Climate Action in Cities
CoCHAP

Coastal Cities Resilience and Extreme Heat Action Project

Coastal Hazards in Cities Fact Sheets #6

Saltwater Intrusion

June 2024

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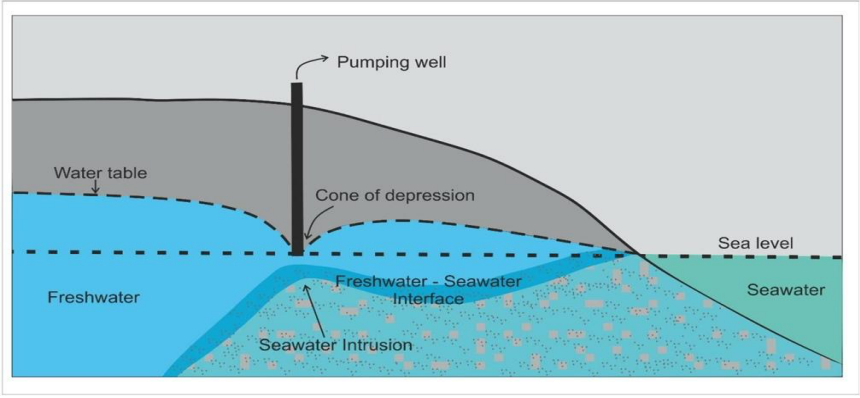
Saltwater Intrusion in Cities

What is Saltwater Intrusion?

Saltwater intrusion is when seawater infiltrates coastal groundwater systems due to natural or human drivers. [i] Presently, about 40% of the world's population lives within 100 kilometers of the coast which often results in overexploitation of groundwater reservoirs, leading to saltwater intrusion. [ii]

Saltwater mixing with fresh water in coastal areas is a natural process, but it becomes an environmental and societal problem when the rate of intrusion increases, and coastal groundwater salinity begins to increase above normal levels. This can result from increasing relative sea level in a coast region, decreased groundwater recharge, or increased abstraction (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. [iii] Saline intrusion into coastal groundwater can impact access to drinking water as well as agricultural uses of coastal groundwater.

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



Globally, freshwater supply problems due to climate change are most likely in developing countries with a high proportion of coastal lowland, arid and semi-arid coasts, coastal megacities particularly in the Asia-Pacific region, and small island states, reflecting both natural and socio-economic factors that enhance the levels of risks. [iv]

Causes of Saltwater Intrusion:

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

Natural Factors

- *Coastal geomorphology:* 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]
- *Sea level rise:* Increasing relative sea level resulting from either coastal subsidence or absolute sea-level rise can contribute to increasing saline 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 is 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]
- *Disasters:* 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 during the 2015/2016 El Nino, reporting a loss of 15,032 billion (approx. US$ 674 million), equivalent to about 0.35% of GDP in 2015.[ix]

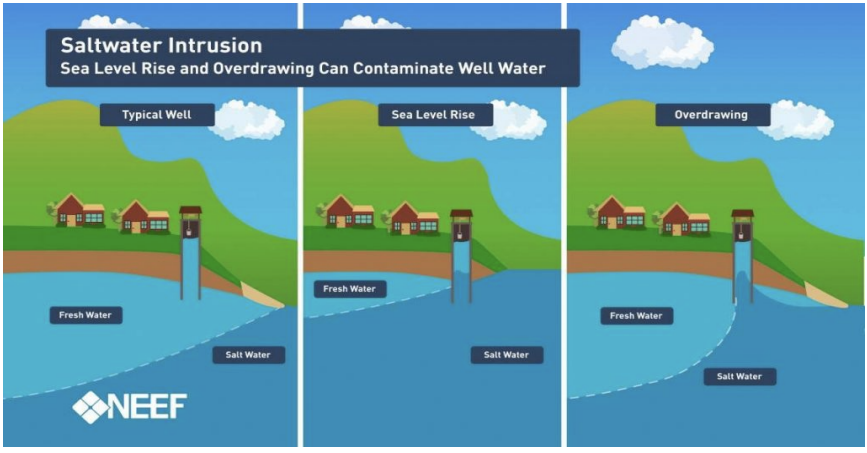
Anthropogenic Factors

- *Over-Extraction of Groundwater*: Rapid population growth led to increased water demand, resulting in excessive groundwater pumping. This over-extraction causes water levels in aquifers to drop, 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] Additionally, rapid urban development and land use changes are leading to land subsidence, especially in coastal areas. As the land sinks, it increases the vulnerability of coastal aquifers to saltwater intrusion by reducing the elevation gradient that separates freshwater and saltwater. This subsidence exacerbates the problem of seawater intrusion caused by over-extraction, creating a compounded risk to freshwater resources in coastal regions.

- *Land Subsidence:* Human activities such as groundwater extraction, oil and gas extraction, and urban development can lead to land subsidence, particularly in coastal areas. As the land sinks, it increases the vulnerability of coastal aquifers to saltwater intrusion by reducing the elevation gradient that separates freshwater and saltwater.

Figure 2: Different scenarios of saltwater intrusion in freshwater level, Source



How does Climate Change impact Saltwater Intrusion?

Climate change has the potential to influence rates of saline intrusion in coastal areas through changes in relative sea-level as well as changes in coastal rainfall and evaporation patterns and reduced coastal river water levels due to lower rainfall in inland catchments. [xv]

Globally, these problems are most likely to be impacting cities in developing countries with a high proportion of coastal lowland, arid and semi-arid coasts, coastal megacities particularly in the Asia-Pacific region, and small island states, reflecting both natural and socio-economic factors that enhance the levels of risks. (ibid)

Below Factors that can cause worsening of climate change impacts on saltwater intrusion are described in the following points:

- *Sea Level Rise:* There is high confidence that sea level rise will increase saltwater intrusion into coastal wetlands (IPCC, AR6, WG1, Chapter 8).
- Furthermore, sea level rise will exacerbate coastal inundation with the potential to increase saltwater intrusion into aquifers in small islands (IPCC 2021, AR6, WG1, Technical Summary). 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]
- *Change in Precipitation Pattern:* The IPCC Report AR6 reports that the increase in greenhouse gas has contributed to drying in some climate regions, including the Mediterranean, southwestern Australia, southwestern South America, Southern 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 saltwater infiltration.
- *Increased Storm Surges and Flooding:* Storm events can cause temporary increases in sea levels and higher water levels along coastlines, which can force saltwater further inland, impacting groundwater sources.
- *Increase in temperature:* 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, could reach 1.5°C around 2040.[xxii] Rising global temperatures cause seawater to expand thermally, contributing to higher sea levels which can in turn contribute to saltwater intrusion.

How does Saltwater intrusion affect city systems?

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

- Contaminated drinking water supply systems: Saltwater intrusion increases groundwater salinity, impacting water supply systems, treatment facilities, and distribution networks.

- 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.

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]

Socio-Economic 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 drinking water, water for irrigation, and damaged infrastructure, communities are forced to migrate to alternative areas.
- Disruption of Livelihoods: Seawater intrusion can lead to reduced crop yield, aquaculture output and tourism activities which may be disrupted due to water quality concerns.
- 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
- 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, economic, and food security impacts, particularly for 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 further inland. [xiii] People in Can Tho city is facing economic challenges and food security issues due to increased salinity in the groundwater.

Environmental Impacts: 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]

Adaptation Strategies for Saltwater intrusion

Community Level

- 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.
- Promote water conservation awareness by encouraging efficient water use, fixing leaks and using water-efficient appliances.
- 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.
- Groundwater management by periodically monitoring the level and preventing over pumping of water.

- Planting of natural barriers like mangroves and restoration of coastal vegetation, and creation of wetlands and marshes.
- 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.
- 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.
- Early warning systems to provide awareness to local communities about upcoming storms or floods that can result in saltwater intrusion.

Municipal/Government Level

- Artificially recharging freshwater aquifers with treated wastewater, stormwater, or excess surface water during periods of lower demand to replenish groundwater levels.
- Develop alternative water sources, such as desalination plants, which produce freshwater by removing salt and other impurities from seawater.
- Periodic inspection and repairs using corrosion inhibitors in city building.
- 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.
- Identifying policies for future exploitation of vulnerable coastal aquifers by creating strategies for sustainable use of groundwater aquifers.
- Maintain and restore wetlands by identifying and protecting ecologically significant high diversity areas.
- 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.
- Preserve and restore vegetation's structural complexity and biodiversity in tidal marshes, seagrass meadows, and mangroves.
- 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]

- 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
- 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]
- 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. [xxvii]

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]

Case Example 4

Tokyo, Japan has implemented a comprehensive flood control system, including seawalls, floodgates, and underground tunnels, to protect against storm surges and saltwater intrusion. Additionally, the city has promoted rainwater harvesting and the use of permeable pavements to reduce runoff and recharge groundwater aquifers. [xxix]

Case Example 5

Copenhagen has implemented a Climate ADAPT plan that includes measures to adapt to rising sea levels and reduce the risk of saltwater intrusion, including constructing coastal barriers, restoring natural habitats along the shoreline, and promoting sustainable urban drainage systems to manage stormwater runoff and protect freshwater
sources. [xxx]

Case Example 6

Bangladesh is highly vulnerable to saltwater intrusion due to its low-lying geography and frequent cyclones. The Coastal Embankment Improvement Project (CEIP) aims to enhance the resilience of the coastal population by improving the embankments that protect against storm surges and saltwater intrusion. The project focuses on rehabilitating and upgrading coastal embankments to prevent flooding and saltwater intrusion, thereby protecting agricultural land and freshwater sources. It includes the construction and rehabilitation of polders (a low-lying tract of land enclosed by dikes) and the installation of improved drainage systems to manage water flow effectively. This initiative has significantly reduced the vulnerability of coastal communities to saltwater intrusion, safeguarded livelihoods, and improved food security. [xxxi]

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