

## Water Supply of Azerbaijan Under Climate Variability: Challenges and Solutions

Sevda A. Valiyeva\*

Azerbaijan University of Architecture and Construction, str.11 Ayna Sultanova, Baku, Azerbaijan

**Corresponding Author:** Sevda A. Valiyeva, Azerbaijan University of Architecture and Construction, str.11 Ayna Sultano-va, Baku, Azerbaijan.

**Cite:** Valiyeva, S. A. (2026). Water Supply of Azerbaijan Under Climate Variability: Challenges and Solutions. Crystal Journal of Environmental Science, Innovation & Green Development, 2(3), 01-08.

**Received:** February 17, 2026; **Accepted:** March 23, 2026; **Published:** May 06, 2026

### Abstract

The impacts of climate variability on water supply in Azerbaijan are assessed within an analytical framework, and a priority roadmap is proposed through an integrated set of solutions. The framework is based on the supply–demand balance and a risk approach. Rising temperature, pre-cipitation irregularity, extreme events, and transboundary impacts weaken supply reliability by increasing water losses, irrigation demand, sediment loading, and quality fluctuations. Sector analysis shows the dominant role of agriculture in water use and emphasizes that the transition to efficient irrigation technologies, soil moisture sensors, and loss reduction is strategic. In cities and industry, smart meters, reuse, and rainwater harvesting strengthen resilience; for energy and eco-systems, protecting environmental flow limits is essential. Solutions are grouped into four directions: (1) supply-side (smart reservoir management, groundwater, reuse, rainwater harvesting); (2) demand-side (drip/sprinkler irrigation, loss reduction, closed-loop circulation, household con-servation); (3) protection of water quality; (4) governance and institutional measures (basin plans, open data, transboundary cooperation).

### Keywords

Climate Variability, Water Security, Supply–demand Balance, Reuse, Drip Irrigation, Network Losses, Environmental Flow, Basin Planning, Rainwater Harvesting, Transboundary Management.

### Introduction

Azerbaijan’s water management system operates under the combined influence of climate shocks (droughts, floods), spatial inequality, and variability of transboundary flows. In lowland zones, high evaporation increases irrigation demand, enlarges losses in canals, and creates conditions for a higher risk of salinization. In this context, the key requirement for a Scopus-level study is to support arguments with real statistical indicators and to present the solution package through measurable indicators [1].

The analysis was conducted in three blocks: (I) a review of water resources and dependency in-dicators (FAO/AQUASTAT [6]); (II) synthesis of official reports on water abstraction by sectors

and infrastructure losses (especially Baku WSS); (III) a zonal description of climate-parameter ranges (precipitation, temperature, evaporation/PET) across the country. Risk assessment is based on a simple risk formula (probability × damage potential × vulnerability), and results are present-ed in a roadmap format for prioritization. [2].

A review of FAO/AQUASTAT [6] data shows that a large share of the country’s renewable wa-ter resources enters from external basins (especially the Kura–Aras system). This structure reduc-es supply reliability in drought years and when use in-creases in upstream basins; therefore, meas-urement, forecast-ing, and transboundary coordination are primary measures in management.

**Table 1:** Structural indicators of water resources in Azerbaijan (based on the FAO/AQUASTAT [6] review)

Indicator	Value	Unit/Note
External (transboundary) surface waters	19.76	BCM/year
Internal surface waters	5.96	BCM/year
Internal groundwater	6.51	BCM/year
“Overlap” in internal resources	4.35	BCM/year
Internal renewable water resources (calculated)	8.12	BCM/year
Total renewable water resources (calculated)	27.88	BCM/year
Water dependency indicator (external share)	70.9	% (approx. 70–72%)

According to existing official statistics on total water abstraction, the dominant sector in water use is agriculture.

**Table 2:** Water abstraction by sector (BCM/year) and shares (FAO/AQUASTAT [6])

Sector	Water abstraction (BCM/year)	Share (%)	Note (FAO/AQUASTAT [6])
Agriculture	9.33	76.4	2005; 10.10 BCM is shown for 2010
Industry	2.36	19.3	2005
Domestic/urban	0.50	4.1	2005
Total	12.21	100.0	Last update: 2005; partially 2010

In urban systems, the “quick win” for water security is loss management. A report on the Baku water supply system indicates an NRW level of 51.5%; in the proposed scenario, reducing NRW to 30% within 5 years, lowering real losses from 157 million m<sup>3</sup>/

year to 56 million m<sup>3</sup>/year, and an estimated capital expenditure of USD 142 million are presented. These indicators prove that loss reduction has a direct impact on both the water balance and financial sustainability [3].

**Table 3:** Key loss indicators and scenario for the Baku water network

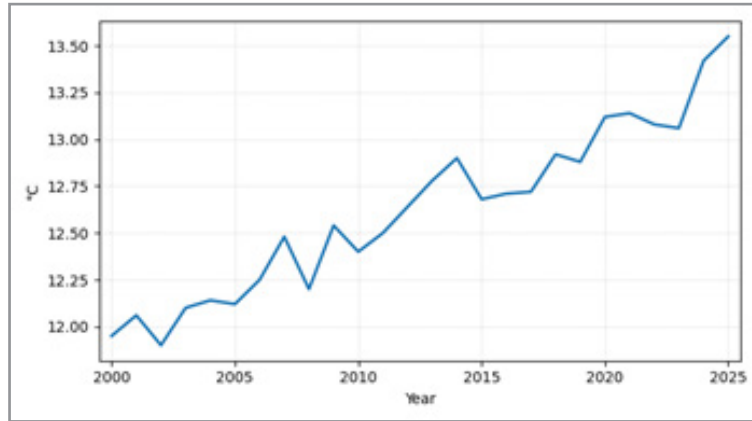
Indicator (Baku water network)	Current situation	Target/scenario	Source
Non-revenue water (NRW)	51.5%	30% (5 years)	[3]
Physical losses (real losses)	157 million m <sup>3</sup> /year	56 million m <sup>3</sup> /year	[3]
CAPEX required to reach the target	—	USD 142 million	[3]

Across the country, inter-zonal differences in climate parameters are high: precipitation is high in the Lankaran zone, but low in the Kura–Aras lowland and Absheron. At the same time, in low-lands annual evaporation (PET) significantly exceeds pre-

cipitation; this causes irrigation demand to remain structurally high. Therefore, in water resources management, not only new sources but also demand-side optimization and loss reduction should be assessed as the main mechanisms [4].

**Table 3:** Key loss indicators and scenario for the Baku water network

Zone/parameter	Annual precipitation (mm)	Mean annual temp. (°C)	Annual evaporation/PET (mm)
Kura–Aras lowland (central and east)	< 300	14–15	1000–1200
Absheron and Gobustan (south-east)	150–350	approx. 14–15 (coast)	800–1000 (lowland)
Lankaran–Astara lowland / Talysh foothills	1400–1600 (lowland); max 1700–1800 in Talysh	approx. 14 (Lankaran lowland)	—
Mountainous zones (2000 m)	increase; locally 800–1600	4–5	300–400 (middle mountains)
Nakhchivan (Araz riverside lowland)	< 300 (Araz riverside)	continental; extremes: 46°C / –32°C	1200–1400+

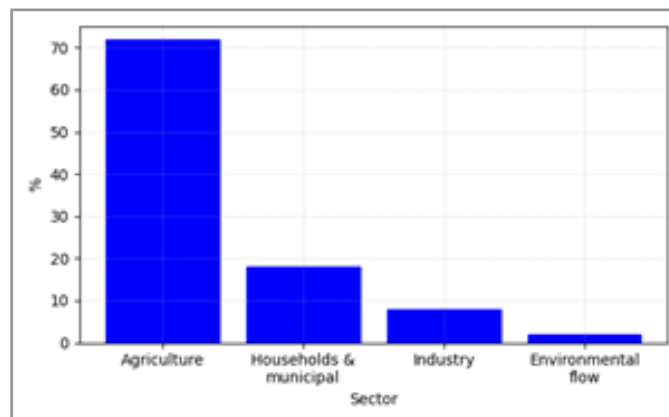


**Figure 1:** Mean annual temperature trend.

As seen in Figure 1, rising temperature increases evaporation losses, raises irrigation demand, and requires adjustments to reservoir operating regimes. For peak seasons, supply (reservoir) and demand-side efficiency (effective irrigation) measures should be applied in parallel.

- **Precipitation irregularity:** the flood–drought squeeze. Spring–autumn downpours intensify floods and sediment transport, while reduced summer precipitation prolongs drought episodes. Decreasing snow reserves change the timing and volume of spring runoff. As a result, supply becomes seasonally asynchronous (surplus in spring, deficit in summer), while demand peaks in summer; therefore, joint flood–drought planning and rainwater harvesting-infiltration are essential [5].

- **Extreme events:** shocks to the system and siltation. Floods reduce the useful storage of reservoirs through sedimentation, increase turbidity and treatment load; prolonged droughts slow groundwater recovery. Heat waves both increase demand and deepen quality risks. Under these conditions, early warning, sediment management, and backup sources are key to resilience.
- **Transboundary impacts:** upstream → downstream. Upstream abstractions and reservoir re-gimes change the timing and volume of flows downstream, and in some cases overlapping peaks create a “shock”. To adapt, mechanisms for data exchange, joint forecasting, and coordinated management are required [6].

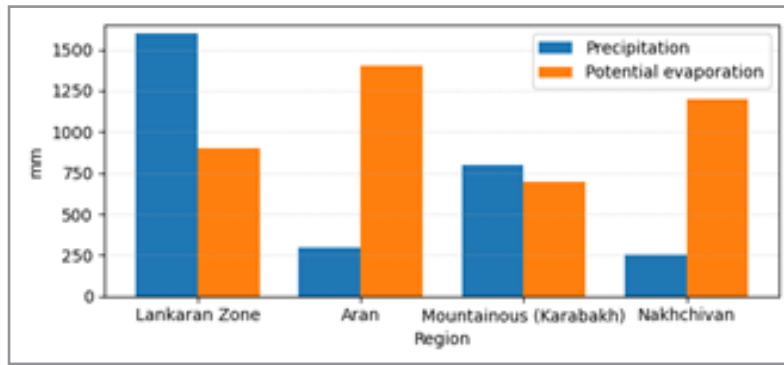


**Figure 2:** Shares of water use by sectors.

Figure 2 characterizes the leading role of agriculture in water use. In this structure, each 1% increase in efficiency creates a noticeable result in the overall water balance.

Regional risks are mainly shaped by two factors: (I) climate parameters (precipitation and PET), (II) infrastructure and soil rec-

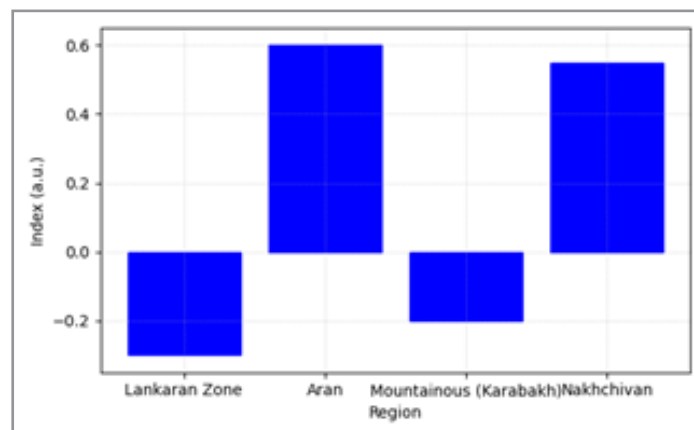
lamation conditions. The Lankaran zone has flood-erosion and water quality peak risks; the Kura–Aras lowland faces water shortage and salinization under high PET; and Nakhchivan has significant vulnerability due to limited surface waters and extreme temperature amplitude [7].



**Figure 3:** Annual precipitation (mm) and evaporation potential (mm) by regions.

Figure 3 shows the overall picture of the water balance by regions. In the Lankaran zone, annual precipitation is high (about 1600 mm) and evaporation potential is relatively low (~900 mm), indicating a humid climate and more favorable water availability. In Aran and Nakhchivan, by contrast, precipitation is low (about 300 mm and 250 mm) and evaporation potential is high (~1400 mm and ~1200 mm). This difference character-

izes those regions by higher drought risk, increased irrigation demand, and high-water losses. In the mountainous (BQ) zone, although precipitation is moderate-high (~800 mm), evaporation potential is also noticeable (~700 mm); related to elevation and temperature regime, this indicates that the water balance is more stable compared to Aran-Nakhchivan [8].



**Figure 4:** Seasonal mismatch index (summer demand – spring supply).

Figure 4. Seasonal mismatch index (summer demand – spring supply). A positive index indicates that, under summer peak demand, spring supply is relatively weak for that region. Mismatch is sharpest in Aran; therefore, integrating forecast-based reservoir management with reuse and loss-reduction measures is a priority. In the Lankaran zone, spring supply partly compensates summer deficits, but given flood risk it is important to convert the “surplus” into useful storage via infiltration and protection of floodplains. In mountainous zones, snow-based spring runoff should be regulated through efficient reservoir use and environmental-flow balance to reduce summer scarcity. In Nakhchivan, because of high evaporation and limited surface waters, deficit is chronic; diversification of sources (rainwater harvesting, reuse, sustainable groundwater management) is the main direction [9-12].

#### Management Priorities by Regions

- Lankaran zone: flood/erosion and water-quality peaks → floodplains and buffer strips, rainwater storage, anti-silt-

ation operation, quality monitoring.

- Aran: high PET, low precipitation, heavy irrigation load → drip/sprinkler + sensors, canal lining, reuse/technical water, drainage and salinity control.
- Mountainous (BQ): changing snow regime, erosion/landslides → forecast-based reservoir balance (irrigation–environmental flow), soil-protection afforestation, restoration of floodplains, environmental-flow conditions in small HPPs.
- Nakhchivan: chronic scarcity → rainwater harvesting, scaling up reuse, metering and leak detection, reserve storage/wells.
- Synthesis: The same problem (supply–demand mismatch) requires different approaches across regions: managing surplus in the Lankaran zone, managing deficit in Aran, managing timing in mountainous zones, and diversifying sources in Nakhchivan. In the next section, these priorities are transformed into a “Solution Toolkit” and a “Roadmap” [13-18].

**Table 5:** Selected solution tools and monitoring indicators

Basket	Solution tool	Expected effect	Monitoring indicator
Supply	Smart reservoir management	Seasonal supply flexibility ↑, flood risk ↓	Environmental flow provision (days %)
Supply	Sustainable use of groundwater	Additional source in scarcity; prevention of over-abstraction	Level trend (m), compliance with extraction limit (%)
Supply	Reuse (re-use of treated water)	Substitution of part of technical/irrigation demand	Reuse share (%)
Supply	Rainwater harvesting	Reduction of urban peak flows, increased infiltration	Collected volume (m <sup>3</sup> ), peak-flow reduction (%)
Demand	Drip/sprinkler + moisture sensors	Irrigation productivity ↑, water use ↓	kg/m <sup>3</sup> ; m <sup>3</sup> /ha
Demand	Reduction of network losses	Reliability ↑, costs ↓	Loss (%)
Demand	Closed-loop circulation in industry	Net water abstraction ↓	Circulation coefficient
Demand	Household conservation (metering, appliances)	Flattening peak demand	Per-subscriber use (L/day)
Quality	Pollution control	Treatment load ↓, ecosystem health ↑	BOD/COD, turbidity, microbial indicators
Quality	Thermal/eutrophication management in reservoirs	Reduced quality fluctuations	Surface–depth DO (mg/L)
Governance	Basin plans + environmental-flow limits	Intersectoral balance and legal assurance	Plan adoption; compliance (%)
Governance	Open data and early warning	Speed and accuracy of operational decisions ↑	Forecast accuracy, warning lead time

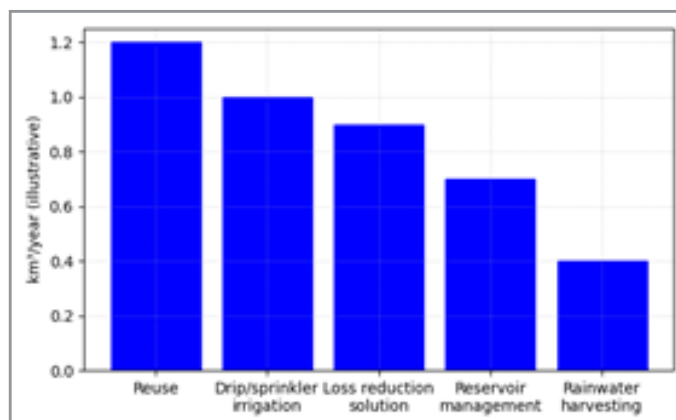
**Figure 5:** Annual water impact of solution tools.

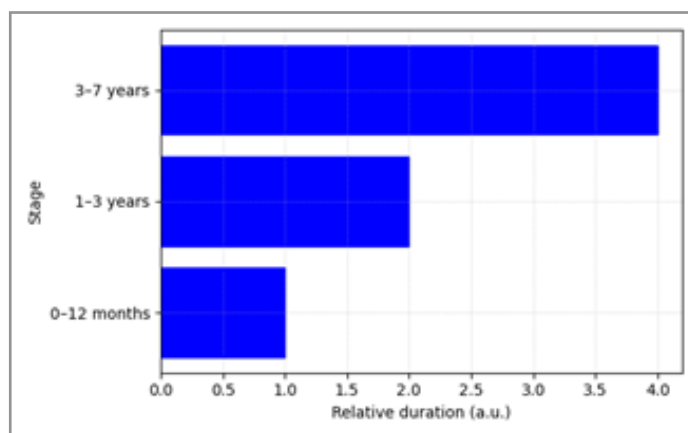
Figure 5 presents a comparison of the annual water impact of different solution tools. The scale effect is observed most strongly in loss reduction and increasing irrigation efficiency.

**Table 6:** Priority Roadmap (by phases)

Phase	Measure	Expected result	Indicator
0–12 months	Leakage audits and metering devices	Loss map and rapid reduction	Loss (%)
0–12 months	5–7 pilot reuse/rain harvesting projects	Technical design basis	Number of pilots / volume
1–3 years	Scaling up drip/sprinkler irrigation	Irrigation productivity ↑	kg/m <sup>3</sup>
1–3 years	15–25% reduction of urban losses	Reliability ↑, costs ↓	Loss (%)
3–7 years	Smart reservoir management + operation centers	Supply flexibility ↑	Environmental flow days %
3–7 years	Scaling nature-based solutions	Reduced flood/erosion risk	Buffer/area km <sup>2</sup>

In Table 6, the first year focuses on measurement-control and pilots within a “learn-and-scale” approach. The main saving vol-

umes emerge in years 1–3; in years 3–7 systems shift to smart operations and nature-based solutions expand.



**Figure 6:** Priority Roadmap — phases.

Figure 6 shows the sequence of measures: measurement-control and pilots in 0–12 months, scaling in 1–3 years, and smart operations and wider application of nature-based solutions in 3–7 years.

for water security, shows data sources, and the connection points between operational management and strategy. Indicators cover supply–demand balance, quality, and environmental flow [19-21].

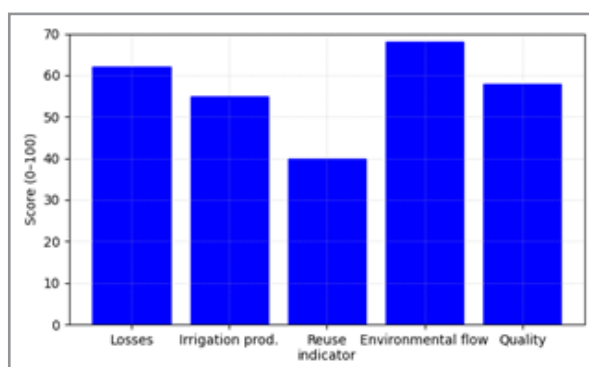
Planning and prioritizing solutions can only be managed through measurable results. This section systematizes the key indicators

**Table 7:** Monitoring indicators and sources

Category	Indicator	Definition/Unit	Source (network/governance/technology)
Demand	Network losses (%)	Shows losses in distribution lines	Urban water utility + smart meters
Demand	Irrigation productivity (kg/m <sup>3</sup> )	Water input per unit of product	Agriculture, field measurements + sensors
Supply	Reuse share (%)	Ratio of treated water reused in total supply	Treatment plants + distribution network
Environmental flow	Days ensured (%)	Share of days per year when environmental flow is met	Hydrometric stations + reservoir operations
Quality	Turbidity/BOD/COD	Key water-quality parameters	Laboratory + online sensors
Quality	Salinity (EC, dS/m)	Soil/water salinity	Field/station measurements

Table 7 clearly shows how indicators create a link between “physical impact” and “management tool”. For example, as network losses decrease, reliability increases and costs fall; as the

reuse share rises, supply gaps during peak demand periods are smoothed; and the share of days with ensured environmental flow is a direct measure of biodiversity impact [22].



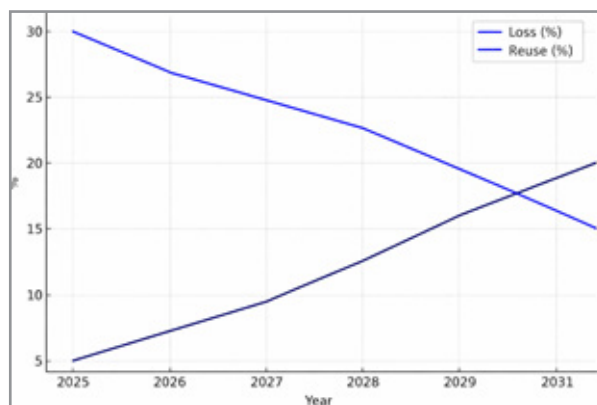
**Figure 7:** Annual indicator score.

In Figure 7, a medium level is observed in loss and quality indicators, while the reuse share shows a relatively low result. This indicates the investment direction: by focusing on reuse and loss

management, it is possible to close the supply gap faster during peak periods [23].

**Table 8:** Target trajectories (illustrative)

Indicator	0–12 months	1–3 years	3–7 years
Network losses (%)	–3 p.p.	–10 p.p.	–20 p.p.
Irrigation productivity (kg/m <sup>3</sup> )	+5%	+15%	+25%
Reuse share (%)	+2 p.p.	+8 p.p.	+15 p.p.
Environmental flow (days %)	+3 p.p.	+10 p.p.	+15 p.p.
Quality (turb., BOD/COD)	Stabilization	Significant reduction	Sustained compliance



**Figure 8:** Indicator trajectories.

In Figure 8 the downward movement of the loss curve increases reliability and affects consumer satisfaction; the steady increase of reuse share reduces peak demand pressure. When these two axes move in sync, the investment effect in terms of “water saving - water supply” accumulates.

### Conclusions and Recommendations

Climate variability intensifies water security in Azerbaijan through the supply–demand balance in both seasonal and multi-year dimensions. Rising temperatures increase evaporation losses, raise irrigation demand, and may reduce useful storage volumes through reservoir siltation. The spatial-temporal irregularity of precipitation and extreme events (floods, droughts, heat waves) weaken supply reliability, especially in aging networks; in transboundary basins, upstream decisions change downstream risks. Agriculture bears the largest burden, while in cities and industry losses, peak demand, and quality fluctuations put pressure on system resilience. Regional risk profiles differ: flood/erosion in Lankaran, high PET and salinization in Aran, snow-regime change and landslides in mountainous zones, and source limitations in Nakhchivan. Overall, maintaining water security resilient to climate risks requires not only “increasing sources”, but simultaneous management of supply and demand, protection of quality, and data-driven governance.

**Recommendations.** (1) Governance: Basin-based planning should be strengthened, environmental-flow boundaries for the Kura–Aras should be regulated, and transboundary data exchange plus joint forecasting/protocols should be ensured; an open data platform integrating meteorological-hydropetric, network, and quality indicators should be established. (2) Supply side: Smart

reservoir management based on seasonal forecasts (balancing irrigation–energy–environmental flow), scaling reuse applications of treated wastewater for technical and irrigation purposes from pilot to mainstream, urban rainwater harvesting and infiltration solutions, and a limit–monitoring–quota discipline for groundwater should be prioritized. (3) Demand side: Drip/sprinkler irrigation and sensor-based irrigation in agriculture, leakage audits and active loss management in urban networks, and closed-loop circulation plus reuse of process waters in industry should be expanded. (4) Quality and resilience: Pollution should be reduced at source; treatment and management of eutrophication/thermal risks in reservoirs should be strengthened. (5) Finance and phasing: Concessional finance instruments and results-based incentives should be applied; an implementation sequence of measurement/audit and pilots in 0–12 months, scaling and 15–25% loss reduction in 1–3 years, and real-time operations plus wider nature-based solutions in 3–7 years should be adopted. (6) Monitoring: A unified indicator set—loss (%), irrigation productivity (kg/m<sup>3</sup>), reuse share (%), environmental-flow provision (days, %), and key quality parameters (EC, BOD/COD, turbidity)—should serve transparent and sustainable decision-making.

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