Review article

Drinking Water Salinity and Its Cardiovascular Health Effects in Coastal Residents: A Systematic Review

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Abstract

Climate change-driven salinity intrusion in coastal regions, particularly in countries like Bangladesh, has significantly increased sodium levels in drinking water. This environmental shift is increasingly linked to higher risks of hypertension and other cardiovascular diseases. Understanding the extent of exposure and associated health effects is essential for informing public health strategies in these vulnerable communities. This systematic review, following PRISMA guidelines, analysed 31 peer-reviewed studies published between 2011 and 2025. The included studies examined the association between drinking water salinity and cardiovascular outcomes, focusing on hypertension among coastal populations in Bangladesh. Data on study design, population characteristics, sodium exposure assessment, and blood pressure outcomes were extracted. Findings consistently showed drinking water sodium concentrations ranging from 200 mg/L to over 900 mg/L, with many populations consuming over 2 g/day of sodium from water alone. Hypertension prevalence was notably higher in coastal areas, especially among pregnant women and older adults. Several studies reported significant associations between elevated urinary sodium, water sodium levels, and increased systolic and diastolic blood pressure. The risk was highest during the dry season when salinity peaks. Systolic blood pressure increases ranged from 4.8 to 9 mmHg per gram of salt intake from water. Overall, the evidence highlights that high sodium levels in drinking water from salinity intrusion substantially contribute to cardiovascular risks in coastal populations. Urgent public health interventions are needed, including the promotion of low-salinity water sources, improved water treatment, and community education to address this emerging health threat.

Keywords: Water salinity, Sodium intake, cardiovascular health, coastal population, Bangladesh.

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Background

Bangladesh, a low-lying deltaic nation, is particularly vulnerable to water-related crises exacerbated by environmental and anthropogenic factors.[1-3] Among the most pressing concerns is salinity intrusion into freshwater systems, which has emerged as a significant threat to both environmental sustainability and public health.[1,4] The country spans an area of approximately 147,570 km², of which the coastal region accounts for nearly 29,000 km² about 20% of the total landmass.[3,4] Alarmingly, more than half of this coastal zone (approximately 53%) is affected by varying degrees of salinity, largely due to seawater encroachment and hydrological changes linked to climate variability.[5,6]

Salinity in drinking water sources in these regions is primarily driven by tidal flooding, reduced upstream

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freshwater flow, soil erosion, and the progressive intrusion of saltwater from the Bay of Bengal.[4-6] These challenges are further intensified by climate change, which has led to rising sea levels and irregular rainfall patterns.[4,7] As a result, surface water bodies such as rivers and ponds, as well as shallow groundwater aquifers, are increasingly contaminated with high concentrations of dissolved salts.[8-15] According to estimates, over 20 million people in Bangladesh's coastal belt depend on these salinity-affected water sources for their daily drinking needs.[4-7]

The chemical composition of salinity is dominated by sodium chloride (NaCl), which accounts for about 65.7% of total salinity content.[11,13] The World Health Organization (WHO) recommends that chloride concentrations in drinking water not exceed 250 mg/L to avoid adverse taste and potential health consequences.[14] However, field measurements in many coastal districts of Bangladesh regularly report chloride and sodium levels far surpassing these thresholds.[4,5,14] Chronic exposure to such saline water is now suspected to have systemic health implications, particularly concerning blood pressure regulation and cardiovascular function.[16]

A growing body of epidemiological evidence has drawn attention to the possible link between high-salinity drinking water and hypertension, especially in vulnerable populations such as pregnant women, children, and the elderly.[9,10,17-25] While the relationship between dietary salt intake and blood pressure is well-established, less attention has historically been paid to sodium intake from environmental sources-particularly through drinking water. In salinity-affected regions, drinking water alone can contribute significantly to daily sodium intake, sometimes exceeding the recommended limits even in the absence of high dietary salt consumption.[17,26-32]

Moreover, the Intergovernmental Panel on Climate Change (IPCC) has projected worsening saltwater intrusion into coastal aquifers in South Asia, including Bangladesh, as global temperatures continue to rise.[8,33-36] This makes the issue not only a present concern but a growing threat to long-term public health and climate resilience.

Bangladesh's coastal population relies on freshwater sources increasingly tainted by sodium-rich seawater intrusion, driven by tidal flooding, reduced upstream flow, and sea-level rise. Salinity levels, dominated by NaCl, frequently exceed WHO guidelines for chloride, adding substantial sodium to daily intake and elevating hypertension and cardiovascular risk, especially in pregnant women, children, and the elderly. With the IPCC forecasting worsened saltwater encroachment, urgent measures such as securing low-salinity water supplies, strengthening treatment infrastructure, and integrating salinity monitoring into public health planning are essential to protect community health and climate resilience.

Given these alarming trends, this systematic review aims to synthesize the existing literature on the association between drinking water salinity and cardiovascular health outcomes- particularly hypertension, in coastal residents of Bangladesh and similar settings. By consolidating current evidence, this review seeks to inform health policy, water resource management, and future research directions targeting climate-induced environmental health risks.

Methods

This systematic review was conducted in accordance with PRISMA guidelines.[37] A comprehensive literature search was performed across four major databases- PubMed, Scopus, Google Scholar, and Web of Science for studies published between 2011 and 2025. The search utilized keywords including "drinking water salinity," "sodium intake," "hypertension," "cardiovascular disease," and "coastal population." Studies were included if they were conducted in coastal regions, assessed sodium levels in drinking water alongside cardiovascular or blood pressure-related outcomes, and employed observational, cross-sectional, cohort, or randomized controlled designs. Only articles published in English were considered. Exclusion criteria included studies focusing on water contaminants other than sodium, those lacking data on blood pressure or hypertension, and non-primary research such as editorials, reviews without original data, and case reports.

The quality of the studies included in this review was evaluated using predefined criteria, which took into account the study design, sample size, methods of assessing sodium exposure, reliability of outcome measurements, and the extent to which confounding variables were controlled. Special consideration was given to studies that utilized validated methodologies, such as 24-hour urinary sodium excretion for exposure assessment, standardized protocols for blood pressure measurement, and statistical adjustments for dietary intake and socio-economic status.

Given the variability in exposure metrics, study populations, and definitions of outcomes, a qualitative narrative synthesis was conducted rather than a meta-analysis. This synthesis systematically compared sodium concentrations across different water sources- such as tube wells, ponds, rivers, rainwater, and managed aquifer recharge systems and examined estimates of total sodium intake from both water and diet. It also explored reported outcomes related to blood pressure and hypertension, paying particular attention to vulnerable populations including pregnant women, adolescents, and older adults. Environmental factors like seasonal variation and geographical differences in water salinity were also considered.

The study selection process adhered strictly to PRISMA (Preferred Reporting Items for Systematic Reviews and

Meta-Analyses) guidelines, ensuring a transparent and reproducible methodology.[37] A thorough search across multiple databases and supplementary sources initially identified 77 records. After removing duplicates and screening titles and abstracts, 35 full-text articles were evaluated for eligibility. Based on the inclusion and exclusion criteria, which focused on relevance to drinking water salinity, blood pressure outcomes, appropriate study design, and English-language publications 29 studies were ultimately included in the final narrative synthesis. The PRISMA flow diagram (Figure I) provides a detailed visual summary of the selection process.

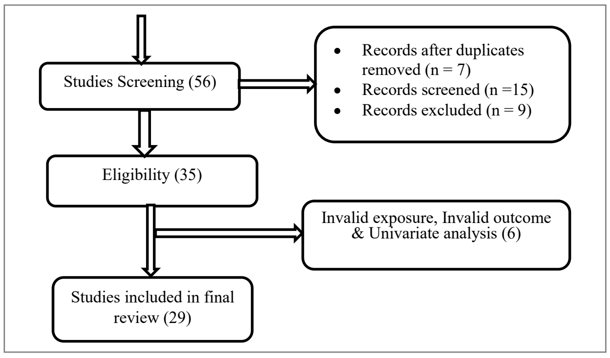

Figure- I: Systematic search and selection of studies on drinking water salinity and cardiovascular health among Bangladesh's coastal residents

Results and Discussion

Seasonality

Seasonal variation plays a crucial role in drinking water salinity and, consequently, sodium exposure in coastal Bangladesh. During the dry season (typically November to May), saline water from the Bay of Bengal intrudes further inland due to reduced upstream river flow, lower rainfall, and tidal backflow. This results in significant increases in salinity levels in rivers, ponds, and shallow aquifers. In contrast, the monsoon season dilutes salinity levels with fresh rainwater and increased river discharge, temporarily improving water quality.

Several studies highlight this seasonal effect. Shammi et al. observed that sodium concentrations in tube wells and ponds in Dacope, Khulna, were significantly higher during the dry season, resulting in a systolic blood pressure increase of approximately 4.85 mmHg compared to rainwater users.[25] Similarly, Khan et al. reported a salinity range of 716–900 mg/L in the dry season versus much lower values post-monsoon.[10] Roy et al. also noted that communities reported a marked increase in blood pressure complaints during the dry months.[21]

This seasonality implies that public health interventions must be dynamic, with heightened risk mitigation during the dry season. Access to low-salinity alternatives such as harvested rainwater or managed aquifer recharge (MAR) systems becomes critical in these months.[38,39] The seasonal nature of exposure also complicates long-term risk assessments, as sodium intake from water can fluctuate drastically within the year. Thus, seasonality should be integrated into surveillance programs and policy interventions.

Sodium concentration in drinking water

The sodium concentration in drinking water in coastal areas of Bangladesh varies widely depending on the water source, season, and geographical proximity to the coast. Most studies included in this review reported sodium levels in tube wells, ponds, and rivers ranging from 200 mg/L to well over 900 mg/L. In extreme cases, river salinity reached as high as 8.21 g/L during the dry season, significantly exceeding the WHO's aesthetic guideline of 200 mg/L for sodium and 250 mg/L for chloride.[29]

Talukder et al. reported sodium concentrations of 885 mg/L in tube wells and 738 mg/L in ponds.[28] Similarly, Khan et al. measured a mean sodium concentration of 516.6 mg/L in drinking water consumed by pregnant women in Dacope, highlighting the substantial sodium load from water alone.[11] The Naser et al. study showed water electrical conductivity (EC) as high as 10 mS/cm in coastal aquifers, translating into significant sodium presence.[15]

These concentrations are particularly concerning because drinking water in these areas contributes up to 50% of daily sodium intake, in contrast to most settings where food is the dominant source. Without appropriate treatment or alternative sources, communities are routinely exposed to sodium levels that may lead to chronic health effects. Understanding sodium concentration trends across different water sources is essential to inform risk communication, infrastructure planning, and community-level adaptation strategies.

Water salinity or Na^+ level

Water salinity, often expressed as electrical conductivity (EC) or in terms of dissolved sodium, is a central determinant of health risk in coastal regions. In the reviewed studies, EC values ranged from <0.7 mS/cm (low salinity) to >10 mS/cm (high salinity), with corresponding sodium concentrations often exceeding 500–900 mg/L, and in some cases reaching over 1000 mg/L in dry months.

The salinity of water varied significantly based on source: pond water generally had lower sodium levels (~300–700 mg/L), while tube wells and rivers- especially those closer to the coast- frequently exceeded the WHO and national safety thresholds. Naser et al. documented that MAR systems offered lower-salinity water compared to traditional tube wells, highlighting a potential mitigation strategy.[14,15] In contrast, Akib et al. found tube well salinity levels reaching 5.11–6.48 dS/m (equivalent to ~3200 mg/L), well beyond safe limits.[2]

High water salinity translates into excessive sodium intake from water alone. Roy et al. estimated that residents consumed 2.3 g/day of sodium solely from drinking water- nearly half of the WHO recommended limit of 5 g/day total sodium.[21] The review indicates that salinity and sodium levels in drinking water are not just aesthetic or environmental concerns, but pressing public health issues requiring urgent attention.

Blood pressure measurement methods

The accuracy of blood pressure (BP) data depends heavily on the measurement methodology, which varied across studies. Most studies used either automated or manual sphygmomanometers, following standardized protocols like WHO STEPS or the American Heart Association (AHA) guidelines.[40,41]

Scheelbeek et al. used an automatic sphygmomanometer on the left arm following WHO protocols, defining hypertension according to the JNC-8 guidelines.[24] Naser et al. employed the Omron HEM-907 device and followed WHO-recommended procedures, taking multiple readings across different time points to ensure validity.[14] Talukder et al. used the OMRON device as well, with readings taken after a 30-minute rest and 10-minute intervals between measurements.[29]

Manual methods were used in earlier or lower-resource studies, such as Khan et al. and Rony et al., where blood pressure was taken using standard mercury or aneroid sphygmomanometers by trained personnel.[11,20] Some community-based studies relied on self-reporting or clinical diagnoses from health facilities, such as in Hossain et al. and Pinchoff et al.[8,18]

Despite some variability, most studies followed protocols consistent with international hypertension classification systems (JNC-7/8 or AHA), allowing for comparability across findings. Nevertheless, the diversity in BP measurement tools and diagnostic thresholds emphasizes the need for standardized monitoring in future research and surveillance programs.

Blood pressure and hypertension outcomes

The studies reviewed present compelling evidence that elevated sodium intake from drinking water is associated with increased blood pressure and a higher prevalence of hypertension. Populations residing in high-salinity coastal zones -particularly pregnant women, middle-aged adults, and individuals with low socioeconomic status -appear to be disproportionately affected.[42-44]

Khan et al. found that women with (pre)eclampsia had significantly higher exposure to sodium-rich water, with a clear dose-response relationship.[11] Scheelbeek et al. reported that systolic blood pressure increased by approximately 4.8 mmHg per 100 mg/L increase in water sodium concentration.[24] Naser et al. found a positive correlation between urinary sodium levels and blood pressure, suggesting that water salinity significantly contributes to systemic sodium burden.[15]

Hypertension prevalence in coastal regions ranged from 30% to over 55%, often exceeding national averages. Roy et al. and Rony et al. both documented total sodium intake exceeding 6 g/day among adults-well above the recommended limit-resulting in consistent findings of elevated SBP and DBP.[20-21]

These outcomes have severe implications, especially as climate change intensifies saline intrusion and increases long-term exposure. The consistent associations across multiple study types- cross-sectional, cohort, and randomized trials- underscore the need for targeted interventions, including sodium reduction strategies and improved water management systems in high-risk areas.

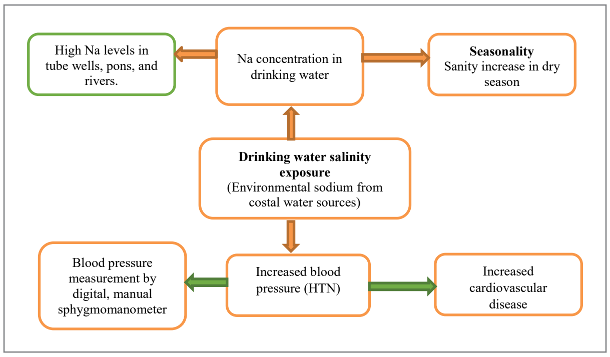

Figure II: Framework of drinking water salinity with high blood pressure

Vulnerable populations

The cardiovascular effects of drinking water salinity are not evenly distributed across all segments of the population. Certain groups exhibit increased susceptibility to high sodium intake from water sources due to physiological, behavioural, and socio-environmental factors. This review identifies pregnant women, children and adolescents, older adults, and socioeconomically disadvantaged populations as the most vulnerable to the health risks associated with drinking water salinity.

Pregnant women are consistently highlighted as a high-risk group. Multiple studies, including Khan et al. and Pinchoff et al., showed significantly higher rates of gestational hypertension and pre-eclampsia among pregnant women exposed to sodium-rich drinking water.[11,18] The physiologic increase in plasma volume during pregnancy, combined with high sodium intake, likely contributes to heightened blood pressure responses. For example, Khan et al. found that sodium levels of ~516 mg/L were associated with a substantially higher risk of hypertensive disorders in pregnancy.[11]

Children and adolescents may also be affected, although fewer studies focus exclusively on this group. One study reported elevated blood pressure among school-aged children in salinity-affected coastal areas, indicating early onset of cardiovascular stress due to environmental exposure.[7,43] Older adults and individuals with pre-existing conditions such as diabetes or kidney disease are at particular risk, given that they are more likely to experience complications from hypertension.[34] Additionally, aging kidneys may have reduced capacity to excrete excess sodium, making even moderate exposures problematic.

Finally, it is reveals that drinking water salinity in coastal Bangladesh varies seasonally, with sodium levels peaking in the dry season due to reduced freshwater flow and tidal intrusion. Sodium concentrations often exceed WHO guidelines, contributing up to 50% of daily sodium intake and driving higher rates of hypertension, especially among pregnant women, children, older adults, and socioeconomically disadvantaged populations. Low-income communities, in particular, are forced to rely on high-salinity sources like ponds and shallow wells, lacking access to safer alternatives and awareness of health risks. To mitigate these impacts, public health strategies must prioritize equitable access to low-salinity water, community education, routine sodium monitoring, and targeted interventions for high-risk groups. Integrating these actions within national climate adaptation and health policies is essential to reduce the growing cardiovascular burden associated with salinity intrusion in Bangladesh's coastal regions.

Table 1 summarizes the characteristics of key studies included in this systematic review. The table includes the study designs, geographic settings, population demographics, salinity levels in drinking water sources, and methods used to assess blood pressure or hypertension outcomes.

Table 1: Summary of studies on drinking water salinity and blood pressure/ hypertension outcomes

Authors & year	Study design	Country	**Population**	**Age / Sex**	**Drinking water source / salinity level**	**BP outcome & measurement**
Naser et al., 2022	Systematic Review	Multiple (incl. BD)	9 studies	Adults / Both	Na^+: <200–>900 mg/L	WHO/JNC7; systolic/diastolic BP
Vineis et al., 2011	Review + Modelling	Bangladesh	General population	Not stated / Both	8.21 g/L (dry season)	Modelled: +9 mmHg SBP per 5 g/day salt
Khan et al., 2011	Cross-sectional	Bangladesh	157	18–60 / Both	River: 8.21 mS/cm	Standard BP; ≥140/90 mmHg
Khan et al., 2011	Cross-sectional	Bangladesh	343 pregnant women	3rd trimester / Female	716–900+ mg/L	Standard BP; HTN + proteinuria (preeclampsia)
Khan et al., 2014	Case-Control	Bangladesh	1,208 (pregnant women)	13–45 / Female	516.6 mg/L	Manual BP; HTN >140/90 mmHg; preeclampsia
Mohammad Ali, 2014	Cross-sectional	Bangladesh	296	≥18 / Both	Mean 0.92 ppt	Sphygmomanometer; >139/89 mmHg
Talukder et al., 2016	Cross-sectional	Bangladesh	282	19–25 / Both	Tube: 885 mg/L; Pond: 738 mg/L	OMRON; >120/80 mmHg
Butler et al., 2016	Mixed-method	Bangladesh	Not specified	Adults / Both	>1000 mg/L	Not specified
Scheelbeek et al., 2017	Cohort	Bangladesh	581	Median 38 / Both	Not reported	WHO STEPS; JNC-8
Ahmed & Hutton, 2017	Cross-sectional	Bangladesh	SES-based residents	18–65 / Both	Mean 854 mg/L	OMRON M2
Akib et al., 2018	Cross-sectional	Bangladesh	Adults (85% >25 yrs)	Both	STW: 5.11–6.48 dS/m	Automated; HTN ≥140/90
Shammi et al., 2019	Review + Case Studies	Bangladesh	120	Adults / Mainly Female	Mean 516.6 mg/L	+4.85 / +2.30 mmHg (tube vs. rain)
Rony et al., 2016	Cross-sectional	Bangladesh	100 (pregnant women)	16–35 / Female	1–376 mg/L	Digital BP; ≥140/90 or on meds
Roy et al., 2020	Mixed Methods	Bangladesh	13 case studies	20–60 / Both	Mean 725 mg/L	Automated BP; ≥140/90
Naser et al., 2019	Cross-sectional + RCT	Bangladesh	1,574	Median 40 / Both	EC: <0.7–10 mS/cm	WHO protocol; AHA stages
Faysal et al., 2020	Cross-sectional	Bangladesh	Clinic patients	45.2±12.4 / Mixed	13.4 ± 6.0 g/day salt	Mercury sphygmo.; JN Criteria
Shuvo et al., 2020	Cross-sectional	Bangladesh	240	≥18 / Both	760–940 mg/L	HTN significant at $p < 0.05$
Khan et al., 2020	Cross-sectional	Bangladesh	6,296	28–49 / Both	Self-reported salinity	Self-reported HTN
Naser et al., 2020	Cluster RCT	Bangladesh	1,191	≥20 / Both	MAR & pond (variable)	OMRON HEM-907
Nahian et al., 2022	Cross-sectional	Bangladesh	402	≥18 / Both	282.93 ± 150.8 mg/L	Digital BP; ≥140/90 or on meds
Rakib et al., 2023	Cross-sectional	Bangladesh	1,653	≥18 / Both	282 mg/L	Digital; ≥140/90 mmHg
Islam et al., 2025	Mixed-Method	Bangladesh	242 women	Various / Female	1000–2000+ mg/L	SBP ≥120; HTN prevalence 55.2%
Hossain et al., 2025	Cross-sectional	Bangladesh	3,917	Adults / Both	Coastal vs. non-coastal proxy	Self-reported HTN

Table 2 presents detailed information on sodium exposure assessment methods, estimated total sodium intake from both drinking water and diet across studies. These data highlight the methodological approaches used to quantify sodium-related cardiovascular risk and reinforce the significance of environmental exposure- particularly from drinking water as a contributing factor to elevated blood pressure in coastal populations.

Table 2: Sodium Exposure, Intake with urinary biomarker

Authors & year	Na^+ exposure assessment	Total sodium intake (g/day)	Urinary Na^+ / biomarkers
Vineis et al., 2011	Modeled from river EC and 2 L/day consumption	~16 g/day (from water only)	None
Khan et al., 2011	Water EC, Na^+ estimated via standard formula	River: 16.2, Piped: 11.5, Pond: 10.2	Not measured
Mohammad Ali, 2014	Digital salinity meter, self-reported salt intake	Not measured	Not reported
Khan et al., 2014	Atomic Absorption (water), ISE (urine)	~1.1 g/day (from water only)	24-h urine (mean 164 mmol/day)
Talukder et al., 2016	Spot urine, INTERSALT formula	~2.4 g/day (estimated)	Not directly provided
Butler et al., 2016	Water salinity analysis	Not stated	Not reported
Rony et al., 2016	24h urine collection	2.7 ± 1.0	24-h urine
Ahmed & Hutton, 2017	Water salinity charted by socio-ecological zones	Not reported	Not reported
Akib et al., 2018	Water EC measured (STW and ponds)	3.28 ± 1.19	Not reported
Shammi et al., 2019	Water Na^+ tests; GIS mapping; urine Na^+	Dry: 5–16 g/day; Wet: 0.6–1.2 g/day	24h urine (mean 3.4 g/day)
Roy et al., 2020	24h recall + water testing	6.5 ± 1.4 (2.3 from water)	Not reported
Naser et al., 2019	24h urine; water EC categorized	3.8 ± 1.7	165 ± 74 mmol/day
Faysal et al., 2020	Self-reported salt intake (converted to Na^+)	~5.2	Not reported
Shuvo et al., 2020	EC meter; FFQ; 24h dietary recall	Not specified; >5 g/day in most	Not stated
Khan et al., 2020	Self-reported salinity level	Not measured	Not reported
Naser et al., 2020	EC tested each visit; 24h urinary Na^+	Not reported (urine used)	24-h urine samples
Naser et al., 2022	Review of 9 studies; water + urine assessments	Varied (some >50% from water)	Mixed (24h urine or modelled)
Nahian et al., 2022	Water testing + 24h recall + FFQ	Not combined (water + food separate)	Not reported
Rakib et al., 2023	24h recall; household water sample	3.6 ± 1.4	Not reported
Islam et al., 2025	Mixed methods + references to Scheelbeek et al.	Not reported	Not reported
Hossain et al., 2025	Area-based (coastal vs non-coastal residency)	Not measured	Not reported

Conclusion

This review highlights a critical environmental health crisis in Bangladesh's coastal zones: rising drinking-water salinity driven by sea-level rise, reduced freshwater flow, and tidal surges is pushing sodium levels well above safety thresholds and accounting for up to half of daily sodium intake. Consistent evidence links these exposures to significant increases in systolic and diastolic blood pressure and higher hypertension rates, especially among pregnant women, older adults, and the socioeconomically disadvantaged. Urgent public health actions\such as rainwater harvesting, managed aquifer recharge, community reverse-osmosis filtration, targeted education, and adaptive surveillance must be integrated into climate and water governance strategies to protect vulnerable communities.

Mitigating the cardiovascular risks of high drinking water salinity in coastal regions requires a multi-level strategy. Community interventions should prioritize low-salinity water access via rainwater harvesting and managed aquifer recharge. Public health education on salt-related health risks and water quality is essential. Routine sodium testing must be included in water safety monitoring, while national policies should integrate salinity management into climate resilience plans. Strengthening epidemiological surveillance and using biomarkers like urinary sodium will help track exposure and guide evidence-based interventions to protect vulnerable coastal populations.

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