Chapter

Anthropogenic Activities as a Source of Stress on Species Diversity in the Mekong River Delta

Charles Nyanga, Beatrice Njeri Obegi and Loi To Thi Bich

Abstract

Deltas are landforms, which come into existence when sediment carried by river or stream empties its load into another water body with slow flow rates or stagnant water. Sometimes, a river may empty its sediment load on land, although this is uncommon. The world's deltas are amongst the most productive and in some cases more populated than even land. This chapter reviews the formation of deltas, the ecology and habitats of deltas as well as the biodiversity in coastal habitats and delta habitats. Additionally, the chapter looks at recent advances in deltas such as the loss of sediment and other stressors currently facing deltas with a focus on anthropogenic activities in the Mekong River Delta (MRD) that is amongst the most resource rich deltas in the world. The Mekong River Delta (MRD) is currently known to be in peril due to anthropogenic activities such as dam construction for hydropower and irrigation, overfishing, agricultural production amongst many others. Additionally, demographical trends like population increase have also been scrutinized to see the impacts on the MRD. The results of the review process have shown that at least 85% of the deltas in the world are subsiding and losing their fertility to the sea. Finally, the chapter has endeavored to come up with suggestions on how best to overcome some of these stressors resulting from the anthropogenic activities.

Keywords: biodiversity, sediment load, stressors, anthropogenic, demographic, subsidence

1. Introduction

A Delta as defined by [1] is "the wetland which forms as the rivers flowing towards another body of water empty the water and sediments they carry into the other bodies of water. The other bodies of water may be oceans, lakes or other rivers".

NASA [2], explains that as the river enters the lake, the flow slows down, sediments drop out, this leads to delta formation. This formation causes a prism of sediment that tapers outwards to the lake to be created. Continual build – out of the delta as time progresses leads to sediment formation that are inclined in the lake-ward direction (**Figure 1**).

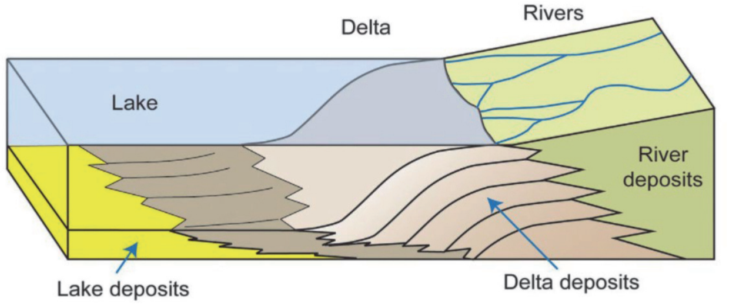


Figure 1.
The is figure which was produced by laboratory computer simulation by National Aeronautics and Space Administration (NASA) shows how a delta is formed as defined by [1]. Source: Adapted from [2].

1.1 Objectives and key scheme followed by this work

The major objective of this work is to: firstly, ascertain the impacts of the arch of anthropogenic activities of like hydropower construction works on the river deltas; secondly, to ascertain the impacts of other anthropogenic activities like agriculture, water abstraction and other industrial activities on biodiversity, thirdly, to ascertain the impacts of the actions by nature on the Mekong River Deltas (MRD).

1.2 Methods and approaches to assessment of anthropogenic activities impact on biodiversity

The methods utilized in this book chapter to achieve the above mentioned in 1.1 above are to review scientific articles, news reports and articles, other research works which are able to provide documented evidence of impacts of human activities on the Mekong River Delta.

Additionally, the methods followed are to review reports, news articles, to provide the levels of stress. These are then examined against the fifteen point stressor analysis framework developed by Scheltinga et al. [3]. The analysis carried out is based on findings by [4–12, 22–25].

1.3 Chapter structure

The chapter sets out by looking at (i) Mechanisms of Delta Formation, (ii) Types of Deltas – their formation, features and habitats, (iii) Deltas in catastrophe - the fifteen feature framework for analyzing the coastal stressors, (iv) The Mekong River Delta is discussed looking at location and then examining the delta against the fifteen point framework for stressor analysis, (v) The anthropogenic impacts on the Mekong is further discussed and supplementary materials are provided and (vi) Conclusions are stated.

2. Mechanisms of delta formation

Deltas are formed as the channel of the river flows across the earth's crust. When the river makes contact with the soil, its flow takes along with it sediments such as gravel, sand, silt and clay. Additionally, when a flowing river in a channel comes into contact with another water body, such a river loses some or most of its speed and tends to deposit the sediments it carries onto a flat area. This sediment which is deposited by a flowing river is termed "alluvium". The slowing speed of a flowing river coupled with the building up of alluvium causes the river to split up from its solitary channel as it gets closer to the mouth. As it flows on, if conditions are right, the river forms a deltaic lobe at its mouth. Additionally, as the deltaic lobe matures, it includes in its formation a distributary network – which is made up of a series of smaller channels which are less developed in depth termed distributaries [1, 13].

As the building-up of alluvium continues, completely new land is formed. This new land forms the mature delta. The delta tends to cause the river's mouth to extend right into the water body into which the river empties its alluvium laden water. River deltas are often divided into two components, namely: (i) the subaqueous, and (ii) the subaerial components [1, 13].

2.1 The subaqueous part of the river delta

The subaqueous component of a river delta is below the surface of water. It is the component which has the greatest slope and contains the silt which is finest. The most recently formed part of the subaqueous delta is referred to as the prodelta, and is most distant from the river mouth [1].

2.2 Subaerial part of the river delta

The subaerial component of a river delta is above the surface of water. The lower delta is that component of the subaerial delta component which is most influenced by waves and tides whilst the upper delta is that component of the subaerial delta most influenced by the river's flow [1].

3. Types of deltas

According to Seybod et al. [14], the terminology 'delta' is of Greek origin. It is believed by many people that the scholar who first coined the term delta nearly 2500 years ago was the ancient Greek historian Herodotus [15]. It comes from the Greek capital letter Δ. This coastal land feature became so called due to the fact that deltas are shaped like this Greek letter, Δ, delta. Accordingly, the delta can be said to be a sedimentary deposit brought to the coast by a flowing river channel with subaerial and subaqueous components. Therefore a river delta is formed by sediment laden river water that deposits its sediment at the edge of still water, an ocean or a lake. The structure of the river delta and sediment disposal processes all depend on the discharge levels, sediment amounts and magnitude of the tides. The sediment deposition characteristics depend on a complicated web of interactions amongst dynamic processes of climate, hydrologic characteristics, wave energy, tidal action amongst many other processes.

Galloway [16] as cited by Seybod et al. [14], provided a classification method on which [16], identifies and provides classes of deltas according to three main forces of river delta formation, namely: (i) river-dominated deltas; (ii) wave dominated deltas; (iii) tide dominated deltas (**Figure 2**).

3.1 River dominated deltas

3.1.1 Formation of River dominated deltas

Literature has not differentiated river-dominated deltas from fluvially-dominated deltas. The reason for this could be that all processes related to streams are referred to as fluvial. The word "fluvial" is obtained from the Latin word "fluvius = river" [18]. Additionally, [19], writes about fluvial systems as the systems in geomorphology which are dominated by rivers and streams.

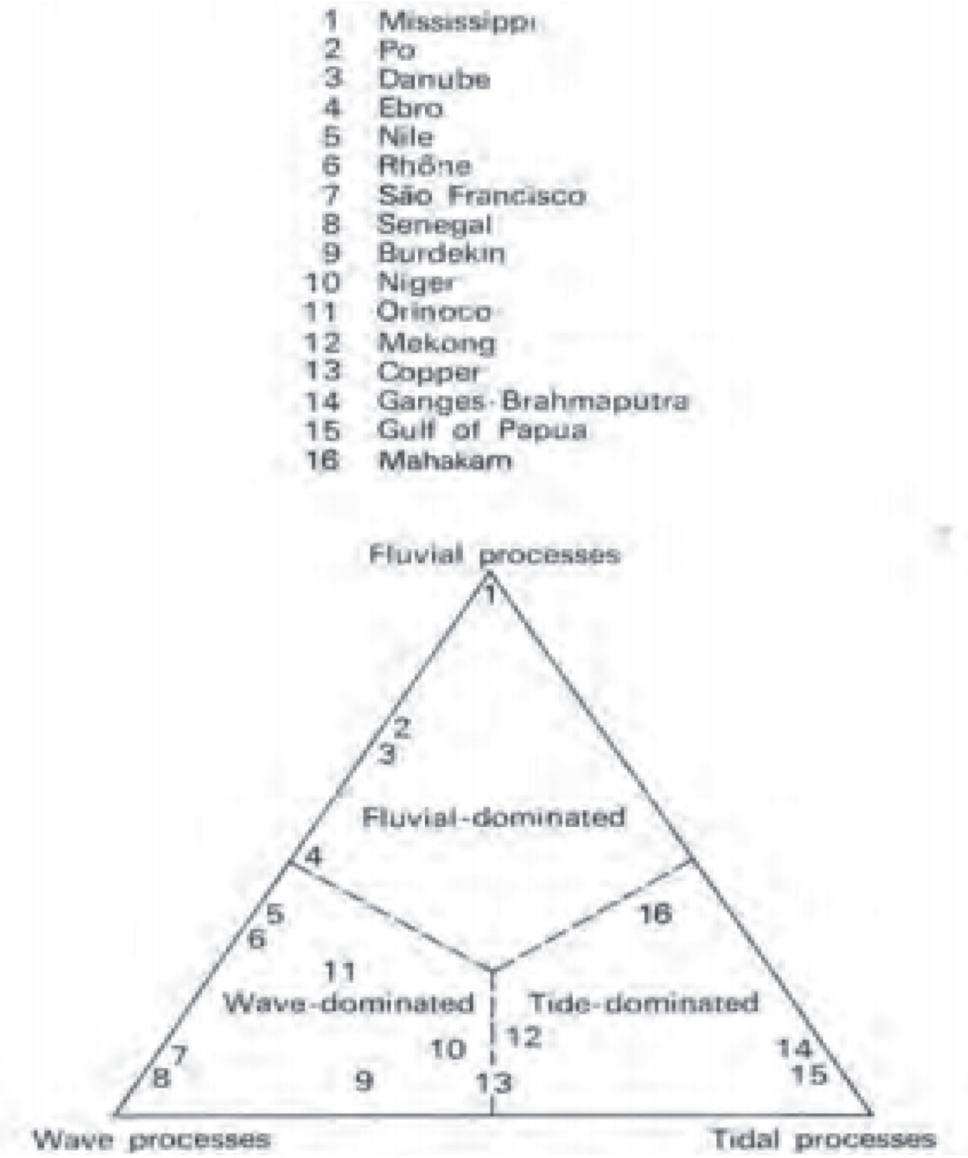


Figure 2.
This ternary is depicting the world's major deltas as well as how they are classified based on the processes involved with that particular delta. It shows that the Mekong River Delta (MRD) is a tide dominated delta and slowly changing to being a wave dominated delta as well. Source: Adapted from [17].

In the article by the Society of Economic Paleontologists and Mineralogists (SEPM), formerly called (Society of Sedimentary Geology) Stratigraphy Web [20] indicates that fluvially-dominated deltas are types of deltas which are mainly under the control of the difference in water density of the flowing water of the river and the standing water of the basin. Further, flow type differences are known to determine the sediments distribution and resulting sedimentary structures.

3.1.2 Features of river dominated deltas

Society of Economic Paleontologists and Mineralogists - SEPM [20], additionally explains that the sedimentary structures are: (i) homopycnal flow – which come into existence whenever the river water density is equal to the basin standing water density; (ii) hyperpycnal flow – which come into existence whenever the river water which flows into the basin has a higher density; (iii) hypopycnal flow – which comes into existence whenever the river water which flows into the basin has a lower density compared to the basin standing water density.

3.1.3 Habitats and ecology of river dominated deltas

Society of Economic Paleontologists and Mineralogists - SEPM [6], furthermore reports that fluvial dominated deltas with low tide and wave energy, after several investigations have shown three structures, namely: (i) inertia – dominated fluvial deltas – which are characterized by flow velocities which are high and large turbulence amounts. In this delta type, sediment deposition does not have a high lateral component; (ii) frictional – dominated fluvial deltas – are characterized by high frictional forces and shear stress at bed level. However, rapid slowing of flow arising from frictional forces and shear stress lead to sediment deposition with a wider lateral extent; (iii) buoyant – dominated fluvial deltas – are characterized by levee formation which result from the existence of a deeper river – basin region of interaction. Other deposit forms popular with buoyance – dominated deltas are distributary mouth bars, bar finger sands, distal bars as well as prodelta clays.

The aforementioned habitats support a variety of marine species. The productivity of plants gains as the tidal range widens. This happens due to pronounced flushing rates and the resulting renewal of nutrients. Grasses, sedges and herbs as well as freshwater wetland and floodplain vegetation occupy the areas above the influence of tides. The lower turbidity of the sea is able to offer support to the growth of phytoplankton.

3.2 Wave dominated deltas

3.2.1 Formation of wave dominated deltas

According to Nienhuis [21], wave dominated deltas are deltas in which the sea waves are the factors that play a dominant role in shaping the fluvial sediment. Examples of wave-dominated deltas are the Nile Delta in Egypt, the St George lobe of the Danube in Romania (Tulcea County) and partly in Ukraine (Odessa Oblast), the Rio Grijalva in Mexico amongst many others.

In another of his studies, Nienhuis [21], reported that the wave dominated deltas attain their shape due to the fact that the coarse-grained fluvial sediment flux which the river supplies to the river mouth becomes less than the largest quantity waves have capacity to transport away through the transportation of sediment along the shore along both flanks of the delta. This is in agreement with [22].

3.2.2 Features of wave dominated deltas

According to [23], the wave dominated deltas, also referred to as riverine estuaries, have the following identifying features:

i. They have variable habitats, mostly, brackish subtidal, intertidal and supratidal.

ii. They have narrow entrances which restricts marine flushing. This leads to very small proportion of water volume exchange at each tide.

iii. The river flow is very high. Whenever there is flooding, marine water is expelled and materials are flushed from the wave-dominated delta.

iv. Turbidity is naturally low. However, whenever there is high fluvial runoff, turbidity levels rise thus turbidity in wave-dominated deltas is dependent in catchment flows inwards.

v. The wave-dominated deltas usually are able to expel sediments into the coastal regions of the ocean.

vi. Wave-dominated deltas tend to have stable morphology due to the maturity of their evolution levels.

3.2.3 Habitats and ecology of wave dominated deltas

The wave-dominated deltas have habitats such as sandy beaches, intertidal flats of mud, marshes of salt and mangrove forests. These deltas are able to support euryhaline estuarine species as well as transient visitor species from the ocean environment whose presence in the delta depend on river flow states.

3.3 Tide dominated deltas

3.3.1 Formation of tide dominated deltas

Goodbred and Saito [24], explain that tide dominated deltas are quiet difficult to characterize. This is due to the major role that fluvial systems have put into action in pronouncing the deltas they are associated with as the rivers vary broadly in their discharge, sediment load, seasonal behavior as well as the sediment material grain size.

3.3.2 Features of tide dominated deltas

Ozcoasts [23], outlines the following as the key features of tide dominated deltas:

i. Tide dominated deltas support a wide range of both marine and brackish, subtidal, intertidal and supratidal estuarine habitats. Most of the delta area is covered by intertidal and supratidal regions whereas seagrass is precluded in certain areas due to turbidity.

ii. The marine flushing delta process is promoted due to the large entrance which tide-dominated deltas have.

iii. Since the flow of rivers is high in tide-dominated deltas, marine water may be expelled due to flooding and material is flooded from the delta by high flowing river.

iv. The turbulence which is induced by tides is strong in tide-dominated deltas which leads to high levels of turbidity.

v. In tide dominated deltas, terrigenous sediments and pollutants are susceptible to being trapped by adjacent environments such as intertidal flats, mangroves, salt marshes and salt flats.

vi. Trapping and processing of loads from land is encouraged by the tidal movements over environments of various features existing side-by-side.

vii. Tide-dominated deltas are stable in morphology since they are mature.

3.3.3 Habitats and ecology of tide dominated deltas

The habitats and ecology of tide dominated deltas are outlined by Ozcoasts [23], further explains that, typically, tide dominated deltas produce habitats such as channels, intertidal mudflats, mangroves, salt marshes, and salt flats.

4. Deltas in catastrophic situations

4.1 Loss of delta health - one of the recent advances in river deltas

According to InteGrate [25], one of the recent advances in river deltas which has been observed in the last decade is that there has been a decrease in the health of the major river deltas of our world. This reduction in the health earth's river deltas has come about due to several reasons. Some the reasons are: over-exploitation of the delta resources by humans, the introduction of pollutants, addition of excessive nutrients to the rivers from poor agricultural practices and industrial production as well as poorly managed river basins that feed the river deltas. All these have largely caused damage to the river deltas' environments which are very sensitive. Additionally, InteGrate [26] reports that one major anthropogenic activity which has upset the river deltas habitats is the reduced sediment loads in many deltas arising from dam construction. Global sea level rise has also resulted in widespread loss of delta based wetlands and other associated habitats like sand barriers along the shoreline.

4.2 Stressors of coastal habitats related to river deltas

4.2.1 Definition of coastal stressor

Coastal habitats and coastal community stressors are defined by Scheltinga et al. [3] as:" Physical, chemical, and biological components of the environment that, when changed by human or other activities, can result in degradation to the natural resources. "Furthermore, Scheltinga et al. [3], explain that stressors can be: (i) an element of the environment capable of transferring the impact of a pressure (for example: an anthropogenic activity) to other parts of the environment after it is changed from its natural state. Examples of such elements are nutrient concentrations which have been changed from the natural level of concentrations, habitat coverage which is less than the natural level, excess salt, amongst many others. There are several elements which are present in a healthy ecosystem. However, if the elements are different from the natural levels, they are taken to be stressors; (ii) an element of the environment that, whenever detected in an environment, might have the potential of causing shifts from natural levels. Such potential stressors are litter and pest species amongst many others.

A framework of fifteen elements on a stressor framework developed by Scheltinga et al. [3] is used here. Scheltinga et al. [3] provides a list of fifteen elements of the environment which have been included in a stressors' (physical, chemical and biological) indicators framework. These elements are:

i. Aquatic sediments (altered from natural levels)

ii. Bacteria/pathogens

iii. Biota removal/disturbance

iv. Excess fresh water (hyposaline)

v. Excess salt (hypersaline)

vi. Fresh water flow regimes (altered from natural levels)

vii. Habitat removal/disturbance

viii. Hydrodynamics (altered from natural levels)

ix. Litter

x. Organic matter (altered from natural levels)

xi. Nutrients (altered from natural levels)

xii. Pests (plant, animal) species

xiii. pH (altered from natural levels)

xiv. Toxicants

xv. Water temperature (altered from natural levels)

5. The great Mekong River Delta

5.1 Geography and location

The Mekong River passes through a basin known as the Greater Mekong [27]. It is a region which holds riches which are irreplaceable. The riches ranges from rare wildlife, plant diversity, natural landscapes to communities with a variety of cultural heritages. The Greater Mekong covers an area of approximately 80.9 hectares which is has some habitats so diverse it is only second to the Amazon (**Table 1**) [27].

The Greater Mekong region is nick named the "rice bowl of Asia" and at the center of the region lies the Mekong River, a transboundary river in East Asia and Southeast Asia. The Mekong River runs through China, Myanmar, Laos, Thailand, Cambodia and Vietnam. It is number 12 in length on the world list and number 6 on

Type of Species	Estimated numbers of species
Mammals	> 430 species
Amphibians	> 800 species
Birds	~1200 species
Fish	> 1100 species
Plants	~20,000 species

**Tiger, Soala, Asian elephants are endangered [27].*
**Mekong dolphin and Mekong giant catfish are endangered [27].*
Source: Compiled by the authors based on information from [27].

Table 1.
This is depicting the species biodiversity in the Mekong.

the Asian list. It runs for an approximate length of 4909 km, drains a region covering 795,000 square kilometers and discharges 475 cubic kilometers of water per year [28]. Before the Mekong River spills its discharge of water into the China Sea in Vietnam, it forms an expanse of distributaries which together constitute a complex delta formation which is known as "The Nine Dragons". That is why the Mekong is sometimes referred to as the "River of the Nine Dragons" [29].

5.2 Biodiversity stressors in the Mekong River Delta

5.2.1 Evidence of altered aquatic sediment levels in the Mekong River Delta (MRD)

Alteration of aquatic sediment from natural levels in Mekong River has been reported in a study by [4]. Piman and Manish [4] report that the Mekong River Commission in 2013 produced sediment monitoring results (for the period before 2003 and after 2009) which showed that average sediment loads in the MRD reduced as follows: at Chiang Saen station, from 60 Million tons/year down to 10 Million tons/year (representing a reduction of 83%); at Pakse, from 120 Million tons/year down to 60 Million tons/year (representing a 50% reduction); at Kratie, the sediment reduction changed from 160 Million tons/year to 90 Million tons/year representing a reduction of 43%. Additionally, Piman and Manish [4] indicate that if all the hydropower stations proposed for the Lower Mekong Basin (LMB) were to be implemented the sediment load reaching the MRD region would reduce to 4% (a 96% reduction).

The implications of the foregoing for biodiversity are dire. Probably this might be indicating that the LMB is advancing towards a tipping point regarding the planetary boundaries and human opportunities for sustainably managing the future natural resources of the earth. Reductions in sediment loads might induce 12% - 27% reduction in primary productivity in the producers in the lower rungs of the food webs in the LMB aquatic ecosystems. Further, fish species such as Lithophils, Psammophils and Pelagophils which are dependent on sediments and nutrients loads might completely fail to adjust to the new nutrient and sediment regime which subsequently might lead to fisheries biodiversity depletion [4].

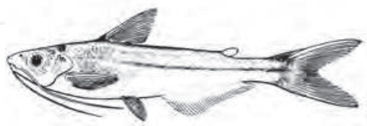
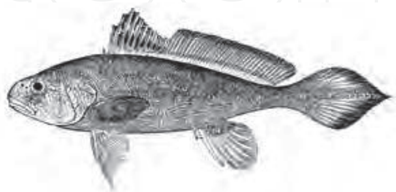
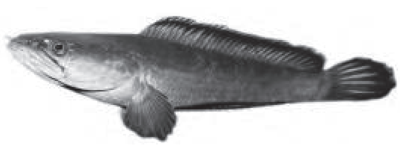
The table below, shows some of the fish species which depend on sediments for reproduction (**Table 2**).

The figure below (**Figure 3**) is adapted from Baran et al. [8] and fully credited to them. It is an expsotion of the composition of the fluvial sediments, both suspended sdiment and bedded sediment. It is clear that if there is a reduction in the sediment all the constituents will reduce accordingly and produce multi- dimensional stress effects on the biodiversity.

5.2.2 Evidence of biota removal, species, habitat and organic matter losses in the Mekong River Delta (MRD)

Allison et al. [5], report that in Lower Mekong River Basin (LMB), at the delta and ocean meeting region, there has been long term reduction in mangrove hectarage due to land-use conversion and utilization of forest products. In 1943 there were 306,000 hectares of mangroves in the delta. This reduced to 253,000 hectares by 1982. This represented a reduction of 17% in the mangrove forest area. However, after some replanting efforts by the Vietnamese government, in 2005 the hectarage stood at 270,000 hectares.

Additionally, the World Wide Fund for Nature (WWF) [6], resounds the dangers faced by Fiona in the MRD by noting that the MRD is home to species like tigers, giant catfish, self-cloning skink, fish with vampire fangs which are all now

Species	Image	Habitats/ reproduction	Impacts of human activities
Probarbus jullieni		Important habitats for spawning are river rapids	
Pangasius macronema		Spawns in rapids at the beginning of the rainy season	
Boesemania macrolepis		Hard rock or pebble with silt or sand substrate, steep rocky sides descending in pools. Spawns in areas at a depth 20 meter with counter-current eddies.	
Probarbus labeamajor		Spawns in rapids	The large dams across the main streams in Stung Treng and Kratie provinces will remove the rapids which are important spawning habitats
Puatioplites proctozystron		Muddy river beds Spawns in slow moving water	If the sediment reduces it will stop spawning.
Channa gachua		River beds with silt or gravel. Spawns in shallow waters	

Source: Adapted and modified from [8].

Table 2.
Habitats and reproduction tendencies of some common fish species in the Mekong Delta.

faced with a future which is uncertain in the face of the rapid development in MRD which is depriving them of their habitats which nature has provided in the form mangrove swamps and forests.

Other sources of information such as [7]; provide detailed accounts of how mangroves forests support fisheries by providing organic matter. These marvelous trees shed off about seven and half tons of leaf litter per acre per year. This litter fall is decomposed by bacteria and metabolized by fungi which release nutrients via the detrital food loop to organisms higher up in the food chains. Detritus is food for shrimp, mullet and many other organisms. Furthermore, Asokan [7], explains that mangroves support fisheries in two major ways, firstly, by providing well protected habitats for larvae and juveniles, secondly, by providing food for the fish from the leaf litter fall in the detrital food web.

The losses of mangrove forests have been producing a negative impact on the biota and the habitats.

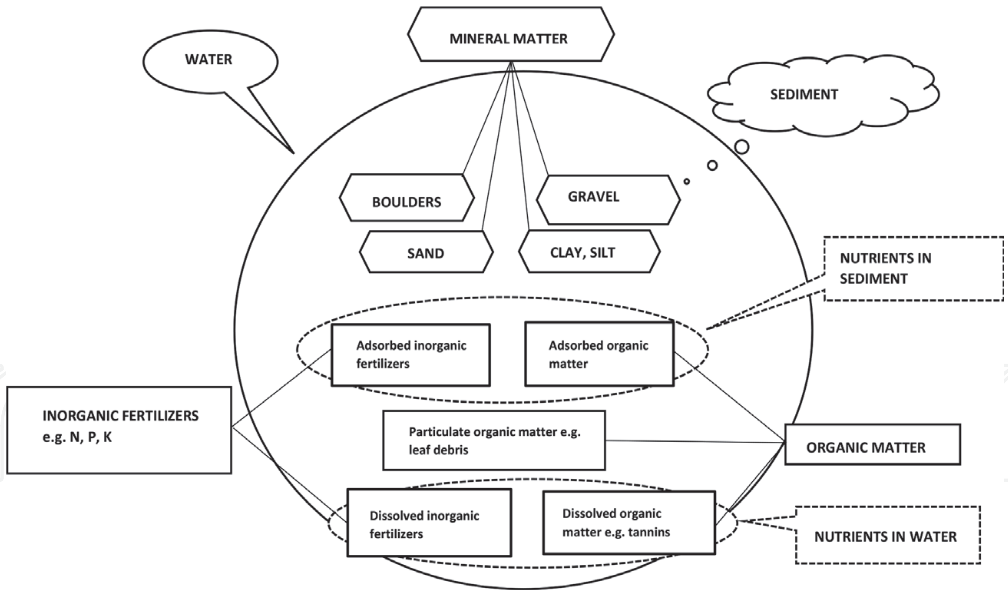


Figure 3.
Composition of river delta sediments. Source: Adapted from [8].

5.2.3 Evidence of nutrient alteration from the normal levels in the Mekong River Delta (MRD)

Alterations of nutrient transport from the natural levels has also been reported by Piman and Manish [4]. Furthermore, Piman and Manish [4] argue that if the full hydropower development which has proposed is implemented at all sites including Kratie, a total projected reduction of 47–53% in Nitrogen transport will be observed and Phosphorus will record a reduction of 57–62%. Additionally, Baran et al. [8] reports that dam developments and the advent of climate change both anthropogenic and natural will result in 53–59% reduction in the amounts of sediments the MRD receives and there will be a reduction of 47–84% in nutrient supply. Furthermore, Baran et al. [8], indicates that dam construction will cause a reduction of 30–38% in the net primary production. This will affect the food webs drastically.

5.2.4 Evidence of salt water intrusion (Hypersalinity) in the Mekong River Delta (MRD)

In their article, Allison et al. [5] report that reduced sediment load in MRD in some cases such as Sang Han distributary have led to salt water intrusion of up to 40 km into the Sang Han distributary channels.

5.2.5 Evidence of pollution from marine litter in the Mekong River Delta (MRD)

Plastics are amongst the most used and disposed off industrial products. The United Nations Environment Programme (UNEP) [12], reported that a colossal 300 million tonnes of plastics debris is produced by humans every year. Of this quantity, 2.7% (or 8 million tonnes) finds its way into the oceans. Additionally, the University of Hull [11] indicated that the Mekong River is amongst the most polluted rivers on Earth. The Mekong transports plastic litter estimated at 40,000 tonnes per year right into the world's oceans (**Figures 4–6**).

Furthermore, Plastics cause a lot of harm to both animals and plants. More than eight hundred marine and coastal species get affected by plastics through ingestion, entanglement, suffocation and many other dangerous ways. The figure below (**Figure 7**) shows how micro plastics affect micro organisms.

Figure 4.
Plastic litter in the Mekong River. Photo credit: United Nations environment programme (UNEP) [12]/ Adam Hodge.

Figure 5.
This figure shows the part of the great Mekong River with mixed litter. This is an opportunity to some sectors of the community while it poses great challenges to some sectors such as the institutions in charge of planning amongst many others. Photo credits: [30].

Figure 6.
This figure expresses the realities in the great Mekong posed by pollution emanating from huge populations in this region. This was sourced from the University of Hull's on-going projects. Photo credits: [11].

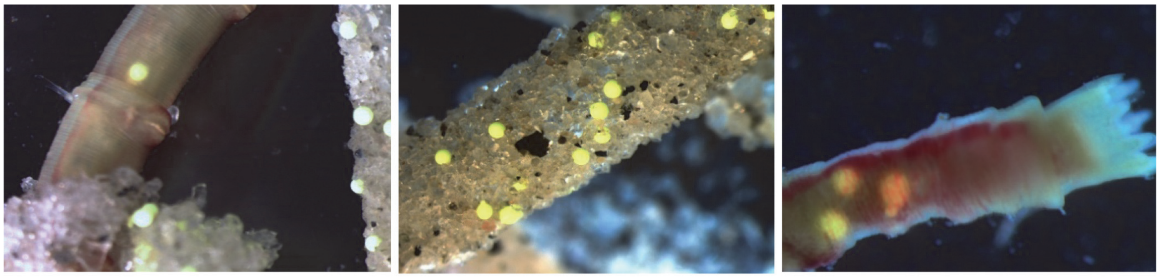


Photo 1 Photo 2 Photo 3

Figure 7.
This figure shows the danger of marine micro plastics to micro biodiversity. Photo 1: Fluorescent polyethylene microbeads incorporated into the tube and also ingested by the bamboo polychaete worm Clymenella torquata. *Photo 2: Fluorescent polyethylene microbeads incorporated into the tube of the bamboo polychaete worm* C. torquata. *Photo 3: Fluorescent polyethylene microbeads ingested by the bamboo polychaete worm* C. torquata. *Photo credits: Center for Coastal Resources Management, Virginia Institute of Marine Science, W&M'.*

5.2.6 Evidence of toxicants, PH and temperature variations in the Mekong River Delta (MRD)

Berg et al. [31], in their article report that in the Mekong River Delta, the Arsenic (As) concentrations in ground- water ranged from 1 microgram per liter to 1610 micrograms per liter (with an average of 217 micrograms per liter) in Cambodia; whilst in South Vietnam the Arsenic concentrations in groundwater ranged from 1 microgram per liter to 845 micrograms per liter (with an average of 39 micrograms per liter). In another research study, Shinkai et al. [9], carried out an assessment of Arsenic and other heavy metal in contamination of groundwater resources in the Mekong River Delta (MRD). Shinkai et al. [9] found that in Tien Giang Province and Dong Thap Province the total Arsenic (As) concentrations in groundwater resources which is utilized for domestic consumption ranged from 0.9 micrograms per liter to 321 micrograms per liter. This was well above the World Health Organization (WHO) guidelines of 10 micrograms per liter. Furthermore, Shinkai et al. [22] indicate that there was evidence of the presence of other heavy metals in groundwater. It was found that 91% and 27% of sampled shallow wells showed concentrations of Manganese (Mg) and Barium (Ba) which are higher than the World Health Organization (WHO) guidelines for drinking water.

The studies reviewed here show evidence of the presence of toxins. However, the levels of the impacts of these toxic elements on biodiversity such as capture fisheries, vegetation, aquatic life and others have not yet been clarified.

On the issue of temperature variation, the Mekong River Commission (MRC) [10] has clarified that there is little temperature variation in Mekong River Delta (MRD). The temperatures in Lower Mekong Basin (LMB) range from 32^{o} C during the warmest months of March and April to 23^{o} C. It can be seen that the temperature stress in the short term might not vary to levels which are dangerous. However, long term temperature variations due to climate change have not been clarified in the region yet.

5.2.7 Other sources of stress due to Anhtropogenic actions

A traveler and researcher [32], the author of the famous book "The Last Days of the Great Mekong", expresses his observations in clear terms. Eyler [32] decided to come up with a book after traveling along the Mekong River and talking to the community members along this river. Eyler [32], provides one very important observation that due to massive dams which have been constructed by the Chinese on the Mekong before it leaves China on its flow route via Myanmar, Laos,

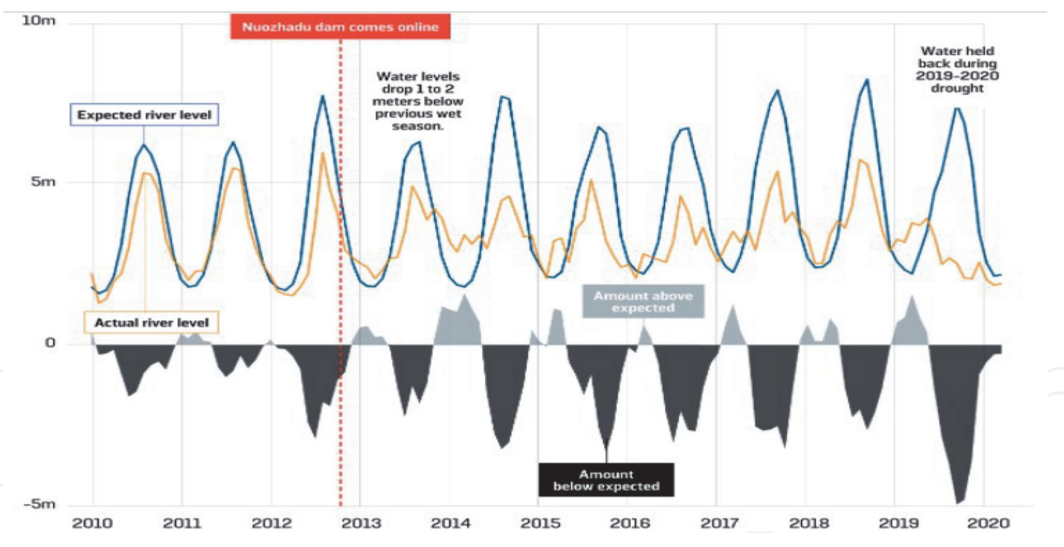


Figure 8.
This figure shows the impact of the Nuozhadu dam on the Mekong River. The dam came on the scene in 2013 and water levels' height in meters has been declining since then. The blue curve is the modeled river water height while the yellow curve is what is actually occurring. Source: Adapted from [32].

Thailand, Cambodia and finally into Vietnam [33, 34]; the Great Mekong which is the source of 20% of the world's freshwater fish catch is heavily dependent on the seasonal monsoon and flow of the river. However, Eyler [32] observes that it is heavily impaired by the Chinese dam construction (**Figure 8**).

6. Further discussions and supplementary materials

The deltas are currently facing many issues apart from the stresses imposed on biodiversity. Additional evidence of concerns is provided by Kazem [35], who indicates that there has been a growing concern owing to poor living conditions for the residents in deltas. Additionally, Safra de Campos [36] found that the Anthropocene has brought about marked changes which occur at scales which are different and speeds which are also varied from one delta region to another delta region.

6.1 Modern trends in deltas

Anthropogenic activities in river deltas and their basins, usually upstream, have dramatically affected delta regions to the level of changing them [37]. As alluded to in earlier sections of this chapter, [38] adds their voice to the devastating level of anthropogenic activities like anti-erosion agriculture, hydrological engineering works like dam construction have reduced river sediment delivery to several deltas in recent decades [39]. Here other key trends in recent decades in delta regions are discussed.

6.1.1 Trend number 1: Decreasing quality of life for populations in river deltas

Two groups of researchers using survey method and Focus Group Discussions (FGD's), namely [35, 40], both point out the environmental degradation that occurs in river deltas. This has subsequently affected the life styles of the populations in deltas. Szabo et al. [41] indicates that there is rapid onset of and creeping processes in deltas which bring about environmental hazards as well as lowering the quality of ecosystems services.

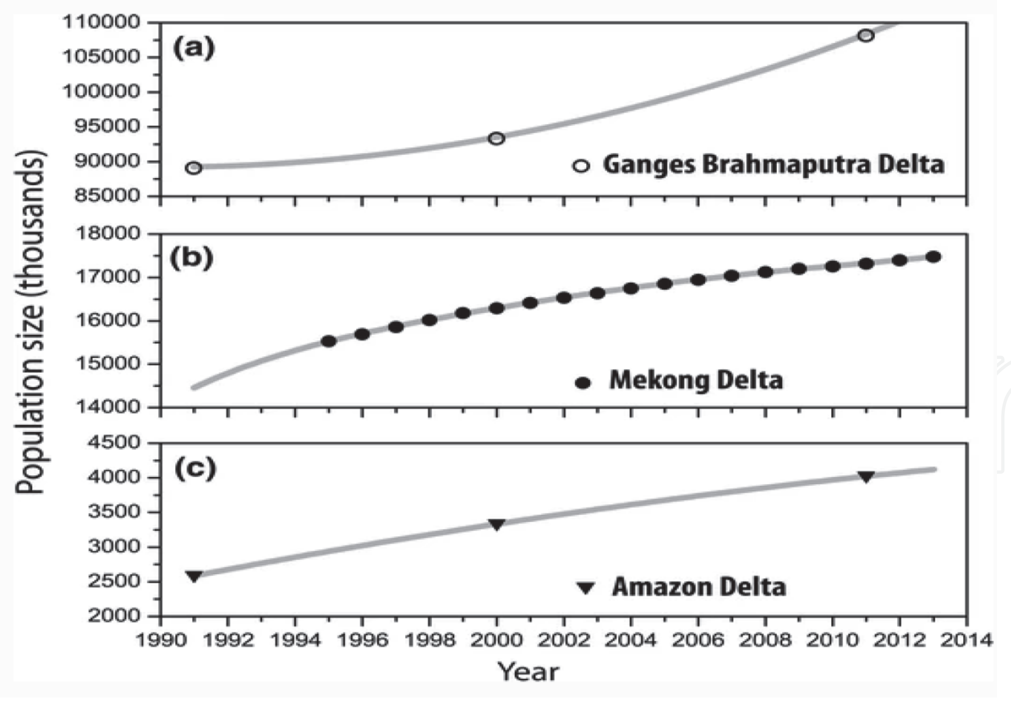


Figure 9.
This figure is depicting the population growths in the rivers deltas namely: Ganges Brahmaputra, Mekong and Amazon based on national statistics. Source: Adapted from [41].

6.1.2 Trend number 2: Increasing populations

Szabo et al. [41] also reports that population in some of the most important river deltas (namely: Ganges Brahmaputra, Mekong and Amazon, see **Figure 9** below) have been rapidly growing. The rapid increase in population has put a lot of stress on ecosystems services in these deltas as well.

6.1.3 Trend number 3: Massive construction activities and sediment losses

The world's river deltas as we know them today were built by long term deposition (aggradation or alluviation) of fertile river sediments over very long time periods [42]. It is due to this alluviation that the river deltas have been providing food-production areas and attracting huge populations [42]. Unfortunately, the river deltas are subsiding. The Mekong River Delta (MRD) is subsiding at the rate of 16 mm per annum [42]. However, the report from Syvitski [38] is showing similar trends but on a lower side (see **Table 3** below). The method Syvitski [38] utilized was to utilize high resolution data sets which were generated by National Aeronautics Space Administration (NASA)'s Shuttle Radar Topography Mission (SRTM). Additionally, the massive dam constructions (see **Table 4** below) has led to a lot of losses in the biodiversity habitats, loss of sediment and decreased levels of water along the Mekong River [32]. The results of studies by Syvitski [38] show that a small number of world river deltas are not under threat. However, Dang et al. [45] in studies of sediment budgets in river deltas using high frequency measurement further provided information on damming along the Mekong River as shown in **Table 4**.

6.1.4 Trend number 4: species threats

The anthropogenic activities have seen many species of fish being endangered, declining or decreasing. Some of the observed disturbances are those suffered by migratory fish species [27], see **Tables 5** and **6**.

Delta	No. Maps	Est. Area km^2 < 2 m ASL	Recent Area km^2 Storm Surge	Recent Area km^2 River Flood	Recent Area km^2 In situ Flooding	% Sediment Reduction	Floodplain or Delta Flow Diversion	% Distributary Channel Reduction	Subsurface Water, Oil & Gas Mining	Early 20th C Aggradation Rate mm/y	21st Century Aggradation Rate mm/y	Subsidence mm/y
Amazon, Brazil	6	1960*	0; LP	0	9340	0	No	0	0	0.4	0.4	?
Amur, Russia	—	1250	0; LP	0	0	0	No	0	0	2	1	0.5–2
Brahmani, India	6	640	1100	3380	1580	50	Yes	0	Major	2	1	0
Chao Phraya, Thai.	2	1780	800	4000	1600	85	Yes	30	Major	0.2	0	50–150
Colorado, Mexico	3	700	0; MP	0	0	100	Yes	0	Major	34	0	2–4
Congo¶ DRC	—	460	0; LP	0	0	20	No	0	0	0.2	0.2	0?
Danube, Romania	4	3670	1050	2100	840	63	Yes	0	Minor	3	1	≈0
Fly, PNG	—	70*	0; MP	140	280	0	No	0	0	5	5	0.5
Ganges¶, Bangl.	9	6170*	10,500	52,800	42,300	30	Yes	37	Major	3	2	18
Godavari, India	6	170	660	220	1100	40	Yes	0	Major	7	2	≈4
Han, Korea	—	70	60	60	0	27	No	0	0	3	2	0
Indus, Pakistan	12	4750	3390	680	1700	80	Yes	80	Minor	8	1	1.3
Irrawaddy, Myan.	2	1100	15,000	7600	6100	30	No	20	Minor	2	1.4	6
Krishna, India	6	250	840	1160	740	94	Yes	0	Major	7	0.4	≈4
Limpopo, Moz.	—	150	120	200	0	30	No	0	0	7	5	0
Magdalena, Col.	14	790	1120	750	750	0	Yes	70	0	6	3	6.6
Mahakam, Borneo	—	300	0; LP	0	370	0	No	?	0	0.2	0.2	0.5
Mahanadi, India	6	150	1480	2060	1770	74	Yes	40	Moderate	2	0.3	0
Mekong, Vietnam	1	20,900	9800	36,750	17,100	12	No	0	Minor	0.5	0.4	>5
Mississippi, USA	15	7140	13,500	0	11,600	48	Yes	?	Major	2	0.3	5–25

Delta	No. Maps	Est. Area km^2 < 2 m ASL	Recent Area km^2 Storm Surge	Recent Area km^2 River Flood	Recent Area km^2 In situ Flooding	% Sediment Reduction	Floodplain or Delta Flow Diversion	% Distributary Channel Reduction	Subsurface Water, Oil & Gas Mining	Early 20th C Aggradation Rate mm/y	21st Century Aggradation Rate mm/y	Subsidence mm/y
Niger, Nigeria	9	350*	1700	2570	3400	50	No	30	Major	0.6	0.3	7.5
Nile, Egypt	15	9440	0; LP	0	0	98	Yes	75	Major	1.3	0	5
Orinoco, Venez.	10	1800*	0; MP	3560	3600	0	No	0	Unknown	1.3	1.3	0.8–3
Parana, Argentina	6	3600	0; LP	5190	2600	60	No	?	Unknown	2	0.5	3
Pearl¶, China	4	3720	1040	2600	520	67	Yes	0	Moderate	3	0.5	7.5
Po, Italy	20	630	0; LP	0	320	50	No	40	Major	3	0	4–60
Rhone, France	11	1140	0; LP	920	0	30	No	40	Minor	7	1	2–6
Sao Francisco, Bra.	—	80	0; LP	0	0	70	Yes	0	Minor	2	0.2	10
Tigris¶, Iraq	7	9700	1730	770	960	50	Yes	38	Major	4	2	5
Tone¶, Japan	—	410	220	0	160	30	Yes	§	Major	4	0	>10
Vistula, Poland	4	1490	0; LP	200	0	20	Yes	75	Unknown	1.1	0	0.3
Yangtze¶, China	8	7080	6700	3330	6670	70	Yes	0	Major	1.1	0	10
Yellow¶, China	11	3420	1430	0	0	90	Yes	80	Major	49	0	8

**Significant canopy cover renders these SRTM elevation estimates as conservative values.*

¶Alternate names: Congo & Zaire; Ganges & Ganges-Brahmaputra; Pearl & Zhujiang; Tigris & Tigris-Euphrates & Shatt al Arab; Tone & Edo; Yangtze & Changjiang; Yellow & Huanghe.

§The Tone R. has long had its flow path engineered, having once flowed into Tokyo Bay; the number of distributary channels has increased with engineering works.

Color key 20^{th}A 21^{st}A > S

20^{th}A > 21^{st}A > S

20^{th}A> > 21^{st}A < <S

20^{th}A> > 21^{st}A < S

20^{th}A > 21^{st}A < <S.

Source: Adapted from [38].

Table 3.
This table is depicting the sediment losses and subsidence of the world's river deltas.

Country	Planned Dams	Proposed Dams	Status	Reference
China	11	2	11 completed	[43]
Laos	43	20	79 completed and planning to reach 100 by 2030	[43, 44]
Myanmar	7	0	No data available from reports	[45]
Thailand	7	0	No data available from reports	[45]
Cambodia	12	0	No data available from reports	[45]
Vietnam	1	0	No data available from reports	[45]
Total	74	22	90 completed	[45]

Source: Adapted and modified from [45].

Table 4.
The number of constructed dams and planned dams on the Mekong River. The data is obtained from various sources and reports as well news articles. Also.

English name	Latin name	IUCN list status	Population status
Goonch	*Bagarius Yarrelli*	near threatened	decreasing
Two head carp	*Bangana behri*	vulnerable	30–50% decrease
Boeseman croaker	*Boesemania microlepis*	near threatened	decreasing, local extirpations
Giant barb	*Catilocarpio siamensis*	critically endangered	80–90% decline
Striped river barb	*Mekongina crythrospila**	near threatened	decreasing
Giant Mekong Catfish	*Pangasianodon gigas**	critically endangered	>80% decline
Striped catfish	*Pangasianodon hypophthalmus*	endangered	~95% decline
Krempf's catfish	*Pangasius krempfi*	vulnerable	~30% decline
Giant pangasius	*Pangasius santiwngsei*	critically endangered	~99% decline
Jullien's barb	*Probarbus jullieni*	endangered	~50% decline
Thicklip barb	*Probarbus labeamajor**	endangered	~50% decline
Laotian shad	*Tenualosa thibaudeaui**	vulnerable	~30% decline
Giant sheatfish	*Wallago attu*	near threatened	decreasing

**Endemic to the Mekong basin.*
Source: Adapted from [46] and other reports.

Table 5.
This table is showing the species threats as reported by on species biodiversity monitoring by the International Union for the Conservation of nature (IUCN) in MRC report.

Migratory guild	Potential range of habitat utilized	Typical characteristics*	Likely impact of mainstream dams on migrations.
Migratory main channel spawner guild	Floodplains to running river upstream	• Spawn in the mainstream, in tributaries and around floodplains • Adults and drifting larvae return to floodplains to feed. • May migrate to deep pools in the mainstream during the dry season. • Sensitive to damming	Very high

DOI: http://dx.doi.org/10.5772/intechopen.101172

Migratory guild	Potential range of habitat utilized	Typical characteristics*	Likely impact of mainstream dams on migrations.
Migratory main channel refuge seeker guild	Floodplains to slow river downstream	• Spawn in floodplains • Migrations between floodplains and mainstream deep pools in the dry sea son. • Sensitive to damming	Very high
Semi-anadromous guild	Estuary and lower slow river downstream	• Enters fresh/brackish waters to breed. • Enters freshwaters as larvae and Juveniles (bligate or opportunistic) • Impacted by river mouth dams that stop migration into the river.	High (for dams located in river mouths or lower potamon)
Catadromous guild	Marine to running river upstream	• Reproduction, early feeding and growth at sea. • Juvenile or sub-adult migration to freshwater habitats • Vulnerable to overexploitation and tend to disappear when river is dammed preventing longitudinal upstream migration. • May respond favorably to fish passage facilities.	Very high

Source: Adapted from [46].

Table 6.
This table is showing the impacts on the migratory pattern of fishery guilds caused by dam construction.

S/N	Resource	Resource contents	Provider
1	<GLOBAL_ANALYSIS_FORECAST_PHY_001_024> (model, 0.083degree x 0.083degree, from 2019 to 2101-01 to Present)	Salinity, Sea Surface Height (SSH)	Copernicus Marine Service
2	<GLOBAL_REANALYSIS_PHY_001_030> (model, 0.083degree x 0.083degree, from 1993 to 2001-01 to 2019-2112-31)	Salinity, SSH	Copernicus Marine Service
3	<GLOBAL_MULTIYEAR_BGC_001_033> (model, 0.083degree x 0.083degree, from 1998 to 2001-01 to 2019-2112-31)	Turbidity, Transparency	Copernicus Marine Service
4	https://help.marine.copernicus.eu/en/articles/5070873-what-are-the-marine-variables-available-to-monitor-the-ocean	All ocean variable monitoring variables	Copernicus Marine Service
5	https://www.mrcmekong.org/about/mekong-basin/geography/	All information about the Mekong River Region	Mekong River Commission (MRC)

Source: Compiled by the Authors for this book chapter.

Table 7.
This table is a collection of various additional resources which readers may refer to.

6.1.5 Trend number 5 – Climate change impacts

In the their article, Safra de Campos et al. [36] indicates that river deltas being in low-lying coastal areas are at risk from both natural climate change impacts and anthropogenic impacts. Examples of this risk are, namely, submergence of the sea front settlements, increased flooding of coastal land, salt water intrusion and changes in the frequency of cyclones.

7. Further resources for readers

The readers who wish to examine and study the issues pertaining to stressors, especially the marine stressors are invited to explore the following resources as indicated in the table below. The Mekong River Commission also has some useful resources available for users (**Table** 7).

8. Conclusions

In conclusion, the anthropogenic activities which have been seen to impact negatively on the shifts of stressor elements from normal levels to levels capable of inducing stress in biodiversity are the dam projects, agricultural practices, industrial operations amongst many other. However, the damming developments have been identified as the most ones prone to inducing stress due to the changes in the sediment loads. This change in sediment loading together with sea-level rise due to climate change have been causing the coastal water to change color from brownish hue to ocean blue in most deltas. This is an indication that the nutrient rich sediment carrying river water is intruded by ocean water with little nutrients impacting negatively on the productivity of coastal habitats.

Therefore, it is advisable to carryout dam development and other developmental activities in a precautionary manner. During planning, developers must take care of all issues pertaining to the sustainability of the projects. Similarly, during implementation care should be taken to ensure all bodied and professionals in the area of marine resources administration and research are consulted.

Acknowledgements

First and foremost, the authors of this chapter wishes to thank all the great writers who have been cited in here. In addition, the authors wish to express their gratitude to the Author Services Manager, Ms. Romina Rovan, for all the support rendered to make this chapter a success. Furthermore, many thanks go to the members of the Deep Ocean Stewardship Initiative (DOSI) from the Center for Coastal Resources Management, Virginia, Institute of Marine Science (W and M) for agreeing to send in the pictures showing the ingestion of micro plastics by small organisms, and of course the authors do not forget to thank the Editor(s) of the book.

Conflict of interest

The authors declare that there is no conflict of interest.

Note of thanks

The lead author wishes to express his thanks to Mr. Joackim Mambwe, from Zambia College of Agriculture - Mpika for helping in modifying Figure 1 from Baran and his team of researchers. Additionally, a hand of gratitude is extended to Mr. Mataa Muimui, a student at Zambia College of Agriculture - Mpika for making his device, the Lenovo Ideapad, available during the periods when the main desk top computer was down to make this work to be submitted on time.

Nomenclature

Aggradation	Also referred to as alluviation. This is the increase of the land elevation due to deposition of sediment in a river delta.
Alluvium	A deposit of clay, silt and sand left by flowing floodwater in a river or delta, typically producing fertile soil
Biodiversity	This term is derived from "biological diversity", it refers to the variety of life on Earth at all its levels, starting from genes to ecosystems.
Biota	Plant and animal life in general
Channel	A water way
Ecology	Ecology is the study of the relationships between living organisms and the environment in which they exist.
Estuary	This is a partially enclosed, coastal water body in which fresh water coming from rivers and streams mixes with the salt water from the ocean.
Fluvial	Of or associated with rivers and streams.
Fluvial process	Processes predominantly associated with rivers or streams.
Geomorphology	The scientific study of the origin and evolution of topographic and bathymetric features on the Earth's surface created by physical, chemical or biological processes (or a combination of these processes)operating at or near the Earth's surface
Habitat	A habitat is a place where an organism makes its home. The 3 components of a habitat are: shelter, water, food, and space.
Hydrodynamics	A branch of Physics that deals with motion of liquids and forces acting on bodies immersed in liquids.
Mangrove	This is a shrub or small tree that grows in coastal saline or brackish water. Mangroves can also grow in fresh water.
Mud flats	Also known as tidal flats,; are coastal wetlands that form in intertidal areas where sediments have been deposited by a tide or river.
River delta	A river delta is a land form which is created by sediment deposition by a river as the flow leaves the river mouth and enters slower moving or stagnant water.
Salt flats	Densely packed slat pans.
Salt marshes	Also known as coastal salt marshes or tidal salt marshes, is a coastal ecosystem I the upper coastal intertidal zone between the land ad open salt water or brackish water that is regularly flooded by the tides.
Sediment	Matter that settles to the bottom of a river or any other body of water.

Stressor	A physical, chemical or biological agent, environmental condition, external stimulus or an event which is observed as causing stress to an organism.
Toxicant	A toxicant is a chemical substance introduced into an environment and is known to be toxic.
Turbidity	The amount of cloudiness of water.
Turbulence	The flow of fluids which is characterized by disorderly changes in pressure and velocity of flow.

Author details

Charles Nyanga[1]*, Beatrice Njeri Obegi[2] and Loi To Thi Bich[3]

1 Zambia College of Agriculture, Mpika, Zambia

2 Kenya Marine and Fisheries Research Institute, Kenya

3 Nha Trang University, Vietnam

*Address all correspondence to: charles.nyanga@gmail.com

References

[1] National Geographic. Delta. 2021. Available from: https://nationalgeographic.org/enclopedia/delta/ [Accessed: May 2, 2021]

[2] NASA. How a Delta Forms Where River Meets Lake. The Jet Propulsion Laboratory, California Institute of Technology; 2014. Available from: https://jpl.nasa.gov/images/how-a-deltaforms-where-river-meets-lake [Accessed: August 24, 2021]

[3] Scheltinga D,Counihan R, Moss A, Cox M, Bennet J. User's Guide to Estuarine, Coastal and Marine Indicators for Regional NRM Monitoring, Report to DEH, MEN, ICAG, Coastal Zone CRC. 2004. Available from: https://ozcoasts.org.au/managemet/emf-frame/user-guide-rm/ [Accessed: June 2, 2021]

[4] Piman T, Manish S. Case Study on Sediment in the Mekong River Basin: Current State and Future Trends, Project Report 2017–03. Stockholm Environment Institute; 2017. Available from: https://www.sei.org/publications/sediment-mekong-river/ [Accessed: June 12, 2021]

[5] Allison MA, Nittroouer CA, Ogston AS, Mullarney JC, Nguyen TT. Sediment and survival of the Mekong delta: A case study of decreased sediment supply and accelerating rates of relative Sea level rise. Oceanography. 2017;**30**(3):98-109. DOI: 10.5670/oceanog.2017.318 [Accessed: June 12, 2021]

[6] World Wide Fund for Nature (WWF). Wildlife of the Great Mekong. 1986. Available from: https://www.fasia.awsassets.panda.org/discovering_the_greater_mekong/species [Accessed: June 9, 2021]

[7] Asokan PK. Mangrove and its Importance to Fisheries. 2012. Available from: https://core.ac.uk/download/pdf/33019864.pdf [Accessed: June 8, 2021]

[8] Baran E, Guerin E, Nasielski J. Fish, Sediment and Dams in the Mekong. Penang, Malaysia: WorldFish, Land and Ecosystems (WLE) 108pp; Available from: https://cgspace.cgiar.org2015 [Accessed: June 10, 2021]

[9] Shinkai Y, Truc DV, Sun D, Canh D, Kumagai Y. Arsenic and other metal contamination of groundwater in the Mekong River Delta, Vietnam. Journal of Health Sciences. 2007;**53**(3):344-346. DOI: 10.1248/jns.53.344. Available from: https://researchgate,net/publication/241759562_Arsenic_and _Other_Metal_Contamniation_of_Groundwater_in_the_Mekong_River_Delta_Vienam/ [Accessed: June 2, 2021]

[10] Mekong River Commission (MRC). Climate. 2021. Available from: https://mrcmekong.org/about/mekong-basin/climate/# [Accessed: June 1, 2021]

[11] University of Hull. River of Plastic – The Journey of Plastics along the Mekong and its Ultimate Fate in the World's Oceans. 2021. Available from: https://hull.ac.uk/work-with-us/research/institutes/energy-and-environment-institute/our-work/river-of-plastic [Accessed: June 7, 2021]

[12] United Nations Environment Programme (UNEP). Plastic Pollution Threatens the Mekong: a wildlife wonderland, UNEP, Ecosystems and Biodiversity. 2021. Available from: https://unep.org/news-and-stories/story/plastic-pollution-threatens-mekong-wildlife-wonderland [Accessed: June 11, 2021]

[13] Contributing Writer. How is a Delta Formed?. 2021. Available from: https://sciencing.com/delta-formed-6643968.html [Accessed: May 2, 2021]

[14] Seybod H, Andrade JS Jr, Herman HJ. Modelling river delta formation. Proceedings of the National Academy of

Sciences of the United States of America (PNAS). 2007. DOI: 10.1073/pnas.0705265104

[15] Briney A. Geography of River Deltas. Thought Co.; 2020. Available from: https://thoughco.com/geography-of-river-delts-1435824 [Accessed: May 7, 2021]

[16] Galloway WE. Process Framework for Describing the Morphologic and Stratigraphic Evolution of Deltaic Depositional Systems. 1975. Available from: https://reserachgate.net/publication/287828682 [Accessed: June 18th, 2021]

[17] Elliot T. Deltas. Available from: https://geoweb.uwyo.edu/geol2100/Deltas.pdf [Accessed August 28, 2021]

[18] Central Connecticut State University. Define Fluvial and Outline the Fluvial Processes: Erosion, Transportation and Deposition. 2021. Available from: https://web.ccsu.edu/faculty/Kyem/geog272/chapter11/rivers_landforms.htm [Accessed: June 4, 2021]

[19] National Park Service. Geology: River Systems and Fluvial Landforms. 2021. Available from: https://nps.gov/subjects/geology/fluvial-landforms.htm [Accessed: June 2, 2021]

[20] SEPM. Fluvial- Dominated Deltas. 2021. Available from: https://sepmstrata.org/page.aspx?pageid=315 [Accessed: May 11,2021]

[21] Nienhuis J. Wave-Dominated River Deltas. 2020. Available from: https://www.coastalwiki.org/wiki/Wave-dominted_river_deltas [Accessed: May 8, 2021]

[22] Universiteit Utrecht. River Deltas Depositional Processes. 2021. Available from: https://geo.uu.nl/fg/gruessink/PPT_files/Lecture%204%20delta%20Systems.pdf [Accessed: May 2, 2021]

[23] Ozcoasts. Wave-Dominated Deltas. Australian Online Coastal Information; 2021). Available from: https://ozcoasts.org.au/conceptual-diagrams/science-models/geographic/wdd [Accessed: May 8, 2021]

[24] Goodbred SL, Saito Y. Tide-dominated deltas. In: Davis RA, Dalrymple RW, editors. Principles of Tide Sedimentology. 2021. pp. 129-149. DOI: 1007/978-94-007-0123-6_7. Available from: https://semanticscholar.org/paper/Tide-Dominated_Deltas-Goodbred_Saito/ [Accessed: May 20, 2021]

[25] InteGrate. Coastal Processes, Hazards, and Society: Deltas in Crisis. 2021. Available from: https://www.education.psu.edu/earth107/node/1024 [Accessed: May 7, 2021]

[26] InteGrate. Coastal Processes, Hazards, and Society: Delta Morphologies and Driving Processes. 2021. Available from: https://www.education.psu.edu/earth107/node/1023 [Accessed May 7, 2021]

[27] WWF. A Biological Treasure Trove. 2021. Available from: https://www.greatermekong.panda.org/discovering_the_greater_mekong/ [Accessed: August 27, 2021]

[28] Wikipedia. Mekong. 2021. Available from: https://www.eu.wikipedia.org/wiki/Mekong [Accessed: August 28, 2021]

[29] Singapore Management University. The Mekong. 2021. Available from: https://researchguides.smu.edu.sg/cp_myanmar [Accessed: August 29, 2021]

[30] Wallonie/Bruxelles au Vietnam. Feel Inspired: The Mekong River, Between Issues and Opportunities. 2018. Available from: https://www.wallonievn/fr/actualities/mekong-river-between-issues-and-opportunities-vn [Accessed: August 23, 2021]

[31] Berg M, Stengel C, Pham TK, Pham H, Sampson ML, Leng M, et al. Magnitude of arsenic pollution in the Mekong and Red River deltas – Cambodia and Vietnam. Science of the Total Environment. 2007;**72**(2–3):13-25. DOI: 10.1016/j/scitoenv.2006.09.010. Available from: https://pubmed.ncbi.nlm.gov.17081593/ [Accessed: June 18, 2021]

[32] Eyler B. Science Shows Chinese Dams Are Devastating the Mekong. FP Special Reports. 2020. Available from: https://foreignpolicy.com/202/04/22/science-shows-chinese-dams-devastating-mekong-river [Accessed: August 23, 2021]

[33] Hoang L, Lauri H, Kumma M, Koponen T, van Vliet M, Supit I, et al. Mekong River flow and hydrological under extreme climate change. Hydrology and Earth System Science. 2016 20.3027-3041.105194/hess-20-3027-2016. [Accessed: August 24, 2021]

[34] Adamson P, Rutherford I, Peel M, Caular I. The hydrology of the Mekong River. 2009. DOI: 10.1016/B978-0-12-374026-7.00004-8 [Accessed: August 24, 2021]

[35] Kazem M. Challenges and Difficulties of Living in River Deltas. A Review of the Major River Deltas in Asia and Africa (Scientific Essay). Munich GRIN Verlag; 2015. Available from: https://www.grin.com/document/3064 [Retrieved: August 23, 2021]

[36] Safra de Campos R et al. Where people live and move in deltas. In: Nichells R, Adger W, Hutton C, Hanson S, editors. Deltas in the Anthropocene. Cham: Palgrave Macmillan; 2020. DOI: 10.1007/978-3-030-23517-8_7 [Accessed: August 23, 2021]

[37] Day et al. Approaches to defining Deltaic sustainability in the 21st Century. Estuarine and Coastal Shelf Science. Sustainability for Future Coasts and Estuaries. 2016;**183**:275-291. DOI: 10.1016/j.ecss.2016.06.018

[38] Syvitski PMJ. Sinking Deltas. 2009. Available from: https://www.core.ac.uk/display/4167699?utm_source=pdf&utm_medium=banner_campaign=pdf-decorative-v1 [Accessed: August 31, 2021]

[39] Dunn et al. Projections of declining fluvial sediment delivery to major Deltas Worldwide in response to climate change and anthropogenic stress. Environmental Research Letters. 2019; **14**(8):084034. DOI: 10.1088/1748-9326/ab304e

[40] Knapman D, Zmud J, Ecola L, Mao Z, Crane K. Quality of Life Indicators and Policy Strategies to Advance Sustainability in the Pearl River Delta. Santa Monica, CA: RAND Corporation. Available from: https://www.rand.org/pubs/research_reports/RR871.html; 2015 [Accessed: August 31, 2021]

[41] Szabo S et al. Population dynamics, Delta vulnerability and environmental change: Comparison of the Mekong, Ganger Brahmaputra and Amazon Delta regions. Sustainability Science. 2016, 2016;**11**:539-554. DOI: 10.1007/s11625-016-0372-6

[42] Schmidt CW. Delta subsidence: An imminent threat to coastal populations. Environmental Health Perspectives. 2015;**123**(8):A204-A209. DOI: 10.1289/ehp.123-A204

[43] ANI. China's Hydroelectric Dams on River Mekong Leaving Region Dry, Livelihoods of Millions Affected. 2021. Available from: https://www.aninews.in/news/world/asia/china's-hydroelectric-dams-on-river-mekong-leaving-region-dry-livelihoods-of-millions-affected [Accessed: August 31, 2021]

[44] Macau-Markar M. Thailand Challenges Laos Dam Building Spree on

Mekong River. NIKKEI Asia; 2021. Available from: https://asia.nikkei.com/Politics/International-relations/Thailand-challenegs-Laos-dam-building-spree-on-Mekong-River [Accessed: August 31, 2021]

[45] Dang T, Ouillon S, Vinh G. Water and suspended sediment budgets in the lower Mekong from high-frequency measurements (2009-2016). Water. 2018. DOI: 10.103390/w10070846

[46] Mekong River Commission. The ISH 0306 Study. Development of guidelines for hydropower environmental impact mitigation and risk management in the lower Mekong, mainstream and tributaries. In: Volume 2 – Hydropower Risks and Impact Mitigation, Key Hydropower Risks, Impacts and Vulnerability and General Mitigation Options for Lower Mekong, Final Version. 2018. Available from: https://www.mrcmekong.org/assets/Uploads/ISH0306-Volume-2-Final-Manual2.pdf [Accessed: August 31, 2021]