Review Article

Rising Salinity in Bangladesh: Implications for Public Health and Sustainable Solutions

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Abstract

Background: Rising water salinity in coastal areas of Bangladesh poses a significant public health threat, exacerbated by climate change, sea-level rise, and human activities such as groundwater over-extraction and shrimp farming. This review explores the sources, health impacts, and public health interventions related to water salinity in Bangladesh. It synthesizes findings from peer-reviewed studies published between 2000 and 2024, focusing on the relationship between salinity and various health outcomes. The coastal regions of Bangladesh, particularly Khulna, Satkhira, and Barisal, experience salinity levels exceeding 1,000 mg/L, far surpassing the WHO guideline of 200 mg/L for aesthetic quality in drinking water. Salinity in drinking water is linked to a variety of adverse health effects, including hypertension, preeclampsia, gestational hypertension, waterborne diseases, and skin disorders. Vulnerable populations, such as pregnant women, children, and the elderly, are particularly at risk. Salinity also increases the incidence of infant mortality and exacerbates existing cardiovascular conditions in the elderly. The review identifies climate change as a primary driver of salinity intrusion, with frequent storm surges and rising sea levels contributing to saltwater contamination of freshwater sources. Additionally, human interventions like the construction of the Farakka Dam and over-extraction of groundwater further aggravate the problem. Public health interventions, such as the installation of saline-free water filters, rainwater harvesting, and awareness programs, have been initiated but face challenges due to resource constraints and inadequate monitoring of salinity levels. The review highlights gaps in research, particularly the need for longitudinal studies on the long-term health impacts of salinity and the effectiveness of current interventions. Addressing these challenges will require a comprehensive approach involving policymakers, healthcare professionals, and researchers to mitigate the health impacts of rising salinity and promote sustainable solutions for affected populations.

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Introduction

Water salinity has been identified as an increasing public health concern affecting thousands of households every year. Salinity intrusion occurs significantly in coastal areas of Asian countries, such as Bangladesh, China, and Vietnam, but has also been reported in California, Brazil, and the Netherlands[1]. Exposure to high levels of saline via drinking water in coastal populations has led to increased cardiovascular and other diseases. Climate change, which leads to sea level rise and exacer bates cyclones and storm surges, is one of the primary drivers of water salinity[2]. Over-extraction of groundwater and the construction of canals and dams are some human activities that aggravate the situation[3-7].

The geomorphology of Bangladesh has always made the country vulnerable to natural hazards such as storm surges, cyclones, inundation, and seawater intrusion. The southern coastal regions of Bangladesh are only 1m to 3m above

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mean sea level[3], which has resulted in seawater contamination of its drinking water[7]. The wide river mouths make drinking water prone to excessive salinity, as they allow the seawater to flow with great rapidity further inland.

Drinking water salinity is expected to further increase due to climate change and the consequent rise in sea level[2]. In addition to natural causes for increased salinity in drinking water in Bangladesh, several anthropogenic reasons are at play. One such is the construction of the Farakka Dam in 1975 on the Ganges River. The freshwater diversion upstream caused a change in the natural water flow downstream. The dry months from December to May saw a significant reduction in flow, which resulted in increased river salinity[8]. Other significant contributing factors are shrimp farming, construction of coastal polders, and over-extraction of groundwater[3-6,9].

Consumption of excess saline in drinking water has been linked to a variety of health effects. Salt in drinking water is generally found in low levels (20 mg/L) and is considered a negligible contributor to daily salt intake. WHO, therefore, does not have a health-based standard, but an aesthetic guideline value of 200 mg/L[10]. However, several studies identified an association between excessive salinity in drinking water with increased risk of hypertension[11,12]. Drinking water salinity has also been linked to risks of preeclampsia and gestational hypertension[13]. In addition, there are reports on associations with infant mortality, cholera outbreaks, and skin and diarrheal diseases[14,15]. Proxies of water salinity are total dissolved solids (TDS) and electrical conductivity. While the US Environmental Protection Agency (EPA) has set a secondary standard (non-mandatory guideline) value of TDS at 500 mg/L, risks of heart diseases have been associated with increased TDS[16,17]. Thus, increased water salinity may lead to several adverse health effects. This may not only improve the hospital visit rates of the affected population but may also drive-up healthcare costs.

Methodology

This review article aims to provide a comprehensive examination of the rising salinity in Bangladesh and its implications for public health. A systematic literature search was conducted to gather relevant studies, reports, and grey literature published between 2000 and 2024. The primary sources of data were peer-reviewed articles from databases such as PubMed, Google Scholar, Scopus, JSTOR, and Web of Science. The search employed keywords including "salinity," "water salinity," "public health," "Bangladesh," "climate change," "coastal regions," "drinking water," "hypertension," "cholera," "gestational hypertension," "infant mortality," "salinity intrusion," "seawater contamination," and "salinity-related diseases." To ensure the relevance and quality of the selected studies, inclusion and exclusion criteria were applied. Studies that focused on salinity and its health effects in Bangladesh or similar coastal regions were included. Only peer-reviewed English-language articles were considered, which explored the impact of salinity on specific diseases or health conditions and provided data on both the physical environment and public health outcomes. Studies that did not align with the topic or focused on irrelevant geographical areas were excluded, as were articles lacking clear health-related outcomes or those inaccessible in full text. The data extraction process involved systematically collecting key information from the selected studies. This included salinity levels and sources (such as seawater intrusion or groundwater extraction), health outcomes related to increased salinity in drinking water (such as hypertension, preeclampsia, and infant mortality), and demographic factors influencing vulnerability. Additionally, the review identified the effects of climate change on salinity levels and examined the measures and policies aimed at mitigating the health impacts of salinity in Bangladesh.

The findings from the selected studies were synthesized to identify common themes and patterns in the health impacts of water salinity. Special attention was given to the relationship between salinity and cardiovascular diseases, particularly hypertension, as well as the effects on pregnancy outcomes, such as gestational hypertension and preeclampsia. The review also explored the links between salinity and infant mortality rates and assessed the role of environmental and social factors in influencing salinity levels. Public health interventions and strategies aimed at reducing salinity-related health risks, including health education, technological solutions, and government policies, were critically analyzed. To assess the quality of the included studies, standard tools for systematic reviews were used. These included the Newcastle-Ottawa Scale (NOS) for evaluating non-randomized studies and the GRADE approach for grading the quality of evidence in health-related research. The quality of the evidence was categorized as high, moderate, low, or very low, based on the methodological rigor and findings of the studies reviewed.

Finally, the article concluded by synthesizing the main findings and providing actionable recommendations for policymakers, healthcare professionals, and researchers. The review also highlighted existing gaps in the literature and suggested directions for future research to further investigate the health implications of salinity in Bangladesh. By drawing from the existing body of knowledge, this review aims to inform ongoing efforts to address the public health challenges posed by rising salinity and promote sustainable solutions for the affected populations.

Results

The systematic review of the available literature revealed several significant findings regarding the rising salinity in Bangladesh and its impact on public health. The results of the study were categorized into key themes, which include the sources of salinity, the health effects associated with increased salinity, the demographic factors influencing vulnerability, and the public health interventions being implemented to mitigate these effects.

Sources and Levels of Salinity in Bangladesh

A combination of natural and anthropogenic factors primarily drives the rising salinity in Bangladesh. Salinity intrusion in the coastal areas of Bangladesh has been exacerbated by climate change, particularly sea level rise and increased frequency of cyclones and storm surges. The southern coastal regions, particularly the Khulna, Satkhira, and Barisal districts, are most affected, with saline water intrusion into freshwater sources. Studies indicated that salinity levels in these regions can reach up to 1,000 mg/L in drinking water, significantly exceeding the WHO aesthetic guideline value of 200 mg/L for drinking water.

Human activities such as the construction of the Farakka Dam in India, shrimp farming, and over-extraction of groundwater for irrigation have contributed to the increase in salinity. These interventions have disrupted the natural hydrological cycle, allowing saline water to intrude further inland. The dry season, which typically lasts from December to May, sees an exacerbation of salinity levels due to reduced freshwater flow, further compounding the issue[18-21].

Health Impacts of Increased Salinity

The review highlighted several health consequences associated with increased salinity in drinking water in coastal Bangladesh. The most prominent health effect identified was an increased risk of hypertension. Multiple studies showed a significant association between high salinity levels in drinking water and elevated blood pressure in coastal populations. A meta-analysis of existing studies confirmed that individuals living in high salinity areas had a higher prevalence of hypertension compared to those in low-salinity areas. Moreover, there was evidence linking increased water salinity to an increased risk of preeclampsia and gestational hypertension among pregnant women. This was particularly concerning given the high rates of maternal and infant mortality in coastal Bangladesh[22-25].

In addition to cardiovascular health risks, salinity exposure was linked to other health problems, including cholera outbreaks, diarrhea, and skin diseases. Several studies documented a direct correlation between high salinity levels and the incidence of waterborne diseases, with salinity-induced changes in the microbial composition of water sources. The risk of infant mortality was also higher in areas with increased salinity, possibly due to dehydration and compromised immune function in infants.

Skin conditions such as eczema and other dermatological disorders were frequently reported in individuals exposed to saline water. These conditions were particularly prevalent among children, who have more sensitive skin, and in communities where access to safe drinking water was limited[22-24].

Vulnerable Populations

The review also highlighted specific vulnerable groups within the population who are more susceptible to the health impacts of salinity. Coastal communities, particularly those living near the river mouths, are at the highest risk due to their dependence on local water sources for drinking and agriculture. Women, especially pregnant women, were found to be at greater risk of hypertension and preeclampsia, which can lead to severe complications during pregnancy.

Children were identified as another vulnerable group, particularly regarding the health effects of waterborne diseases like cholera and diarrhea. Increased salinity was associated with a higher incidence of gastrointestinal disorders among children, leading to dehydration and higher rates of hospital admissions.

Additionally, the elderly population, already prone to cardiovascular diseases, was found to suffer more severe effects from hypertension caused by high salinity. The poor, who often have limited access to healthcare and clean drinking water, were disproportionately affected by the salinity crisis.

Public Health Interventions

Several public health initiatives were identified in the reviewed studies as efforts to mitigate the adverse effects of salinity. The government and non-governmental organizations (NGOs) have been working on improving access to safe drinking water by providing saline-free water filters, promoting rainwater harvesting, and improving sanitation facilities in affected areas. Awareness programs focusing on the health risks of salinity and educating the population about the importance of using filtered or purified water were also highlighted as key interventions.

Despite these efforts, the implementation of effective interventions remains a challenge due to resource constraints, particularly in rural and remote coastal areas. Additionally, there is a lack of sufficient monitoring and regulation of salinity levels in drinking water, which hinders the effectiveness of health interventions.

Gaps in Research and Future Directions

While the existing studies provided valuable insights into the health impacts of salinity in Bangladesh, several gaps in research were identified. A major gap was the limited longitudinal data on the long-term health effects of salinity exposure, especially regarding its effects on chronic diseases like hypertension and cardiovascular diseases. Additionally, there is a need for more research on the effectiveness of existing interventions and the development of low-cost, sustainable technologies to remove or reduce salinity from drinking water.

Furthermore, future research should focus on the intersection of climate change, human interventions, and salinity levels, with particular attention to the potential impacts of future sea level rise. Investigating the socio-economic determinants of vulnerability to salinity-induced health risks could also help target interventions more effectively.

Discussion

Bangladesh's geographical and climatic vulnerability is a major concern when assessing the implications of rising sea levels and cyclonic activity. The nation's low-lying topography, with half of its land area located less than 5 meters above sea level, significantly heightens the risk of inundation due to storm surges and saltwater flooding. As highlighted in previous studies, Bangladesh has experienced frequent cyclonic activity, with over 178 cyclones recorded from 1891 to 2008[21]. The deadliest cyclones, including those in 1970, 1982, 1991, Sidr in 2007, and Ayla in 2009, have caused extensive damage and flooding along the coastline[22]. In fact, it is expected that Bangladesh will face more than one cyclone annually, with moderate surges occurring at an average interval of every 5.4 years. This suggests that over 12% of the country is at high risk of saltwater flooding every 5.4 years, and 1-2% of the country could experience seawater flooding annually. In the Shyamnagar Upazila, this means that 64% of the area could be flooded by saline water over time, with 5.6% affected annually[23].

In extreme scenarios, storm surges can reach up to 9 meters, and while these are less frequent, they remain plausible. Historical records reveal that 10-15 meter storm surges have occurred in the past, such as the 13-meter surge in 1876 and a 10-meter surge in 1970[24]. The prediction of a 10-meter wave hitting the coast every 20 years emphasizes the potential for widespread saltwater intrusion, particularly in coastal regions like Shyamnagar. With projections indicating sea levels will continue to rise due to climate change, these storm surges are likely to become more frequent and intense. The vulnerability of coastal areas will increase as storm intensity, driven by rising ocean surface temperatures, is expected to intensify[28].

The review of chemical archives from stations in Kalaroa, Benarpota, and Elarchar demonstrates clear evidence of saltwater intrusion, with significant spikes in salinity levels during major storms[28]. These salinity spikes reflect the damage caused by these storm surges and the resulting contamination of freshwater systems, both in terms of surface waters and groundwater. The data shows that during these events, Electrical Conductivity (EC) levels in affected areas exceeded 10,000 dS/m, indicating severe salinization[29,30].

Saltwater intrusion, driven by storm surges, has permeated far into Bangladesh's soil and freshwater systems. Soil samples from affected regions reveal high salinity levels, which can cause metal salt toxicity and phosphorus deficiency in crops. These conditions severely impair agricultural productivity, with studies confirming high salinity in soils in areas like Gabura and Burigoalini, where soil salinity ranged from 4.21% to 8.02%[31]. Such soil conditions, combined with the competition for essential nutrients like potassium and calcium due to sodium dominance, undermine crop and fish cultivation. This has led to significant challenges for local farmers, particularly those involved in shrimp farming, where increased salinity is causing shrimp mortality[32,33]. The suggestion to relocate shrimp farms to inland regions less affected by salinity and climate change is a viable strategy but highlights the growing challenges to the agricultural economy.

Furthermore, high sodium concentrations in water are causing public health concerns, particularly in terms of elevated blood pressure among local populations. Excessive sodium also affects plant health by limiting nutrient absorption, exacerbating agricultural challenges. The presence of chloride in seawater further accelerates the corrosion of metal infrastructure, including pipes, which can increase the concentration of harmful metals in the water supply and pose a risk to human health[34,35].

The analysis of the correlation between water and soil salinity reveals a direct link, with higher salinity in water correlating with increased potassium in the soil, a pattern consistent with findings from other studies[36] This indicates that rising salinity levels will not only damage agricultural productivity but also worsen the quality of the soil, further complicating the region's agricultural prospects. Water and soil salinity have a negative correlation, meaning that salt stored in soils during dry periods is more likely to dissolve and enter the water system during monsoons, compounding the problem[37-39]

Conclusion

The rising salinity in Bangladesh, driven by both cyclonic activity and sea-level rise, presents significant challenges for agriculture, public health, and the overall sustainability of the coastal population. Storm surges and their aftermath lead to long-lasting impacts on water quality, soil fertility, and the local economy, particularly for farming and aquaculture. The urgency of addressing the growing risks of salinity intrusion through sustainable management practices, improved infrastructure, and targeted relocation strategies is paramount to mitigating these adverse effects. With climate change predicted to worsen the intensity and frequency of cyclones, the need for comprehensive coastal protection strategies and resilient farming systems is more pressing than ever.

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