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The Mekong Delta in Vietnam and Cambodia Is Subsiding and in Need of Remediation

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Abstract

Land subsidence and rising sea levels could result in 40% of the Mekong Delta being covered by the South China Sea within the next few decades. The impact of groundwater withdrawal, in the SE Asia mega deltas of Ganges-Brahmaputra Delta, Jakarta Delta, Chao Phraya Delta and Mekong Delta, is a major reason these deltas are sinking. There are lessons to be learned from both failures and successful remediation efforts in other mega deltas as Vietnam policy makers seek to address Mekong Delta subsidence. Without a significant Vietnam government remediation and mitigation efforts, land subsidence in the Mekong Delta will continue. Land subsidence has occurred in the Mekong Delta as a result of the retention of sediments behind the China and Laos dams on the main stem of the Mekong River, reduced flooding peaks, climate change, sea level rise, storm surges and flooding. In addition, subsidence has been exacerbated by compaction, groundwater extraction for shrimp ponds, rice paddies and the household and drinking water needs of approximately 20 million people living on the Mekong Delta in Vietnam and Cambodia. The Mekong Delta shorelines are eroding and significant land areas, including wetlands, are becoming open water. The wetlands and land mass are also subsiding as a result of the reduction in sediment deposition. Large dams on the mainstem of the Mekong River in China and Laos have reduced peak flows and reduced sediment loads in lower Mekong River. Population and industrial growth have increased groundwater extraction and salt water intrusion as the delta subsides leading to consolidation and reduction in the current plumes flowing into the South China Sea. The primary objective of this paper is to assess the impact of groundwater withdrawals for rice paddies, shrimp ponds, aquaculture, industry and drinking water on Mekong Delta land subsidence. The secondary objective is to identify mitigation efforts used in other Southeast Asia deltas and make remediation recommendations for the sinking Mekong

Delta. Promising mitigation approaches are injecting river water deep into the underlying alluvial sediments, return of the sediments trapped in China and Laos reservoirs to the Mekong River mainstem, increase in the Mekong River flooding peaks, and construction of sea and floodwalls, dykes, polders and levees. The addition of Mekong River sediments to build up existing floodplains, the reduction of coastal shoreline erosion, the planting of mangroves and protection of urban and agricultural areas from being covered by the South China Sea are strategies that could help remediate land subsidence in the Mekong Delta.

Keywords

Dykes, Ho Chi Minh City, Jakarta, Mekong Delta, Sea Walls, Subsidence, Sediments

1. Introduction

The deltas of the world were built up by the deposition of fertile river sediments and aggradation over thousands of years [1]. These alluvial deltas are important food-production areas and support increasingly large populations. A warming climate is thought to cause a sea-level rise and threatens to inundate coastlines around the world. Roughly 500 million people live in delta regions of the world threatened by subsidence and rising seas levels. Subsidence is the result of compaction, sedimentation, tectonics and anthropogenic activities. Sea level rise and subsidence can affect the millions of people living on the world's deltas [2]. Deltas are important and are constantly being reshaped and reformed. Urban areas on the deltas often experience rapid economic growth and industrialization that require intensive water and land resources which can lead to the degradation of ecosystem services. Environmental changes have occurred because of dredging, channeling and reservoirs used to control water availability for navigation and to reduce flood risk.

The flat delta plains common to Southeast Asia are the most vulnerable to subsidence. Land subsidence, induced by local human activities can be more impacting than sea-level rise [1]. Jakarta, Indonesia, one of the most affected delta cities in the world is sinking at an average annual rate of 50 to 100 mm, a much higher rate than sea-level rise at approximately 3.2 mm per year. Jakarta could sink up to 6 m by the end of the 21st century. In 2007, Jakarta experienced catastrophic flooding with vast areas of the city inundated for weeks and 200,000 people were displaced. Approximately 1400 were hospitalized with waterborne diarrhea diseases [3].

Subsidence threatens human health by accelerating the contamination of river water resources with saltwater which makes them unsuitable for agriculture and drinking water. Subsidence can stress and crack gas lines, sewage pipes as land heaves or buckles. Infrastructure failures can increase risk of explosion and contamination of ground and surface water. People's sense of well-being can be stressed by a threat to drinking water supplies, livelihoods and homes. Subsidence is a multifaceted problem requiring researchers to identify targeted solutions and investigate site-specific causes.

The Mekong Delta of Vietnam and Cambodia is experiencing rapid economic growth that is stressing water supplies and many other ecosystem services. First the geology and soils of SE Asia river basins are discussed followed by the impacts of delta subsidence. Three case studies of SE Asia deltas, the Ganges-Brahmaputra Delta, the Jakarta Delta, and the Chao Phraya Delta are presented. Then the Mekong Delta and the impact of sediment reduction; groundwater withdrawals for drinking water; agricultural uses including rice paddies, shrimp ponds, and aquaculture; and industry on land subsidence in the Mekong Delta are analyzed. Lessons learned from successful remediation efforts in the other Southeast Asia deltas are used to develop mitigation recommendations for the sinking Mekong Delta.

2. Location

2.1. Geology and Soils of Mekong River Basin

Early Quaternary and older alluvial deposits reveal the sea level and tectonic adjustments, fold and fault lines, subsidence and uplifts that characterize the evolving Mekong River [4]. The Mekong River (**Figure 1**) is one of the most diverse and unique great rivers of the world with a flood pulse that drives a productive and extensive ecological system.

About 40 million years ago, its precursor, the Red River (**Figure 2**), drained into the sea just south of Hanoi, Vietnam. About 13 million years ago earthquakes and volcanic activity of the Himalayas re-directed the mountain drainage southward via steep gorges [5] [6]. Below this area was a wide inland sea during the Upper Mesozoic. It is likely that the ancient Mekong River flowed directly south and to the west of the Korat Upland, joining what has become the Chao Phraya River in Thailand [5]. There is evidence in Cambodia that subsidence in the Tonle Sap basin (**Figure 3**), during the last 12,000 years, re-aligned the Mekong River eastward, away from its former Chao Phraya connection and the Tonle Sap basin, to its present course which now flows into the South China Sea [7].

The modern day Mekong River [8] [9] carries a large amount of arsenic rich fine sediments and sands, that originated in the Himalayan and Tibetan mountainous region, to the Mekong Delta. These fluvial transported alluvial deposits have been mediated over time by glaciation, evapotranspiration and precipitation [4].

Sediments rich in soil organic carbon, such as peat, oxidize when dried. Carbon in soils (**Figure 4**) binds with oxygen to create carbon dioxide that is released into the atmosphere. Soils lose mass and become compacted after being deprived of carbon. In addition, organic matter is a food source for microbes,

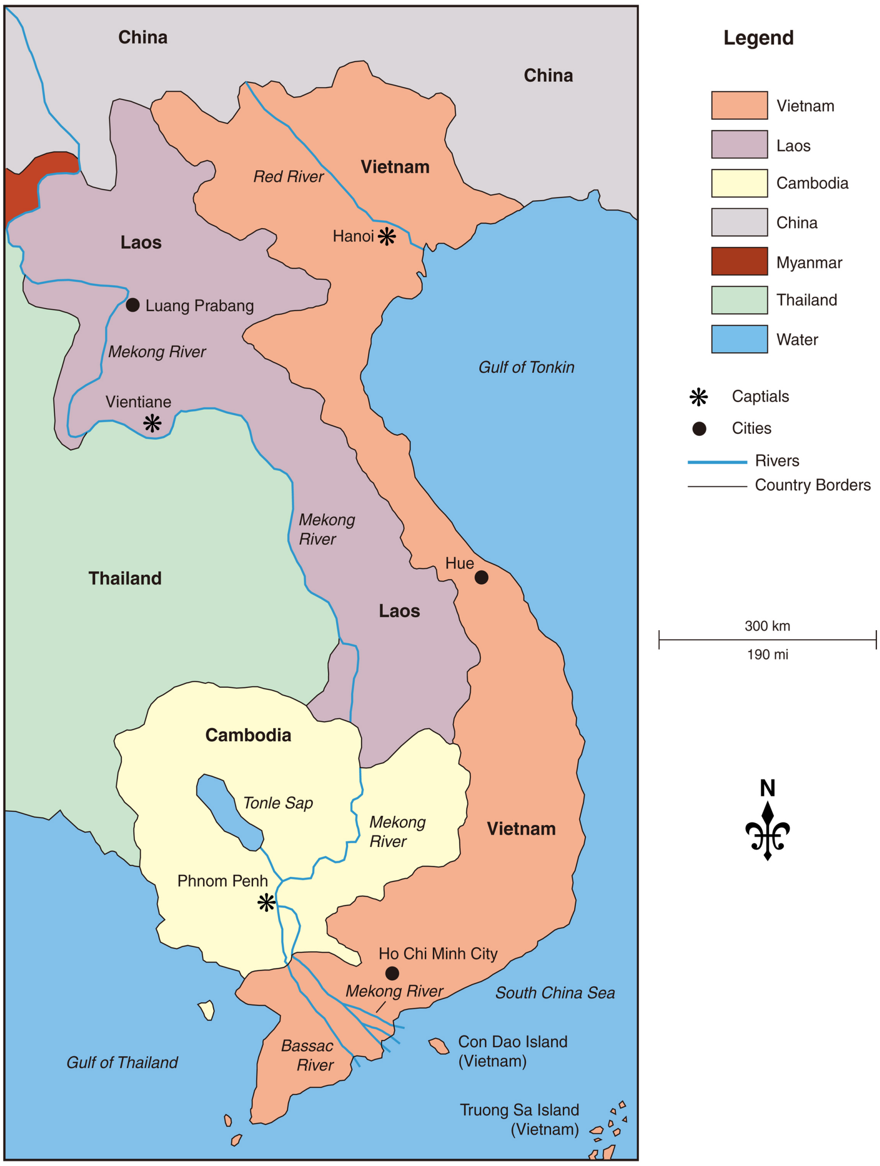

Figure 1. As the Mekong and Bassac rivers flow south, through the Mekong Delta, they water a diverse landscape bringing freshwater to the lowlands around the flooded mountains to saltwater river regions in the wet season and sediment loads that replenish the fertility of rice fields. Reprinted with permission from Open Journal of Environmental Protection Editor. JEP 8: 431-459. Map by Mic Greenberg.

which release carbon dioxide to the atmosphere and contribute to the soil mass loss [10].

2.2. Subsidence

Subsidence is a phenomenon of all deltas of the world due to natural and anthropogenic processes. These changes include coastal and river erosion, sediment compaction, tectonics, changes in land use and agricultural practices such as irrigation, mining, deforestation, groundwater removal, levees, embankments, polders and coastal zone management [11] [12]. Collectively these factors can

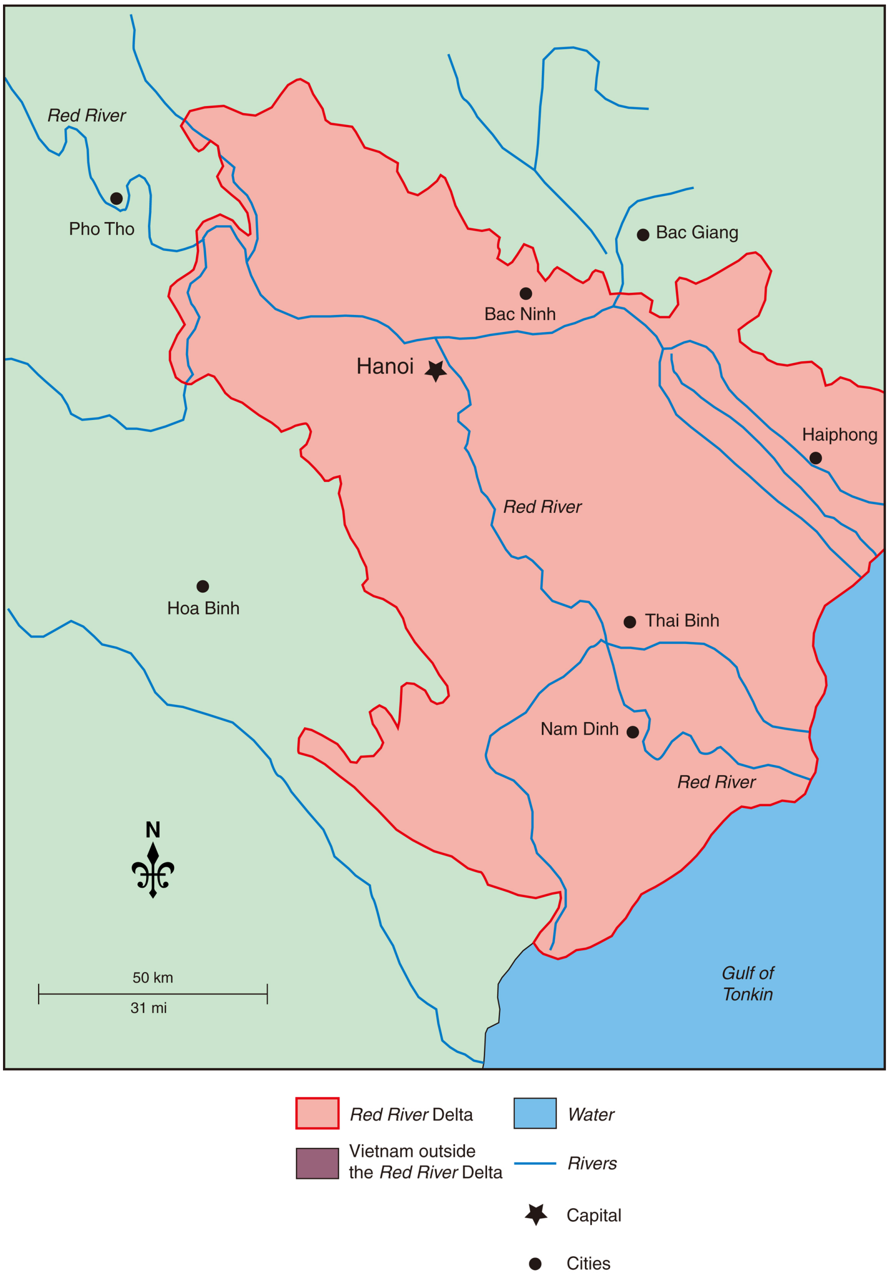

Figure 2. The Red River near Hanoi, Vietnam. Historically the Mekong River drained through the Red River Valley. The Red River Valley was not sprayed with Agent Blue during the Vietnam War. However, the groundwater still has elevated arsenic levels and spikes. Map by Mic Greenberg.

result in either uplift or subsidence. Net subsidence combines the effect of rising sea levels, lack of sedimentation, deposition and sinking as a result of subsidence, which can cause land loss, shoreline retreat and flooding. Anthropogenic changes include dredging, sand extraction, channeling and reservoir construction to manage and control water availability for navigation or to reduce flooding risk. Rising sea levels can magnify the consequences of land subsidence. Subsidence can increase salinization, void the efficiency of levees and other flood defenses, impact

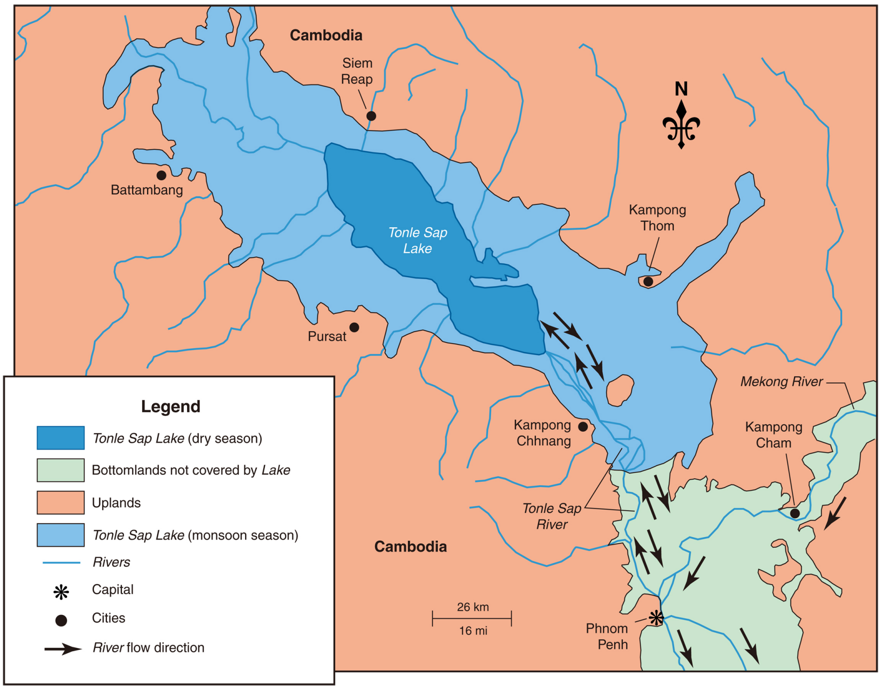

Figure 3. Tonle Sap basin in Cambodia. The Tonle Sap Lake and River reverse their flow in the monsoon season with the Mekong river floods back up into the Tonle Sap River and Lake. Reprinted with the permission of the Editor of the Journal of Soil and Water Conservation. JSWC 73(3) 60A.-66A. Map by Mic Greenberg.

agriculture use and adversely affect livelihoods of millions of people [11].

Subsidence can result from compaction, sedimentation tectonics and anthropogenic causes. These processes continually shape, form, reshape and reform delta land, water, and human relationships. Sea level rise and subsidence affect the quality of life, livelihoods, and availability of food for people living in the world's deltas. Delta urbanized areas experience rapid economic growth leading to intensive ecosystem service needs. Three deltas, Ganges-Brahmaputra, Jakarta, and the Chao Phraya, have approximately 200 million people living on them and all are experiencing subsidence.

3. Results

3.1. Case Study No. 1. Ganges-Brahmaputra Delta

The Ganges-Brahmaputra delta southwest Bangladesh (**Figure 5**) was flooded in 2009 because of Cyclone Aila which displaced more than 100,000 people (**Figure 6**). The storm inundated the island polders and deposited fresh silt that reached depths up to 70 cm in thickness. This demonstrated the natural system still had the ability to replenish the delta. And revealed the downside of sea walls (**Figure 7**) and dyking huge stretches of the delta shoreline to prevent flooding. Further, dykes must be regularly raised to protect subsiding land and to keep pace with steadily rising sea levels.

A delta's elevation above seas level depends on vertical movement resulting

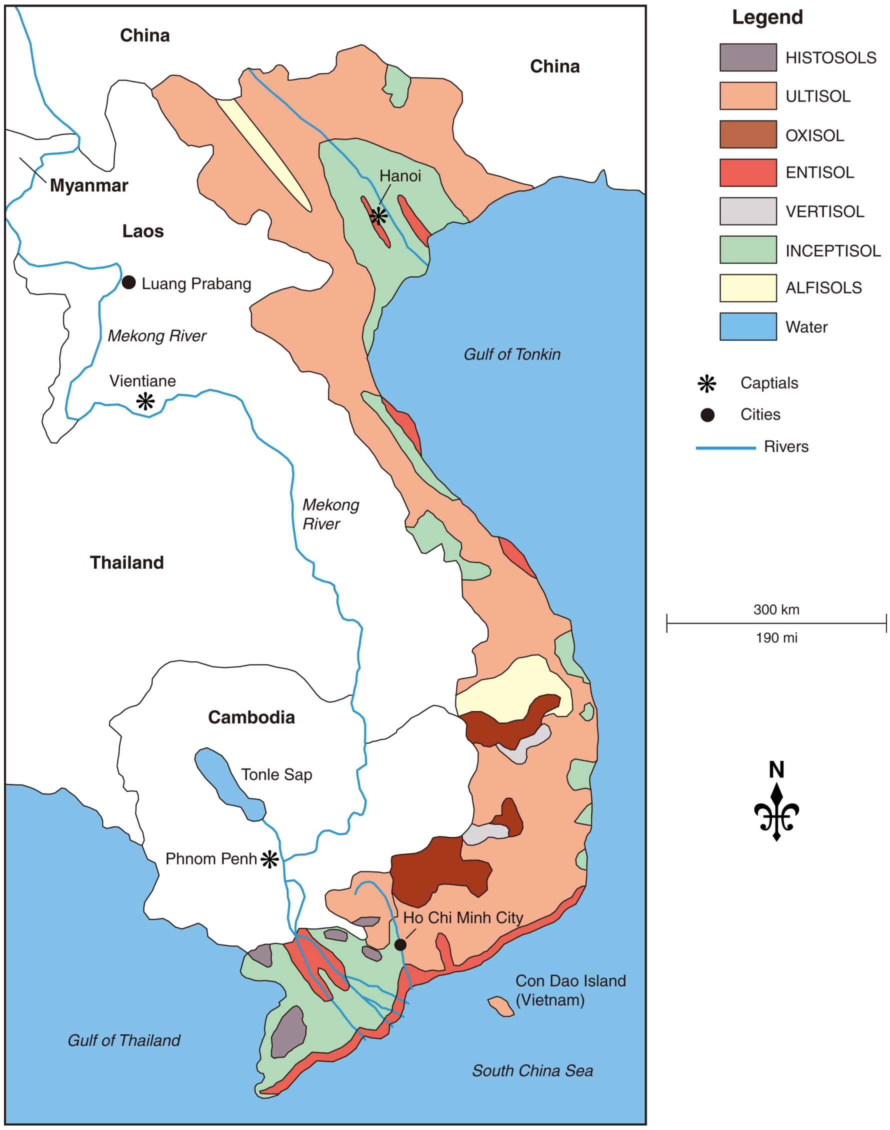

Figure 4. A soil map of Vietnam. Adapted from FAO/UNESCO preliminary definitions legend and correlation. Table of the soil map of the world. world soil resources report no. 12. Rome 1964. Reprinted with the permission of the Editor of the Open Journal of Soil Science. OJSS 7: 34-35. Map by Mic Greenberg.

from plate tectonics and other geophysical processes, aggradation, sediment compaction and the global volume of the ocean. Sea levels are rising because of natural and human induced climate change. As oceans warm, the ice sheets near the poles melt, increasing the volume of available water and resulting in sea level rise.

Dams, levees, polders, dykes and embankments that trap silt and starve deltas of new sediment severely limit aggradation. Extraction of groundwater and hydrocarbons increase sediment compaction. The total weight of urban infrastructure, such as Bangkok, Thailand [13], contributes to compaction. Groundwater recharge is reduced when pavements and nonporous structure roofs prevent surface water from percolating into the soil and underlying sediments.

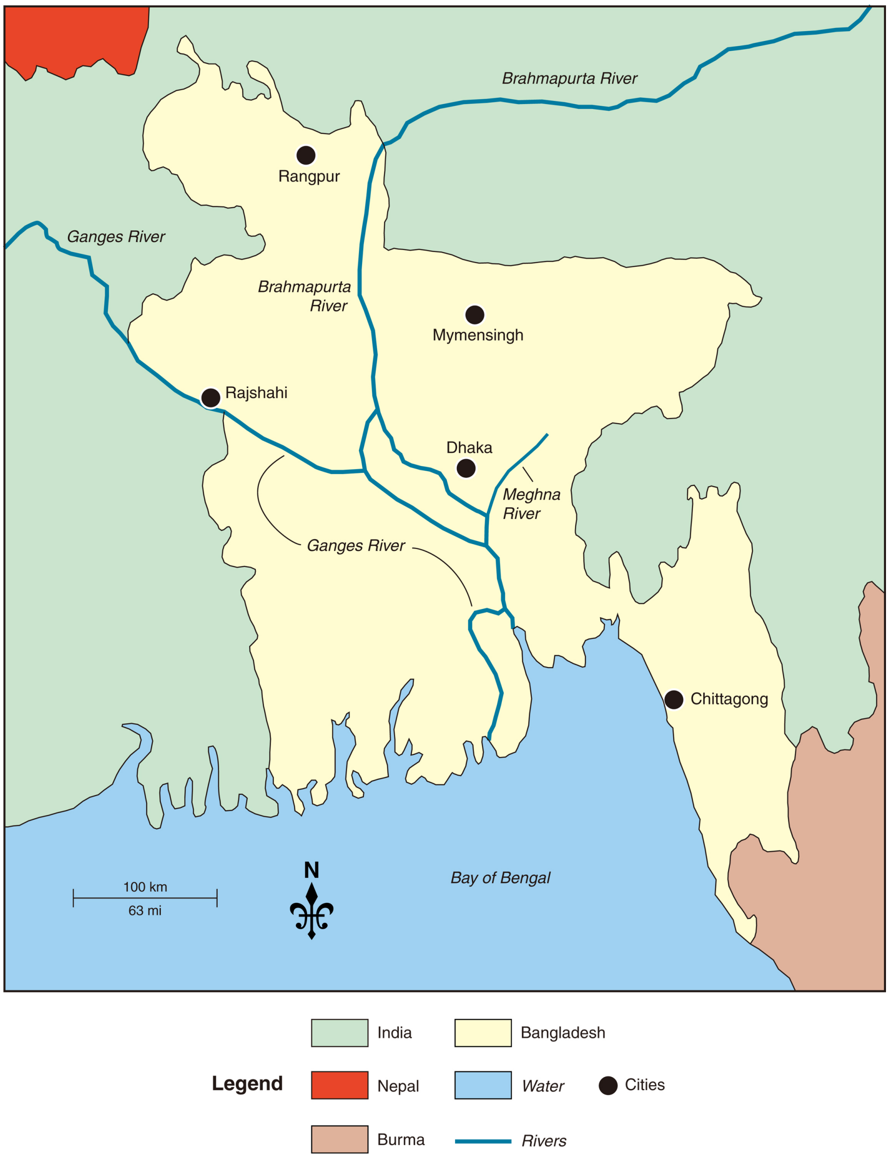

Figure 5. Bangladesh map showing the location of the Ganges and Brahmaputra rivers and delta. Map by Mic Greenberg.

Increasing compaction and reduced aggradation has put most of the world's mega deltas in danger especially in Southeast Asia. Delta areas are sinking below sea level and the tributary and sea flooding is worsening. The biggest threat is the possibility that a mega delta will collapse. The Indus River Delta in Pakistan has already collapsed. For 140 days a year, the Indus River runs dry before reaching the Arabian Sea. The overexploited river, used for agriculture and irrigation, contributes to the river running dry. The Indus River will soon run dry during most of the year. The Indus River Delta is now only 1/10th of its original size. Intruding seawater has displaced hundreds of thousands of people, submerged coastal villages, and contaminated adjacent groundwater reservoirs.

The Ganges-Brahmaputra Delta with 170 million people is sinking and could collapse also. Dams and levees [14] have reduced sediment delivery to

Figure 6. Ganges-Brahmaputra delta. Monsoon rains flooding a city street in Bangladesh. Credit line: Courtesy of Al Jazeera English.

Figure 7. Concrete sea wall in Jakarta. Indonesia ponders plan to move capital from Jakarta. Credit line: Courtesy of Deutsche Welle.

Ganges-Brahmaputra Delta. The worst subsidence has occurred in the tens of thousands of square kilometers of river islands southwest of Bangladesh. Concrete (**Figure 8**) and earthen embankments were built to hold back the sea [15]. Polders were built in 1960s around lower lying plots of land. The embankments blocked replenishment of the delta with river sediments carried downstream by annual monsoon floods. These islands have lost 1 - 1.5 m of elevation. Now storm surges can breach or damage the walls around the polders and create crater lakes that can last for years [16].

3.2. Case Study 2: Jakarta Delta

Jakarta pumps 180 - 250 million·m^3 of groundwater per day (including legal and

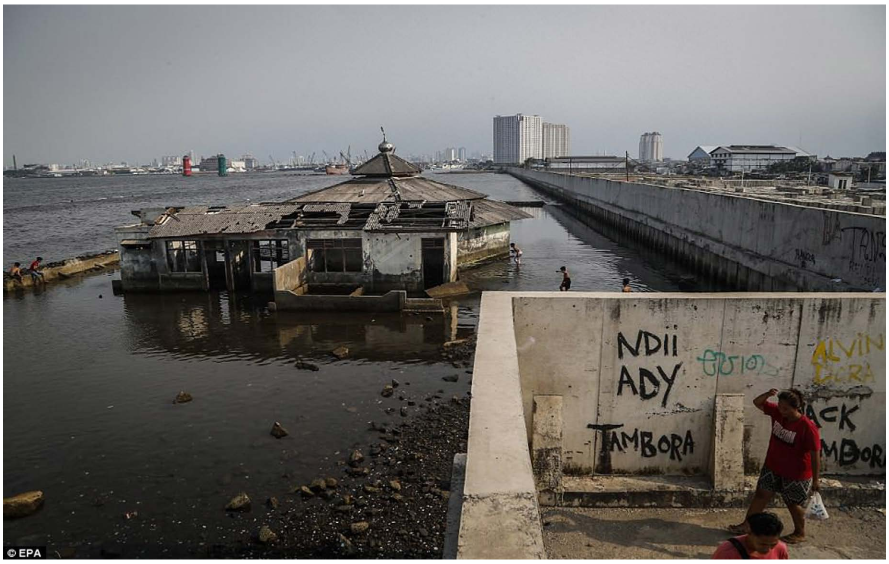

Figure 8. Jakarta sea wall with building trapped on the seaside of the wall. Credit Line: Courtesy of Seattle Times.

illegal usage). The extraction of deep groundwater has accelerated the compaction of overlying clays in the Jakarta Delta. The trend is worse in northwest Jakarta (Figure 9) where subsidence rate is 20 cm per year. Shallow groundwater contaminated with surface pollution can remain trapped for months under the city (Figure 10) during the dry season when no water is available to flush low-lying areas.

Companies that supply treated surface water, in place of groundwater, complain they have few customers and cannot afford to make upgrades. The city's high-rise buildings, hotels and industry prefer deep groundwater over the poor quality treated surface water. Jakarta officials suggest that if the deep groundwater use cannot be curtailed by 2030 subsidence will continue to be a problem. Either the existing population of 4 million people living in northwest Jakarta will have to evacuate to higher ground, including the entire government, or else a giant seawall (Figure 8) which is being planned by the government must be built to block the Bay of Jakarta.

Rising sea levels can magnify the consequences of land subsidence (Figure 11). In Jakarta subsidence has been rapid (Figure 12) and the experiences and lessons learned could help guide other Southeast Asia delta's subsidence mitigation and remediation approaches.

3.3. Case Study 3: Chao Phraya Delta (Thailand)

Bangkok is located on a nearly level deltaic-marine plain (Figure 13) in 0.5 to 1.5 m above mean sea level. The pumping of groundwater in Bangkok metropolitan, during the last 50 years, has resulted in a compression of silts and surficial deposits, reduction in pore pressure, dramatic lowering of piezometric levels, and more than 0.5 m of ground subsidence (Figure 12) with a maximum settlement rate of 10 to 12 cm per year [13].

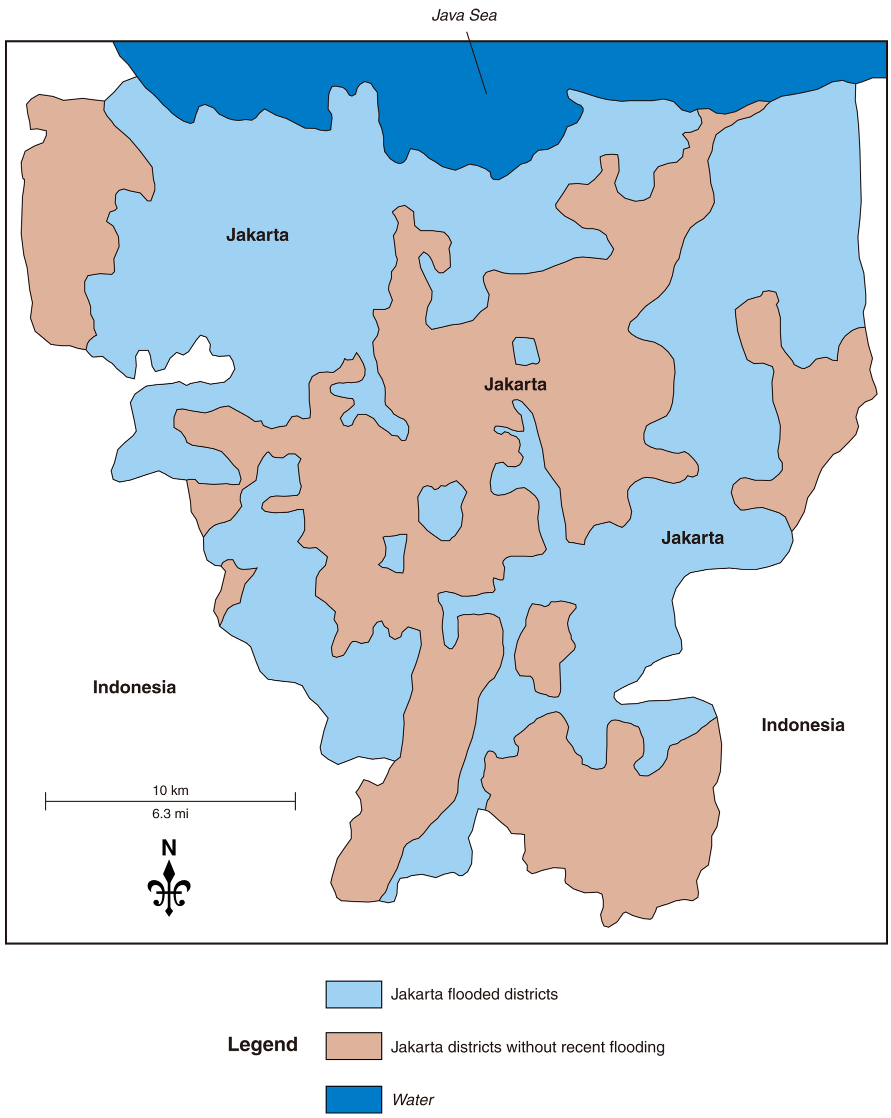

Figure 9. Jakarta flood map. Approximately half of the city districts flood. Map by Mic Greenberg.

The intensive groundwater extraction is causing up to 3 cm/yr of land subsidence and a total 27 cm land surface drop between 1988 and 2020. Erban *et al.* [17] suggested the deep groundwater extraction is causing interbedded clays to compact and expel water containing dissolved arsenic-mobilizing solutes (e.g.) dissolved organic carbon and competing solutes to deep aquifer over decades.

The capital of Thailand, Bangkok is home of 20 million people and situated on the Chao Phraya River and Delta floodplain (**Figure 13**). The city is 28 km north of the Gulf of Thailand. It is known as "The Venice of the East" with dozens of large canals (Klongs) which drain into the Chao Phraya River [18]. Throughout the Bangkok area (Chao Phraya Delta), the water table is at or near the surface. Many areas in Bangkok flood quickly during the monsoon season. The city has been subsiding or sinking with some areas having already subsided 150 cm or more. Parts of the city are now below sea level. In the southeastern metropolitan

Figure 10. Trapped water flooding at Jakarta drainage ditch, which is lined with home sites. The ditch was dredged to improve the flow of drainage water. Courtesy of the Jakarta Post.

Figure 11. River back landslides in Jakarta. Credit Line: Courtesy of the Jakarta Post.

area, the floodwater resides there for much longer times and drainage has become less efficient because of reduced gradients in canals and storm drains. Artificial recharge is needed to restore piezometric heads of the multi-aquifers system.

Experts suggest that eroding shorelines and unchecked urbanization will leave Bangkok residents in a critical situation. The weight of infrastructure and people has contributed to the city's gradual descent into the water. Bangkok has become a victim of its own developmental success. Making the situation worse is a

Figure 12. Approximately 30 cm of subsidence around a pump station structure in Jakarta. Credit Line: Courtesy of the Jakarta Post.

network of bridges and roads that have replaced the canals that are used to traverse the city. The canals were part of a natural drainage system throughout the city. Shore erosion has exacerbated loss of land and subsidence. Aquaculture development and shrimp farms have replaced the shore stabilizing mangrove forests.

Bangkok can be trapped by monsoonal tributary flooding from the north and flooding from the Gulf of Thailand to the south. In the future, more intense storms are expected occur in this region and continue to erode the shoreline and flood the city. The city weakness is a result of hyper-development of neighborhoods with small tunnels that drained water from the land. These small tunnels previously acted as water storage basins but are now inadequate due to population pressures and increasingly more frequent high precipitation events. The government is constructing a 2600 km municipal canal network with pumping stations and eight underground tunnels to mitigate the effects of potential climate change and evacuate water faster if disaster strikes. In 2017, Chulalongkorn University built a four ha park that is designed to re-direct several million liters of rainwater so surrounding neighborhoods are not flooded; however, these fixes may not be sufficient in the long term.

3.4. Case Study 4: Mekong River and Delta

The Mekong River discharges 457 km^3 of fresh water annually from a 795,000 km^2 watershed area. Discharge volume and flood timing historically have been highly predictable and concentrated in an extremely regular wet season peaks [19]. The wet or monsoon season begins when warm moist winds from the ocean blow eastward over Cambodia, Thailand, Lao PDR and Vietnam and bring heavy rainfall. The onset of flood season usually occurs near the end of June each year and lasts about 130 days. The start and end of the annual flood occurs within a period of two weeks with little variation. The dry season onset

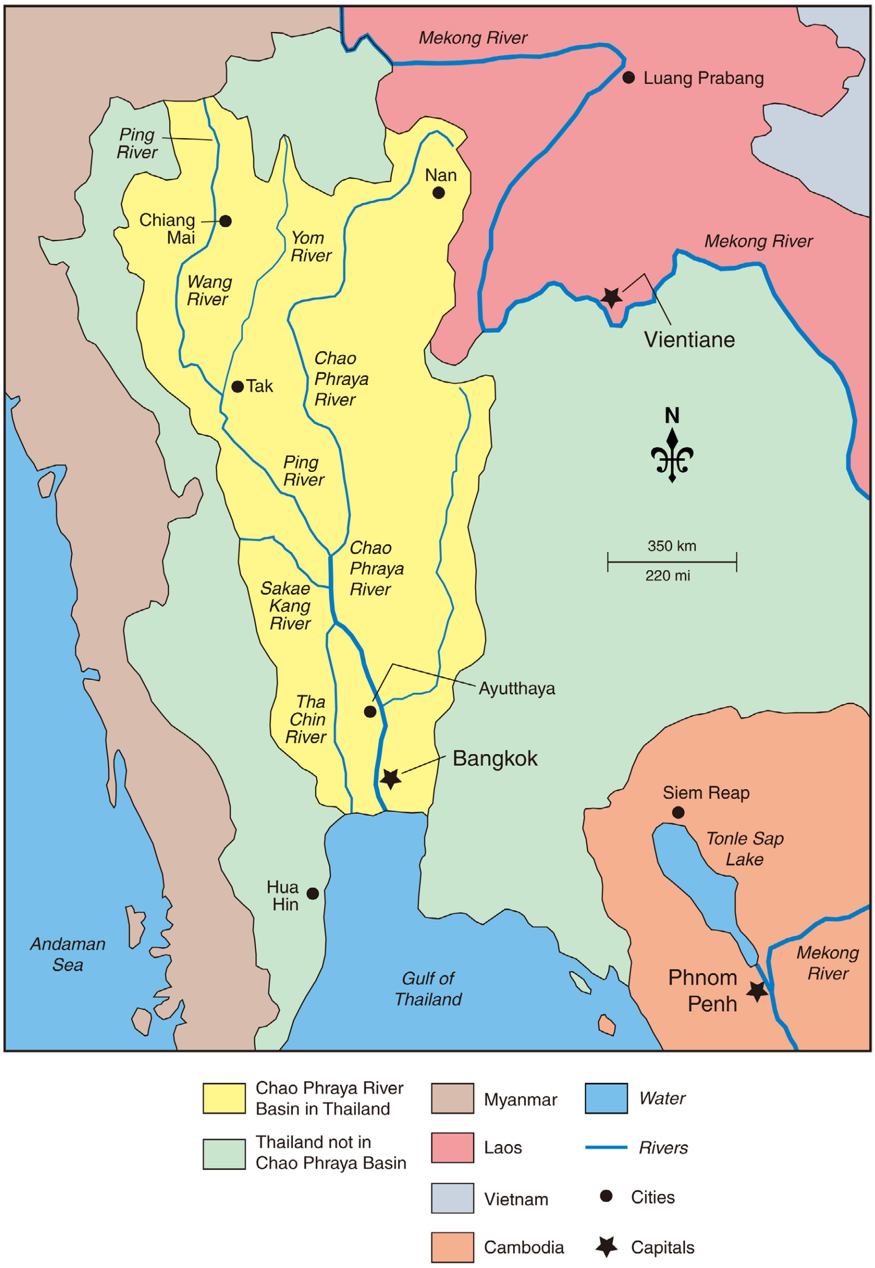

Figure 13. Bangkok map-Thailand. Chao Phraya River and tributaries and Chao Phraya Delta. Reprinted with the permission of the Editor of the Open Journal of Soil Science. OJSS 11: 197-215. Map by Mic Greenberg.

begins in late November.

As moisture-laden winds encounter the ridges and mountains of Lao, the left-bank (eastern) tributaries of the Mekong receive high levels of monsoon rainfall. The 14 tributaries in northern Laos all drain into the Mekong River (**Figure 1**), including the 447 km Nam Ou River longest tributary river in Lao. Runoff from Laos tributaries of the Mekong are the source of major wet season flooding, discharge and sediment load [20]. The longest single tributary of the Mekong is the 673 km Mun River of northern Thailand. Despite its length, the

Mun River contributes very little of the Mekong's discharge and sediment load since the river drains a dry, flat region.

The Mekong Delta, with 20 million people is subsiding at the rate of 1.6 cm per year [12]. The Mekong Delta is one of the world's major rice exporters. Delta plains have low bearing strength and soils are soft and easily compressed. These plains are usually held up above sea level by fresh groundwater that flows through the pores of sediment deposits. When those resources are extracted, such as in the Mekong Delta, the sediment compresses, the land shrinks, and the surface is lowered.

4. Discussion

Population growth and rapid urbanization have resulted in Ho Chi Minh City land subsiding at the rate of 8 cm per year for the past 20 years with no end in sight. By 2050, according to a report by United Nations Intergovernmental Panel on Climate Change, sections of Ho Chi Minh City could slip underwater. Approximately 40 percent of the Mekong Delta is only 1 m or less above sea level and is increasingly vulnerable to rising seas level, flooding (**Figure 14**) shoreline erosion (**Figure 15**), storms and heavy rainfall.

Vietnamese construction engineers have begun raising Ho Chi Minh City homes by 2 m especially in the areas where the local roads are being raised by 1 m. The reason is that these homes flood every year during the May to November monsoon season. The flooding has been getting worse every year and is causing stream bank erosion (**Figure 15**). Ho Chi Minh City, with a population of 9 million, is facing a changing climate where the extreme conditions are occurring more frequently. Infrastructure is required to mitigate flooding which to date has not been forth coming [19].

Solutions offered by Vietnam government include building a giant dyke at the

Figure 14. Scouters in floodwater on street with stores flooded along the Saigon River. Courtesy of Derrick A. Paulo, Channel News Asia.
https://www.channelnewsasia.com/cnainsider/siege-climate-man-made-problems-sinking-ho-chi-minh-city-floods-2052231.

Figure 15. Vietnam shore erosion along the Mekong River. The house is failing into the river. Credit Line: Courtesy of DTi News.

mouth of the Mekong Delta (Figure 16). Many sections of Ho Chi Minh City is currently subjected to periodic tidal floods. However, climate change is not the only cause of the city's problem. The disappearance of green spaces via removal and old canals being filled in has reduced the city's water storage and internal drainage. The density of green space is about two square meters per person. The green space is needed to temporarily hold rainwater during storms. This reduction in green space and canals is a result of adding nearly 2.0 million residents to the Ho Chi Minh City population between 2009 and 2020 [19].

Land subsidence is occurring where high-rises are built and concentrated on the alluvial soils (Figure 17) with a low bearing strength. Currently most flooded areas are next to new high-rise developments. An additional land subsidence cause is over-extraction of groundwater that can create underground cavities and cause the land surface to collapse or sink.

The rapid expansion of Ho Chi Minh City population has outpaced the city's water supply distribution system [19]. Many businesses and residents have had to extract groundwater-using thousands of household and industrial wells. For the past 20 years more than 1 million cubic meters per day of groundwater has been extracted.

The government authorities have begun to restrict the private extraction of groundwater to reduce land subsidence. These restrictions and improving the distribution of piped water into Ho Chi Minh City has reduced the groundwater extraction rate to 300,000 cubic meters per day.

Southern Vietnam includes the Saigon River (Figure 18 and Figure 19) and Delta and the Mekong Delta (Figure 17) and both deltas are sinking as a result of land subsidence caused by excessive pumping of groundwater for shrimp ponds, rice paddies and to meet the drinking water and household needs of 20

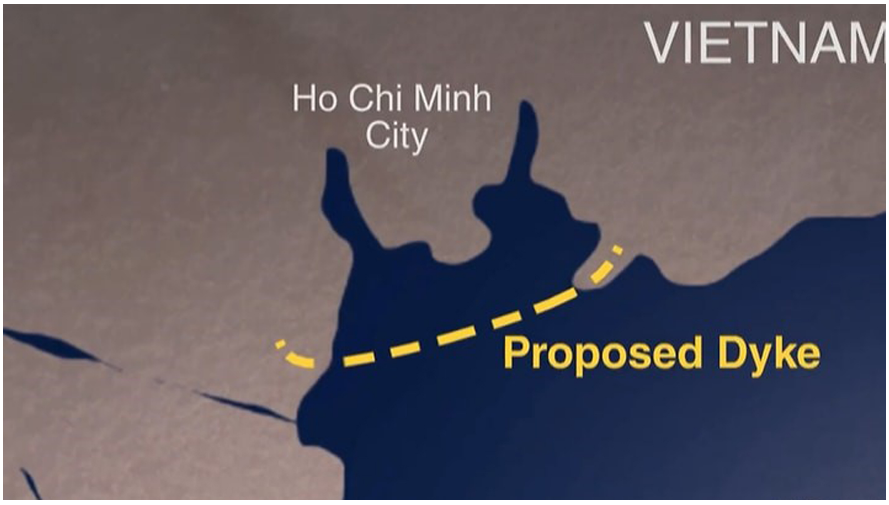

Figure 16. Proposed location of the Dutch dyke system at the mouth of the Mekong River. Courtesy of Ikhwan Rivai, Channel News Asia.
https://www.channelnewsasia.com/cnainsider/siege-climate-man-made-problems-sinking-ho-chi-minh-city-floods-2052231.

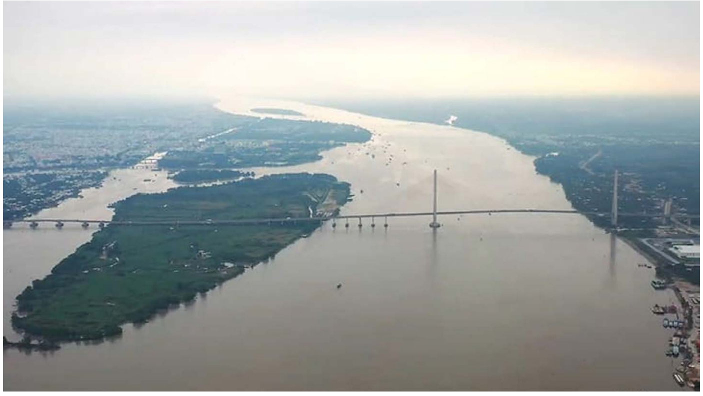

Figure 17. Mekong river with island and a bridge. Courtesy of Derrick A. Paulo, Channel News Asia.
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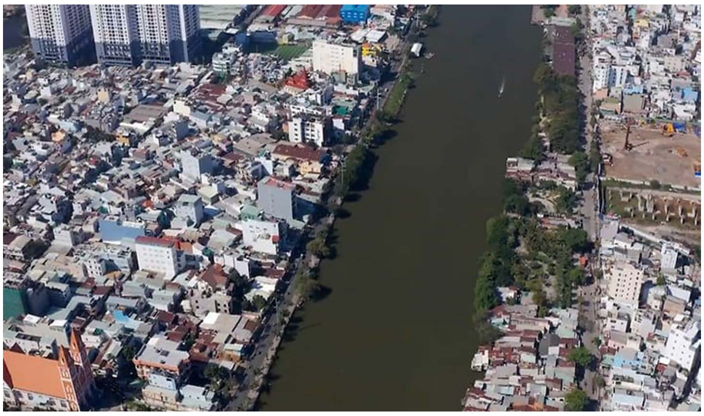

Figure 18. Saigon river with extensive commercial urban development on riverbanks in Ho Chi Minh City. Credit Line: Courtesy of MediaCorp.

Figure 19. Saigon river in Ho Chi Minh City with trees and green space on the riverbank and high-rise structures in the background. Courtesy of Derrick A. Paulo, Channel News Asia. https://www.channelnewsasia.com/cnainsider/siege-climate-man-made-problems-sinking-ho-chi-minh-city-floods-2052231.

million Vietnamese living in the Mekong Delta. The entire delta is sinking at up to 10 times faster in these hotspots than the China Sea is rising. This groundwater extraction problem is aggravated by sand removal since the sand is no longer being replenished.

The mitigation solution to excessive sand extraction is to ensure more replacement sediment is deposited by floodwaters on the floodplains. With the construction of the China and Laos dams on the main steam of the Mekong River and tributaries this is no longer possible. In addition, the creation of polders, earthen levees, dikes, polders and flood or sea walls reduced the sediment deposition on the Mekong Delta floodplains.

The cost of extreme flooding in Ho Chi Minh City could cause between $200 to $300 million in damages. If a 100-year flood occurred in 2050, the economic impact could be 5 to 10 times higher. According to the World Bank and the United Nations Intergovernmental Panel on Climate Change (UN IPCC), Vietnam and other SE Asia countries with major cities on deltas could become the most affected cites because of global warming and rising sea levels. At the port city of Vung Tau, the average sea level increase is 0.45 cm per year. The Mekong Delta in Vietnam is one already one of the most affected deltas.

The Vietnam authorities have proposed a 23 km sea wall across the mouth of the Mekong River (**Figure 16**) to protect Ho Chi Minh City and surrounding region governments and to prevent the rising seawater from entering the Mekong Delta. Some scientists and engineers have suggested the Dutch dyke system proposal was meaningful and far-sighted. Others consider dykes a short-term measure that only addresses the problem of rising sea levels but not the other key environmental and habitat issues. The dyke system does not really solve the sea rise problem; it only moves the locale of the problem. Earthen levees and dykes also stop water from bringing sediment deposits to the floodplain which could re-build the land surface on the floodplain. Sediment deposition on the floodplains is critical and is the real solution.

The high cost of constructing a dyke system at the mouth of the Mekong River, similar to the Dutch system, has led some analysts to question the Mekong River dyke system project's financial viability since they are also expensive to maintain. The risk of the dyke system to the ecosystem is another reason not to build dykes. Dykes block the movement of nutrients which are the food source for living organisms [19]. These dykes are artificial barriers to tributaries entry where fish go to spawn and feed and affects the fish life cycle. Even the Dutch, who have one of the stablest and safest deltas in the world, realize they lost bio-diversity and fisheries and are now starting to remove some of their dikes. The Mekong Delta already has dykes along the riverbanks to protect agricultural lands. However, these do not solve the problem of flooding. When high tides from the South China Sea occur, the seawater pushes the Mekong River water backupriver and the river can no longer find sufficient floodplain space because the agricultural lands are blocked by high dykes that disrupt the natural sediment deposition process. Sometimes the backed-up river finds room in adjacent urban areas that are not protected by high dikes and floods streets and homes (**Figure 20**).

A super-dyke plan has a very high economic cost, environmental impact and would take decades to construct. Ho Ci Minh City has only 3 decades left to address the issue before 2050. With land subsidence, infrastructure shortcomings and rising sea levels, can anything be done to save the Mekong Delta of Vietnam? Yes. A multi-pronged solution is needed including: 1) Government authorities swiftly and effectively dealing with the excessive ground water extraction problem. The Vietnam government authorities should consider the proposed Bangkok river water injection system approach to replacing the extracted

Figure 20. Flooded streets between the saigon river and commercial buildings in Ho Chi Minh City, Vietnam. Courtesy of Ikhwan Rivai, Channel News Asia. https://www.channelnewsasia.com/cnainsider/siege-climate-man-made-problems-sinking-ho-chi-minh-city-floods-2052231.

groundwater. 2) Develop more green spaces and reservoirs in Ho Chi Minh City area. 3) Restore and enhance the cities current drainage and canal system. The Vietnam government needs to develop a multi-pronged "living with nature" approach, which utilizes ecosystem processes and builds in harmony with nature rather than authorities just trying to control nature including the South China Sea and the Mekong River by engineering only.

5. Summary, Conclusions and Recommendations

Significant Mekong Delta land areas and wetlands are being lost each year because of coastal shoreline erosion. The wetlands and land mass are also subsiding as a result of the sediment deposition reduction caused by dams on the mainstem of the Mekong River, groundwater extraction, salt-water intrusion, and consolidation, reduced sediment loads in lower Mekong River and reduction in the current plumes flowing into the South China Sea. The loss of sediments from the China, Laos and perhaps future Cambodia dams needs to be addressed. The trapped, sediment behind these huge reservoir dams, needs to be dredged and transported over the dams and returned to the mainstem of the Mekong River to flow to the Mekong Delta. This process needs to be repeated at each dam site in China and Laos. In addition, artificial recharge is needed to restore piezometric heads of the multi-aquifers system. The mangrove forests along the South China Sea need to be restored. Without sediment additions over time, the Mekong Delta will continue to sink into the South China Sea.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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