Mekong River Delta

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1 Physical Setting

1.1 The Mekong River

Mekong River (MR) is the 12th longest river in the world with a total length of 4800 km (Li et al., 2017). From its source in the Tibetan Plateau, MR flows across six different countries, namely China, Myanmar, Laos People's Democratic Republic (Laos PDR), Thailand, Cambodia and finally Vietnam before draining into the South China Sea (Fig. 1). The river has a drainage area of 795000 km^2 (Hoang et al., 2016).

In its natural and undisturbed state, MR annually transports approximately ~470 billion m^3 of water and 160 million tons of sediment to the delta (Li et al., 2017; Wild & Loucks, 2014). Following various human interferences, the delta presently receives 400 billion m^3 of water and only 37 million tons of sediment (Thi Ha et al., 2018). MR basin is dominated by Asian monsoon climate, which generates distinct wet (June–November) and dry (December–May) seasons. Tropical typhoons in the Pacific Ocean also significantly contribute to the rainfall during the later parts of the wet season (August to early October).

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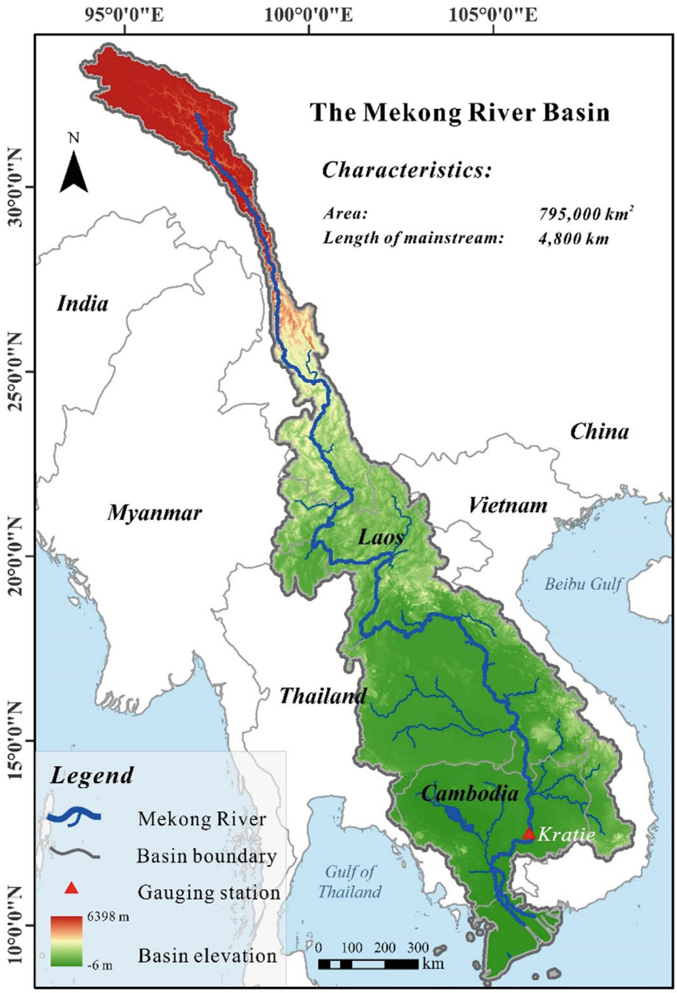

Fig. 1 Map of Mekong River basin

1.2 The Mekong Delta

The Vietnamese part of the Mekong Delta (MD, also known as the *Cuu Long* or "Nine Dragons") is the region in the far south of Vietnam (Fig. 2). The delta roughly forms a triangle of over 39,000 km^2 stretching from Mỹ Tho in the east to Châu Đốc and Hà Tiên in the northwest, down to Cà Mau at the southernmost tip of Vietnam (12.7% of the total land area of Vietnam) (Hoa, 2008; Ta et al., 2002).

The MD is a wave-influenced tide-dominated delta. The mean tidal range is 2.5 m and the maximum tidal range is 3.2–3.8 m (Nguyen et al., 2000). The mean wave height is 0.9 m (Ta et al., 2002). Southwestward coastal and longshore currents

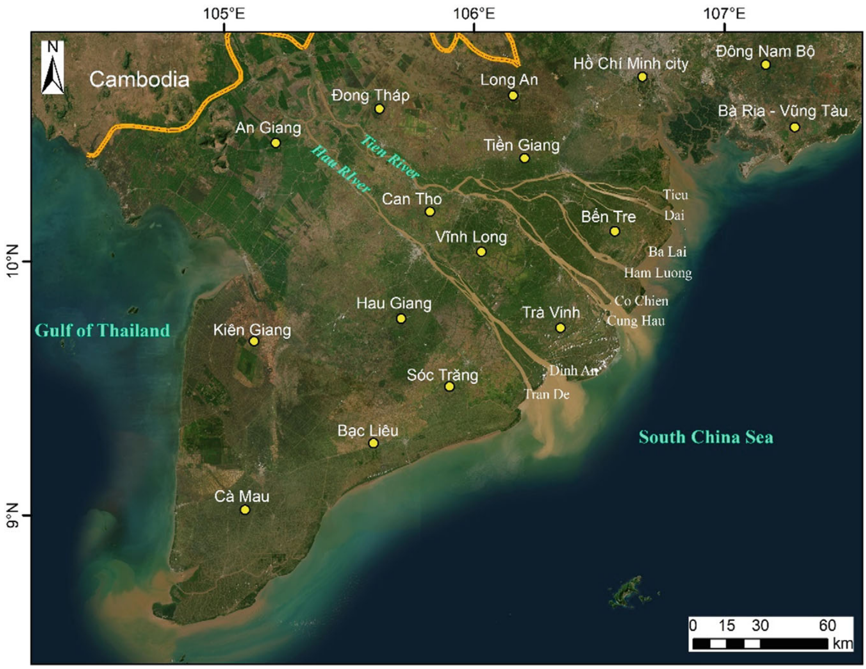

Fig. 2 Schematised map of the Mekong Delta

generated by winter monsoons are dominant and they are the cause of the formation of a beach ridge and spit system.

The subaerial delta plain of the MD is composed of two parts: an upper (inner) delta plain dominated by fluvial processes, and a lower (outer) delta plain characterized by a well-developed beach-ridge system and mainly influenced by marine processes (Nguyen et al., 2000; Szczuciński et al., 2013). In addition, the MR-system has a relatively young subaqueous delta (≤1000 yr), a shallow rollover at 4–6 m water depth, gentle foreset gradients (0.03–0.57°), and a short cross-shelf dimension of 15–20 km within 20 m water depth (Liu et al., 2017a; Tamura et al., 2012).

The MD comprises highly fertile soils. The coastal wetlands are featured by mangrove forest and peatland Melaleuca forest wetlands. These nature wetlands, along with manmade ones, such as rice fields and aquaculture ponds, provide vital ecosystem services to the region (Dang et al., 2021; Leinenkugel et al., 2011).

2 Socio-economic Characteristics

Home to nearly 18 million people (approximately 20% of the Vietnamese population), the Vietnamese MD covers 13 provinces and plays a key role in the demographic fabric of the Vietnam region (Schmitt et al., 2019). With its catchment, the delta has a comparatively high population density of 435 people/km^2, of which about 20% is urbanised, leaving an 80% rural population (GSO, 2020; Vo, 2012). Despite its economic significance, the MD belongs to the regions with the lowest population growth in Vietnam, due to a high out-migration (Berchoux et al., 2023). Since the 1990s, population growth has been a steady 1.8–2% per year. Approximately 85% of the population lives from agricultural activities (GSO, 2011).

The economies and societies along the MD are strongly linked to good water access and highly fertile land. As the "rice bowl" of Asia, the MD is a major rice-growing region, accounting for not less than 54% of Vietnam's paddy production in 2018 (23.6 million tons) and over 95% of Vietnam's rice exports over the last decade. It also produces around 70% of Vietnam's fruit, including oranges, tangerines, bananas and mangoes. The Mekong Delta is also a major contributor to Vietnam's fisheries and aquaculture industries (56.0% and 69.9%, respectively in 2018). It accounts for some 60% of national fish exports, with shrimp, pangasius fish and tilapia as key aquaculture products, making Vietnam the world's third largest exporter of aquatic products and the fifth largest producer of rice (FAO, 2016). The fishing and aquaculture industries in the region alone employ over 2.8 million people—10% of Vietnam's entire labour force.

The Mekong Delta houses 11.1% of Vietnam's industry and construction (I&C) sector. It is the third largest industrial region in Vietnam after the metropolitan areas of Ho Chi Minh City (HCMC) and Hanoi. Activities in the region's services sector account for 14.8% of the national services output. Annual tourism-related revenues alone were estimated at around $400 million in 2019. The region is a net supplier of labour to the rest of the country. The net out-migration from the Mekong Delta has averaged 0.53% per annum in the years 2005–2018 (GSO, 2020, with over 90% of these migrants reportedly relocating to the neighbouring South East region of the country (particularly to HCMC). Overall, the Delta has close economic ties with the Southern Economic region (which includes HCMC) and the dependence on national road connections means that almost all Mekong Delta's output presently passes through HCMC before being traded within Vietnam or abroad. As economic growth centred on HCMC has expanded in recent years, there has been an expansion of activities (particularly light industrial) out of the formal industrial areas of HCMC and towards the south—effectively coalescing the two economic regions, such that provinces such as Long An may be de facto in both regions. This physical encroachment is in part facilitated by the over-development of industrial parks by local authorities and contributes to the urban fragmentation and low economic density which is described later.

The 2018 composition of the region's GDP by sector in comparison with Vietnam as a whole is shown in Fig. 3. Due to the rural nature of the Mekong Delta's economy,

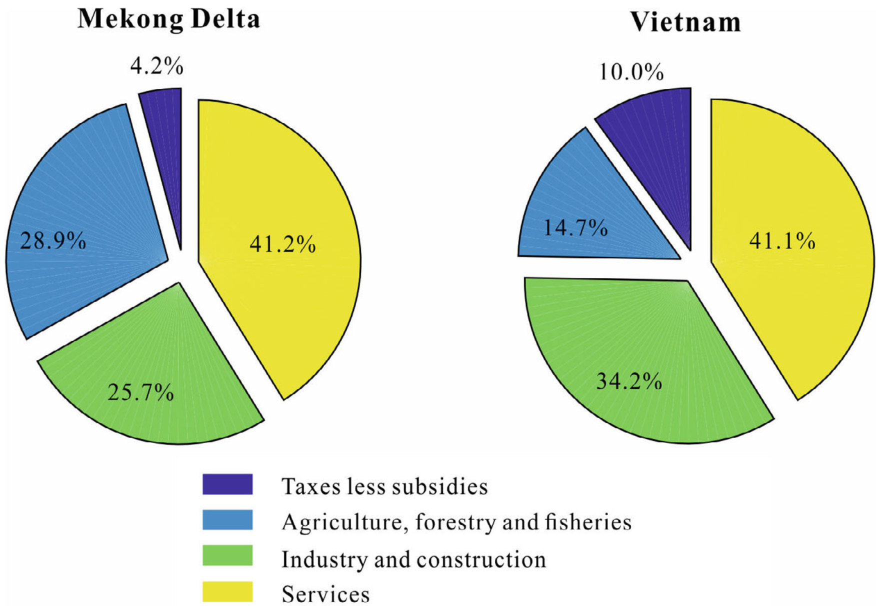

Fig. 3 GDP composition of Mekong Delta and Vietnam. *Data source* GSO (2020)

the share of agriculture, fisheries and forestry in the regional GDP is very high (at 28.9%) compared to the national average of 14.7% of GDP, while I&C's share is low (at 25.7% regionally vs. 34.2% nationally). However, with the industry and construction and services sectors now growing much more quickly than agriculture, fisheries and forestry (i.e., at 7.2% per annum for industry and construction and 8.5% per annum for services but only 2.4% per annum for agriculture, fisheries and forestry during the 5 years 2013–2018), the region is now undergoing a process of industrialisation and structural transformation, although later and at a slower pace than the rest of the country.

3 Current Issues

3.1 Relative Sea Level Rise and Land Subsidence

Continuing sea level rise in the coming centuries potentially has large impacts on the MD, in particular by increasing salinization, inundation and flood risks. The rate of sea-level rise, however, is still uncertain depending atmospheric temperatures rises and the rate of glacier and snow melt particularly in Greenland. According to the IPCC Fourth Assessment Report, a prediction has been made for the coast of southern Vietnam that the sea level will experience a rise of 30 cm by the year 2050 (Wassmann et al., 2004). Based on the Fifth Assessment Report by the IPCC have confirmed this prediction, with a 5–95% uncertainty range of approximately 20–40 cm for IPCC's Representative Concentration Pathway 8.5 (Katzfey et al., 2014).

Analyzing the impacts of sea-level rise in the MD requires calculation of the relative sea-level rise, which also takes land subsidence into account. Land subsidence due to unsustainable ground water extraction and/or morphological changes caused by changing sediment load from upstream will exacerbate the impacts of sea-level rise in delta areas. This issue is particularly relevant in the MD, given the current situation of unsustainable ground water extraction and reduced sediment load, potentially aggravated by further dam and reservoir construction upstream (Gupta et al., 2012). If the current rate of groundwater pumping continues, it is expected that land subsidence throughout the delta will have reached 0.35–1.4 m by 2050 (Erban et al., 2014). The local subsidence rates of 2.5 cm per year exceed the global sea level rise by nearly ten times (Fig. 4; Minderhoud et al., 2017). Besides, this subsidence rate is likely to increase in the future due to increased groundwater demand (Minderhoud et al., 2017, 2020). Considering that a significant portion of the lower MD is only slightly above 2 m in elevation, the combined effects of subsidence and rising sea levels would pose a significant threat to the long-term sustainability of the delta. Additionally, with the acceleration of subsidence and sea level rise, coupled with the construction of planned dams and ongoing sediment mining, the MD will face the risk of almost complete disappearance by the end of this century (Schmitt et al., 2017).

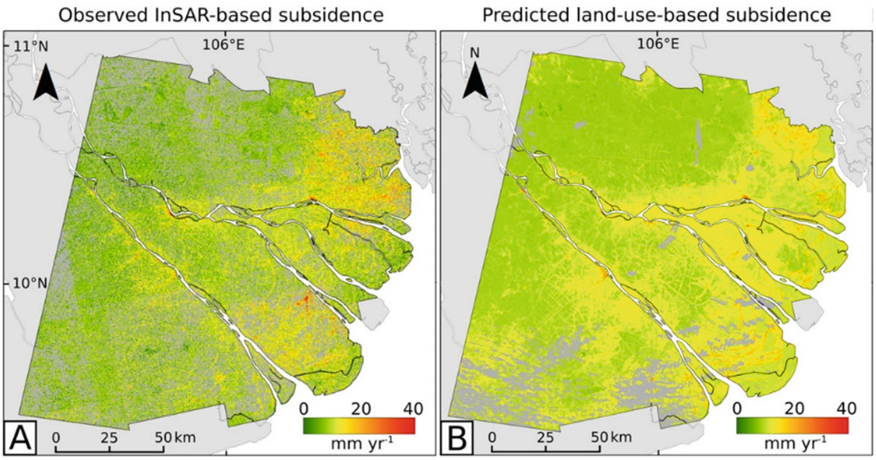

Fig. 4 **a** Observed InSAR-based subsidence rate. **b** Predicted subsidence rates for the period 2006–2010 (from Minderhoud et al., 2017)

3.2 *Floods and Storm Surges*

The MD experiences annual widespread flooding, which constitutes the region's primary natural hazard (Heiko et al., 2012). The delta has been significantly impacted by a series of major floods this century, notably those in 2000, 2001, and 2002 (Pengel et al., 2007). These floods have led to loss of lives (nearly 500 casualties), livestock and property, inflicted damage on agriculture and rural infrastructure, and disrupted socio-economic activities. The total economic cost of the flood damage was estimated at $400 million (Weichselgartner, 2005). The flood regime in the MD is shaped by a complex interplay of four influencing factors. Type 1 floods are primarily triggered by the MD's flood pulse and overland flow. Type 2 floods are artificial floodwaters distributed via a dense network of canals and controlled by dykes and sluice gates. Type 3 floods are short-term floods resulting from extreme local precipitation events. Type 4 floods are primarily associated with high tides during storms. Typically, no single flood occurrence in the MD can be exclusively attributed to one of these four factors. Instead, flood occurrences are invariably triggered by a combination of several of these sources (Hoang et al., 2016).

Storm surge, associated with tropical storms and typhoons, is a recurrent issue in the MD (MRC, 2015). Extreme wind speeds, along with the associated storm surges, cause most of the damage in coastal regions because of its low topography, high population density and inadequate protection (Tung et al., 2020). Typhoon Linda in 1997, considered to be the worst storm in recent times, claimed more than 3000 lives and caused severe damage in the delta and the remote islands (Anh et al., 1997, 2022). An area of 9800 km^2 of the MD is estimated to be susceptible to storm surges with potentially serious damage on agriculture, transportation, and threats to lives of the local inhabitants (Syvitski et al., 2009). Furthermore, the situation can be exacerbated during floods due to sea-level rise (SLR) induced by climate change (Gupta et al., 2003).

3.3 *Sediment Starvation, Sand Mining and Coastal Erosion*

The MR is one of the world's most crucial sediment-carrying rivers, continuously transporting sediment to the MD. For the past 3000 years, the average sediment discharge of the MR was nearly 150.000 Mt/yr, almost equivalent to the present value. Consequently, the delta's leading edge continuously advanced towards the sea, and its steepness increased during this period (Ta et al., 2002). However, in recent decades, due to human activities and climate change, the sediment load of the MR is rapidly decreasing, leading to intensified erosion in the MD (Kondolf et al., 2014; Tamura et al., 2020). Specifically, with 38 dams already constructed or under construction, sediment reaching the delta is expected to decrease by 51%. If all planned dams are completed, the cumulative sediment retention will reach 96% (Kondolf et al., 2014). Moreover, Kummu et al. (2008) indicated that between 1995 and 2000, the Tonle

Sap Lake supplied 0.65 ± 0.6 Mt/yr to the downstream MR. However, since 2001, the Tonle Sap Lake has become a sediment sink, accumulating an average of 1.35 ± 0.7 Mt/yr. The net sediment storage in the lake has further exacerbated the impact of reduced sediment supply due to upstream dam development and sand mining in the river (Sok et al., 2021). The suspended sediment flux in the lower MR is expected to change to 43 Mt/yr by 2020–2029 (Bussi et al., 2021). In addition, Darby et al. (2016) stated that in recent years (1981–2005), the suspended load delivered to the delta has decreased by 52.6 ± 10.2 million tons due to a shift in tropical-cyclone climatology, which may pose further risk to the vulnerable coastal systems. Schmitt et al. (2017) predicted through models that, under the current situation of planned dam construction, sand mining, and groundwater extraction, the sediment supply to the delta will be completely cut off. Coupled with the increased subsidence rate of the delta and rising sea levels, by the end of this century, the MD will almost completely disappear.

Since the 1990s, extensive sand mining in the downstream area of the MR has been attributed to land reclamation and civil industrial activities, making it one of the most severely impacted deltas by riverbed mining (Bravard et al., 2013). Hackney et al., (2020) revealed that the total sand flux entering the MR is about 6.18 ± 2.01 Mt/yr, significantly lower than the current sand extraction rate of 50 Mt/yr. Furthermore, Jordan et al., (2019) demonstrated that sand mining, averaging about 17.8 million m^3/yr, has resulted in extensive fluvial erosion. The large-scale sand extraction has resulted in the creation of numerous pools and mine pits. In Vietnam, the deepest mine pit reaches up to 45 m (Brunier et al., 2014). These deep pits actively trap sediment that should have flowed downstream (Anthony et al., 2015). The depletion of sand sources due to massive extraction has hindered the normal sedimentation process of rivers, leading to the destruction of river and delta ecosystems and negatively impacting delta landform development.

Main cause of erosion along coastlines of the MD is due to sediment depletion associated with increasing number of dams, large-scale sand mining and accelerated subsidence (Fig. 5; Anthony et al., 2015). The sediment is transported by waves and currents and is redistributed along the coast and transported in southwesterly direction. Due to the appearance of sand bars around the river mouths, caused by siltation from river branches, most of the coastline sections about 10–20 km downstream (southern side) of every river mouth are eroded. Study of the past years of Landsat images indicates that the coastal erosion occurs very quickly, with an average erosion rate of about 50 m/y (Li et al., 2017). The MD changes from accreting to eroding around 2005. From 1973 to 2005, the MD's seaward shoreline growth decreased gradually from a mean of 7.8 m/yr to 2.8 m/yr, and after 2005 it became negative, with a retreat rate of −1.4 m/y (Liu et al., 2017b). Strong wave action causes coastal erosion from November to March every year. The erosion rate of the shoreline is increasing, especially in the silty east coast that is influenced by the northeast monsoon while the west coast is mainly affected by the southwest monsoon, which causes coastal erosion every year from June to October (Le Xuan et al., 2022). These erosion trends and their spatiotemporal disparities generate considerable risks to residents, rendering the MR one of the most vulnerable and threatened deltas (Besset et al., 2019).

3.4 Freshwater Resources and Saline Water Intrusion

Freshwater availability during the dry season is bound to decrease in the MD, due to a combination of factors. On the supply side, both dry season local rainfall and MR discharge are likely to decrease under climate change conditions (Anh et al., 2019; Ruiz-Barradas & Nigam, 2018). The ground water resource in the delta is also rather limited, not to mention the fact that groundwater stocks are currently under stress and already show signs of depletion (Erban et al., 2014; Shrestha et al., 2016). On top of potential reduction in rainfall and river discharge, increased evaporation due to rising temperature could further decrease water availability in the delta (Hu & Mo, 2021). On the demand side, water demand for different sectors is likely to increase in the future (MRC, 2018; Tang et al., 2023). Reduced freshwater availability in combination with salt water intrusion and higher water demands may cause severe water stress in the dry season. In fact, local drought events seem to occur with higher frequencies in the MD during dry months (Nguyen, 2017; Nghia et al., 2022). In the dry season, the average discharge of the MR is less than 2,500 m^3/s, and even as low as 1,700 m^3/s, with the groundwater table lowering by 0.01–0.55 m/y in some places (Duy et al., 2021; Lu & Chua, 2021; Tuan & Wyseure, 2006). This will affect nearly 15 billion m^2 of cultivable land and may affect domestic and industrial water supply (Nguyen et al., 2021). The current strains on the water resources base of the delta are threefold: seasonal fresh water flooding during the wet season and seasonal fresh water scarcity during the dry season (Nguyen et al., 2021; MRC, 2022); water quality degradation, in terms of salinity, acidity, and water pollution (Eslami et al., 2021; MRC, 2021; Phong et al., 2014; Smajgl et al., 2015); coastal flooding (Phung et al., 2016).

Groundwater is a primary freshwater source for various domestic, industrial and agricultural purposes, especially in the MD where there is a lack of surface water supply (Tran et al., 2020). Groundwater exploitation in the MD has increased dramatically over the past 25 years. The exploitation in the southern MD in 2019 was 567,364 m^3/d. The most exploited aquifers are the upper-middle Pleistocene and the middle Pliocene, accounting for 63.7% and 24.6%, respectively. The least exploited aquifers are the upper Pleistocene and the upper Miocene, accounting for 0.35% and 0.02%, respectively. In the deeper aquifers, the change in storage is negative due to the high exploitation rate, leading to a decline of the stocks in these aquifers (Hoan et al., 2022). The delta has transformed from an almost undisturbed hydrogeological state to a situation with increasing aquifer depletion (Minderhoud et al., 2017). As groundwater levels drop, the consequent compaction of sediment layers causes land subsidence, at these locations at an average rate of 1.6 cm/yr. If pumping continues at

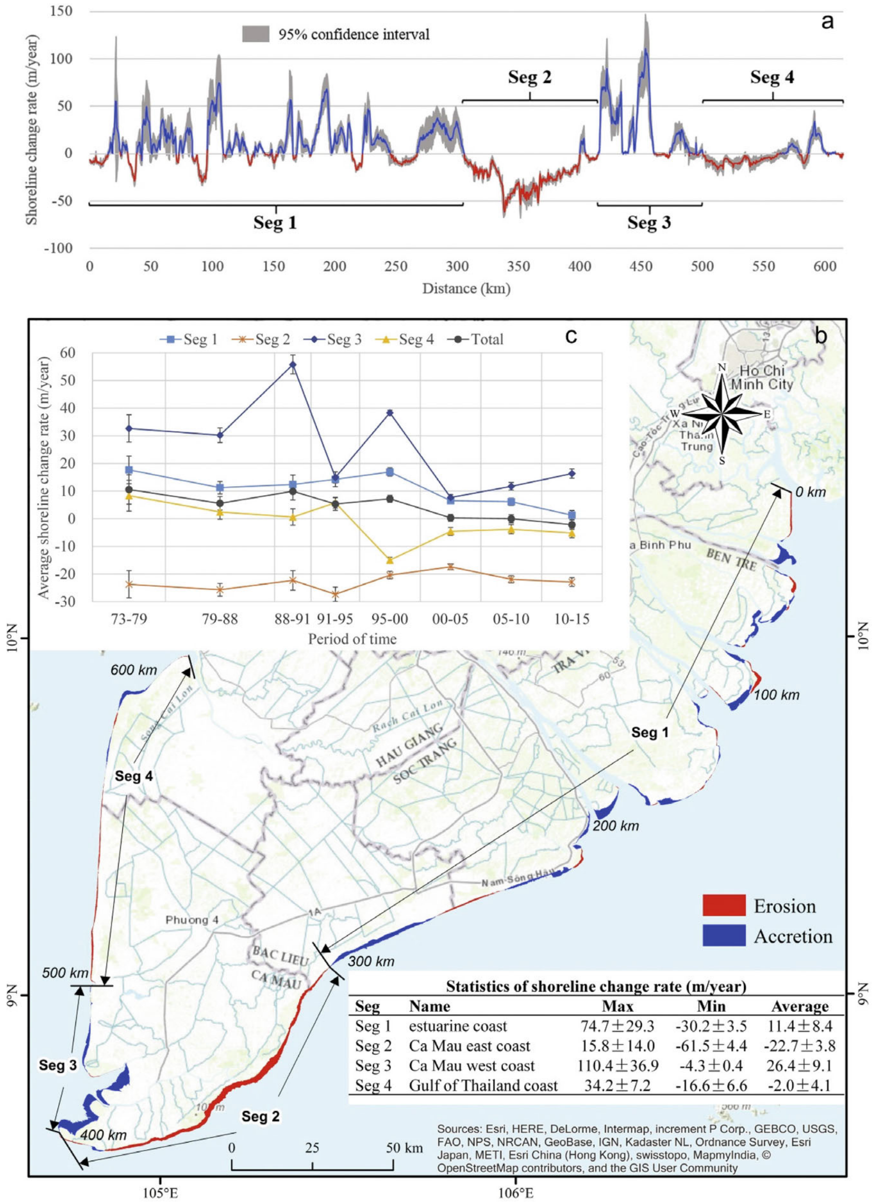

Fig. 5 Graph of shoreline changes for the Mekong Delta between 1973 and 2015. According to **a** the shoreline change rates along each transect, **b** the delta's shoreline can be divided into four segments: estuarine coast (Seg 1), Ca Mau East Coast (Seg 2), Ca Mau West Coast (Seg 3), and the Gulf of Thailand (GoT) coast (Seg 4). (c)The line graph shows the average shoreline change rates for the four segments, and the table (lower right) displays the maximum, minimum, and average shoreline change rates of the four segments (from Li et al., 2017)

present rates, about 0.88 m of land subsidence is expected by 2050. Hence, groundwater extraction is suggested as the main driver of land subsidence, which in coastal areas poses a flood inundation hazard that is compounded by continued sea level rise (Erban et al., 2014). Additionally, excessive groundwater extraction also amplifies saltwater intrusion into coastal freshwater aquifers (Klessens et al., 2022). Failure to mitigate groundwater extraction-induced subsidence and saltwater intrusion may strongly increases the delta's vulnerability to flooding, salinization, coastal erosion and, ultimately, threatens its nearly 18 million in habitants with permanent inundation (Minderhoud et al., 2020).

The MD, as one of the world's regions most susceptible to saline water intrusion, suffers significantly from salinity (Fig. 6; Loc et al., 2021). For instance, in the 2015–2016 dry season, saltwater intruded over 90 km inland, causing substantial crop damage in 11 out of the 13 provinces in the MD, including nine coastal provinces (Thanh et al., 2023). Given the projected climate change characterized by reduced dry season river discharge, rising sea levels, and increased evaporation, saline water intrusion in the MD is expected to increase significantly. The anticipated sea-level rise by 2030 could affect more than 240 km^2 of agricultural land through salinity intrusion, significantly impacting local water resources that are vital to life and production (Phuong et al., 2020).

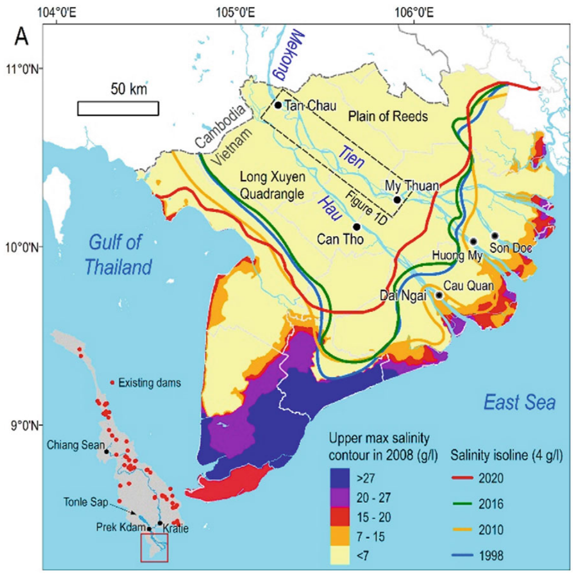

Fig. 6 Saltwater intrusion in the Mekong Delta over 1998, 2010, 2016 and 2020 (from Loc et al., 2021)

3.5 Land Use Changes

The predominant transformation of land use in the MRB has been characterized by the extensive conversion of forested regions into cultivated lands (Fig. 6; Liu et al., 2020; Tang et al., 2021). Over the period of 2003–2014, the estimated area converted to plantations was approximately 33,617 ± 7342 km^2, while agricultural expansion covered about 14,915 ± 4682 km^2. Notably, 82% of the deforested areas were transformed into tree plantations. Sam and Khoi (2022) indicated that between 1997 and 2010, the MD experienced significant land use changes, witnessing a 2.35% decline in forested areas and a corresponding 2.29% rise in agricultural land. It is also clear that aquaculture began to develop in coastal areas from the 1980s and expanded rapidly from coastal to inland areas (Fig. 7).

Land use changes in the MR Basin (MRB) have raised significant attention due to their potential and substantial impacts on hydrological processes, ecological systems, and the livelihoods of residents (Sam & Khoi, 2022; Shrestha et al., 2018; Zhai et al., 2016). Zhai et al. (2016) demonstrated that the significant expansion of forest, woodland, and grassland areas in the specified region of MRB from the mid-1980s to 2000 contributed to a notable reduction in runoff. This expansion of green cover likely had a positive impact on water retention and infiltration, leading to fluvial discharge decrease. Shrestha et al. (2018) indicated that the presence of uncertainty in land use demand gives rise to the most significant variations in streamflow and sediment load, leading to potentially substantial implications for water and sediment management strategies in regions experiencing rapid development.

3.6 Water Pollution

Water in estuarine and nearshore coastal areas in the MR is facing more and more pollution from agricultural and industrial chemicals and domestic untreated wastewater (Wilbers et al., 2014). Specifically, the intensification of rice agriculture and aquaculture, accompanied by a more intensive use of agro-chemicals, is rapidly increasing the non-point source pollution. In addition, the rapid urbanization and industrialization of urban centers in the delta is accompanied by an exponential growth of waste water effluents. Most of which are discharged untreated into the surface waters of the delta. Pollution loads (e.g., heavy metals, agro-chemical residues) are increasing, and strongly affecting the dilution and flushing capacities of present river and canal flows (Chau et al., 2015). Meanwhile, groundwater contamination by heavy metals and arsenic was also documented in the delta (Buschmann et al., 2008).

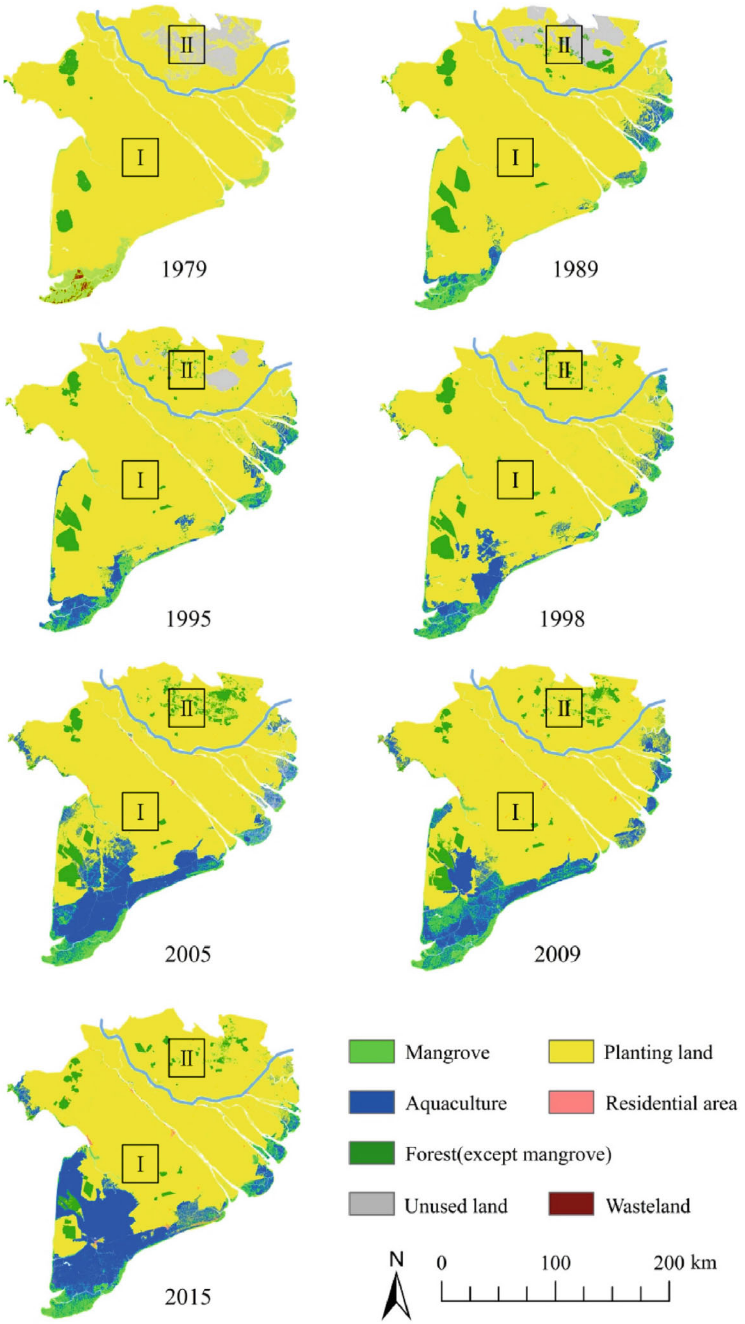

Fig. 7 LULC classification maps of the Mekong Delta in the year 1979, 1989, 1995, 1998, 2005, 2009, and 2015 based on Landsat and HJ1B-CCD1 images (from Liu et al., 2020)

4 Solutions for the Problems, Trends and Forecast

4.1 International Policy Development

For regional dialogue and cooperation in the lower MR, the Mekong River Commission (MRC), an intergovernmental organization, was established in 1995 based on the Mekong Agreement between Cambodia, Lao PDR, Thailand and Vietnam (Nguyen, 2007). The organization serves as a regional platform for water diplomacy and a knowledge hub of water resources management for the sustainable development of the region. In addition, MRC provides scientific analysis and advice for the lower Mekong countries and various stakeholders and interested parties to sustainably manage and develop the MR Basin.

4.2 Policy Development Within Vietnam

A series of government initiatives have been issued by Vietnam to cope with the rapidly changing environmental conditions (Nguyen et al., 2020). For example, the government has issued Resolution 120 on sustainable development and climate–resiliency of the MD in 2017 and the Resolution's 2019 Action Programme to cope with water related natural disasters such as storms, droughts, floods, together with sea level rise and saline intrusion (Nguyen et al., 2021; Socialist Republic of Vietnam, 2017, 2019). Apart from aforementioned general orientations, plan implementation is supported by a number of sectoral policies. For instance, a Water Act has been issued to restrict groundwater exploitation to alleviate land subsidence (HCMC, 2007). The Forest Land Allocation policy, issued in 1991 by the Ca Mau and Bac Lieu provincial authorities, has given forest land for 20-year lease to farmers with a Green Certificate (Green Book), on the condition that 70% of the area should be replanted with mangrove trees and the rest (30% of total area) be exploited for agriculture, aquaculture, livestock and residential area.

4.3 Development of an Integrated Regional Plan of the Vietnamese Mekong Delta

With support from the World Bank, the Vietnamese government recently has developed a planning program namely "the Mekong Delta Integrated Regional Planning" (MDIRP) for a time horizon of 2021–2030 with an outlook to 2050. This has been built on the earlier Mekong Delta Plan established with Dutch donor support in 2013. The MDIRP combines investment, economic development planning and a planning governance structure for the Vietnamese Mekong Delta (13 provinces/ cities) based on hydrological, spatial, agricultural and climate change analysis. This planning program is expected to be the key reference for the on-going and future developments of natural disaster risk reduction strategies, climate-change resilient strategies, land use planning, infrastructure investments and socio-economic policies, taking due account of the adaptability and sustainability of future changes. The strategy is designed to both "manage challenges" and "create value". It aims to protect people, improve livelihoods, promote a more balanced regional development and improve the environment. The overall vision is to have prosperous and thriving communities, together turning challenges into opportunities, utilizing and protecting Mekong Delta resources. The strategy is based on a simple and widely accepted premise that agriculture is the most advantageous sector in the region, and that much productive land is currently being underused relative to its potential suitability for higher-value crops. Zones are defined regarding water management and flood protection: protection of the core freshwater zone and coastal areas, improved water quality (especially in relation to agriculture and aquaculture), climate change adaptation and management of natural disaster risks.

4.4 Coastal Restoration and Protection Forecast

Coastal restoration and protection have not adequately taken off and without focused interventions it will not take off in the future. Continued dependence on groundwater exploitation for rural and urban water supply, mono-culture based aquaculture and agriculture in the coastal zones will accelerate land subsidence and must be addressed. They will make coastal areas more vulnerable to coastal erosion, tidal inundation and storm surge induced coastal flooding. Initial response will be to strengthen the sea dyke along the coast, with a refurbished road and sluice gates to close the systems at times of storm surges. Coastal mangrove regeneration, however, is expected to remain limited without key interventions, as it causes sub-optimal water management conditions for the aquaculture sector. By 2030 and beyond, environmental degradation of aquaculture and farmlands may cause accelerating land abandonment in the coastal zones. This would provide opportunities for restructuring of the coastal areas, including re-greening of coastal zones to forests that may be sustainably exploited for diverse sea (food) products. As sea level rise (severely aggravated by land subsidence in the coastal zone) is set to accelerate, active sedimentation of the peninsula should become a priority goal of mangrove regeneration.

4.5 Hydrological Measures

Although several solutions were executed and planned, structural solutions remain predominant. Comprehensive infrastructural measures are implemented by the government of Vietnam for a safe delta and to enhance sustained economic development. Specifically,

(1) Canals, high and low dykes have been built extensively on the delta plain to prevent river flooding and facilitate crop production;
(2) Sea dikes have been built to protect low-lying coastal regions. But the sea dikes are rather low and their main function is to prevent inundation during spring tides;
(3) At some place a setback line to a distance of 3–5 km from the coastlines has been set. The outer land is then accepted to be inundated by sea water. This actually works as a buffer zone where both aquaculture has been developed in combination with mangrove forests;
(4) A surface water supply plant was constructed, and larger facilities for the entire VMD are currently being planned to reduce pressures on groundwater resources;
(5) Tidal barriers and/or sluices with control gates at small sea water entrances/cannels to address salinity intrusion; At the same time careful studies on impacts and effectiveness large scale storm-surge and tidal barriers at main (large) river entrances are implemented;
(6) Natural defenses by the remained mangrove systems (about 15% of the coastlines, mainly in far south provinces i.e. in Bac Lieu and Ca Mau) as an alternative of hard engineering approach.

5 Future Challenges

The resilience of the MD is threatened by higher temperature, accelerated land subsidence, reduced fluvial sediment supply and a rising sea level (Dang et al., 2022). The task to prepare the MD for an uncertain future is complex. It is important to note that the most severe impacts will be caused by a combination of these uncertain and rapidly changing threats. For example, the MD may experience a much higher flood risk due to a combination of sea level rise, higher fluvial peak flows, and possibly more frequent and severe typhoons. Reduced water availability in combination with salt water intrusion and higher water demands could potentially cause severe water stress in the dry season. Such low-probability, high-impact events will significantly affect agricultural production, especially rice and fruit crops and can potentially have an impact on domestic and industrial water supply over MD.

Given the foreseen future change in the delta, while understanding the changes and complexity of the various social-ecological systems in the MD, it is equally important to implement solutions and relevant policies (Nguyen et al., 2020). An ensemble of hard and soft policies is likely to provide the most effective results for people's livelihoods in the MD (Smajgl et al., 2015). Furthermore, integrated planning at basin and delta scale can provide critical information to make delta management robust to future uncertainty and help in establishing delta resilience as a crucial objective in river basin management (Schmitt et al., 2021).

References

Anh, L. T., Takagi, H., & Thao, N. D. (2019a) Storm surge and high waves due to 1997 Typhoon Linda: Uninvestigated worst storm event in Southern Vietnam. *Journal of Japan Society of Civil Engineers. Ser. B3 (Ocean Engineering), 75*(2), 73–78.

Anh, D. T., Hoang, L. P., Bui, M. D., & Rutschmann, P. (2019b). Modelling seasonal flows alteration in the Vietnamese Mekong Delta under upstream discharge changes, rainfall changes and sea level rise. *International Journal of River Basin Management, 17*(4), 435–449.

Anh, L. T., Takagi, H., Thao, N. D., & Esteban, M. (2022). Investigation of awareness of typhoon and Storm Surge in the Mekong Delta-Recollection of 1997 typhoon Linda. *Journal of Japan Society of Civil Engineers, 73*(2), 168–173.

Anthony, E. J., Brunier, G., Besset, M., Goichot, M., Dussouillez, P., & Nguyen, V. L. (2015). Linking rapid erosion of the Mekong River delta to human activities. *Scientific Reports, 5*(1), 14745.

Berchoux, T., Hutton, C., Hensengerth, O., Voepel, H., Tri, V., Vu, P., Hung, N. N., Parsons, D. R., & Darby, S. (2023). Effect of planning policies on land use dynamics and livelihood opportunities under global environmental change: Evidence from the Mekong Delta. *Land Use Policy, 131*, 106752.

Buschmann, J., Berg, M., Stengel, C., Winkel, L., Sampson, M. L., Trang, P. T. K., & Viet, P. H. (2008). Contamination of drinking water resources in the Mekong Delta floodplains: Arsenic and other trace metals pose serious health risks to population. *Environment International, 34*, 756–764.

Besset, M., Gratiot, N., Anthony, E., Bouchette, F., Goichot, M., & Marchesiello, P. (2019). Mangroves and shoreline erosion in the Mekong River delta, Viet Nam. *Estuarine, Coastal and Shelf Science, 226*, 106263.

Bravard, J. P., Goichot, M., & Gaillot, S. (2013). Geography of sand and gravel mining in the Lower Mekong River: First survey and impact assessment. *EchoGéo, 26*, 2–18.

Brunier, G., Anthony, E. J., Goichot, M., Provansal, M., & Dussouillez, P. (2014). Recent morphological changes in the Mekong and Bassac river channels, Mekong Delta: The marked impact of river-bed mining and implications for delta destabilisation. *Geomorphology, 224*, 177–191.

Bussi, G., Darby, S. E., Whitehead, P. G., Jin, L., Dadson, S. J., Voepel, H. E., Vasilopoulos, G., Hackney, C. R., Hutton, C., Berchoux, T., Parsons, D. R., & Nicholas, A. (2021). Impact of dams and climate change on suspended sediment flux to the Mekong delta. *Science of the Total Environment, 755*, 142468.

Chau, N. D. G., Sebesvari, Z., Amelung, W., & Renaud, F. G. (2015). Pesticide pollution of multiple drinking water sources in the Mekong Delta, Vietnam: Evidence from two provinces. *Environmental Science Pollution Research, 22*, 9042–9058.

Dang, A. T. N., Kumar, L., Reid, M., & Nguyen, H. (2021). Remote sensing approach for monitoring coastal wetland in the Mekong Delta, Vietnam: Change trends and their driving forces. *Remote Sensing, 13*, 3359.

Dang, A. T. N., Reid, M., & Kumar, L. (2022). Assessing potential impacts of sea level rise on mangrove ecosystems in the Mekong Delta, Vietnam. *Regional Environmental Change, 22*, 70.

Darby, S. E., Hackney, C. R., Leyland, J., Kummu, M., Lauri, H., Parsons, D. R., & Aalto, R. (2016). Fluvial sediment supply to a mega-delta reduced by shifting tropical-cyclone activity. *Nature, 539*(7628), 276–279.

Duy, N. L., Nguyen, T. V. K., Nguyen, D. V., Tran, A. T., Nguyen, H. T., Heidbüchel, I., Merz, B., & Apel, H. (2021). Groundwater dynamics in the Vietnamese Mekong Delta: Trends, memory effects, and response times. *Journal of Hydrology: Regional Studies, 33*, 100746.

Erban, L. E., Gorelick, S. M., & Zebker, H. A. (2014). Groundwater extraction, land subsidence, and sea-level rise in the Mekong Delta. *Vietnam. Environmental Research Letters, 9*(8), 084010.

Eslami, S., Hoekstra, P., Minderhoud, P. S. J., Trung, N. N., Hoch, J. M., Sutanudjaja, E. H., Dung, D. D., Tho, T. Q., Voepel, H. E., Woillez, M. N., & van der Vegt, M. (2021). Projections of salt

intrusion in a mega-delta under climatic and anthropogenic stressors. *Communications Earth and Environment, 2*(1), 142.
FAO. (2016). Fishery and Aquaculture Statistics. Food and Agriculture Organization of the United Nations, 2016.
GSO (General Statistics Office). (2011). Statistical data on Vietnam. Database of the GSO website.
GSO (General Statistics Office). (2020). Data on Population of Mekong Delta, Vietnam in the year 2018. General Statistics Office of Vietnam. Database of the GSO website.
Gupta, A. D., Babel, M. S., & Ngoc, P. (2003). Flood damage assessment in the Mekong Delta, Vietnam. In *Proceedings of the 2nd International Conference of Asia-Pacific Association of Hydrology and Water Resources* (Vol. I, pp. 109–117).
Gupta, H., Kao, S. J., & Dai, M. (2012). The role of mega dams in reducing sediment fluxes: A case study of large Asian Rivers. *Journal of Hydrology, 464*, 447–458.
Hackney, C. R., Darby, S. E., Parsons, D. R., Leyland, J., Best, J. L., Aalto, R., Nicholas, A. P., & Houseago, R. C. (2020). River bank instability from unsustainable sand mining in the lower Mekong River. *Nature Sustainability, 3*, 217–225.
HCMC. (2007). Ho Chi Minh City Water Act 2007. Retrieved 23, 2016.
Heiko, A., Nguyen, N. H., Trinh, T. L., & Vo, K. T. (2012). Flood hydraulics and suspended sediment transport in the plain of reeds, Mekong Delta. In F. Renaud & C. Kuenzer (Eds.), *The Mekong Delta system—Interdisciplinary analyses of a River Delta* (pp. 221–232). Springer.
Hoa, L. T. V. (2008). Infrastructure effects on floods in the Mekong River Delta in Vietnam. *Hydrological Processes, 22*, 1359–1372.
Hoan, T. V., Richter, K. G., Börsig, N., Bauer, J., Ha, N. T., & Norra, S. (2022). An improved groundwater model framework for aquifer structures of the quaternary-formed sediment body in the Southernmost parts of the Mekong Delta, Vietnam. *Hydrology, 9*, 61.
Hoang, L. P., Lauri, H., Kummu, M., Koponen, J., van Vliet, M. T. H., Supit, I., Leemans, R., Kabat, P., & Ludwig, F. (2016). Mekong River flow and hydrological extremes under climate change. *Hydrology and Earth System Sciences, 20*(7), 3027–3041.
Hu, S., & Mo, X. (2021). Attribution of long-term evapotranspiration trends in the Mekong River basin with a remote sensing-based process model. *Remote Sensing, 13*(2), 303.
Jordan, C., Tiede, J., Lojek, O., Visscher, J., Apel, H., Nguyen, H. Q., Quang, C. N. X., & Schlurmann, T. (2019). Sand mining in the Mekong Delta revisited—Current scales of local sediment deficits. *Scientific Reports, 9*(1), 17823.
Katzfey, J., Mcgregor, J., & Ramasamy, S. (2014). High-resolution Climate Projections for Vietnam: Technical Report.
Klessens, T. M. A., Daniel, D., Jiang, Y., Van Breukelen, B. M., Scholten, L., & Pande, S. (2022). Combining water resources, socioenvironmental, and psychological factors in assessing willingness to conserve groundwater in the Vietnamese Mekong Delta. *Journal of Water Resources Planning and Management, 148*(3), 05021034.
Kondolf, G. M., Rubin, Z. K., & Minear, J. T. (2014). Dams on the Mekong: Cumulative sediment starvation. *Water Resource Research, 50*(6), 5158–5169.
Kummu, M., Penny, D., Sarkkula, J., & Koponen, J. (2008). Sediment: Curse or blessing for Tonle Sap Lake?. *AMBIO: A Journal of the Human Environment, 37*(3), 158–163.
Le Xuan, T., Ba, H. T., Thanh, V. Q., Wright, D. P., Tanim, A. H., & Anh, D. T. (2022). Evaluation of coastal protection strategies and proposing multiple lines of defense under climate change in the Mekong Delta for sustainable shoreline protection. *Ocean and Coastal Management, 228*, 106301.
Leinenkugel, P., Esch, T., & Kuenzer, C. (2011). Settlement detection and impervious surface estimation in the Mekong Delta using optical and SAR remote sensing data. *Remote Sensing of Environment, 115*, 3007–3019.
Li, X., Liu, J. P., Saito, Y., & Nguyen, V. L. (2017). Recent evolution of the Mekong Delta and the impacts of dams. *Earth-Science Reviews, 175*, 1–17.

Liu, J. P., DeMaster, D. J., Nittrouer, C. A., Eidam, E. F., & Nguyen, T. T. (2017a). A seismic study of the Mekong subaqueous delta: Proximal versus distal sediment accumulation. *Continental Shelf Research, 147*, 197–212.

Liu, J. P., DeMaster, D. J., Nguyen, T. T., Saito, Y., Nguyen, V. L., Ta, T. K. O., & Li, X. (2017b). Stratigraphic formation of the Mekong River Delta and its recent shoreline changes. *Oceanography, 30*(3), 72–83.

Liu, S., Li, X., Chen, D., Duan, Y., Ji, H., Zhang, L., Chai, Q., & Hu, X. (2020). Understanding the land use/land cover dynamics and impacts of human activities in the Mekong Delta over the last 40 years. *Global Ecology and Conservation, 22*, e00991.

Loc, H. H., Van Binh, D., Park, E., Shrestha, S., Dung, T. D., Son, V. H., Truc, N. H. T., Mai, N. P., & Seijger, C. (2021). Intensifying saline water intrusion and drought in the Mekong Delta: From physical evidence to policy outlooks. *Science of the Total Environment, 757*, 143919.

Lu, X. X., & Chua, S. D. X. (2021). River discharge and water level changes in the Mekong River: Droughts in an era of mega-dams. *Hydrological Processes, 35*(7), e14265.

Mekong River Commission (MRC). (2015). Annual Mekong Flood Report 2013. Mekong River Commission.

Mekong River Commission (MRC). (2018). Irrigation database improvement for the lower Mekong Basin. MRC Secretariat.

Mekong River Commission (MRC). (2021). 2018 Lower Mekong water quality monitoring report. MRC Secretariat.

Mekong River Commission (MRC). (2022). Mekong low flow and drought conditions in 2019–2021: Hydrological conditions in the Lower Mekong River Basin. MRC Secretariat.

Minderhoud, P. S. J., Erkens, G., Pham, V. H., Bui, V. T., & Stouthamer, E. (2017). Impacts of 25 years of groundwater extraction on subsidence in the Mekong Delta, Vietnam. *Environmental Research Letters, 12*(6), 064006.

Minderhoud, P. S. J., Middelkoop, H., Erkens, G., & Stouthamer, E. (2020). Groundwater extraction may drown mega-delta: Projections of extraction-induced subsidence and elevation of the Mekong delta for the 21st century. *Environmental Research Communications, 2*, 011005.

Nghia, B. P. Q., Pal, I., Pramanik, M., & Dasgupta, R. (2022). The impact of climate change on drought and its adaptation strategies: Findings from general circulation models and households in Tien Giang Province, Vietnam. *Climate Change, 175*, 18.

Nguyen, N. A. (2017). Historic drought and salinity intrusion in the Mekong Delta in 2016: Lessons learned and response solutions. *Vietnam Journal of Science, Technology and Engineering, 59*(1), 93–96.

Nguyen, V. L., Ta, T. K. O., & Tateishi, M. (2000). Late Holocene depositional environments and coastal evolution of the Mekong River Delta. Southern Vietnam. *Journal of Asian Earth Sciences, 18*(4), 427–439.

Nguyen, H. N. (2007). Flooding in Mekong River Delta, Viet Nam. Human Development Occasional Papers (1992–2007).

Nguyen, Q. H., Tran, D. D., Dang, K. K., Korbee, D., Pham, L. D. M. H., Vu, L. T., Luu, T. T., Ho, L. H., Nguyen, P. T., Ngo, T. T. T., Nguyen, D. T. K., Wyatt, A., van Aalst, M., Tran, T. A., & Sea, W. B. (2020). Land-use dynamics in the Mekong delta: From national policy to livelihood sustainability. *Sustainable Development, 28*, 448–467.

Nguyen, M. N., Nguyen, P. B., Van, T. D., Phan, V. T., Nguyen, B. T., Pham, V. T., & Nguyen, T. H. (2021). An understanding of water governance systems in responding to extreme droughts in the Vietnamese Mekong Delta. *International Journal of Water Resources Development, 37*, 256–277.

Pengel, B., Malone, T., Tes, S., Katry, P., Pich, S., & Hartman, M. (2007). Towards a new flood forecasting system for the Lower Mekong River Basin (pp. 1–10). Third South-East Asia Water Forum.

Phong, N. D., Hoanh, C. T., Tuong, T. P., & Malano, H. (2014). Effective management for acidic pollution in the canal network of the Mekong Delta of Vietnam: A modeling approach. *Journal of Environmental Management, 140*, 14–25.

Phung, D., Rutherford, S., Dwirahmadi, F., Chu, C., Do, C. M., Nguyen, T., & Duong, N. C. (2016). The spatial distribution of vulnerability to the health impacts of flooding in the Mekong Delta. *Vietnam. International Journal of Biometeorology, 60*, 857–865.

Phuong, T. H., Hung, H. P., Hung, N. T., Man, D. B., Mon, D., Vinh, D. H., Thuc, P. T. B., Thuong, T. V., Ninh, N. T., Phuong, T. A., & Long, N. H. D. (2020). Assessment of changes in the structure land use in Tra Vinh Province under the scenarios of climate change and sea level rise. *Vietnam Journal of Science and Technology, 58*, 70–83.

Ruiz-Barradas, A., & Nigam, S. (2018). Hydroclimate variability and change over the Mekong River Basin: Modeling and predictability and policy implications. *Journal of Hydrometeorology, 19*, 849–869.

Sam, T. T., & Khoi, D. N. (2022). The responses of river discharge and sediment load to historical land-use/land-cover change in the Mekong River Basin. *Environmental Monitoring and Assessment, 194*(10), 700.

Schmitt, R. J., Rubin, Z., & Kondolf, G. M. (2017). Losing ground-scenarios of land loss as consequence of shifting sediment budgets in the Mekong Delta. *Geomorphology, 294*, 58–69.

Schmitt, R. J., Bizzi, S., Castelletti, A., Opperman, J. J., & Kondolf, G. M. (2019). Planning dam portfolios for low sediment trapping shows limits for sustainable hydropower in the Mekong. *Science Advances, 5*(10), eaaw2175.

Schmitt, R. J., Giuliani, M., Bizzi, S., Kondolf, G. M., Daily, G. C., & Castelletti, A. (2021). Strategic basin and delta planning increases the resilience of the Mekong Delta under future uncertainty. *Proceedings of the National Academy of Sciences, 118*(36), e2026127118.

Shrestha, S., Bach, T. V., & Pandey, V. P. (2016). Climate change impacts on groundwater resources in Mekong Delta under representative concentration pathways (RCPs) scenarios. *Environmental Science and Technology, 61*, 1–13.

Shrestha, B., Cochrane, T. A., Caruso, B. S., & Arias, M. E. (2018). Land use change uncertainty impacts on streamflow and sediment projections in areas undergoing rapid development: A case study in the Mekong Basin. *Land Degradation and Development, 29*, 835–848.

Smajgl, A., Toan, T. Q., Nhan, D. K., Ward, J., Trung, N. H., Tri, L. Q., Tri, V. P. D., & Vu, P. T. (2015). Responding to rising sea levels in the Mekong Delta. *Nature Climate Change, 5*, 167–174.

Socialist Republic of Vietnam. (2017). Resolution 120/NQ-CP on Sustainable and Climate Resilient Development in the Mekong Delta.

Socialist Republic of Vietnam. (2019). Decision 417/QĐ-TTg: Action Program on Sustainable Development of the Mekong Delta in Response to Climate Change.

Sok, T., Oeurng, C., Kaing, V., Sauvage, S., Kondolf, G. M., & Sánchez-Pérez, J. M. (2021). Assessment of suspended sediment load variability in the Tonle Sap and Lower Mekong Rivers, Cambodia. *Catena, 202*, 105291.

Syvitski, J. P. M., Kettner, A. J., Overeem, I., Hutton, E. W. H., Hannon, M. T., Brakenridge, G. R., Day, J., Vörösmarty, C., Saito, Y., Giosan, L., & Nicholls, R. J. (2009). Sinking deltas due to human activities. *Nature Geoscience, 2*(10), 292–300.

Szczuciński, W., Jagodzinski, R., Hanebuth, T. J. J., Stattegger, K., Wetzel, A., Mitrega, M., Unverricht, D., & Phung, P. V. (2013). Modern sedimentation and sediment dispersal pattern on the continental shelf off the Mekong River delta, South China Sea. *Global and Planetary Change, 110*, 195–213.

Ta, T. K. O., Nguyen, V. L., Tateishi, M., Kobayashi, I., Tanabe, S., & Saito, Y. (2002). Holocene delta evolution and sediment discharge of the Mekong River, southern Vietnam. *Quaternary Science Reviews, 21*(16), 1807–1819.

Tamura, T., Saito, Y., Nguyen, V. L., Ta, T. K. O., Bateman, M. D., Matsumoto, D., & Yamashita, S. (2012). Origin and evolution of interdistributary delta plains; insights from Mekong River delta. *Geology, 40*, 303–306.

Tamura, T., Nguyen, V. L., Ta, T. K. O., Bateman, M. D., Gugliotta, M., Anthony, E. J., & Saito, Y. (2020). Long-term sediment decline causes ongoing shrinkage of the Mekong megadelta, Vietnam. *Scientific Reports, 10*(1), 8085.

Tang, X. J., Woodcock, C. E., Olofsson, P., & Hutyra, L. R. (2021). Spatiotemporal assessment of land use/land cover change and associated carbon emissions and uptake in the Mekong River Basin. *Remote Sensing of Environment, 256*, 112336.

Tang, R. N., Dai, Z. J., Mei, X. F., Zhou, X. Y., Long, C. Q., & Van, C. M. (2023). Secular trend in water discharge transport in the Lower Mekong River-delta: Effects of multiple anthropogenic stressors, rainfall, and tropical cyclones. *Estuarine, Coastal and Shelf Science, 281*, 108217.

Thanh, T. N., Huynh Van, H., Vo Minh, H., & Tri, V. P. D. (2023). Salinity intrusion trends under the impacts of upstream discharge and sea level rise along the Co Chien River and Hau River in the Vietnamese Mekong Delta. *Climate, 11*(3), 66.

Thi Ha, D., Ouillon, S., & Van Vinh, G. (2018). Water and suspended sediment budgets in the lower Mekong from high-frequency measurements (2009–2016). *Water, 10*, 846.

Tran, D. A., Tsujimura, M., Vo, L. P., Nguyen, V. T., Kambuku, D., & Dang, T. D. (2020). Hydrogeochemical characteristics of a multi-layered coastal aquifer system in the Mekong Delta, Vietnam. *Environmental Geochemistry and Health, 42*, 661–680.

Tuan, L. A., & Wyseure, G. (2006). Water environmental governance in the Mekong River Delta, Vietnam. In *The 2nd International Symposium on Water Environment Partnership in Asia.*

Tung, T. T., Chien, N. Q., Le, H. T., & Hai, L. T. (2020). Modelling storm surge hazard to Mekong Delta. In N. Trung Viet, D. Xiping & T. T. Tung (Eds.), *APAC 2019*. Springer.

Vo, K. T. (2012). Hydrology and hydraulic infrastructure systems in the Mekong Delta, Vietnam. In F. Renaud & C. Kuenzer (Eds.), *The Mekong Delta system—Interdisciplinary analyses of a River Delta, The Mekong Delta System* (pp. 49–82). Springer.

Wassmann, R., Hien, N. X., Hoanh, C. T., & Tuong, T. P. (2004). Sea level rise affecting the Vietnamese Mekong Delta: Water elevation in the flood season and implications for rice production. *Climatic Change, 66*, 89–107.

Weichselgartner, J. (2005). From the field: flood disaster mitigation in the Mekong Delta. In *Proceedings for the 7th European Sociological Association Conference, 'rethinking inequalities', Torun, Disaster and Social Crisis Research Network* (pp. 9–12).

Wilbers, G. J., Becker, M., Nga, L. T., Sebesvari, Z., & Renaud, F. G. (2014). Spatial and temporal variability of surface water pollution in the Mekong Delta, Vietnam. *Science of the Total Environment, 485–486*, 653–665.

Wild, T. B., & Loucks, D. P. (2014). Managing flow, sediment, and hydropower regimes in the Sre Pok, Se San, and Se Kong Rivers of the Mekong Basin. *Water Resource Research, 50*(6), 5141–5157.

Zhai, H. J., Hu, B., Luo, X. Y., Qiu, L., Tang, W. J., & Jiang, M. (2016). Spatial and temporal changes in runoff and sediment loads of the Lancang River over the last 50 years. *Agricultural Water Management, 174*, 74–81.