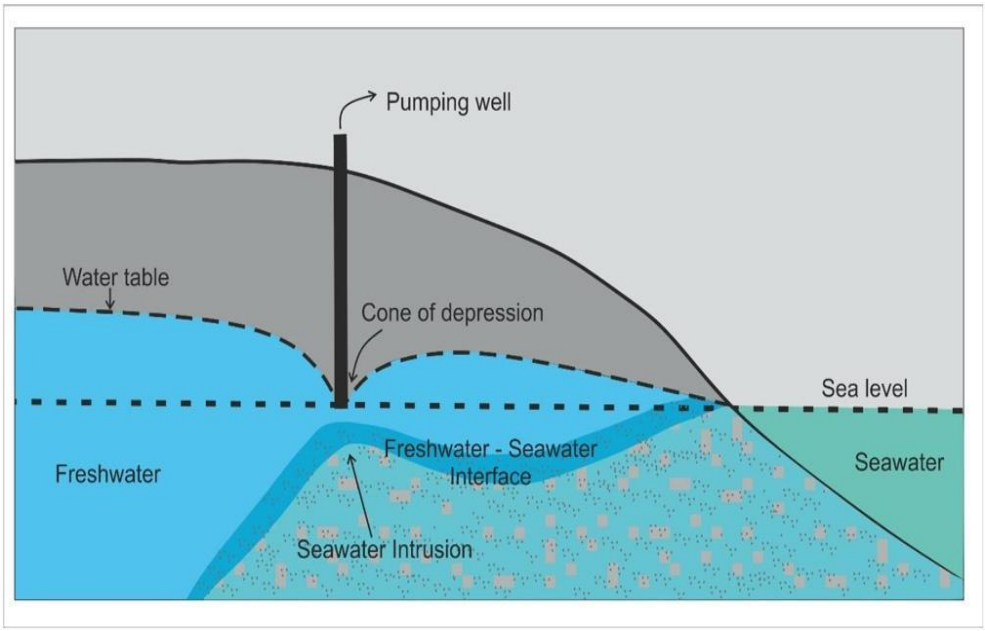
Coastal hazards Fact Sheets #4: Saltwater Intrusion in Cities

What is Saltwater Intrusion?

Saltwater intrusion is when seawater infiltrates the coastal groundwater systems due to natural cycles or human interventions. [i] Approximately 70% of the world's population is located in coastal areas, which often results in overexploitation of groundwater reservoirs, leading to saltwater intrusion. [ii]

Saltwater intrusion is a natural process, but it becomes an environmental problem when there is excessive pumping of fresh water from a groundwater aquifer. Fresh water is a scarce resource. According to the World Meteorological Organization, only 2.5 per cent of the total water volume on the Earth is fresh water, and the remainder is saline. [3] When freshwater levels drop, saltwater intrusion can proceed inland, resulting in saline water from wells and pumps unfit for drinking or other water usage.

Figure 1: Schematic diagram of seawater intrusion into the coastal aquifer



(Source: https://www.sciencedirect.com/science/article/pii/S2589757820300123)

Causes of Saltwater Intrusion

The causes of salt water intrusion that takes place due to natural and human induced activities are described as follows:

1. *Overextraction of ground water:* Rapid urbanization, industrialization, and population growth cause increased water demand, subsequently leading to excessive groundwater pumping. As a result, the water levels in aquifers get dropped, creating a pressure imbalance that allows seawater to intrude into freshwater aquifers. In Chennai, Tamil Nadu of, India, excessive groundwater pumping led to seawater intrusion of 10 m depth up to the extent of 2 km, i.e. nearly 2600 sq km of fresh water below mean sea level was affected by sea water due to over-extraction of groundwater by coastal communities.[iv]
2. *Coastal geomorphology:* The natural geographical location of the coastal land can and the permeability of sand and rocks can influence the mixing of groundwater and seawater. Due to its proximity to the Bay of Bengal, Dhaka in Bangladesh is exposed to saltwater intrusion. The study conducted by the World Bank suggests that climate change is likely to increase the river salinity leading to a decline in rice yield by 15.6% and causing significant change to aquatic ecosystems by 2050.[v]
3. *Sea level rise:* The rise in sea level can increase the pressure exerted by seawater against groundwater hence leading to seawater intrusion. Chesapeake Bay in Maryland, USA, has already experienced the loss of several islands and shorelines due to sea level rise and erosion. Due to climate change, the area are experiencing threats from storms, inundation and sea level rise, which is occurring at nearly twice the global average.[vi] The increased salinity has already made some of its coastal farmland unusable and is altering the ecological landscape of Maryland's wetlands and coastal forests.[vii]
4. *Natural events:* Natural disasters like storm surges and tsunamis can lead to temporary seawater intrusion. Prince Edward Island in Canada is particularly vulnerable to saltwater intrusion due to natural conditions like tidal action, changing recharge rates and numerous estuaries penetrating inland.[viii] The Mekong Delta in Vietnam suffered heavily due to the El Niño-induced saline water intrusion period since late 2015, reporting a loss of 15,032 billion (approx. US$ 674 million), equivalent to about 0.35% of GDP in 2015.[ix]

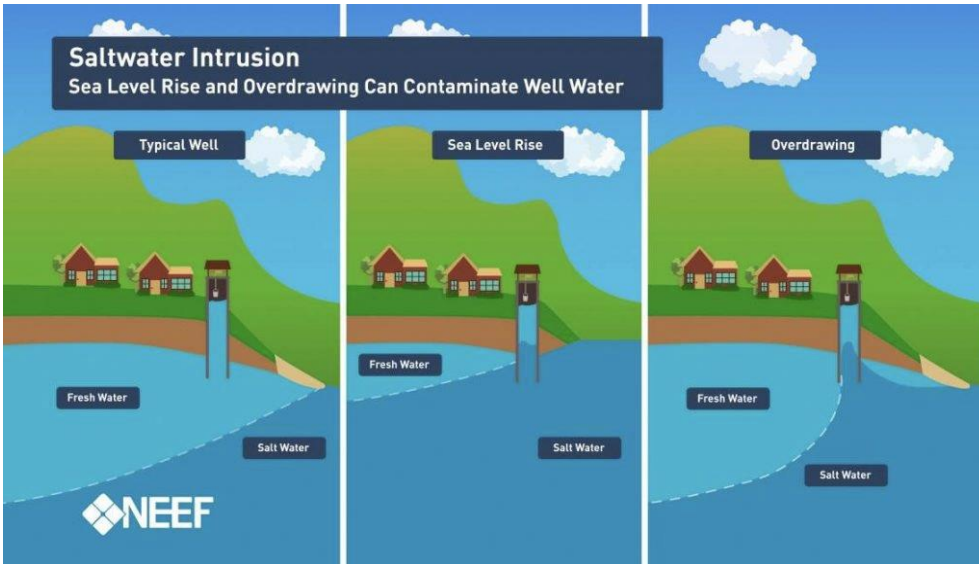


Figure 2: Different scenarios of salt water and fresh water level during normal

(Source: The National Environmental Education and Training Foundation)

How does Saltwater Intrusion affect city systems?

City infrastructure: Coastal cities experiencing saltwater intrusion face challenges in terms of infrastructure and building damage.

- Saltwater in groundwater systems can corrode pipes, wells, and other water supply and distribution infrastructure.
- *Contaminate drinking water supply systems:* Excess extraction of groundwater causes excess salinity and contaminates drinking water, causing it to impact water supply systems, treatment facilities and distribution networks
- *Corrosion of sewage and drainage pipes:* Pipes and wells are prone to corrosion due to the salinity of water leading to leakage and pollution of water bodies.
- *Damage to roads and bridges:* Salt water can cause cracks and potholes in roads and bridges, affecting transportation systems and leading to increased risks of accidents
- Damage to residential buildings and essential services like hospitals, schools, community buildings, electrical lines and telecommunication
- Disruption of economic activities and costs by increasing the costs of repairs and maintenance of infrastructure

The Katrina's floodwaters in New Orleans's City Park (2005) damaged 122 park buildings and submerged 90 percent of City Park in saltwater. [x] More than four feet of water in the parks administration building ruined computers, archives and records. A portion of the maintenance building collapsed and nearly every piece of equipment was destroyed. Total park damages are estimated at well over $43 million.[xi]

A study conducted by Abdelhafez in 2022, predicted that the annual expected repair costs for the foundations of the studied homes i.e. nearly 137,000 residential buildings in low-lying areas may reach as much as US$90 million by 2100 in Mobile Bay, Gulf of Mexico caused due to salt water intrusion.[xii]

Social Impacts: Saltwater intrusion can have a significant social impact on communities that are highly dependent on groundwater for livelihood, such as agriculture, fisheries, forestry etc., described as follows:

- *Population Displacement:* Due to deteriorating living conditions, including lack of safe water and damaged infrastructure, communities are forced to get displaced
- *Disruption of Livelihoods:* seawater intrusion lead to declined crop yield, impacts pisciculture and tourism activities may be disrupted due to water quality concerns
- *Migration and Relocation:* Low-income communities can lack the necessary resources to adapt. Hence, they are forced to migrate or relocate to new places
- *Loss of Cultural Heritage*: Due to the impact on infrastructures, it can also threaten traditional practices, indigenous knowledge, and cultural heritage associated with land and water use of local communities
- *Social Stress and Mental Health:* The disruption can lead to social disparity among communities and increased social stress, anxiety, and mental health issues among affected individuals and communities
- Health Risks and safety concerns due to outbreak of diseases and limited access to health care and facilities, especially to waterborne diseases due to water contamination
- *Access to Clean Drinking Water:* Increased salinity can hinder access to clean drinking water and can demand costly water treatment or desalination processes

The city of Can Tho in the Mekong Delta of Vietnam faces several social impacts on communities relying heavily on agriculture and fisheries for their livelihoods. Salty seawater began to enter the delta early in mid-November 2019, and by January, seawater was projected to reach 30-40 km deeper.[xiii] People in Can Tho city are facing economic challenges and food security issues due to increased salinity in the groundwater.

Ecosystem Disruption: Coastal ecosystems like wetlands and estuaries thrive on the delicate balance between freshwater and saltwater. Saltwater intrusion can disrupt these ecosystems by affecting plant and animal species and their habitats and disturb the delicate ecological balance, and have the following impacts:

- *Habitat Alteration:* Saltwater intrusion can change the physical composition of lands like soil structure and vegetation composition, and

changes in hydrological patterns can lead to a significant alteration in the habitat of plants and animals in coastal areas

- *Biodiversity Loss:* Alteration of habitat as well as the inability of species to adapt to the highly saline environment, can lead to displacement and loss of plants and animals with significant ecological significance
- *Invasive Species:* Salt-tolerant species can invade the natural habitat of local species and outgrow them
- *Erosion and Habitat Loss:* Habitat fragmentation and degradation can lead to coastal erosion and increase habitat loss of important species
- *Ecosystem Services:* Valuable ecosystem services provided by the coastal environment, such as water purification, flood prevention and carbon sequestration, can be impacted due to increasing loss of biodiversity loss and ecological damage

An example of this is the diminishing salt marshes of Florida in the USA. The ecosystem, home to 301 plant species, 422 invertebrate species, 217 fish species, 11 amphibians, 31 reptiles, and 15 mammals, is in threat due to saltwater intrusion.[xiv]

How does Climate Change impact Saltwater Intrusion?

Climate change is likely to impact saltwater infiltration into aquifers, along with increasing groundwater salinity levels due to heightened evapotranspiration. [xv] Factors that can cause worsening of climate change impacts on salt water intrusion are described in the following points:

1. **Sea Level Rise**: In the study conducted by Shefif and Singh, it has been discussed that a 50 cm rise in the Mediterranean Sea level causes an additional intrusion of 9km in the Nile Delta Aquifer.[xvi] In Bangladesh, climate experts predict that by 2050, rising sea levels will submerge 17% of the nation's land and displace about 20 million people.[xvii] Due to their low-lying deltaic geography, countries are subjected to sea level rise induced by climate change and face saltwater intrusion.
2. **Change in Precipitation Pattern**: The IPCC Report AR6 reports that the increase in greenhouse gas has contributed to drying in dry summer climates, including the Mediterranean, southwestern Australia, southwestern South America, South Africa and western North America (medium to high confidence).[xviii] Decreased rainfall can affect the

recharge of groundwater aquifers, and the resulting gradient created can cause salt water infiltration.

3. **Increased Storm Surges and Flooding**: A global flood database based on in situ measurement and satellite remote-sensing during 1985–2015 shows that floods have increased 4-fold and 2.5-fold in the tropics and northern mid-latitudes, respectively.[xix] The World Meteorological Organization in 2021 reported that between 1970 to 2019, 44% of all disasters and 31% of all economic losses were flood related.[xx] These events can cause temporary increases in sea levels and higher water levels along coastlines, which can force saltwater further inland, impacting groundwater sources.
4. **Melting of Glacier Lakes and Polar Ice:** There is a worldwide growth in the number, total area and total volume of glacial lakes by around 50% between 1990 to 2018 due to the global increase in glacier melt rate.[xxi] The melting of glaciers and polar ice contributes to rising sea levels. As freshwater from melting ice enters the oceans, it can affect the salinity balance in coastal areas and potentially worsen saltwater intrusion.
5. **Thermal Expansion:** Global temperature is currently rising by 0.2°C (±0.1°C) per decade; human-induced warming reached 1°C above pre-industrial levels around 2017 and, if this pace of warming continues, would reach 1.5°C around 2040.[xxii] Rising global temperatures cause seawater to expand thermally, contributing to higher sea levels. This thermal expansion can also increase the pressure on coastal aquifers and contribute to saltwater intrusion.

Adaptation Strategies for Saltwater Intrusion

I. Community Level

1. Encourage rainwater harvesting and storage techniques at household and community levels in uses like cleaning, flushing and irrigation to reduce the demand for water from wells and pumps.
2. Diversifying water needs at the community level by applying a mixed ratio of surface and groundwater supply and desalination and treatment of seawater for use at regular intervals to minimize the demand for groundwater

3. Promote water conservation awareness by encouraging efficient water use, fixing leaks and using water-efficient appliances.
4. Periodic inspection and repairs using corrosion inhibitors in city buildings
5. Adoption of sustainable agriculture practices by using water-efficient irrigation systems like drip irrigation or sub-surface irrigation and use of salt-tolerant species to adapt to increasing salinity conditions
6. Groundwater management by periodically monitoring the level and preventing over pumping of water
7. Plantation of natural barriers like mangroves and restoration of coastal vegetation, and creation of wetlands and marshes
8. Coalition building and networking through combined workshops and engagements by bringing residents, technical experts, environmental experts, businesses and local leaders, and provincial and municipal government bodies together for consultation.
9. Raise awareness and education among local communities and policymakers in the sustainable use of groundwater and the importance of taking initiatives at the local level for adapting to negative consequences of saltwater intrusion, climate change and sea level rise.
10. Capacity building of local communities by providing them with training and education in the risks and management of saltwater intrusion
11. Early warning systems to provide awareness to local communities about upcoming storms or floods that can result in saltwater intrusion
12. Emergency response planning by developing and practicing ways to cope with disasters caused by saltwater intrusion

II. Municipal/Government Level

1. Artificially recharging freshwater aquifers with treated wastewater, stormwater, or excess surface water during periods of lower demand to replenish groundwater levels.
2. Develop alternative water sources, such as desalination plants, which produce freshwater by removing salt and other impurities from seawater.
3. Improve the knowledge of present and future salt ingression situations by creating a numerical simulation model to predict sea level rise and worst-case global warming scenarios.[xxiii]

4. Identifying and mapping needs and barriers in the management of coastal fresh groundwater by assessing the risks and potential economic damages for human activities and natural systems through the creation of a cooperation network
5. Identifying policies for future exploitation of vulnerable coastal aquifers by creating strategies for sustainable use of groundwater aquifers.
6. Maintain and restore wetlands by identifying and protecting ecologically significant high diversity areas
7. Maintain water quality and availability by managing water demand through water reuse, recycling, rainwater harvesting and desalination, and prevent or limit groundwater extraction from shallow aquifers.
8. Preserve and restore vegetation's structural complexity and biodiversity in tidal marshes, seagrass meadows, and mangroves.
9. Install a low-head dam for saltwater wedge and freshwater pool separation to prevent upstream movement, creating a barrier for saltwater to intrude on freshwater recharges.[xxiv]
10. Designing enhanced stormwater management systems to drain out excess sea water caused during times of storms and floods and reduce the risk of saltwater intrusion
11. Creation of robust and highly effective elevated city infrastructures like buildings, roads and bridges to address the prevalence of increasing salinity and sea level rise conditions
12. Maintenance of shoreline using soft measures like creating marsh by planting appropriate species, planting grasses on the dunes, planting salt tolerant plants and planting submerged aquatic vegetation to stabilize sediment and increase the water recharge capacity of coastal land [xxv]
13. Ensuring sustainable groundwater use by implementing regulations and policies for groundwater extraction and maintaining a balance between salt water and groundwater aquifers.

Case Examples

Case Example 1

The Marina Barrage in Singapore is a compelling success story in saltwater intrusion adaptation. It is a dam and a reservoir that regulates the flow of freshwater storage, controls floods, provides recreational water activities and

prevents intrusion of salt water. By effectively managing freshwater resources and creating a buffer against seawater encroachment, Singapore has enhanced its resilience to the impacts of climate change and rising sea levels. [xxvi]

Case Example 2

The city of Rotterdam in the Netherlands is another success showcasing effective water management strategies through human-engineered structures to mitigate saltwater intrusion. Innovative techniques and infrastructures like dams, sluices, locks, dikes, and storm surge barriers have been constructed to protect the Dutch coastline from the North Sea during floods. Extensive water systems to capture and store freshwater during excess rainfall and strategically use them during dry spells have been implemented in the city. They also effectively control the flow of freshwater from rivers, use sluices and gates to manage the balance of saltwater and freshwater, and use natural measures like planting salt-tolerant crops. By strategic planning and building innovative human-engineered structures, Rotterdam serves as an example to mitigate climate change-induced saltwater intrusion. [xxviii]

Case Example 3

Perth, located in Western Australia, faced significant challenges related to saltwater intrusion into its groundwater due to its semi-arid climate and heavy dependence on groundwater for water supply. Perth constructed large-scale desalination plants using advanced technology to remove salt from seawater which provides a substantial portion of the city's drinking water supply, reducing the reliance on groundwater. Perth also introduced managed aquifer recharge (MAR) systems, where treated wastewater is injected into aquifers during wet periods. This helps create a barrier against saltwater intrusion and replenishes groundwater reserves. [xxviii]

End Notes/ References:

i. efaidnbmnnnibpcajpcglclefindmkaj/http://www.gov.pe.ca/photos/original/cle_WA1.pdf
ii. Darnault, C.J.G., and I.G. Godinez, 2008. Coastal aquifers and saltwater intrusion. In Overexploitation and Contamination of Shared Groundwater Resources, 185–201. Springer Science+Business Media B.V.
iii. https://www.who.int/news-room/fact-sheets/detail/drinking-water
iv. https://www.thehindu.com/news/cities/chennai/seawater-intrusion-seen-north-of-city/article30437575.ece
v. https://www.worldbank.org/en/news/feature/2015/02/17/salinity-intrusion-in-changing-climate-scenario-will-hit-coastal-bangladesh-hard

vi. https://eri.iu.edu/erit/case-studies/maryland-analyzes-coastal-wetlands-susceptibility-climate-change.html
vii. https://planning.maryland.gov/Documents/OurWork/envr-planning/2019-1212-Marylands-plan-to-adapt-to-saltwater-intrusion-and-salinization.pdf
viii. CCME (Canadian Council of Ministers of the Environment). 2010. Review and Assessment of Canadian Groundwater Resources, Management, Current Research Mechanisms and Priorities. PN 1441.
ix. https://www.undp.org/sites/g/files/zskgke326/files/migration/vn/Recovery-draft-Sep-2016_final.pdf
x. https://www.nyc.gov/html/sirr/downloads/pdf/final_report/Ch_1_SandyImpacts_FINAL_singles.pdf
xi. https://www.researchgate.net/profile/Vereda-Williams/publication/41892496_Identifying_the_Economic_Effects_of_Salt_Water_Intrusion_after_Hurricane_Katrina/links/0046353bc041fd176b000000/Identifying-the-Economic-Effects-of-Salt-Water-Intrusion-after-Hurricane-Katrina.pdf
xii. https://www.nature.com/articles/s41598-022-18467-
xiii. https://www.aljazeera.com/features/2020/4/22/the-great-salt-drought-desiccating-vietnams-mekong-delta
xiv. https://eri.iu.edu/erit/case-studies/southwest-florida-assesses-salt-marsh-vulnerability-to-sea-level-rise.html
xv. https://archive.ipcc.ch/publications_and_data/ar4/wg2/en/ch3s3-4-2.html
xvi. https://www.sciencedirect.com/science/article/pii/S2589757820300123
xvii. https://www.nrdc.org/stories/bangladesh-country-underwater-culture-move#:~:text=Climate%20experts%20predict%20that%20by,a%20city%20of%20last%20resort.
xviii. https://www.ipcc.ch/report/ar6/wg2/chapter/chapter-4/
xix. Najibi, N. and N. Devineni, 2018: Recent trends in the frequency and duration of global floods. Earth Syst. Dynam. , 9 (2), 757–783, doi:10.5194/esd-9-757-2018.
xx. WMO, 2021: Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970-2019). WMO, Geneva, Switzerland
xxi. Shugar, D.H., et al., 2020: Rapid worldwide growth of glacial lakes since 1990. Nat. Clim. Chang. , 10 (10), 939–945
xxii. https://www.ipcc.ch/sr15/faq/faq-chapter-1/#:~:text=Given%20that%20global%20temperature%20is,1.5%C2%B0C%20around%202040.
xxiii. https://programming14-20.italy-croatia.eu/documents/276485/0/ASTERIS_Abstract+%281%29.pdf/45cf718a-bf80-38b5-fa8d-288864efc811?t=1630995811018
xxiv. https://programming14-20.italy-croatia.eu/documents/276485/0/ASTERIS_Abstract+%281%29.pdf/45cf718a-bf80-38b5-fa8d-288864efc811?t=1630995811018
xxv. https://eri.iu.edu/erit/case-studies/maryland-analyzes-coastal-wetlands-susceptibility-climate-change.html
xxvi. https://eri.iu.edu/erit/case-studies/southwest-florida-assesses-salt-marsh-vulnerability-to-sea-level-rise.html
xxvii. https://eri.iu.edu/erit/case-studies/san-juan-bay-estuary-program-assesses-vulnerability-and-targets-adaptation-measures.html
xxviii. https://www.sciencetheearth.com/uploads/2/4/6/5/24658156/igel-marina-barrage.pdf
xxix. https://www.sierraclub.org/sierra/2019-1-january-february/innovate/how-netherlands-preparing-for-sea-level-rise
xxx. https://www.sciencedirect.com/science/article/pii/S0303243421003445