Water Quality in India: A Contemporary Perspective

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Overview-

The processes and practices used to protect and enhance the quality of water in different water resources such as-Ground water, ocean water and freshwater is known as Water Quality Management System (WQMS). It involves monitoring, assessing, controlling and improving water quality to ensure that it meets the required standards for various uses including drinking, industrial and agricultural purposes, etc.

India, as a rapidly developing country, faces significant challenges in maintaining water quality due to ongoing urbanization, agricultural runoff, climate change and inadequate wastewater treatment. Studies have shown that nearly 80% of Punjab's groundwater is used for agriculture, leaving limited resources for drinking purposes. This shows that the same water is being supplied for all purposes including domestic, agricultural, industrial, recreational and many other applications. While using water for domestic usage we are using the same water for drinking and as well as for sanitation. And the conventional system does not provide water availability based on its quality across different applications.

Various studies highlight that poor water quality has severe implications for ecosystem causing a huge biodiversity loss, public health and economy. Contaminated water can lead to waterborne diseases, reduce agricultural productivity and harm aquatic life. Therefore, there is an urgency to have the concept of real-time water quality assessment.

One approach for a better water quality management system could be the introduction of Underwater Domain Awareness (UDA) framework in this field. UDA is a holistic approach that translates to transparency in water bodies through real-time spatio-temporal monitoring of developments below the water surface which is a critical starting for any water quality management initiative. Research shows that a data-driven policy framework might enable good governance, and digitizing the entire water quality management system would allow us for prediction of future trends and facilitate well-informed policy and technological interventions. Also, accurate and precise data gathering on different aspects of water quality, along with the detailed analysis of past, present and future conditions are necessary for decision-making. Hence, the UDA framework can be a key to comprehensive water quality management. A properly integrated and coordinated water resource and water quality management is therefore critically important. By integrating expertise from diverse disciplines, the complex challenges (that we can understand throughout this article) of water resources might be solved.

Nearly all of India’s maritime waters are tropical hence, it is very important for us to understand the tropical characteristics of waters. Water quality in tropical areas differs from other areas in three major characteristics: 1) Physical and chemical 2) Biological 3) Socio-economic. We will discuss each of three characteristics below-

Physical and Chemical Characteristics of Tropical Waters

There have been several researches to study the water quality in coastal and tropical waters (for e.g., Evaluation of Physiochemical characteristics of coastal waters of Nellore, southeast coast of India) which show that different coastal regions have different physical and chemical characteristics, affected by various natural and anthropogenic factors that are discussed later in this report. So, having a clear understanding about these characteristics is crucial for an effective water quality management system.

Physical Characteristics

1. Temperature- According to previous studies the temperature of tropical waters should be typically between 15°C to 25°C, however in Indian tropical waters (Indian Ocean Region) the temperature may rise above 25°C and go up to 32°C in summer months which may not be good for the aquatic life, flora and fauna. These variations may also impact water quality through changes in dissolved oxygen levels, nutrient contents, salinity and biological processes.
2. Turbidity- Turbidity is caused by suspended solids, sediments and organic matters in the water. During the monsoon season, inland runoff increases turbidity due to soil erosion and sedimentation. Urban and industrial discharge also elevate the turbidity levels.
3. Dissolved Oxygen (DO)- Dissolved Oxygen levels are crucial for marine life. But, due to high temperatures in tropical waters the oxygen solubility decreases and increase in organic pollution leads to hypoxic conditions for aquatic life.
4. Salinity- Coastal and estuarine waters show varying salinity levels due to climate change including precipitation patterns, sea level rise and increased temperatures. During monsoons, freshwater influx reduces salinity, while in dry seasons it increases due to evaporation. For e.g., A case study on the Sundarbans mangrove forest highlights the significant salinity changes due to climate change.
5. Colour- The colour of tropical water varies from colourless to brownish, influenced by dissolved organic matter, algae and sediments.

Chemical Characteristics

1. PH- In tropical waters the PH generally ranges from 6.5 to 8.5 and it is influenced by factors like acid rain, industrial discharge and agricultural runoff.
2. Nutrients- Nutrients, specifically nitrates and phosphates, are essential for aquatic ecosystems but, their concentrations need to be within certain limits to maintain water quality. According to Environmental Protection Agency, USA- the nitrates levels in drinking water should not exceed 10 mg/L and phosphates levels should not exceed 0.05-0.1 mg/L. High nutrient levels often result from agricultural runoff which leads to eutrophication and algal blooms.
3. Total Dissolved Solids (TDS)- TDS refers to the combined content of total organic and inorganic substances present in water in any of the forms, ionized, molecular, colloidal or suspended form. According to WHO, Low TDS

level(<500mg/L) supports aquatic life and is suitable for drinking, high TDS level(>1500mg/L), may cause stress to aquatic life and is not suitable for drinking, very high TDS levels(>3000mg/L), harmful for most aquatic life and are not suitable for human consumption at all.

4. Hardness- Hardness of water is determined by the concentration of calcium and magnesium ions. Tropical waters in India vary from soft to hard, influenced by geological characteristics of the region and dissolved organic matters.
5. Heavy Metals- Industrial and mining activities introduce heavy metals like lead (<10 ppb), mercury (<50 ppb), Cadmium (< 3 ppb) and arsenic (<1000 ppb) into the tropical waters and according to WHO guidelines higher concentrations of these metals may significantly impact water quality and pose serious risk like cancer and skin diseases to human.

Biological Characteristics of Tropical Waters

Diverse biological communities across the tropical waters are influenced by climate change, hydrology and human activities. Some of the key biological characteristics of tropic waters are explained below-

1. Phytoplankton and Zooplankton- Tropical waters are rich in phytoplankton (including green algae, cyanobacteria, diatoms, etc.) and zooplankton (including protozoans, rotifers, etc.) diversity. They are influenced by temperature, climate change and nutrient content.
2. Microorganism and Benthic Organisms- Microorganisms such as bacteria and fungi play a vital role in decomposing organic matter and recycling nutrients. Some of them also serve as bioindicators of water quality and ecosystem health.
3. Fish and other Aquatic Vertebrates- Tropical waters support a wide variety of fish species along with amphibians, reptiles and aquatic mammals. Many fish species are important for local fisheries and aquaculture, providing food and livelihoods for communities.

Socio-economic Characteristics of Tropical waters

Tropical waters play a significant role in the socio-economic fabric of the country as they support diverse activities and communities, influencing livelihood, cultural practices and economic development.

1. Agriculture- Tropical waters are crucial for irrigating agricultural lands, especially in regions where monsoon rains are unreliable. Rivers like the Ganges, Brahmaputra and Godavari provide essential water resources for crop production. A sustainable portion of India's rural population depends on agriculture, which is majorly dependent on the availability of water from tropical rivers and lakes.
2. Drinking water and sanitation- These waters are a primary source of drinking water for many communities. Hence, ensuring the quality and sustainability of water in tropical regions is critical for public health.
3. Tourism and Recreation- A huge number of tourists are attracted by the coastal areas for activities like boating, fishing, etc. Wetlands and riverine ecosystems are popular for ecotourism and supporting local economies. The number of

Foreign Tourist Arrivals (FTAs) in India during 2022 increased to **6.44 million** as compared to 1.52 million in 2021, registering a positive growth of 321.54% and achieved 58.9% recovery as compared to pre-pandemic year 2019 (India Tourism Statistics 2023).

4. Industry and Commerce- Industries such as textile, paper and chemicals rely heavily on water from tropical sources. These industries provide significant employment and economic output but also pose challenges related to water pollution and sustainable development. These water resources also contribute to hydropower generation which finally contributes to the country's energy supply. However, it also raises concerns about environmental and social impacts, including displacement of communities.

Current Status of Water Quality in India

According to the Central Pollution Control Board (CPCB), as of 2023, more than **70%** of India's surface water resources are contaminated. The National Green Tribunal (NGT) has identified around 351 polluted river stretches across the country, indicating widespread and severe water quality issues.
Groundwater, which is a crucial resource for drinking and irrigation, is also heavily contaminated. A 2022 study by the Indian Institute of Technology (IIT) Kanpur found that nearly 60% of groundwater samples across India contained nitrate levels above permissible limits. Additionally, the Ministry of Jal Shakti reported in 2023 that 275 out of 650 districts face severe water stress, causing water quality challenges.

Water quality in India is a critical issue that intersects significantly with the country's economic growth as well. As India continues to develop rapidly, the challenges of ensuring clean and safe water for its population and industries become increasingly complex. Recent data highlight the severe water quality issues facing India and their far-reaching implications for public health, agriculture, industry, and overall economic stability.

A World Bank report indicates that water-related health issues alone cost India about **6%** of its GDP annually, underscoring the economic importance of water quality.

Sources of Water Quality degradation and its effects

Despite having approximately 71% of earth's surface covered by water, we face severe water pollution issues, resulting in around **50,000 fatalities annually**. Contaminated water sources significantly contribute to this public health crisis,

affecting both rural and urban populations. Industrial discharge, agricultural runoff, and inadequate sewage treatment intensify the problem, leading to waterborne diseases like cholera, typhoid, diarrhea, etc. The major factors of water quality degradation are-

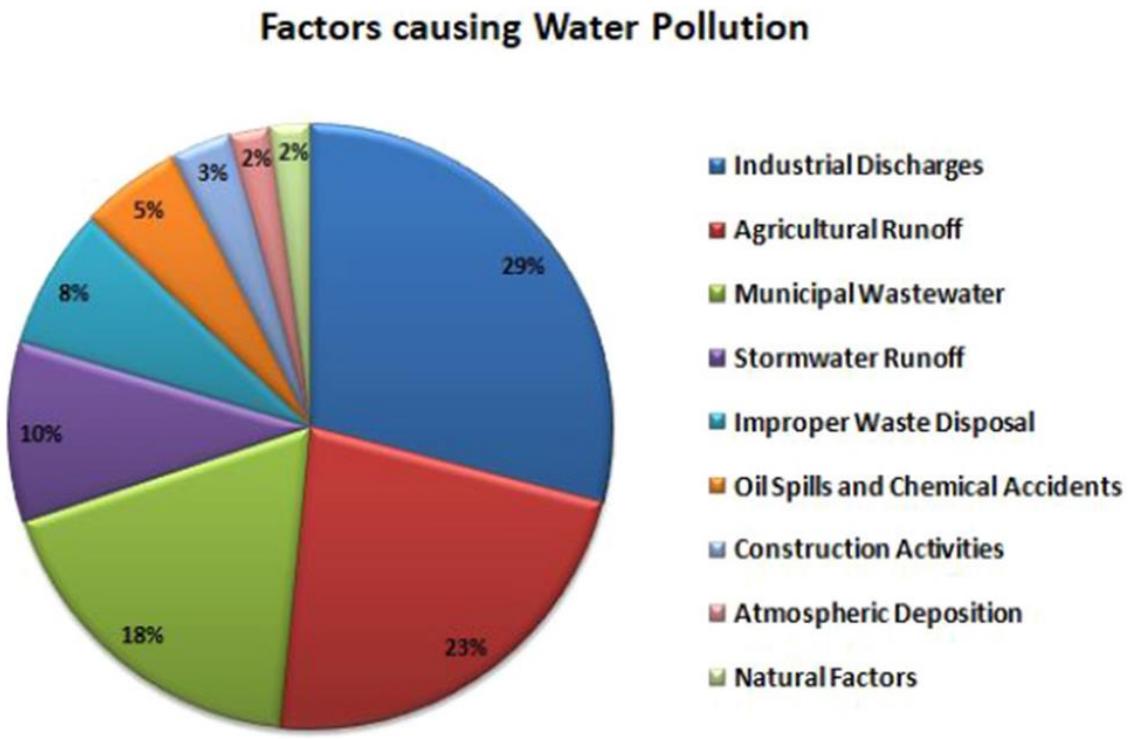
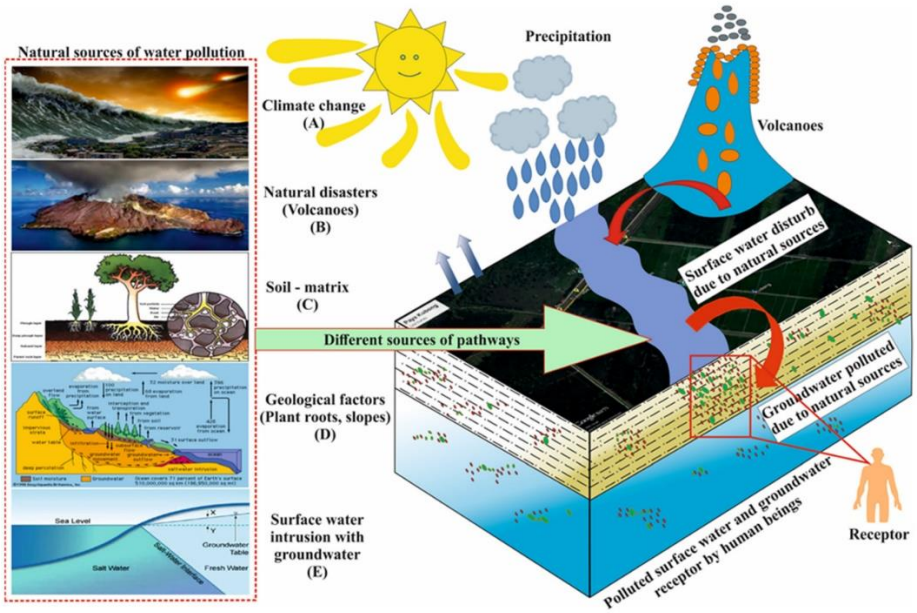


Image source: https://www.nature.com/articles/s41598-024-56775-y/figures/1

Natural Factors-



This diagram demonstrates the natural factors affecting the quality of surface water and groundwater, their pathways, and different types of sources Image source: https://www.mdpi.com/water/water-13-02660/article_deploy/html/images/water-13-02660-g003.png

Geological Factors:

- Mineral Composition: The type of rocks and soil through which water flows can affect the mineral content such as calcium, magnesium, iron, etc.
- Weathering and Erosion: Breaking of rocks due to natural process can cause sedimentation into the water

Hydrological Factors:

- Flow rate and volume: The speed and the volume of water flow can influence the concentration of pollutants and sediments
- Seasonal variations: Seasonal changes such as snowmelt and rainfall can affect water quality by altering the volume and composition of water

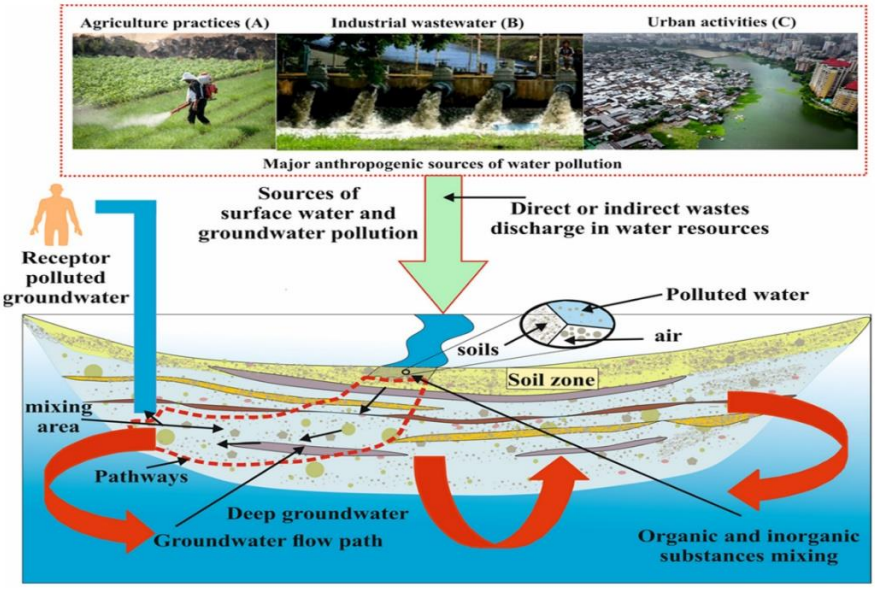
Biological Factors:

- Microorganisms: Naturally occurring bacteria, algae, and other microorganisms can influence water quality by their metabolic processes
- Vegetation: Plants and trees also affect the water quality through transpiration and nutrient uptake

Climate Change:

- Temperature Changes: As discussed above in the physical characteristics of tropical waters, altering the temperature of water bodies affects the solubility of oxygen and other chemicals in water, impacting aquatic life.

Anthropogenic Factors-



This diagram illustrates several anthropogenic activities contaminating the surface water and groundwater systems, as well as pollutants moved various pathways and effect on receptor. Image source- https://www.mdpi.com/water/water-13-02660/article_deploy/html/images/water-13-02660-g004.png

Agricultural Activities:

- Fertilizers and Pesticides: Runoff from agricultural fields can introduce nutrients such as nitrogen and phosphorous and other chemicals into water bodies leading to eutrophication and contamination
- Livestock Waste: Manure and other animal waste can introduce pathogens into water resources

Industrial Activities

- Chemical Discharges: Factories and industrial plants release pollutants such as heavy metals, organic chemicals and toxic substances into water bodies
- Thermal Pollution: Discharge of heated water from industrial processes can alter the temperature of water bodies which affect the aquatic ecosystem

Urbanization

- Stormwater Runoff: Urban areas can contribute to water pollution through runoff that carries oil, grease, plastics and other pollutants
- Sewage and Wastewater: Improperly treated sewage and wastewater introduce pathogens, nutrients and chemicals into water bodies

A 2023 CPCB report highlighted that over 70% of surface water resources are contaminated, primarily due to these factors.

Applications of water based on its quality

High Quality (Drinking water)

- Must meet safety standards set by authorities (e.g., WHO, BIS)
- Must be free from harmful pathogens and toxic chemicals
- Must be suitable for household consumption and drinking

Moderate Quality (Agricultural and Industry use water)

- Must be free from high levels of salinity and toxic substances that can harm crops
- Should be low in suspended solids for industrial purposes
- Must be suitable for supporting aquaculture, irrigation of crops and watering livestock

Basic Quality (Recreation and Environment use water)

- Must be safe for human contact, free from pathogens and harmful chemicals
- They are used in swimming pools, water parks, beaches and lakes for boating and fishing

Utility Quality (Municipal and Firefighting use water)

- Must be suitable for non-drinking household uses
- Should be free from contaminants that would cause damage to firefighting equipments

How do we improve the existing management?

Effective water quality management is essential for ensuring the sustainability and safety of water resources. However, there are significant gaps in both the technologies and policies currently available, particularly in countries like India. Addressing these gaps is crucial for improving water quality and managing water resources more efficiently.

Stakeholders-

Effective water quality management requires collaboration and coordination among these diverse groups to address the multifaceted challenges of water pollution and ensure sustainable use of water resources. Therefore, the key stakeholders include- Central Government (CPCB), State Government (SPCB), Local Government and Municipalities, NGOs, Private Sector, Academic and Research Institutions, local communities and residents.

Technological Gaps-

Limited Monitoring and Data Collection- Water Quality prediction of the Yamuna River using Hybrid Neuro-Fuzzy Models which estimated the COD levels in the river but the researchers found that the main limitation of the model was the use of limited data as the data interval used was monthly, and the available data period was very short. In order to justify the models' robustness and/or generalization capability, more data from different regions should be applied. However, it was clearly seen from the scatterplots that the hybrid methods could detect the extreme values well, and this can be explained by the limited number of training examples, especially for the COD extremes.

Insufficient Wastewater Treatment plants- Many researchers have highlighted the presence of microplastics and endocrine-disrupting chemicals in the Ganga River. The untreated or partially treated wastewater from nearby cities and industrial areas contributes to this pollution and indicates the inefficiency of existing wastewater treatment plants.

Limited Adoption of Sustainable Practices- Technologies for recycling and reusing water, such as greywater systems, are not widely adopted due to lack of awareness, regulatory support, and economic incentives. Even in areas with significant economic resources, such as Bangalore's IT parks, rainwater harvesting is not universally implemented. Companies often cite high initial costs and space limitations as barriers, despite the long-term benefits of such systems in mitigating water scarcity.

Policy Gaps-

Inadequate Regulation and Enforcement- Even where regulations exist, enforcement is often weak due to lack of resources, corruption, and bureaucratic inefficiencies. Vapi, a major industrial hub in Gujarat, has faced severe water pollution issues due to inadequate enforcement of environmental regulations. Despite regulations under the Water (Prevention and Control of Pollution) Act, industries in Vapi have been found discharging untreated or partially treated effluents into water bodies. The local enforcement agencies often lack the resources and capacity to monitor and control pollution effectively.

Public Awareness and Education- There is a significant gap in public awareness about the importance of water quality and conservation. For e.g. despite being a sacred river, the Ganga faces severe pollution issues due to the dumping of industrial waste, sewage, and religious offerings. Many people are unaware of the impact their actions have on water quality. Campaigns to clean the Ganga, such as the National Mission for Clean Ganga, have struggled with local buy-in due to a lack of comprehensive public awareness efforts.

Research and Development (R&D) Funding- Investment in research and development for new water treatment technologies and pollution control methods is often insufficient. This limits innovation and the development of more effective solutions. According to researchers Punjab's extensive use of fertilizers and pesticides has led to severe groundwater contamination. There is a critical need for R&D in sustainable agricultural practices and pollution control technologies. However,

insufficient investment in this area has resulted in continued reliance on traditional, less effective methods, amplifying water quality issues.

Capacity and Capability building

The UDA framework (explained in the overview) is therefore essential for a more comprehensive Water Quality Management System (WQMS). This framework necessitates policy and technological interventions, along with the development of capacity and capability building. National Centre for Coastal Research (NCCR), Ministry of Earth Sciences is also committed towards its capacity building programmes which aims to increase the coastal stakeholders' knowledge at different level on coastal zone problems, implications of adaptive and integrated coastal zone management (ICZM) for informed decision making. Till date about 80 training programmes designed with practical sessions have been conducted to generate manpower capacity through participation of local state governments, NGOs and academia.

To achieve the above, the following activities were taken up

- To develop the resources available in coastal States through structured training programmes with an even mix of theory and hand-on sessions for effective management of coastal areas and related issues.
- Strengthening institutional mechanisms for handling coastal issues related to pollution, hazards, processes and ecosystems through structured training and capacity building programmes.
- Promoting interaction among coastal stake holders by networking and facilitating exchange of information, experience and expertise.

Challenges

Infrastructure- Inadequate sewage treatment and waste management infrastructure lead to widespread pollution. Many urban and rural areas lack sufficient treatment facilities.

Regulatory Compliance- Ensuring industries and municipalities comply with pollution control norms is challenging due to limited enforcement capabilities and communication.

Public Awareness- There is a need for greater public awareness and participation in water conservation and pollution prevention efforts.

Climate Change- Changing precipitation patterns and extreme weather events lack of water quality and their availability issues.

Accessibility- Buying water for drinking is not feasible for everyone, especially in rural and low-income urban areas. Dependence on bottled water is increasing, but it is not a sustainable solution. Government initiatives like the Jal Jeevan Mission aim to provide safe drinking water to rural households, but challenges remain in ensuring consistent quality and coverage due to exploitation of freshwater in different sectors like industries and agriculture.

Way Ahead

Water quality in tropical waters is influenced by several factors such as climate change, demography, chemical, physical and biological characteristics. Effective monitoring of these parameters is crucial for human and environmental health. Technological advancements like satellite and sensor-based monitoring systems enhance water quality monitoring by providing real-time, cost effective and comprehensive data. Integarting machine learning with satellite data improves the accuracy of analysis. However, the limitations always do exist. It is evident that the UDA framework can be a key factor which aims to combine technology, infrastructure and pollution control methods to provide a comprehensive solution to the of ongoing freshwater crisis and a sustainable Water Quality Management System.

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