

Analyzing Long-Term Freshwater Pollution Trends Under Land-Use and Climate Pressure: A Global Water-Quality Assessment Using Real Monitoring Data

Saleh Egreira Ali Abu Hamrah*

Department of Geology and Environmental Sciences, Faculty of Science, Bani Waleed University - Libya

*Email: salehabohamra@bwu.edu.ly

تحليل اتجاهات تلوث المياه العذبة على المدى الطويل في ظل ضغوط استخدام الأراضي والمناخ: تقييم عالمي لجودة المياه باستخدام بيانات رصد حقيقية

صالح اقريرة علي ابوحمرة*

قسم الجيولوجيا والعلوم البيئية، كلية العلوم، جامعة بني وليد - ليبيا

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Abstract:

Freshwater pollution is increasing in many river, lake, and groundwater systems. The problem is linked with land-use change, wastewater discharge, agricultural runoff, and climate stress. This paper analyzes long-term freshwater pollution trends using real public monitoring data. The main dataset is SDG Indicator 6.3.2, reported by countries in 2017, 2020, and 2023. The paper also reviews open archives, including GEMStat, GRQA, GLORICH, and HydroWASTE. The analysis compares global, regional, and selected country scores for good ambient water quality. It also evaluates monitoring capacity and climate-related water-quality evidence. The global share of monitored water bodies with good quality changed from 57.0% in 2017 to 56.0% in 2023. River water bodies showed a larger fall, from 53.7% to 49.7%. Groundwater scores stayed higher than river scores, but small changes can still hide local risks. Regional results show uneven change across Africa, Asia, Europe, Oceania, and Latin America. The results also show a large monitoring gap. High-income countries reported far more water bodies than low-income countries. Climate evidence shows that droughts, heatwaves, floods, and long-term warming often worsen river quality. The paper proposes an integrated monitoring framework. It combines routine field data, open databases, land-use control, wastewater treatment, and climate early warning. The study shows that pollution control must be linked with land and climate policy.

Keywords: freshwater pollution, water quality, SDG 6.3.2, land use, climate change, GEMStat, long-term monitoring, river pollution.

المخلص:

يتزايد تلوث المياه العذبة في العديد من الأنهار والبحيرات وأنظمة المياه الجوفية. وترتبط هذه المشكلة بتغير استخدام الأراضي، وتصريف مياه الصرف الصحي، والجريان السطحي الزراعي، والضغوط المناخية. تحلل هذه الورقة البحثية اتجاهات تلوث المياه العذبة على المدى الطويل باستخدام بيانات رصد عامة حقيقية. وتعتمد بشكل أساسي على مؤشر أهداف التنمية المستدامة 6.3.2، الذي أبلغت عنه الدول في أعوام 2017 و2020 و2023. كما تستعرض الورقة البحثية الأرشيفات المفتوحة، بما في ذلك GEMStat وGRQA وGLORICH وHydroWASTE. ويقارن التحليل الدرجات العالمية والإقليمية ودرجات دول مختارة لجودة المياه المحيطة الجيدة. كما يقيم قدرة الرصد والأدلة المتعلقة بجودة المياه والمناخ. وقد تغيرت النسبة العالمية للمساحات المائية المرصودة ذات الجودة الجيدة من 57.0% في عام 2017 إلى 56.0% في عام 2023. وشهدت المساحات المائية النهرية انخفاضا أكبر، من 53.7% إلى 49.7%. وظلت درجات المياه الجوفية أعلى من درجات الأنهار، إلا أن التغيرات الطفيفة قد تخفي مخاطر محلية. تُظهر النتائج الإقليمية تفاوتاً في التغيرات عبر أفريقيا وآسيا وأوروبا وأوقيانوسيا وأمريكا اللاتينية. كما تُظهر النتائج فجوة كبيرة في الرصد، حيث أبلغت الدول ذات الدخل المرتفع عن وجود مساحات مائية أكثر بكثير من الدول ذات الدخل المنخفض. وتشير الأدلة المناخية إلى أن الجفاف وموجات الحر والفيضانات والاحترار طويل الأمد غالباً ما تؤدي إلى تدهور جودة الأنهار. تقترح هذه الورقة

البحثية إطارًا متكاملًا للرصد، يجمع بين البيانات الميدانية الروتينية وقواعد البيانات المفتوحة والتحكم في استخدام الأراضي ومعالجة مياه الصرف الصحي والإنذار المبكر بالمناخ. وتُبين الدراسة ضرورة ربط مكافحة التلوث بسياسات الأراضي والمناخ.

الكلمات المفتاحية: تلوث المياه العذبة، جودة المياه؛ ، أهداف التنمية المستدامة، استخدام الأراضي، تغير المناخ ، الرصد طويل الأمد، تلوث الأنهار.

1. Introduction

Freshwater is a small but essential part of the global water system. It supports drinking water, irrigation, food production, energy, and ecosystems. Yet many rivers, lakes, and aquifers now receive growing pollutant loads. These loads come from farms, cities, industries, and poorly treated wastewater. Climate pressure can make these loads more harmful.

Water quality is not only a local environmental concern. It is also a global development issue. Poor water quality can reduce food production and harm human health. It can also slow economic growth in downstream areas. The World Bank showed that organic pollution can reduce economic growth downstream (Damania et al., 2019).

Land use is a major driver of freshwater pollution. Agriculture can release nitrogen and phosphorus through leaching and erosion. Urban areas add wastewater, road runoff, plastics, pathogens, and chemicals. Natural vegetation can reduce these pressures by filtering runoff. This relation is widely noted in water-quality research (Kronvang et al., 2020; Nguyen et al., 2023).

Climate change adds a second pressure. Heatwaves can warm rivers and reduce dissolved oxygen. Droughts reduce dilution and raise salinity. Heavy rain can wash nutrients, sediments, pathogens, and metals into rivers. A review of 965 cases found that river quality often worsens under climate extremes (Van Vliet et al., 2023).

The present paper studies this combined problem with real monitoring data. The main data source is SDG Indicator 6.3.2. This indicator measures the proportion of water bodies with good ambient water quality. It is reported through national monitoring systems and coordinated by UNEP and UN-Water (UNEP, 2024).

The paper asks four research questions. First, what do recent monitoring results show about global freshwater quality? Second, which water body types show the clearest decline? Third, how do land-use and climate pressures explain the results? Fourth, what monitoring and management steps are most useful?

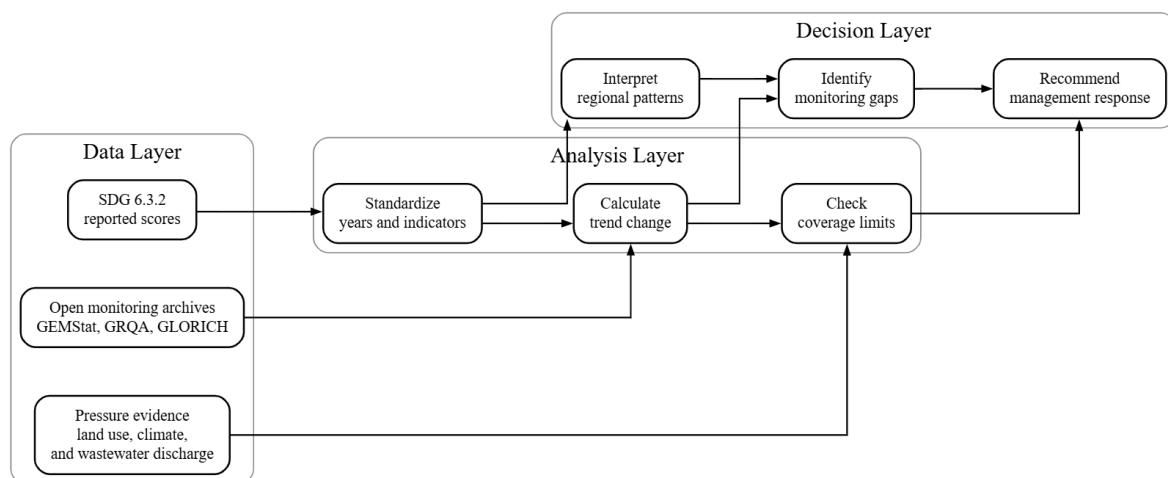


Figure 1 Research design used to combine monitoring data, open archives, land-use pressure, and climate evidence.

Background and Literature Review

Freshwater pollution has many forms. Common indicators include nutrients, oxygen, salinity, pH, turbidity, pathogens, metals, and synthetic chemicals. SDG 6.3.2 uses core physico-

chemical parameters at Level 1. These include nitrogen, phosphorus, dissolved oxygen, electrical conductivity, and pH (UNEP, 2024).

The SDG 6.3.2 method classifies a water body as good when at least 80% of monitoring values meet targets. These target values can be national or subnational. This method lets countries use their own monitoring systems. It also creates some comparison limits between countries (UNEP, 2024).

Large global water-quality datasets are improving. GEMStat provides inland water-quality data from national and organizational monitoring networks. Its open archive includes more than 20 million measurements. These cover 608 parameters, 13,660 stations, 37 countries, and 1906 to 2023 (ICWRGC, 2025).

GRQA was built to improve river data coverage. It combines GEMStat, GLORICH, Waterbase, WQP, and Canadian data. It contains more than 17 million measurements for 42 water-quality parameters from 1898 to 2020 (Virro et al., 2021).

GLORICH is another major river chemistry archive. It contains about 1.27 million samples across more than 17,000 locations. It includes major ions, nutrients, carbon, alkalinity, oxygen, pH, and temperature. It also links samples to catchment properties (Hartmann et al., 2019).

Wastewater data are also important. HydroWASTE maps 58,502 wastewater treatment plants worldwide. It includes plant characteristics, population served, treatment level, and effluent flow. This supports large-scale river pollution studies (Ehalt Macedo et al., 2022; Lamma et al., 2018).

Land-use research shows a strong link between agriculture and nutrient pollution. Excess nitrogen and phosphorus can reach groundwater and surface water. These losses can cause nitrate contamination and eutrophication. Agriculture is therefore central to water-quality management (Kronvang et al., 2020; LAMMA, 2023).

Urbanization adds multiple pollutants at the same time. (Strokal et al. 2021) modeled nutrients, pathogens, microplastics, and chemicals for 10,226 rivers. They found that urban pollution may become severe in many sub-basins without improved wastewater treatment.

Climate pressure does not act alone. It changes flow, temperature, dilution, and pollutant transport. It can also interact with agriculture and cities. IPCC AR6 identifies climate change, land-use change, and water pollution as key drivers of freshwater ecosystem loss (Caretta et al., 2022).

Recent global modelling also shows that pollution can increase water scarcity. Wang et al. (2024) found that nitrogen pollution can triple the number of river sub-basins facing quality-related scarcity. This result shows that clean water scarcity must include quality, not only quantity.

Table 1 Public datasets and data products reviewed in this paper

Dataset or product	Main content	Spatial and temporal coverage	Use in this paper
SDG 6.3.2	Proportion of water bodies with good ambient quality	Country reporting for 2017, 2020, and 2023	Main trend dataset
GEMStat	Global freshwater quality database	Open archive: 1906 to 2023	Source context and future station analysis
GRQA	Harmonized river quality archive	1898 to 2020; 42 parameters	Evidence on open monitoring coverage
GLORICH	Global river chemistry database	More than 17,000 locations	Chemistry and catchment-property context
HydroWASTE	Wastewater treatment plants	58,502 global plants	Wastewater pressure context
Climate evidence review	Water-quality response to extremes	965 case studies	Climate-pressure interpretation

Materials and Methods

This paper is based on a reproducible public-data analysis. No invented laboratory values were used. The core analysis used published SDG 6.3.2 results from UNEP's 2024 progress report. These results are country-reported monitoring outputs from 2017, 2020, and 2023 (UNEP, 2024).

The analysis used three spatial levels. The first level was the global score. The second level was broad regions. The third level was selected country examples. Country examples were used only to show trend patterns. They were not used to rank national performance.

The main indicator was the percentage of water bodies with good ambient water quality. This score was analyzed for all water bodies, open water bodies, river water bodies, and groundwater. The data were extracted from Annex 1 and Annex 2 of the UNEP report (UNEP, 2024; Lamma, 2024).

A simple trend calculation was applied. The change for each region was calculated as the 2023 score minus the 2017 score. A positive value means improvement. A negative value means decline. This calculation is transparent and easy to reproduce.

Monitoring capacity was also analyzed. UNEP reported the mean number of water bodies per country by GDP quartile. These values were used to show how reporting strength differs by income group. This step is important because monitoring gaps can hide pollution risk.

A second evidence layer came from published climate research. (VanVliet et al. 2023) summarized 965 cases of river water-quality responses. Their results were used to compare monitoring trends with known climate mechanisms.

The land-use interpretation used peer-reviewed literature and global datasets. Agriculture, urban growth, wastewater discharge, and land cover loss were treated as major pressure pathways. The purpose was not to model every basin. The purpose was to explain the trend evidence in a careful way.

The analysis has clear limits. SDG 6.3.2 results depend on national thresholds and monitoring coverage. Some countries report fewer water bodies than others. Some country scores do not cover all water bodies. These limits are stated before the results are interpreted.

Table 2 Core data-analysis steps

Step	Action	Output
1	Extract SDG 6.3.2 scores for 2017, 2020, and 2023	Global, regional, and country trend tables
2	Separate all water bodies, rivers, open waters, and groundwater	Water-body type comparison
3	Calculate 2017 to 2023 score change	Regional increase or decline
4	Compare monitoring capacity by GDP quartile	Data gap diagnosis
5	Link trends with land-use and climate evidence	Pressure interpretation
6	Develop a monitoring and response framework	Practical contribution

Table 3 SDG 6.3.2 core parameters and their meaning

Parameter group	Main meaning	Likely pressure signal
Nitrogen	Nutrient enrichment and nitrate risk	Fertilizer, manure, sewage, urban runoff
Phosphorus	Eutrophication risk in rivers and lakes	Agriculture, wastewater, eroded soil
Dissolved oxygen	Aquatic habitat condition	Organic pollution, warming, algal decay
Electrical conductivity	Salinity and dissolved ions	Irrigation, mining, seawater intrusion, drought
pH	Acidity or alkalinity stress	Industrial discharge, mining, natural geology

Results

Global trend in good ambient water quality

The global SDG 6.3.2 score stayed almost flat across the three reporting years. The score was 57.0% in 2017. It increased to 58.2% in 2020. It then fell to 56.0% in 2023 (UNEP, 2024).

This result should be read carefully. It does not mean that every country has the same trend. It also does not mean that all water bodies are monitored equally. The global score is an aggregate of reported water bodies. It is still useful because it shows limited global progress. The 2023 value means that only a little more than half of monitored water bodies had good ambient quality. This is a serious result. It shows that the world is not clearly moving toward SDG Target 6.3.

Figure 2 Global proportion of monitored water bodies with good ambient water quality in 2017, 2020, and 2023.

Table 4 Global scores by water body type

Water body type	2017	2020	2023	Change 2017-2023
All water bodies	57.0%	58.2%	56.0%	-1.0 pp
Open water bodies	49.5%	51.3%	52.2%	+2.7 pp
River water bodies	53.7%	54.4%	49.7%	-4.0 pp
Groundwater	77.5%	81.5%	79.9%	+2.4 pp

Trends by water body type

Water body type gives a clearer signal than the single global score. River water bodies fell from 53.7% good quality in 2017 to 49.7% in 2023. This is a decline of 4.0 percentage points. Open water bodies increased from 49.5% to 52.2%. Groundwater stayed higher than surface water. It changed from 77.5% in 2017 to 79.9% in 2023. This does not mean groundwater is safe everywhere.

River decline is important because rivers receive many pressures directly. They receive wastewater, storm runoff, farm drainage, and industrial discharge. They also respond quickly to flow and temperature change.

Groundwater can respond more slowly. It may also hide pollution for years. Nitrate stored in aquifers can keep moving after surface practices change. This delay is a known water-quality management problem.

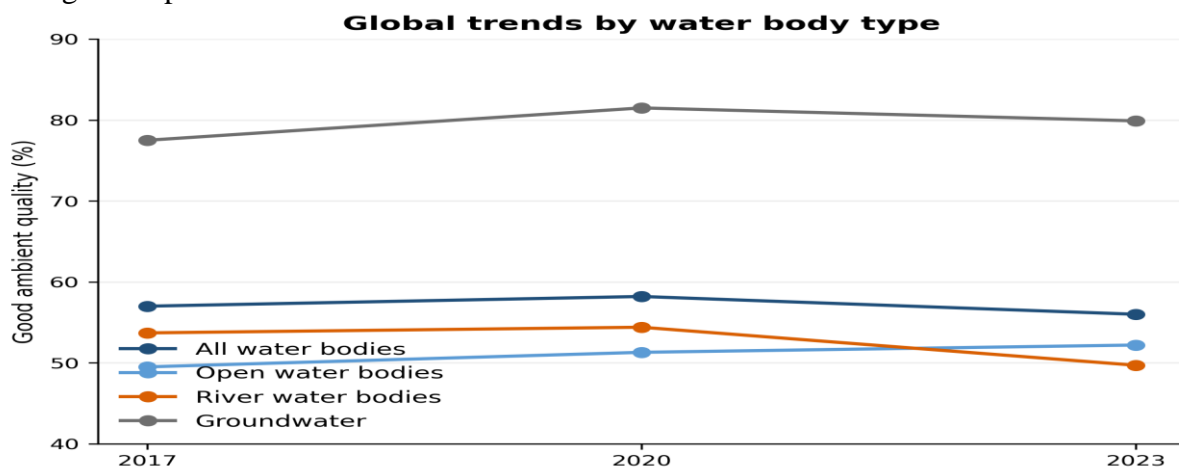


Figure 3 Trends by water body type for all monitored water bodies, open water bodies, river water bodies, and groundwater.

Regional comparison in 2023

Regional scores show large differences in the reported data. In 2023, Oceania and Africa showed high aggregate values. Europe and South America showed lower values. The world aggregate was 56.0% (UNEP, 2024).

These results should not be read as a simple league table. Monitoring coverage differs between countries and regions. Some countries report many water bodies. Others report only a small number. In some regions, data gaps are still large.

The regional pattern still matters. It shows where reported data suggest improvement or decline. It also shows where monitoring capacity must be strengthened before risk can be judged well.

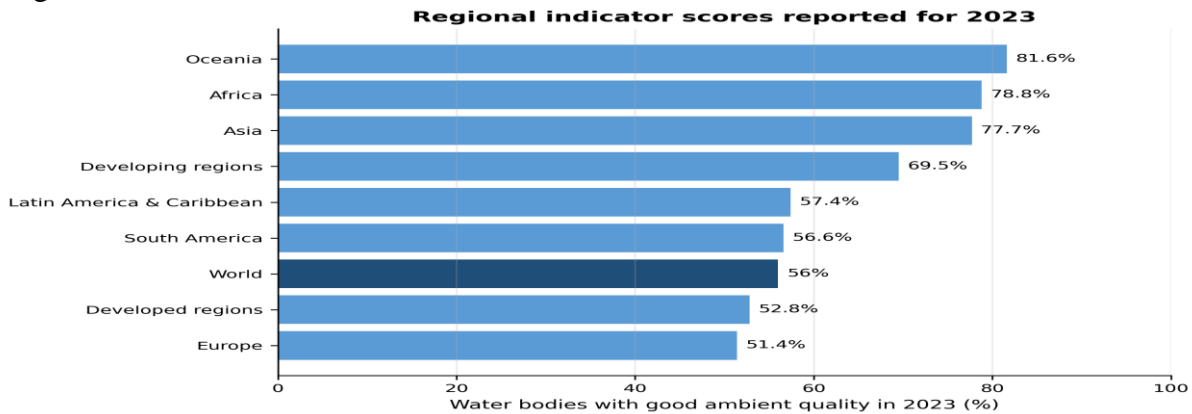


Figure 4 Reported regional scores for good ambient water quality in 2023.

Table 5 Regional indicator scores for selected regions

Region	2017	2020	2023	Change 2017-2023
World	57.0%	58.2%	56.0%	-1.0 pp
Africa	71.4%	66.7%	78.8%	+7.4 pp
South America	64.5%	53.5%	56.6%	-7.9 pp
Oceania	97.9%	86.8%	81.6%	-16.3 pp
Asia	76.0%	83.6%	77.7%	+1.7 pp
Europe	53.8%	56.9%	51.4%	-2.4 pp
Sub-Saharan Africa	70.8%	66.4%	78.7%	+7.9 pp
Latin America & Caribbean	65.0%	54.6%	57.4%	-7.6 pp

Regional change from 2017 to 2023

The change analysis gives a clearer view of long-term direction. Africa increased by 7.4 percentage points in the reported aggregate. Sub-Saharan Africa increased by 7.9 percentage points. Asia increased by 1.7 percentage points.

Other regions declined. Oceania fell by 16.3 percentage points. South America fell by 7.9 percentage points. Latin America and the Caribbean fell by 7.6 percentage points. Europe fell by 2.4 percentage points.

The decline in Oceania is large in the reported data. It may reflect actual pressure, reporting changes, or both. This is why monitoring metadata must accompany every trend analysis.

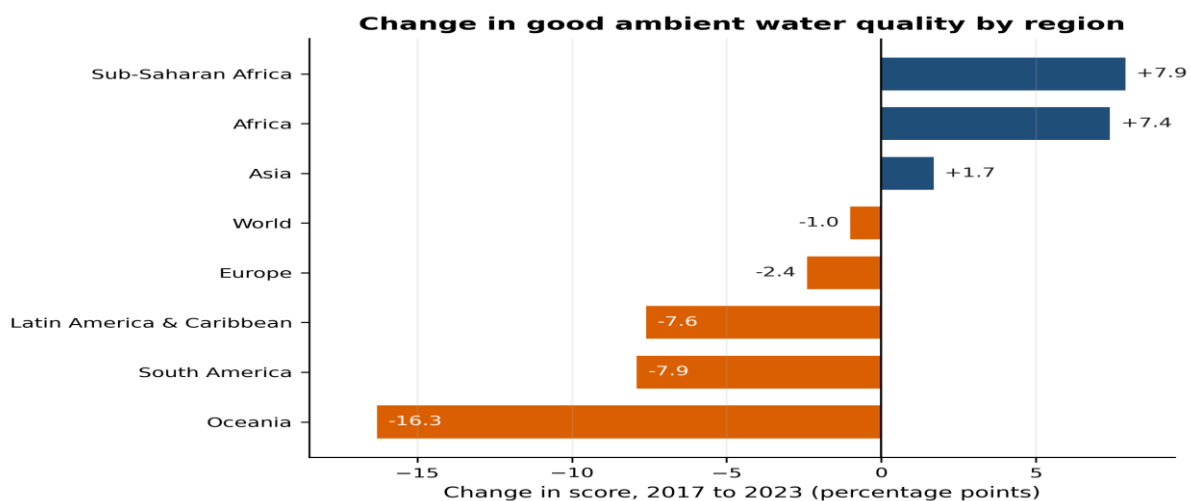


Figure 5 Change in regional indicator score from 2017 to 2023.

Selected country examples

Selected country trends show very different paths. China increased from 70.84% in 2017 to 88.52% in 2023. India fell from 36.67% to 10.00%. South Africa rose from 46.92% to 70.69%.

The Netherlands had low reported scores in all three years. Its score increased from 7.32% to 12.67%. Austria remained above 80% in all three years. Brazil stayed near the middle range and ended at 68.23%.

These examples are not rankings. National thresholds, water body definitions, and monitoring coverage differ. The value of these examples is the trend signal within each reporting system.

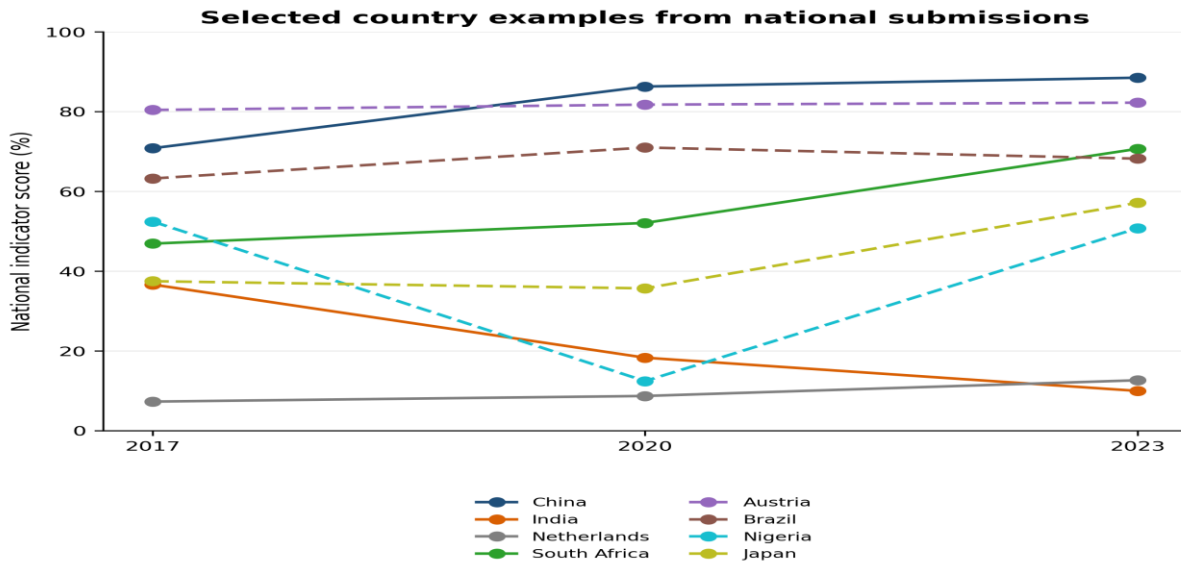


Figure 6 Selected country examples from SDG 6.3.2 national submissions.

Table 6 Selected country examples from national submissions

Country	2017 total	2020 total	2023 total	Pattern
China	70.84%	86.31%	88.52%	Large increase
India	36.67%	18.33%	10.00%	Large decline
Netherlands	7.32%	8.73%	12.67%	Low but rising
South Africa	46.92%	52.11%	70.69%	Strong increase
Austria	80.44%	81.77%	82.26%	Stable high
Brazil	63.25%	71.02%	68.23%	Middle range
Nigeria	52.46%	12.46%	50.78%	Variable
Japan	37.50%	35.71%	57.14%	Recent increase

Monitoring capacity and data bias

The data show a strong monitoring-capacity gap. UNEP reported that the highest-income countries used an average of 1,842 water bodies. The lowest-income countries used an average of 131 water bodies (UNEP, 2024).

This means high-income countries reported about 14 times more water bodies than low-income countries. The gap is even larger when the number of parameter measurements is considered. UNEP noted that high-income countries used more than 1.2 million measurements in total (UNEP, 2024).

This gap affects interpretation. A low score from a strong monitoring system may reveal many real problems. A high score from a small monitoring system may miss pollution hotspots. Therefore, data coverage should be reported beside every water-quality score.

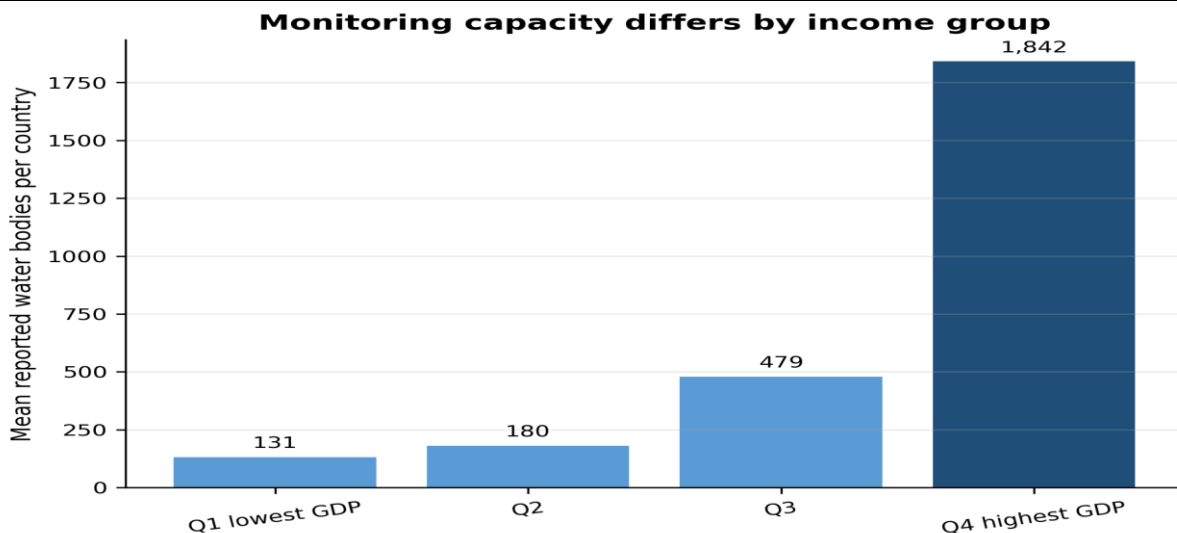


Figure 7 Mean number of reported water bodies by GDP per capita quartile.

Climate pressure and freshwater quality

Climate evidence supports the trend interpretation. (Van Vliet et al., 2023) reviewed 965 water-quality cases. They found deterioration in 68% of drought and heatwave cases. They found deterioration in 51% of rainstorm and flood cases. They also found deterioration in 56% of long-term climate-change cases.

Droughts can reduce dilution. They can raise temperature, salinity, and pollutant concentration. Heatwaves can lower dissolved oxygen and support algal growth. Floods can mobilize sediments, nutrients, plastics, metals, and pathogens.

These mechanisms can explain why rivers are highly vulnerable. Rivers link land surfaces, cities, farms, and wastewater outlets. They also respond quickly to climate extremes. This makes river quality a key early warning signal.

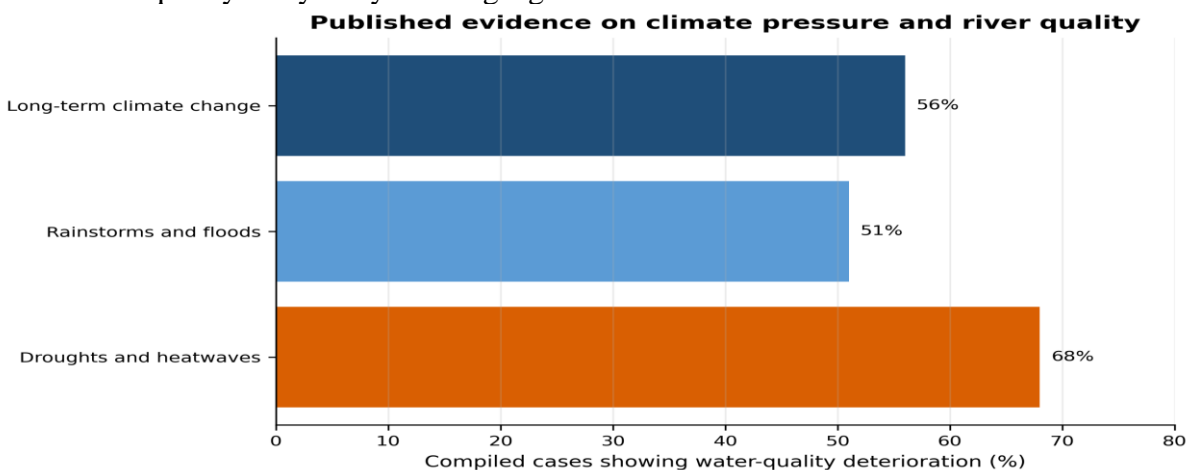


Figure 8 Share of published case studies showing river water-quality deterioration under major climate pressures.

Discussion

What the monitoring results mean

The results show weak global progress. The 2023 global score was lower than the 2020 score. It was also slightly lower than the 2017 score. This means that reported monitoring does not show a clear improvement path.

The river result is more concerning than the global result. River water bodies declined by 4.0 percentage points. This decline matters because rivers carry many combined pressures. They also connect upstream land use with downstream health and ecosystem risks.

Groundwater scores were higher than river scores. Yet groundwater pollution can remain hidden. Nitrate, salinity, and other contaminants may move slowly through aquifers. This delay makes groundwater management difficult.

Regional patterns are uneven. Some regions improved in the reported aggregate. Others declined sharply. Such differences can reflect real policy change, climate events, monitoring design, or reporting coverage. The safest conclusion is that water-quality trend analysis needs more consistent data.

The country examples support this point. Some countries showed improvement. Others showed decline. Some showed large variability. These changes should be studied with station-level data before national causes are claimed.

Why land use matters

Land use explains many freshwater pollution pathways. Agricultural land often adds nitrogen and phosphorus. Fertilizer and manure can move through runoff, drains, and groundwater. Erosion can move phosphorus-rich soil into streams.

Urban land adds different pressures. Wastewater can add nutrients, organic matter, pathogens, pharmaceuticals, and household chemicals. Storm drains can carry oils, metals, plastics, and sediments. These pollutants often enter rivers quickly after rain.

Vegetation loss can increase runoff and reduce natural filtration. Riparian vegetation slows flow, traps sediment, and supports nutrient uptake. When these buffers are removed, more pollutants reach water bodies.

The literature shows the same pattern. Agriculture has proven pressure on groundwater and surface water through nutrient losses (Kronvang et al., 2020). Urbanization can raise multiple pollutant inputs to rivers unless wastewater systems improve (Strokal et al., 2021).

This paper therefore treats land-use policy as water-quality policy. Water quality cannot be protected only inside the channel. It must also be protected across the catchment.

Land-use and climate pressure pathways

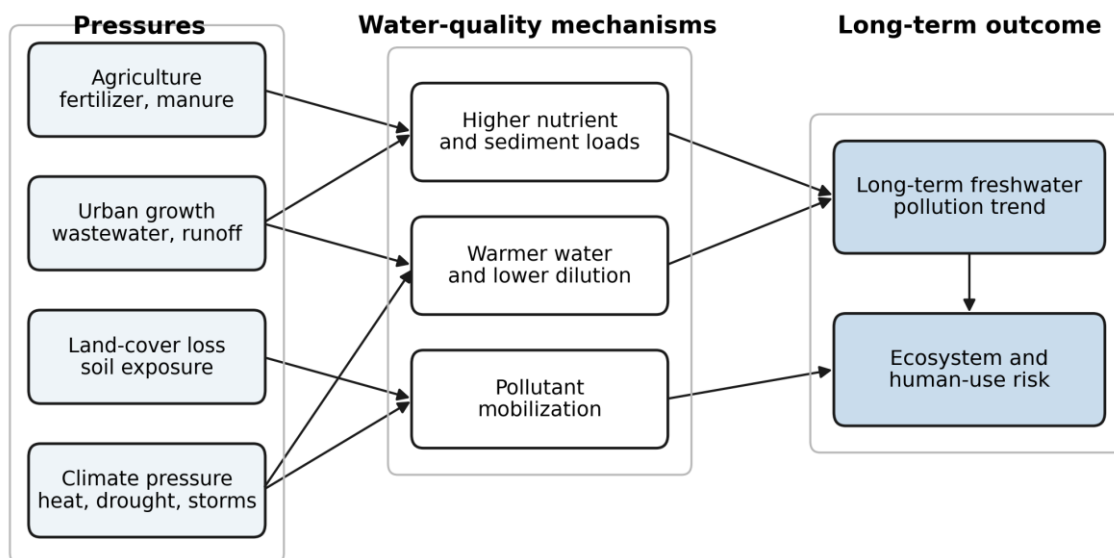


Figure 9 Main pathways connecting land use, climate pressure, and long-term freshwater pollution trends. Source: (Kronvang et al., 2020), (Strokal et al. 2021), (Nguyen et al., 2023), (Caretta et al. 2022), and (Van Vliet et al. 2023).

Why climate pressure changes pollution risk

Climate pressure changes both water quantity and water quality. Drought can make the same pollution load more concentrated. Heat can speed biological processes and reduce oxygen. Heavy rain can transport pollutants from land into rivers.

IPCC AR6 states that climate change, land-use change, and water pollution drive freshwater ecosystem loss (Caretta et al., 2022). This finding supports the combined approach used in this paper.

Climate pressure can also weaken existing policy. A wastewater plant may meet standards during normal flow. It may still create poor river quality during drought. A farm field may have acceptable runoff in dry weather. It may release high nutrient loads during storms.

That's why water-quality monitoring should include weather and flow context. A pollutant measurement without flow data is incomplete. A trend without drought and flood data may mislead decision makers.

Monitoring gaps as a major result

The monitoring gap is one of the strongest findings. High-income countries reported far more water bodies. This gives them better evidence, but it can also reveal more failures. Low-income countries may have fewer recorded failures because fewer sites are measured.

The SDG 6.3.2 report notes that 120 countries reported in 2023. This is a clear improvement from 89 countries in 2020. Yet the report also notes regional gaps, especially in North Africa, West Asia, Central Asia, and South-East Asia (UNEP, 2024).

Open archives can reduce this gap. GEMStat, GRQA, GLORICH, and WQP-style systems make existing measurements reusable. They also make quality checks easier. Metadata must improve at the same time. Poor metadata can make a large dataset hard to use.

Citizen science can also help. It cannot replace accredited monitoring. It can add coverage, flag hotspots, and increase public trust. UNEP reported that Sierra Leone and Zambia combined citizen science data with official data for SDG 6.3.2 reporting (UNEP, 2024).

Table 7 Literature-based interpretation of key pressures

Pressure	Water-quality effect	Main evidence source	Management implication
Agriculture	Nitrogen and phosphorus losses	Kronvang et al. (2020)	Nutrient planning and riparian buffers
Urbanization	Multiple pollutants from wastewater and runoff	Strokal et al. (2021)	Wastewater upgrades and stormwater control
Climate extremes	Deterioration during droughts, heatwaves, and floods	van Vliet et al. (2023)	Climate-aware water-quality monitoring
Water scarcity plus pollution	Clean-water scarcity rises when quality is included	Wang et al. (2024)	Treat water quality as part of water security
Weak monitoring	Pollution risk may remain unknown	UNEP (2024); Virro et al. (2021)	Open data, metadata standards, and capacity support

Proposed Monitoring and Management Framework

The analysis supports a combined framework. Monitoring must be linked with land-use planning, wastewater policy, and climate adaptation. A narrow station-only approach is not enough for long-term pollution control. The first part is routine monitoring. Countries should measure core chemistry at fixed sites. They should keep long-term station records. They should also collect flow and weather data with water samples. The second part is pressure mapping. Monitoring stations should be linked to upstream land use. They should also be linked to wastewater outlets, population, agriculture, and climate hazards. This step turns monitoring into diagnosis. The third part is open data. Datasets should use clear names, units, methods, dates, and coordinates. The FAIR data principles can make water-quality data more reusable. GRQA shows how harmonization can support global analysis (Virro et al., 2021).

The fourth part is response targeting. Nutrient control should focus on high-risk agricultural areas. Wastewater upgrades should focus on urban discharge hotspots. Climate planning should focus on drought-sensitive and flood-sensitive rivers. The fifth part is public participation. Citizen science can add rapid local coverage. It can also strengthen public support. It should be quality controlled before it is used in national reporting.

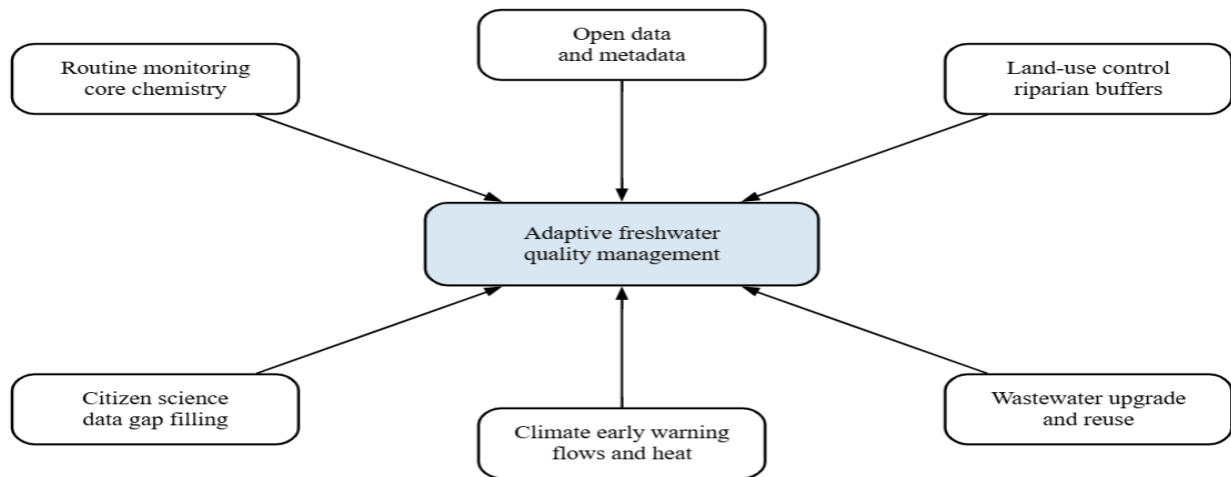


Figure 10 Integrated response framework for freshwater quality under land-use and climate pressure.

Table 8 Recommended monitoring plan for long-term freshwater pollution assessment

Component	Minimum practice	Best practice	Why it matters
Station design	Fixed river, lake, and groundwater sites	Basin-wide network with pressure coverage	Allows trend detection
Parameters	N, P, oxygen, pH, conductivity	Add pathogens, metals, organics, and temperature	Captures wider pollution risk
Frequency	Seasonal sampling	Monthly sampling plus event sampling	Captures floods and droughts
Metadata	Date, site, unit, method	Full FAIR metadata and QA flags	Makes data reusable
Pressure data	Land use and wastewater locations	Time-varying land use and climate layers	Supports source diagnosis
Public data	Annual summary tables	Open station-level archive	Improves transparency

Policy Implications

The results support four policy messages. First, global monitoring must expand. The world cannot manage pollution that it does not measure. Monitoring expansion is most urgent in regions with limited data. Second, river quality needs special attention. The river score declined more than the overall score. Rivers are directly exposed to land-use and climate pressure. They are also central to downstream human use. Third, pollution control must be catchment-based. Farming, urban drainage, wastewater outlets, and riparian land must be managed together. Separate policies can miss combined effects. Fourth, climate adaptation plans should include water-quality targets. Many adaptation plans focus on water quantity. They should also include temperature, salinity, nutrients, dissolved oxygen, and harmful algal bloom risk.

Wastewater treatment remains a key policy tool. Globally, only 56% of domestic wastewater was safely treated in 2024 according to SDG 6.3.1 data. Industrial wastewater data remain much weaker (UN-Water, 2024).

The framework proposed here is simple enough for low-resource settings. It begins with core parameters and fixed stations. It then adds pressure maps, citizen science, and open data as capacity improves.

Limitations

This paper has several limits. The main analysis uses published aggregate scores. It does not use raw station-level time series. A stronger future study should download station data from GEMStat, GRQA, WQP, and Waterbase.

The SDG 6.3.2 method uses national or subnational target values. These values can differ between countries. Therefore, country scores are best used for national trend tracking, not direct ranking.

Monitoring coverage differs widely. Some countries report many water bodies. Others report few water bodies. This can bias regional interpretation.

The land-use and climate interpretation is literature-based. It explains likely mechanisms. It does not prove causation for each region. Causation would need basin-level data and statistical modeling.

The paper does not include all pollutants. Emerging pollutants, pesticides, PFAS, microplastics, and many metals are not fully covered by Level 1 SDG 6.3.2 reporting. Future monitoring should add these where risk is high.

Conclusion

This paper analyzed long-term freshwater pollution trends using real public monitoring data. The global SDG 6.3.2 score did not show clear improvement from 2017 to 2023. The 2023 global score was 56.0%. This means many monitored water bodies did not meet good ambient quality status. Rivers were the most concerning water body type in the global trend. The river score fell from 53.7% in 2017 to 49.7% in 2023. This decline fits the known vulnerability of rivers to land-use and climate pressure. Regional and country patterns were uneven. Some areas improved, and others declined. These results must be read with monitoring coverage. The income-related monitoring gap is large and important.

The study shows that freshwater pollution cannot be managed as a single-sector problem. It is linked with agriculture, cities, wastewater, land cover, climate extremes, and data systems. A practical solution must connect all these parts. The paper proposes an integrated monitoring and response framework. It combines core water-quality monitoring, open data, land-use control, wastewater improvement, climate early warning, and citizen science. This approach can help countries track trends and reduce pollution risk. The most important conclusion is direct. Water quality must be treated as part of water security. Quantity alone is not enough. A river with water can still be unsafe, unusable, and ecologically damaged.

Data Availability

The study uses published SDG 6.3.2 results from UNEP (2024). The data are available in the report annexes. Additional public data sources discussed in this paper include GEMStat, the GEMStat open archive, GRQA, GLORICH, and HydroWASTE. Source links are included in the figure captions and references.

Ethics Statement

This study used public environmental monitoring data and published literature. It did not involve

REFERENCES

1. Caretta, M. A., Mukherji, A., Arfanuzzaman, M., Betts, R. A., Gelfan, A., Hirabayashi, Y., Lissner, T. K., Liu, J., Lopez Gunn, E., Morgan, R., Mwanga, S., & Supratid, S. (2022). Water. In H.-O. Pörtner et al. (Eds.), *Climate change 2022: Impacts, adaptation and vulnerability* (pp. 551–712). Cambridge University Press. <https://doi.org/10.1017/9781009325844.006>
2. Damania, R., Desbureaux, S., Rodella, A.-S., Russ, J., & Zaveri, E. (2019). Quality unknown: The invisible water crisis. World Bank. <https://openknowledge.worldbank.org/handle/10986/32245>
3. Ehalt Macedo, H., Lehner, B., Nicell, J., Grill, G., Li, J., Limtong, A., & Shakya, R. (2022). Distribution and characteristics of wastewater treatment plants within the global river network. *Earth System Science Data*, 14(2), 559–577. <https://doi.org/10.5194/essd-14-559-2022>

4. Hartmann, J., Lauerwald, R., & Moosdorf, N. (2019). GLORICH: Global river chemistry database PANGAEA. <https://doi.org/10.1594/PANGAEA.902360>.
5. Asanousi Lamma, O., Swamy, A. V. V. S., & Alhadad, A. A. (2018). Assessment of Heavy Metal Pollution in Ground Water and its Correlation with other Physical Parameters at Selected Industrial Areas of Guntur, AP, India. AP, India.
6. Hartmann, J., Moosdorf, N., Lauerwald, R., Hinderer, M., & West, A. J. (2014). A brief overview of the GLOBAL River Chemistry Database, GLORICH. *Procedia Earth and Planetary Science*, 10, 23–27. <https://doi.org/10.1016/j.proeps.2014.08.005>
7. International Centre for Water Resources and Global Change. (2025). UNEP GEMS/Water Global Freshwater Quality Archive [Data set]. IHP-WINS. <https://ihp-wins.unesco.org/dataset/unep-gems-water-global-freshwater-quality-archive>.
8. Lamma, O. A., & Sallam, R. M. A. (2018). Analysis of water quality of Lingala Munner Krishna district, AP, India. *J. Adv. Stud. Agricult. Biol. Environ. Sci*, 5(3), 22-27.
9. Kronvang, B., Wendland, F., Kovar, K., & Fraters, D. (2020). Land use and water quality. *Water*, 12(9), 2412. <https://doi.org/10.3390/w12092412>
10. Nguyen, T. A., Can, L. D., Nhan, N. T., Schmalz, B., & Luu, T. L. (2023). Influences of key factors on river water quality in urban and rural areas: A review. *Case Studies in Chemical and Environmental Engineering*, 8, 100424. <https://doi.org/10.1016/j.cscee.2023.100424>.
11. Lamma, O. A. (2024). Innovative Remediation Strategies for Tackling Groundwater Pollution: A Comparative Analysis. *African Journal of Advanced Pure and Applied Sciences*, 90-98.
12. Strokhal, M., Vriend, P., Bak, M. P., Kroeze, C., van Wijnen, J., & van Vliet, M. T. H. (2021). Urbanization: An increasing source of multiple pollutants to rivers in the 21st century. *npj Urban Sustainability*, 1, Article 24. <https://doi.org/10.1038/s42949-021-00026-w>
13. United Nations Environment Programme. (2024). Progress on ambient water quality: Mid-term status of SDG Indicator 6.3.2 and acceleration needs, with a special focus on health. UNEP. <https://www.unwater.org/publications/progress-ambient-water-quality-2024-update>
14. UN-Water. (2024). Progress on wastewater treatment: 2024 update. <https://www.unwater.org/publications/progress-wastewater-treatment-2024-update>
15. LAMMA, O. A. (2023). Beneath the Surface: Unveiling the Silent Threat of Groundwater Contamination. *Bani Waleed University Journal of Humanities and Applied Sciences*, 8(5), 380-393.
16. van Vliet, M. T. H., Thorslund, J., Strokhal, M., Hofstra, N., Flörke, M., Ehalt Macedo, H., Nkwasa, A., Tang, T., Kaushal, S. S., Kumar, R., Bouwman, L., & Mosley, L. M. (2023). Global river water quality under climate change and hydroclimatic extremes. *Nature Reviews Earth & Environment*, 4, 687–702. <https://doi.org/10.1038/s43017-023-00472-3>
17. Virro, H., Amatulli, G., Kmoch, A., Shen, L., & Uemaa, E. (2021). GRQA: Global River Water Quality Archive. *Earth System Science Data*, 13, 5483–5507. <https://doi.org/10.5194/essd-13-5483-2021>
18. Wang, M., Bodirsky, B. L., Rijnveld, R., Beier, F., Bak, M. P., Batool, M., Droppers, B., Popp, A., van Vliet, M. T. H., & Strokhal, M. (2024). A triple increase in global river basins with water scarcity due to future pollution. *Nature Communications*, 15, Article 880. <https://doi.org/10.1038/s41467-024-44947-3>
19. World Health Organization & UN-Habitat. (2024). Progress on the proportion of domestic and industrial wastewater flows safely treated: Mid-term status of SDG Indicator 6.3.1 and acceleration needs. World Health Organization. <https://www.who.int/publications/i/item/9789240099081>

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