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WATER POLLUTION AND ITS IMPACT ON ENVIRONMENTAL SUSTAINABILITY AND HUMAN HEALTH.

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Abstract

Objectives: *Water pollution represents one of the most pressing environmental and public health challenges, particularly in developing regions where canal systems serve as primary sources for domestic and agricultural needs. This study investigates the extent of water contamination and its implications for human health and environmental sustainability in Balochistan, Pakistan.*

Aims: *The research aimed to (i) assess the biological, chemical, and physical quality of canal water, (ii) examine the prevalence of waterborne diseases across different age groups, and (iii) establish associations between specific pollutants and disease incidence.*

Methodology: *A cross-sectional descriptive–analytical design was adopted. Water samples were systematically collected from four major canals (Pat Feeder, Kirthar, Kachhi, Uch) and analyzed against WHO standards for microbial, chemical, and physical parameters. Parallelly, clinical data from 2,816 patients (aged 1–60 years) residing along the canals were reviewed. Statistical analysis employed chi-square and regression models using SPSS v29.0 to explore pollutant–disease linkages.*

Results: *Canal waters showed severe contamination, with coliforms, E. coli, arsenic, lead, nitrates, and pesticides exceeding WHO permissible limits by 2–7 folds. Physical quality indicators (turbidity, TDS, conductivity) also surpassed thresholds. The 21–40-year age group exhibited the highest prevalence of hepatitis B (22%) and C (18%), while diarrheal and typhoid cases predominated in the 1–20-year group. Strong associations were observed between microbial pollutants and cholera/typhoid, and between heavy metals/pesticides and hepatitis.*

Conclusions: *The findings reveal a critical public health emergency linked to deteriorating water quality in Balochistan's canals. Effective interventions—ranging from stringent regulatory enforcement, wastewater treatment, and safer agricultural practices to community awareness are urgently needed to safeguard water sustainability, reduce disease burden, and advance progress toward the UN Sustainable Development Goals.*

INTRODUCTION

Water is essential to all life, and we rely on it within our environment, which stretches under more than 70% of the Earth's surface. However, rapid industrialization, urbanization, and ill-maintained agriculture have resulted in the widespread pollution of water bodies on a global scale (1). Water pollution threatens environmental integrity due to the disruption of aquatic habitats and risks public health through exposure to harmful chemicals and pathogens (2). Heavy metals, chemicals as well as untreated effluent is let into the rivers and coastal water causing toxicity and bioaccumulation in fish. Substance the pollution of marine communities by oil spills also interferes with this habitat (3).

Excessive fertilizers, pesticides and animal waste find their way into water systems leading to nutrient imbalance that results in algal growth and pathogen propagation (4). Millions of tons of plastic waste flow into waterways every year, and can remain hundreds of years there, posing a threat to marine life that either ingests or becomes entangled in it (5). The impact on the human health by the polluted water is profound and diverse. Waterborne pathogens infectious diseases such as diarrhea, cholera, dysentery, typhoid and other related diseases affect children and other vulnerable groups in the world through unsafe water (6).

Ghazy et al. (2025) stated that >800, 000 deaths per year are related to diarrheal diseases caused by unsafe water and hygiene related to the practice of sanitation and it puts emphasis on the health costs of water contamination. Besides infectious diseases, chronic sources of pollutants such as arsenic, heavy metals, and chemical carcinogens have heightened dangers of cancers, neurological diseases and skin diseases. Immunological difficulties and reduced development in children, particularly young children are secondary issues of water contamination that further complicate population health (7). Water chemistry and water habitats are also disturbed by water pollution that contributes to environmental degradation as an addition. The reduction of oxygen due to chemical and nutrient pollution, which results in the formation of dead-zones where aquatic life could no longer survive, causes a break in the food chains and ecosystem services that support clean water provision or climate regulation (8).

The solution to the problem of water pollution and its effect on human health and environmental sustainability will demand concerted measures (9). Strict enforcement of the law, incorporation of stricter discharge limits will facilitate the reduction of pollutant discharges. The up-scaling of effective wastewater solutions and safe water storage reduces the chances of contamination by microbes. Public health training facilitates knowledge on the community about the risks associated with pollution and the ways, in which water can be protected (10).

According to Borah et al. (2020) state that water pollution is a complicated environmental problem seriously affecting aquatic ecosystems, biodiversity, and human health. Inorganic pollutants (e.g., heavy metals: arsenic, lead, mercury; organic pollutants (e.g., POPs such as PCBs and PBDEs) are discharged into water bodies by industrial waste, agricultural runoff and urban garbage or waste collection (11). Water pollution is rampant and depends on geographical, industrial and agricultural activities (Mishra, 2023). It impacts surface waters as rivers, lakes and oceans. as well groundwater sources needed for drinking and irrigation. In developed areas sewerage, untreated industrial

effluent and improper treatment of sewage in rural areas are the main reasons for high pollution levels (12).

According to the reports by World Health Organization and United Nations over two billion people lack access to safe drinking water, so tens of millions become ill due to the diseases they contract with the help of polluted water each year. In developing world, the issues are further exacerbated by lack of sanitation facilities that do not or very weakly exist through which pollutants are permitted components: (i) analysis of water quality from selected canals, and (ii) evaluation of disease prevalence among patients exposed to polluted water.

2.2. Research Area

This study was conducted in Balochistan, focusing on four major canal systems such as, to enter the water supply. The excessive pollution of water demands urgent international and national action against water pollution so as to safeguard water quality, and human health (13).

Research Methodology

Research Design

This study was based on a cross-sectional descriptive and analytical design to evaluate the impact of water pollution on environmental sustainability and human health. The research integrated two Pat Feeder Canal, Kirthar Canal, Kachhi Canal, and Uch Canal within the Naseerabad Division. These sites were chosen because they represent the major irrigation networks that supply water for domestic, agricultural, and industrial use in the region.

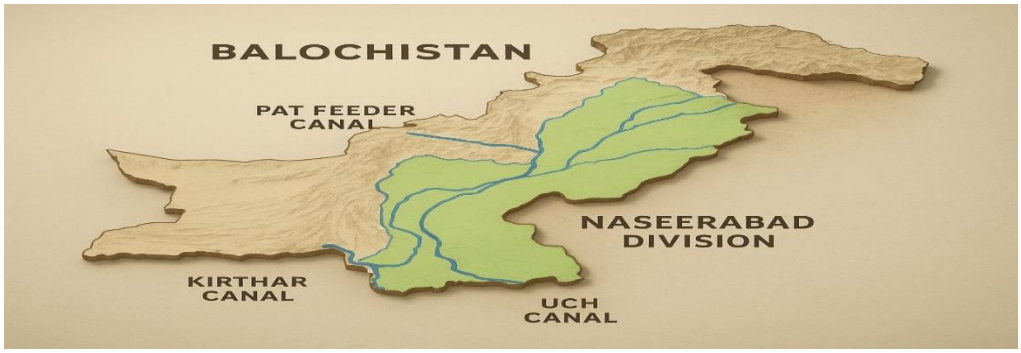


Figure 1: Map of Study Area (Naseerabad Division, Balochistan).

Study Population

The study population consisted of 2816 patients, both male and female, residing in the communities along the selected canal systems. Patients were divided into three age groups for analysis: 1–20 years, 21–40 years, and 41–60 years, in order to examine variations in disease prevalence across different life stages.

Inclusion Criteria

The inclusion criteria comprised patients aged between 1 and 60 years who were clinically or laboratory diagnosed with waterborne or water-related diseases such as hepatitis B, hepatitis C, cholera, typhoid, diarrhea, gastrointestinal disorders, and skin infections. Only permanent residents of the study area with complete medical records were included.

Exclusion Criteria

The exclusion criteria involved patients above 60 years of age, individuals with non–waterborne diseases, those with incomplete medical records, and patients who had recently migrated to the study area without documented exposure to canal water.

Data Collection

Data collection was carried out in two phases:

Water Sampling:

Water samples were collected from multiple points along each canal (main channel, branches, minors) using standard sampling procedures.

Patient Data:
Medical records of 2816 patients were obtained from hospitals and diagnostic centers located within the study area. The data included age, gender, residence, and disease diagnosis.

Sample Analysis
Water Analysis:
The collected water samples were analyzed in the laboratory for biological, chemical, and physical pollutants. The biological parameters were the coliform bacteria, the E. coli and other pathogens. The chemical parameters were pH, nitrates, phosphates, pesticides, and the heavy metals like arsenic, lead, cadmium, and chromium. The physical parameters were turbidity, total dissolved solids (TDS) and electrical conductivity. The findings were contrasted to the World Health Organization (WHO) drinking water standards.

Patient Analysis:
Medical records were filtered to verify a diagnosis of waterborne diseases. The patients were divided into three age groups (1–20, 21–40, 41–60 years), and each group was analyzed in terms of disease prevalence.

Data Analysis
Data were processed and analyzed using SPSS version 29.0. Descriptive statistics (frequencies, percentages, means) were applied to determine disease prevalence across the age groups. The Chi-square test (χ^2) was used to assess associations between categorical variables, while regression analysis evaluated the effect of water pollutants on disease prevalence. Results were presented in tables and graphs and interpreted within the context of environmental sustainability and public health impacts.

Ethical Considerations
Ethical approval was obtained from the relevant institutional review board. Patient confidentiality was ensured by anonymizing records, and informed consent was obtained from hospitals and diagnostic centers for the use of medical data. Water sampling and laboratory analyses were conducted following environmental safety standards.

Results
Disease Distribution by Age Groups
Out of 2816 patients, the highest prevalence of waterborne diseases was observed in the 21–40 years' age group, followed by 1–20 years. Hepatitis B and C were the most frequently reported diseases, while diarrhea and skin infections were common among children and young adults.

Table 1: Distribution of Waterborne Diseases by Age Groups (n = 2816)

Disease	1–20 Years (n=912)	1–40 Years (n=1164)	1–60 Years (n=740)	Total (%)
Hepatitis B	142 (15.6%)	256 (22.0%)	178 (24.0%)	576 (20.5)
Hepatitis C	128 (14.0%)	210 (18.0%)	156 (21.0%)	494 (17.5)
Cholera	95 (10.4%)	122 (10.5%)	56 (7.6%)	273 (9.7)
Typhoid	180 (19.7%)	210 (18.0%)	95 (12.8%)	485 (17.2)
Diarrhea	220 (24.1%)	182 (15.6%)	82 (11.0%)	484 (17.2)
Gastrointestinal Disorder	87 (9.5%)	110 (9.4%)	72 (9.7%)	269 (9.5)
Skin Infections	60 (6.6%)	74 (6.3%)	41 (5.5%)	175 (6.2)
Total	**912**	**1164**	**740**	**2816**

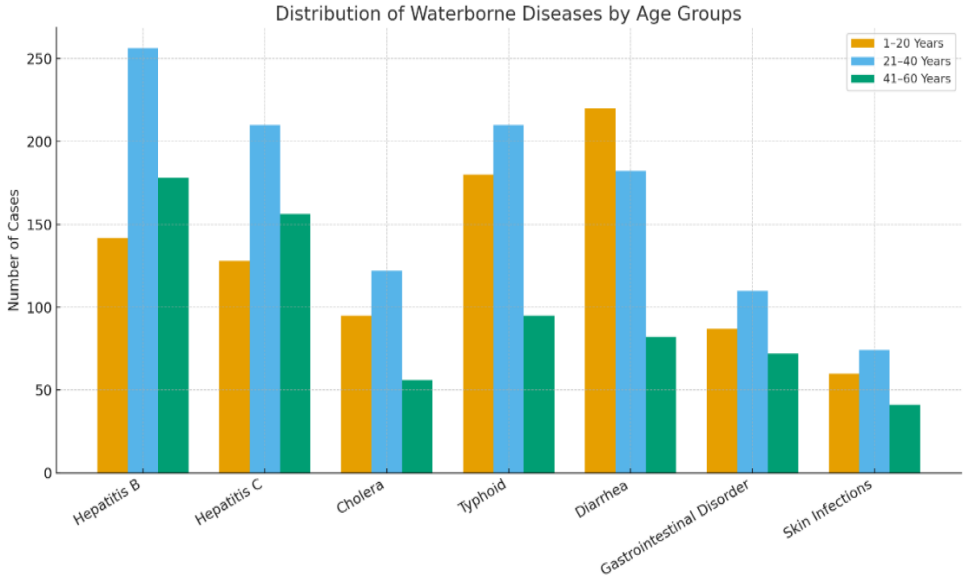


Figure 2: Distribution of Waterborne Diseases by Age Groups (n = 2816)

The table 1 and figure 2 shows that the hepatitis B was most common in the 21–40 years' age group (22.0%), totaling 576 cases (20.5%). Hepatitis C affected 18.0% of the 21–40 age group, with a total of 494 cases (17.5%). Cholera was most prevalent in the 1–20 age group (10.4%), with 273 cases (9.7%). Typhoid was common in the 1–20 age group (19.7%) and totaled 485 cases (17.2%). Diarrhea affected 24.1% of the 1–20 age group, with a total of 484 cases (17.2%). Gastrointestinal disorders and skin infections were more evenly distributed, with 9.5% and 6.2% of total cases, respectively. The highest disease burdens were found in the younger populations (1–20 and 21–40 years).

Water Pollutants in Canal Systems

Water samples collected from Pat Feeder, Kirthar, Kachhi, and Uch canals indicated high levels of biological contamination (E. coli, coliforms), presence of chemical pollutants (heavy metals, nitrates, pesticides), and poor physical quality (turbidity, TDS, conductivity).

Table 2: Water Pollutants Detected in Canal Systems

Parameter Type	Major Findings	WHO Permissible Limit	Status
Biological	Total Coliforms, E. coli, Fecal bacteria	0 CFU/100 ml	Above limit
Chemical	Arsenic (0.05 mg/L), Lead (0.04 mg/L), Nitrates, Phosphates, Pesticides	Arsenic <0.01 mg/L, Lead <0.01 mg/L	Above limit
Physical	High Turbidity (25 NTU), High TDS (1200 mg/L), Conductivity (850 µS/cm)	urbidity <5 NTU, TDS <500 mg/L	Above limit

The table 2 highlights water pollutants detected in canal systems exceeding WHO permissible limits. Biological parameters, including total Coliforms, E. coli, and Fecal bacteria, exceeded the permissible limit of 0 CFU/100 ml. Chemical pollutants, such as Arsenic (0.01 mg/L) and Lead (0.01 mg/L), also exceeded the permissible threshold. Physical parameters showed high turbidity (25 NTU), high TDS (1200 mg/L), and conductivity (850 µS/cm), surpassing WHO limits of <5 NTU and <500 mg/L for TDS.

Relationship Between Water Pollutants and Diseases

Biological contaminants were strongly associated with cholera, typhoid, and diarrhea, while chemical pollutants (arsenic, lead, pesticides) were linked with hepatitis B, hepatitis C, and gastrointestinal disorders. Physical parameters (turbidity, TDS) contributed to skin infections and general gastrointestinal distress.

Table 3: Association of Water Pollutants with Major Diseases

Disease	Associated Pollutant(s)	Strength of Association
Hepatitis B	Heavy Metals (Arsenic, Lead), Pesticides	High
Hepatitis C	Heavy Metals, Nitrates, Unsafe pH	High
Cholera	Coliforms, E. coli	Very High
Typhoid	Fecal Bacteria, Biological Contamination	High
Diarrhea	Coliforms, Nitrates	High
Gastrointestinal Disorder	Chemical Pollutants, Pesticides	Moderate
Skin Infections	High Turbidity, TDS, Conductivity	Moderate

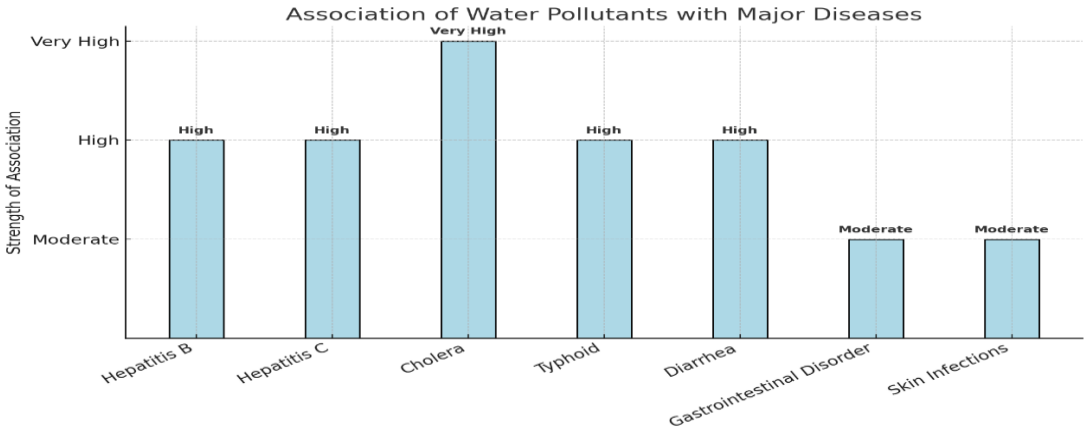


Figure 3: Association of Water Pollutants with Major Diseases

The table and figure 3 shows the association of water pollutants with diseases. Hepatitis B and C are strongly linked to heavy metals and pesticides. Cholera's association with coliforms and E. coli is very high. Typhoid and diarrhea are highly associated with fecal bacteria and coliforms. Gastrointestinal disorders and skin infections are moderately linked to chemical pollutants, pesticides, and high turbidity, TDS, and conductivity. Cholera has the strongest association, while gastrointestinal disorders and skin infections have moderate ties

Water Quality Analysis of Chemical Parameters

The water samples collected from the Pat Feeder, Kirthar, Kachhi, and Uch canal systems were analyzed for chemical and physical parameters to assess their quality in comparison with the World Health Organization (WHO) drinking water standards. The chemical parameters measured included pH, nitrates, phosphates, pesticides, and heavy metals (arsenic, lead, cadmium, and chromium). The physical parameters included turbidity, total dissolved solids (TDS), and electrical conductivity.

Table 4: Chemical Parameters of Canal Water Compared with WHO Standards

Parameter	WHO Standard Limit	bserved Range in Samples	atus Compared to WHO
pH	6.5 – 8.5	7.8 – 8.9	ightly Above in some sites
Nitrates (mg/L)	≤ 50	60 – 95	Above Limit

Phosphates (mg/L)	≤ 5	6 – 12	Above Limit
Pesticides (µg/L)	≤ 0.1 each	0.2 – 0.6	Above Limit
Arsenic (mg/L)	≤ 0.01	0.04 – 0.07	Above Limit
Lead (mg/L)	≤ 0.01	0.02 – 0.05	Above Limit
Cadmium (mg/L)	≤ 0.003	0.006 – 0.012	Above Limit
Chromium (mg/L)	≤ 0.05	0.06 – 0.12	Above Limit

The table 4 shows the analysis of canal water. pH exceeded WHO's 8.5 limit at 20–30% of sites. Nitrates (60–95 mg/L) were 20–90% above the 50 mg/L standard, while phosphates (6–12 mg/L) exceeded by 20–140%. Pesticides (0.2–0.6 µg/L) were 2–6 times higher. Heavy metals like arsenic (0.04–0.07 mg/L), lead (0.02–0.05 mg/L), cadmium (0.006–0.012 mg/L), and chromium (0.06–0.12 mg/L) exceeded safe limits by 2–7 times, indicating severe health risks.

Water Quality Analysis of Physical Parameters

In addition to chemical pollutants, the physical quality of canal water was also assessed. Parameters such as turbidity, total dissolved solids (TDS), electrical conductivity etc. were compared with WHO permissible limits. The results showed that all physical parameters were well above the recommended standards, indicating poor water clarity, high dissolved substances, and elevated salinity levels.

Table 5: Physical Parameters of Canal Water Compared with WHO Standards

Parameter	WHO Standard Limit	Observed Range in Samples	Status Compared to WHO
Turbidity (NTU)	≤ 5	18 – 28	Above Limit
Total Dissolved Solids (mg/L)	≤ 500	850 – 1300	Above Limit
Electrical Conductivity (µS/cm)	≤ 400	650 – 950	Above Limit
Temperature (°C)	20 – 25	28 – 33	Above Limit
Color (TCU)	≤ 15	20 – 35	Above Limit
Odor	Acceptable	Unpleasant/Earthy	Not Acceptable
Total Hardness (mg/L as $CaCO_3$)	≤ 300	320 – 480	Above Limit
Dissolved Oxygen (mg/L)	≥ 6	3 – 4.5	Below Standard
Salinity (ppt)	≤ 0.5	0.8 – 1.3	Above Limit

The table 5 compares the physical parameters of canal water with WHO standards. Several parameters exceed WHO limits: turbidity (18–28 NTU), total dissolved solids (850–1300 mg/L), electrical conductivity (650–950 µS/cm), temperature (28–33°C), color (20–35 TCU), total hardness (320–480 mg/L), and salinity (0.8–1.3 ppt). Dissolved oxygen (3–4.5 mg/L) is below the WHO standard of 6 mg/L. The water also has an unpleasant, earthy odor, making it unacceptable. These findings indicate significant water quality issues.

Discussions

Our results indicate that the canal system in Balochistan is strongly contaminated with hydrological, chemical and biological parameters above WHO limits causing potentially severe public health risks. High populations of E. coli, coliforms and fecal gangs point to severe biological pollution and the excessive amounts of chemical contaminants such as arsenic, lead, and nitrates that go well above accepted concentrations are devastating to both nature and the human wellbeing. Its physicochemical

characteristics such as high turbidity, TDS, and EC indicate that the water is of poor quality and therefore cannot be used either as drinking or irrimental. Moreover, the chemical contaminants of arsenic and lead are also long-term health hazards including cancer and neural damages, particularly in children. Such findings explain why the higher environmental standards, increased treatment capacity of wastewater and increased public health educational campaigns are needed to curb water pollution and protect human health.

Rajak et al. (2024) assert that water pollution is very intrusive to certain aquatic habitat and human health when oils, chemicals, detergents and plastic materials are introduced that are usually toxic and consume oxygen that leaves other forms of life without leaving amidst a call of sustainable practices to protect rivers and water ways as well as a stronger regulatory environment with a language of fines to speak on behalf of local goods.

Madhav et al. (2019) further assert that microbial and chemical contamination of the water have a significant negative impact on the human health by linking microbes to diseases such as diarrhea, hepatitis and cancer. Their assessment brings into focus the heterogeneity of disease burden regionally, by age and gender and the need to improve water treatment and hygiene such that such threats to health can be mitigated globally (15).

According to Oluwasanya et al., (2024), the cause of environmental risks and health impacts in the entire globe is due to differences in water quality. This review highlights the role of combined pollution control measures and technological intervention to reduce contamination and the importance of equitable access to clean drinking water both to sustain the environment and human health (16).

Kumar et al. (2024) elaborated that sustainable water management should combine the economic growth, social equity and environmental protection. The former focuses on an integrated approach to dealing with pollution and overuse through integrated frameworks in line with the Sustainable Development Goals so as to realize long term security of water resources and health benefits (17).

El-Halwagi. P (2025) has indicated how the deterioration of resources and environmental loss require the sustained industrial management of water pollution as a mandatory one. Their work advocates environmentally friendly methods and relevant policies to guarantee water quality, which is significant to sustain ecosystems, and safeguard human health between generations (18).

A general based study by Ishaque et al. (2024) revealed that 80 per cent of Pakistani population daily consumes polluted water and risks their life due to chemical, microbial cum heavy metal contamination. The research also indicates that water quality is deteriorating drastically and this has endangered the achievement of the UN Sustainable Development Goals (SDGs) that places located hitting the target of accessing clean water by 2030. Such findings are the focus of research and it indicates that systems surveillance and treatment plants, along with implementation of public policies are required to effectively realize sustainable water management in Pakistan (19).

A review of the water pollution situation in Pakistan conducted by Azizullah et al. (2011) established that absence of management and monitoring leave chances of drinking water contamination by microbial organisms and toxic metals like coliforms. The biggest sources of pollution were industrial and urban waste dumping, pesticides and the residue of agrochemicals. The review notes that deviations in the WHO water quality standards increase and a variety of health problems in connection with pollution appear, and suggests that the further control of the water quality is urgently required (20).

Conclusions

The present study draws attention to the fact that the water in Balochistan canals is at present in alarming levels of contamination with biological, chemical and physical contaminants exceeding the value of the guideline levels provided by WHO. This close

linkage of contamination with hepatitis, cholera, typhoid and diarrhea taking the greatest toll on the youth is a very grave social challenge. In order to manage these issues, there is a need to not only have highly enforced regulations but also better wastewater treatment systems, but more sustainable agricultural and industrial methods. Equally important are the creation of awareness and participation of the communities in the conservation of the ecosystems in order to enable the safe access to water to support drinking and sustainability of human health.

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