.227)	(0.213)
Assessment criterion = odour (ref.: other/unspecified)	0.107	0.101	0.101	0.123	0.126
	(0.254)	(0.257)	(0.257)	(0.248)	(0.245)
Connected to piped water network	-0.107	-0.108	-0.0859	-0.0959	-0.0926
	(0.229)	(0.225)	(0.218)	(0.207)	(0.201)
Age	0.0251*	0.0274	0.0292	0.0242	0.0190
	(0.0137)	(0.0178)	(0.0191)	(0.0153)	(0.0151)
Age squared	-0.000226	-0.000254	-0.000279	-0.000224	-0.000178
	(0.000156)	(0.000192)	(0.000203)	(0.000162)	(0.000161)
Male	0.105	0.108	0.120	0.0928	0.0833
	(0.0964)	(0.0982)	(0.0988)	(0.0736)	(0.0870)
Log(monthly income)	-0.0442	-0.0444	-0.0405	-0.0421	-0.0466
	(0.0394)	(0.0391)	(0.0416)	(0.0337)	(0.0338)
Household size	-0.0131	-0.0113	-0.0133	-0.00953	-0.00962
	(0.0105)	(0.00961)	(0.0102)	(0.00774)	(0.00758)
Single (ref.: divorced/widowed)	-	-0.0894	-0.0544	-0.0724	-0.0482
		(0.147)	(0.130)	(0.134)	(0.149)
Married (ref.: divorced/widowed)	-	-0.112	-0.113	-0.118	-0.120
		(0.144)	(0.151)	(0.156)	(0.158)
Endogenous (ref.: Celestial)	-	0.000444	-0.0162	0.0171	0.0350
		(0.225)	(0.229)	(0.169)	(0.163)
Atheist (ref.: Celestial)	-	0.0177	0.00979	-0.0316	-0.0518
		(0.183)	(0.184)	(0.131)	(0.128)
Muslim (ref.: Celestial)	-	-0.0754	-0.0776	-0.0660	-0.0779
		(0.156)	(0.146)	(0.163)	(0.171)
Christian (ref.: Celestial)	-	0.0699	0.0672	0.0477	0.0460

Variables	(1) Mod1	(2) Mod2	(3) Mod3	(4) Mod4	(5) Mod5
		(0.109)	(0.108)	(0.0492)	(0.0623)
Primary (ref.: none)	-	-	-0.0743	-0.0969	-0.110*
			(0.0676)	(0.0637)	(0.0634)
Lower secondary (ref.: none)	-	-	0.0897	0.0442	0.0241
			(0.140)	(0.0949)	(0.0964)
Upper secondary (ref.: none)	-	-	-0.101	-0.158	-0.181
			(0.140)	(0.117)	(0.122)
Higher (ref.: none)	-	-	-0.293*	-0.380***	-0.411***
			(0.159)	(0.147)	(0.142)
Rural (ref.: urban)	-	-	-	-0.303	-0.261
				(0.206)	(0.204)
Family home (ref.: tenant)	-	-	-	-	-0.276***
					(0.0943)
Owner (ref.: tenant)	-	-	-	-	-0.0609
					(0.0503)
Threshold 1 (/cut1)	-1.534**	-1.537**	-1.509**	-1.861***	-2.120***
	(0.615)	(0.734)	(0.745)	(0.389)	(0.443)
Threshold 2 (/cut2)	-0.552	-0.553	-0.522	-0.861**	-1.115**
	(0.637)	(0.747)	(0.757)	(0.423)	(0.472)
Threshold 3 (/cut3)	0.0763	0.0757	0.109	-0.224	-0.473
	(0.598)	(0.711)	(0.723)	(0.400)	(0.461)
Threshold 4 (/cut4)	1.302**	1.301**	1.339**	1.015***	0.772*
	(0.515)	(0.653)	(0.668)	(0.379)	(0.415)
Observations	3 052	3 052	3 052	3 052	3 052

*Notes: standard errors in parentheses, adjusted for clustering by commune (6 clusters). * p < 0.10; ** p < 0.05; *** p < 0.01. Same reference categories as Table 3. Mod1: organoleptic factors and basic demographics. Mod2: + marital status and religion. Mod3: + educational attainment. Mod4: + place of residence. Mod5: + housing tenure (full specification). This model assumes homoskedasticity and proportionality of effects across categories of the dependent variable, two assumptions rejected by the tests reported in the notes to Table 3; it is presented here for comparison and to illustrate the stability of the estimated effects as blocks of covariates are added.*