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MINI REVIEW

Unveiling the Issues on Water Pollution Narrative, Focus on Quality and Quantity Dynamic

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The 2015 United Nations Sustainable Development Goal 6 (SDG 6) aims to solve the global water concerns by emphasising access to safe drinking water, sanitation and wastewater management. Significant populations, however, continue to lack these basics, contributing to child mortality and waterborne illnesses. Water pollution exacerbates the worldwide water problem, having an impact on ecosystems and human health. This study delves into the intricate problems of water pollution, including its causes, health consequences and ecological disruptions. It also looks at worldwide policies and legislative attempts like the Safe Drinking Water Act and international mandates like the Water Framework Directive. These regulations indicate a shift towards more comprehensive approaches, such as Integrated Water Resources Management (IWRM), which strike a balance between fairness, ecological integrity and efficiency principles.

Keywords: Water pollution, Water quality, Clean water, Health, Ecosystem.

INTRODUCTION

Clean water and sanitation are one of the goals or SDG 6 of the seventeen interrelated Sustainable Development Goals (SDGs) that the United Nations endorsed in 2015. Improving international hygienic standards and addressing the problem of water shortage are the primary goals of this project. SDG 6 addresses a wide range of issues, such as access to clean drinking water, improved sanitation and hygiene, wastewater management and recycling. This goal is closely related to other SDGs, such as sustainable cities (SDG 8) and health (SDG 3). Water resources are essential to development in every way, from ensuring food security, promoting health and reducing poverty to fostering industrial and agricultural expansion and maintaining healthy ecosystems [1].

It is essential for everyone's health and welfare to have access to better water and sanitation services, which is a fundamental human right. However, a sizable portion of the world's population still lacks access to these fundamental needs [2]. Individuals without access to better sanitation and water resources are less likely to realise their full potential. Undoubtedly, inadequate sanitation and drinking water quality are major global contributors to child mortality [3]. Approximately 10,000 individuals perish from diseases brought on by inadequate access to clean water and sanitation every day and many more endure a range of debilitating illnesses. The prevalence of waterborne illnesses is significantly decreased when people have access to better water sources and sanitation [4,5]. A plethora of research papers, including those by Vorosmarty *et al*. [6], have examined the connection between population increase, size and water supply within the last 10 years. Water scarcity has historically been more acute in rural places, but current trends show that urban areas are becoming worse off. Numerous factors are to blame for this, such as changes in land use and freshwater resources brought about by climate change, population growth related increases in demand, inadequate sanitation and water treatment facilities and poor management [7,8].

Water pollution is one of the main hazards and problems facing humanity today, along with biodiversity loss, climate change, energy concerns and socioeconomic difficulties. Human activities and the discharge of materials and waste products from human activity into rivers, lakes, groundwater reservoirs and the ocean cause changes to the water's environmental quality and make large amounts of water unfit for use in several ways [9-11]. Since clean, freshwater is fundamental to all forms of life, this impacts both terrestrial and aquatic ecosystems, in addition to human-related activities such as drinking, bathing, and irrigation of agricultural and industrial processes. Water pollution exacerbates what is often referred to as the 'global water crisis' by diminishing the quantity of available freshwater resources for both human populations and ecosystems. Freshwater scarcity has become a tangible issue in numerous regions across the world, affecting not only developing countries like India, China and various African nations but also impacting countries and regions historically regarded as water-abundant, such as the United States and Europe [12].

Water pollution is a complex problem with many facets. Since water pollution brings pathogens like bacteria and viruses into surface and groundwater sources, it has a significant negative impact on human health [13]. This pollution affects the quality of drinking water and is harmful to health. Additionally, the nutrition of plants and animals is directly impacted by water pollution, which has implications for human health. Excessive levels of nutrients, such as phosphorus, nitrogen and other elements that support the growth of aquatic plants, can cause problems including overgrowth of weeds and algal blooms [14-17]. As a result, water may take on strange tastes, smells, or even discolorations. Eventually, the natural balance that exists within a body of water will be disrupted. This leads to affected quality and reduced quantity of good drinkable and usable water. The intricate web of challenges posed by water pollution has a profound impact on the quality and quantity of precious freshwater resources [18-21]. The repercussions are far-reaching, influencing not only the purity of drinking water but also the health of ecosystems and ultimately human well-being. The delicate balance in aquatic environments is disrupted and the need for a comprehensive understanding of this dynamic relat-ionship between water quality and quantity becomes evident. The aim of this review is to delve deeply into the complex inter-play between water pollution, its effects on the quality and quantity of available water and the consequential implications for society and the environment.

Water pollution quality dynamics: Waste disposal by cities in close-by streams has a long history and influences both local and regional ecosystems. Urban wastewater became a major challenge when governments started to regulate waste discharge into shared resources [22]. When landowners downstream were harmed by cities and factories, complaints about water contamination throughout the 19th century generally depended on nuisance laws to resolve the issue. Nevertheless, the problem's scope grew as the 20th century went on [23,24]. Concerns over threats to public health, contamination of drinking water supplies and extinction of animals because of emissions from upstream neighbours were voiced by states and cities downstream. Urban-industrial complexes have been identified as the primary cause of declining water quality in most cases when government intervention was necessary in response to the pollution concerns. Cities have been instrumental in determining the direction of water pollution management initiatives for most the last two centuries. The government of the world has just recently taken a more active role in resolving these concerns by making conscious policies in safeguarding their water [25]. Legislation on water contamination from different continents has greatly influenced the development of approaches to deal with this pressing problem. The Safe Drinking Water Act (1974) [26] and the Clean Water Act (1972) established regulatory frameworks for drinking water safety and water pollution prevention in the United States. Comprehensive criteria for water management and urban wastewater treatment were established by Europe's Water Framework Directive (2000) and Urban Wastewater Treatment Directive (1991) [27]. Ambitious targets to lower water pollution are outlined in China's Water Pollution Prevention and Control Law (2008) [28] and Water Pollution Prevention and Control Action Plan (2015). Guidelines for managing water quality can be found in Australia's Environmental Protection (Water) Policy (2009) and National Water Quality Management Strategy (2018) [29]. The National Water Resources Policy (2004) of Nigeria emphasises sustainable water resource management and the protection of water quality, which is in line with the National Water Act (1998) and Minimum Requirements for Water Use (2013) of South Africa. These international legislative efforts highlight the vital necessity of protecting water resources for both the current and future generations and offer a variety of strategies to address water pollution [30-33]. The significance of regulations becomes increasingly apparent as the sources of pollution continue to multiply daily. Recognizing and comprehending these sources empowers stakeholders within the sector to make informed decisions and take proactive measures.

Sources of water pollution: Water pollution can be classified into two basic categories *viz.* point and non-point [34]. Water supplies are susceptible to contamination from both point and non-point sources. Point sources are identifiable, usually smaller locations that contaminate rivers. These sites include pipes from industries or sewage treatment plants, animal factory farms that raise cattle and combined sewer systems that collect rainwater runoff and sewage. Rainfall can cause combined sewer systems to overflow, resulting in the discharge of raw sewage into surface waters. Conversely, non-point sources, which are larger and more dispersed areas that contaminate streams, include cities, abandoned mines and agricultural fields. Pollutants from urban areas and agricultural fields, such as oil and antifreeze, fertilizers, herbicides and pesticides, as well as acid and hazardous components from abandoned mines, are transferred into surface water bodies and groundwater during rainy seasons [35-38]. Due to its low concentration, numerous sources and larger water volume, non-point source pollution is usually far more difficult and costly to control than point source pollution [39].

Water pollutants impact on water bodies: One of the main causes of natural water pollution is the discharge of wastewater into receiving bodies of water. This is because it modifies the chemical makeup of bottom sediment and water, upsetting the biological balance of self-cleaning mechanisms and possibly causing unanticipated changes in the ecosystem. Heavy metals are the most dangerous persistent contaminants found in wastewater because of their tendency to move and collect among species within ecosystems [40,41]. Also, the impact of increased nitrogen content in freshwater is a critical aspect of water quality assessment. Presence of nitrate in freshwater, originating from waste disposal and agro-based industries, can lead to eutrophication and algae blooms. Nitrate concentration in surface and ground waters can vary due to leaching or runoff from agricultural fields, contamination from human or animal wastes and sources like agrochemicals and sewage leaks [42]. Phosphorus, an essential nutrient, enters water through various sources, including leached soils, industrial effluents and fertilized farmlands. Elevated phosphate levels contribute to eutrophication, affecting water quality by promoting plant growth and altering species composition. Understanding phosphorus behaviour in shallow waters, where it adsorbs at mud surfaces and re-enters the water column, provides insights into concentration differentials. Heavy metals such as lead, cadmium, iron, copper and chromium pose significant environmental risks. Their presence in freshwater can be attributed to atmospheric fallout, mining consequences and unregulated landfills. Copper, highly toxic to aquatic life, impacts growth and reproduction, while chromium's mutagenic and carcinogenic effects are associated with industrial processes [43-47]. Sources of heavy metal pollution, including industries, vehicles and domestic sewage, contribute to their accumulation in water bodies. These pollutants degrade the water supply since they are usually the product of human activities. Moreover, they have a ripple effect on humans, occasionally threatening the human health.

Human health response to water pollutants: Disruption of environmental balance by pollution has significant health implications. When wastewater enters naturally occurring bodies of water, it alters the chemical makeup, endangering self-cleaning mechanisms and bringing about erratic changes in ecosystems. The accumulation and migration of persistent contaminants, particularly heavy metals, in wastewater presents a serious risk to organisms. Environmental disruptions have health related consequences as well; one such consequence is the rise of water pollution as a primary cause of many human diseases. Pollution-related waterborne diseases include cholera, malaria, typhoid, respiratory infections, malignancies, genetic problems and neurological abnormalities [9,15,48,49]. They can range in severity from quite benign to severe. Over 10% of population depends on contaminated water for sustenance, increasing the danger of disease transmission. The consumption of polluted water is associated with a number of potential health risks. Proliferative problems and higher death rates are associated with rural areas, poverty and limited availability to quality water. Infertility poses risks for women in their reproductive periods, while exposure to contaminated water can lead to the mutations in foetuses. Exposure of crops and cattle to contaminated water disturbs the balance of the food chain, hence affecting aquatic life and public health [50-54].

Waterborne diseases are classified into three categories based on their pathogens *viz.* parasitic, viral and bacterial. Among waterborne bacterial infections, diarrhoea is a prevalent ailment, frequently attributed to *Campylobacter jejuni*, contributing to 15% of global diarrhoea cases. Cholera, caused by *Vibrio cholerae* bacteria, induces severe diarrhoea and vomiting, with contaminated water serving as a significant transmission source. Shigellosis, stemming from the Gram-negative bacterial group *Shigella*, manifests as diarrhoea, fever and cramps. Parasitic diseases, arising from the parasitic organisms, encompass a spectrum of health issues by invading host organisms, disrupting nutrient absorption and inciting diseases. Cryptosporidiosis linked to the protozoan parasite *Cryptosporidium pavum*, particularly affects immunocompromized individuals through water contamination. Another parasitic culprit is *Entamoeba histolytica*, causing amoebiasis and impacting the stomach lining, often transmitted through contaminated food and water. Giardiasis, initiated by *Giardia lamblia*, spreads through sewage and leads to gastrointestinal complications [55-57].

Viral diseases transmitted through contaminated water predominantly target the liver, eliciting hepatitis. The hepatotropic nature of these viruses triggers hepatic inflammation and toxicity, resulting in symptoms such as jaundice, anorexia and abdominal pain. Both acute and chronic hepatitis can progress to cirrhosis or even liver cancer. Preventative measures involve maintaining hygienic conditions, avoiding untreated water and undergoing vaccination. This classification elucidates the diverse spectrum of waterborne diseases, each with its specific pathogenic origin, transmission vectors and health implications. Understanding these distinctions is crucial for implementing targeted preventive strategies and ensuring public health safety [58-60].

Managing the quantity-dynamic of water resources

Water scarcity and quantity dynamics: A persistent state in which there is a discrepancy between the amount of water required and the amount of water available is known as water scarcity. The inherent unequal distribution of water supplies around the world in terms of time and location can be made worse by variables like human involvement or periodic droughts. This difference fluctuates with the season and is most noticeable in arid as opposed to humid climates [61]. Even in areas that appear to have an abundance of water, problems might occur. These problems can include restricted accessibility because of insufficient infrastructure, expensive expenses related to extracting certain resources or weak institutional arrangements that make planning, funding and execution difficult. The availability of ground and surface waters at the regional and local levels, both now and in the future, is closely linked to demographic (population growth) climatic and physio-geographic factors such topography, land cover and land use. With its far-reaching effects, climate change presents significant concerns for many locations worldwide [62].

The Intergovernmental Panel on Climate Change (IPCC) emphasises the abundant evidence of significant climate change consequences on continents and seas, affecting agricultural crops, water supplies, human health and global biodiversity. It attributes global warming to growing greenhouse gas concentrations, especially from the use of fossil fuels [63]. The effects of climate change are widespread and obvious, necessitating major international efforts to cut greenhouse gas emissions caused by human activity. Numerous scenarios have been investigated, such as solar radiation management and fusion energy, but the shift to renewable energies free of CO_2 presents difficulties because of population and economic expansion [64,65]. Therefore, considering its significant implications on global water security, assessing the relationship between climate and the hydrologic cycle is essential.

Water shortages and global water security are predicted to worsen because of climate change's amplified direct and indirect effects on the water cycle. It is predicted that semi-arid and desert areas would get drier and that wet areas will get more precipitation, leading to an overall increase in variability. Water availability, distribution and agricultural planning will be impacted by altered rainfall patterns, which are characterized by shorter wet seasons with heavy rainfall and longer dry seasons. Lowering the amount of stormwater that reaches surface water bodies would have a negative impact on aquatic systems. It will change the hydrological cycle, destroy wetlands, lower biodiversity and interfere with the normal processes of aquatic ecological systems and the oases that surround them [66-69]. It is crucial to address the issues that climate change presents to water bodies, such as modifications to water supply, quality and essential ecosystem characteristics. Millions of people might not have access to consistent water sources for necessities if rainfall patterns change. Governments and international organizations are actively tackling these issues in response to this concerning scenario in order to guarantee sufficient living conditions for people all over the world [66,70].

The last half-century has seen a rapid doubling of the global human population, which has been accompanied by economic development and industrialization. This has resulted in a profound transformation of the world's ecosystems and a significant loss of biodiversity. With the population now at critical levels, there is a growing concern about the availability of water, particularly since approximately 41% of the world's population lives in river basins that are under water stress [71,72]. Freshwater resources are under unsustainable pressure due to the growing demand for necessities including food, shelter and other demands. Because of the anticipated 70% increase in food demand by 2050, the demand for water is likely to rise along with the world's population. It is predicted that the increase in agricultural water demand alone will be at least 19%. The industry and production sectors are also experiencing higher consumption patterns, which is driving up the need for water. The confluence of an expanding world population and increasing urbanization exacerbates issues associated with stress and scarcity of water [73,74]. By 2050, 66% of people on Earth are expected to live in cities, which raises worries about overuse and contamination of water supplies. As seen by the daily water shortages experienced by several large Indian towns, several regions, especially in Africa and Asia, are already struggling with inadequate urban water supply and sanitation [75,76].

Water resources management: A variety of techniques are used in water resource management, such as decentralized management, strategies based on watersheds and water sensitive urban planning. Each focus on a different facet of water governance and conservation. Integrated Water Resources Management (IWRM), on the other hand, is unique in that it considers the interdependence of socio-economics, the environment and water systems. IWRM provides a thorough approach to sustainable water management by integrating a variety of variables, including governance, quantity and quality of water. Given its ability to address complicated water concerns and its inclusive nature, this technique is commonly used in the literature. Integrated water resources management (IWRM) is a process, which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems, according to the definition provided by the Global Water Partnership's Technical Advisory Committee [77]. To help with the implementation of Integrated Water Resources Management (IWRM) techniques, the Global Water Partnership created an IWRM toolbox. The toolbox provides a large selection of instruments divided into three primary groups: There are 49 tools in total: (a) Enabling Environment; (b) Institutional Roles and (c) Management Instruments. Setting water consumption targets and ensuring sustainable resource allocation are the main concerns of the Enabling Environment, which also focuses on financing, legal structures and regulations. Institutional roles emphasise decentralized and participatory water management through delving into organizational structures and capacity-building. Assessment of water resources, efficiency, social inclusion, dispute resolution, legal measures, financial incentives and information management are only a few of the concerns that management instruments tackle [78-82].

Global response to water security: Integrated Water Resources Management (IWRM) is a critical strategy to address the complex difficulties of water resource management around the world. It is a comprehensive approach that integrates different factors for water use and security. Various countries have embraced IWRM concepts, with each developing tactics tailored to their specific conditions. A nation like France has a long history of IWRM application, extending back to its founding Water Law in 1964. This statute established a framework for basin-level management and signalled France's intention to use IWRM methods and principles. During a period of strong economic growth following World War II, the need for a basin-oriented strategy became apparent. Nevertheless, due to the lack of attention to water in key sectors like agriculture and industry, this expansion led to significant deterioration in water quality and increased strain on water resources. Industrial discharges, such as those from paper mills, sugar factories and oil refineries, considerably polluted water bodies, causing the Water Planning Commission to recognise the unsustainable nature of water resource management in the late 1950s. The 1964 Water Law, which provided the groundwork for modern water resource management, catalyzed a transformational shift in French water management. Significantly, analogies exist between this statute and the Dublin principles of 1992, even though the former predates the later by more than 25 years. This demonstrates France's proactive approach to IWRM long before the ideas received international recognition [78].

In contrast to France's early embrace of IWRM, South Africa has faced challenges implementing a comprehensive approach. The Department of Water Affairs and Forestry initially prioritized domestic water supply and sanitation, sidelining integrated water management due to a lack of clear IWRM concepts. There have been proposals for redefining IWRM, with an emphasis on the National Water Resource Strategy, equitable water access and environmental sustainability. While the DWAF evolved from an implementing to a regulatory agency focused on sectoral water management, overall water management remains a top concern. This encompasses measures such as planning, capacity building, quality control, infrastructure and conservation. Problems including funding, political backing and knowledge gaps continue to exist, underscoring the need for more specialized IWRM strategies. Prioritizing the ecosystem sustainability and streamlining IWRM criteria are critical. Concerns about the shift from IWRM have been voiced in South Africa, highlighting the significance of giving water management objectives top priority [83].

Many Asian governments have also adopted IWRM-style policies because of the global water debate, although the results of these initiatives have frequently been questionable. Recent attempts by Sri Lanka to enact IWRM-style changes in the water sector were met with strong opposition from the public and media. The administration quickly withdrew the proposed reforms, which included state control of water, water price and the creation of organizations for river basins, due to resistance. On the other hand, a few Southeast Asian nations, such as Thailand, Indonesia and Vietnam, saw less resistance and were able to pass water legislation that included IWRM tools [84].

The United States has also made significant strides in environmental policy since the establishment of the National Environmental Policy Act (NEPA) in 1969. This act and subsequent statutes like the Clean Water Act and the Endangered Species Act laid the groundwork for federal agencies to consider environmental impact in resource development. The formation of the Water Resources Council in 1965 and subsequent guidelines for water management reflected the NEPA principle and set objectives for water projects. Internationally, concepts like sustainable development gained prominence through initiatives such as the World Commission on Environment and Development and the President's Council on Sustainable Development. These concepts were integrated into policies, notably within the Civil Works Program of the U.S. Army Corps of Engineers, focusing on sustainable use of water resources and balancing economic, environmental and social considerations. Despite these advancements, there remains a fragmented and evolutionary approach in the implementation of Integrated Water Resources Management (IWRM) and sustainable development within national water resources policies. There is a requirement for a more precise statement regarding the connection between Integrated Water Resources Management (IWRM) and sustainable development in order to establish a more cohesive and unified approach in both national and international plans for a sustainable earth [85-87].

Several countries are currently implementing reforms to their water policies in order to shift towards a more comprehensive water management system. Generally, these policies lay out core values and objectives, like socio-economic advancement and sustainable development. This paradigm is guided by three key policy principles, which Postel dubbed the "three 'E's" [88]:

(i) Equity: Since access to enough clean freshwater is a fundamental human right and water is a basic human necessity, it is important to acknowledge equity. Water must be used for the public welfare, including protection against natural disasters like floods and droughts, according to this principle, which highlights water as a public good.

(ii) Ecological integrity: Stressing the need for a healthy ecosystem that can replenish freshwater of an appropriate quality in order to maintain water supplies. It underscores the importance of utilizing water in a sustainable manner to ensure that future generations have the same access to resources that humans already do.

(iii) Efficiency: Since water is a limited resource, it must be used effectively. Institutional arrangements strive for water service cost recovery in order to maintain sustainability without sacrificing equality. Discussions concerning the cost of water and whether it is worth the money are common in these.

One of the main challenges in water resources management is striking a balance between these policy concepts, which can occasionally conflict with one another and with the different facets of Integrated Water Resources Management (IWRM) and hence require compromises [89].

Conclusion

The global water policy environment is undergoing a critical shift, showing a collaborative commitment to addressing the multidimensional concerns of water pollution, scarcity and resource management. The continuing reforms highlight the critical necessity of values like fairness, ecological integrity and efficiency in developing long-term water management policies. The road ahead, however, necessitates a careful balance of these values, needing collaborative efforts, technology innovation, community participation, adaptable methods and data-driven decision-making. Adopting these techniques will pave the road for a more resilient and equitable water management system, ensuring that this valuable resource is preserved for future generations.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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