Science of the Total Environment 770 (2021) 145125

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Moving towards sustainable coastal adaptation: Analysis of hydrological drivers of saltwater intrusion in the Vietnamese Mekong Delta

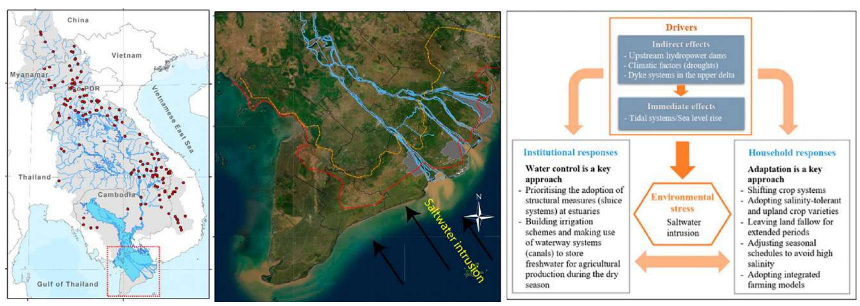
Thong Anh Tran [a,b,c,*], Thanh Duc Dang [d,**], Tri Huu Nguyen [e], Van Huynh Thanh Pham [f]

[a] Asia Research Institute, National University of Singapore, AS8, Level 7, 10 Kent Ridge Crescent, Singapore 119260, Singapore
[b] Fenner School of Environment and Society, College of Science, The Australian National University, Canberra, Australia
[c] Research Centre for Rural Development, An Giang University, VNU-HCM, 18 Ung Van Khiem, Long Xuyen City, An Giang, Viet Nam
[d] Pillar of Engineering Systems and Design, Singapore University of Technology and Design, 8 Somapah Road, Tampines, Singapore 487372, Singapore
[e] Faculty of Economics and Business Administration, An Giang University, VNU-HCM, 18 Ung Van Khiem, Long Xuyen City, An Giang, Viet Nam
[f] Faculty of Agriculture and Natural Resources, An Giang University, VNU-HCM, 18 Ung Van Khiem, Long Xuyen City, An Giang, Viet Nam

HIGHLIGHTS

- Hydrological alterations in the Vietnamese Mekong Delta are manipulated by multiple drivers.
- Saltwater intrusion in the study areas is largely driven by tidal systems and sea level rise of the Vietnamese East Sea.
- Saltwater intrusion events place heavy pressures on coastal agroecosystems and resource-dependent communities.
- The dual 'adaptation and control' policy has been exercised to deal with saltwater intrusion across governance scales.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 3 April 2020
Received in revised form 11 December 2020
Accepted 7 January 2021
Available online 27 January 2021

Editor: Animesh Gain

Keywords:
Adaptation
Saltwater intrusion
Hydropower dams
Sea level rise
Transboundary impacts
Vietnamese Mekong Delta

ABSTRACT

Coastal lowlands are of particular importance in providing food, shelter, and livelihoods for large populations; yet aggravating effects caused by human activities and climate change have exposed these areas to multiple challenges. Located in the southernmost part of the Lower Mekong Basin, the Vietnamese Mekong Delta (VMD) is adversely affected by upstream hydropower development, localised water-engineering systems (dykes), climatic factors, and sea level rise. This paper examines how these drivers shape the adaptation strategies of rural communities in the coastal areas. Using mixed sources of historical measured data, numerical modelling and qualitative data gathered in three coastal provinces (Ben Tre, Tra Vinh, and Soc Trang), we find that hydrological alterations are manipulated by various drivers with more immediate effects of the tidal systems and sea level rise in the Vietnamese East Sea. The study results suggest that while these impacts are not adequately addressed by delta-scale measures, a mixed policy approach including control and adaptation measures has been adopted to tackle saltwater intrusion on the local scale. The paper provides a holistic insight into the complex temporal-spatial dimensions of hydrological change which have distressed coastal agroecosystems and resource-dependent communities. The paper argues that while voicing concerns over transboundary hydropower impacts is essential, in situ collaborative efforts among salinity-affected jurisdictions are equally important in addressing high uncertainty and complexity of saltwater intrusion in the future.

* Correspondence to: T.A. Tran, Asia Research Institute, National University of Singapore, AS8, Level 7, 10 Kent Ridge Crescent, Singapore 119260, Singapore.
** Corresponding author.
E-mail addresses: thong.tran@nus.edu.sg (T.A. Tran), thanh_ducdang@sutd.edu.sg (T.D. Dang).

https://doi.org/10.1016/j.scitotenv.2021.145125
0048-9697/

1. Introduction

Coastal systems are characterised by the interactions of inherent natural-human systems (Wong et al., 2014; Gain et al., 2019). Burgeoning literature has recently focused on human exposure to climate change and related factors in coastal areas (Hossain et al., 2018; Mukhopadhyay et al., 2018). The IPCC Climate Change Report in 2014 highlights that coastal deltas are particularly vulnerable to climatic events, including variability of rainfall, rising temperatures, cyclones, droughts, and saltwater intrusion (Wong et al., 2014; Perera et al., 2018). Under the seasonal effects of tropical monsoons in Southeast Asia, Vietnam is seriously affected by climate change (e.g., extended drought, rising temperature, saltwater intrusion), especially in coastal areas (Eckstein et al., 2017).

The Mekong Basin, which is home to 70 million people living across China, Myanmar, Laos, Thailand, Cambodia, and Vietnam, has undergone rapid economic growth over the last few decades. Population growth, increased expansion of energy markets for regional industrialisation and human demands have triggered extensive investment in hydropower projects across Mekong tributary and mainstream channels (Grumbine et al., 2012; Middleton et al., 2015; Hecht et al., 2019; Tran and Suhardiman, 2020). Transboundary impacts associated with extreme events of water flows across the Mekong region have been cited as one of the critical issues arising from such developments (Sneddon and Fox, 2006; Sithirith, 2016; Hirsch, 2020). These processes, coupled with climate variability, have directly impacted hydrological flows of the Mekong River (Li et al., 2017; Cosslett and Cosslett, 2018; Hoang et al., 2019), not only surrounding the hydropower project sites but also across territorial boundaries, especially downstream regions.

The rural landscapes of the Vietnamese Mekong Delta (VMD) have undergone remarkable transformation, driven by state-led rice-based agricultural production policies to ensure national food security and export demands (Chu et al., 2014; Demont and Rutsaert, 2017). This has entailed large-scale investment in water-engineering systems (dykes, sluices) to address differential hazards across the upper (flooding) and lower (salinity) parts of the delta (To et al., 2003; Tran et al., 2019; Arias et al., 2019). These structural systems, while effectively contributing to the seasonal control of excessive floodwater in the upper delta, have had unexpected hydrological implications for surrounding unprotected areas (Dang et al., 2016; Vo et al., 2020).

Coastal plains of the VMD have experienced significant hydrological alterations. Effects of tidal systems and rising sea levels, coupled with other hydrological processes, have triggered the propagation of saltwater intrusion (Smajgl et al., 2015; Dang et al., 2019; Apel et al., 2020). While the intensity and magnitude of these drivers are increasingly evident (Hoang et al., 2019; Nguyen et al., 2019), there lacks a systematic understanding of how transboundary flows, while interfering with local hydrological dynamics, trigger extreme saltwater intrusion in coastal areas. Simultaneously, while various models have been built to examine impacts of future dam development scenarios and other climatic events (e.g., distribution of rainfall) on downstream regions (Räsänen et al., 2012; Wang et al., 2016; Hecht et al., 2019), these efforts have not incorporated the spatial (transboundary-local) and temporal (wet-dry) dimensions of hydrological change into the technical assessment of saltwater intrusion in the VMD.

This study investigates how the altered hydrological flows induced by hydropower development in the upper Mekong River and local infrastructural systems (dykes in the upper part of the delta), while interacting with tidal systems and rising sea levels, have implications for saltwater intrusion in the study areas. Drawing on qualitative data and the modelling of hydrological systems in the VMD, the paper argues that while the impacts of hydropower dams on the Mekong River and local infrastructural systems (dykes in the upper delta) on hydrological flows are observed, tidal systems and rising sea level have immediate effects on saltwater intrusion in the study areas. The findings contribute to understanding how the mixed ‘adaptation and control’ policy has been exercised to deal with saltwater intrusion. While adaptation is predominantly practised at the district and commune level, greater priority is given to the control approach (e.g., sluices) to seal off the estuaries and prevent the propagation of saltwater on a larger scale. The systematic understanding of hydrological effects would assist central and local governments in making informed decisions towards enhancing the delta's resilience against further impacts of saltwater intrusion in the future.

2. Description of study areas

The high seasonal variability of the Mekong River (e.g., reduced streamflow discharge in the dry season), compounded by climatic impacts (e.g., extended droughts), has induced saltwater intrusion in the VMD (see Fig. 1). An update on Vietnam drought and saltwater intrusion in January 2020 reported that 10 out of 13 provinces in VMD suffered from drought and saltwater intrusion in 2020, threatening approximately 700,000 people and 500,000 ha of agricultural land (Vietnam Disaster Management Authority (VDMA), 2020).

Three provinces which span the coastline of the Vietnamese East Sea were selected for the study, including: (1) Ben Tre, (2) Tra Vinh, and (3) Soc Trang. Respectively, Binh Dai, Cau Ngang, and Long Phu Districts were selected to explore the trends of saltwater intrusion, its impacts and the adaptive responses of local communities. Aquacultural production and integrated (rice-shrimp) farming systems form the primary means of livelihoods (Nguyen et al., 2019). Upland crops (e.g., peanuts) are particularly prevalent due to their high adaptability to the local dry and saline environments. Details of the three coastal areas are described below:

Binh Dai is a coastal district of Ben Tre Province. It has a total area of 42,758 ha (ha), of which 33% (14,243 ha) is devoted to agricultural production, and 37% (15,861 ha) to aquacultural production (Ben Tre Statistical Office, 2018). The district is located in An Hoa islet and bordered by two rivers (Cua Dai and Ba Lai). The Ba Lai irrigation scheme, which came into operation in 2002, plays an important role in local socio-economic development (Hoang et al., 2009). The physical demarcation provided by the irrigation scheme creates two distinct ecological zones (freshwater and salinity) in the district. This division characterises various forms of livelihoods between the two zones amidst adaptation patterns to accommodate with the respective environments.

Cau Ngang District is located in the southeast region of Tra Vinh Province, occupying an area of 32,836 ha (accounting for 14.31% natural total land of the province). It shares borders with the Co Chien river and Cung Hau estuary in the Northeast. The geographical location of Cau Ngang District makes it highly exposed to intense saltwater intrusion in the dry season (Cau Ngang People's Committee, 2015).

Long Phu is a rural district of Soc Trang Province. The district occupies more than 263,000 ha of natural land and is home to 113,856 people (Soc Trang Statistical Office, 2019). Over the past few years, Long Phu District has been severely hit by extreme saltwater intrusion. This impacts freshwater supply and local farming systems (i.e., shrimp farming, rice crops) in the district (Soc Trang Department of Agriculture and Rural Development, 2019).

3. Data collection and research methods

3.1. Gauged data analysis and numerical modelling

Understanding human and climate-induced changes to saltwater intrusion in the VMD is essential for mitigating their negative impacts. Historical data analysis and numerical modelling are the two typical methods to assess changes in water quality due to hydroclimatic variability and other ongoing environmental challenges. In the absence of

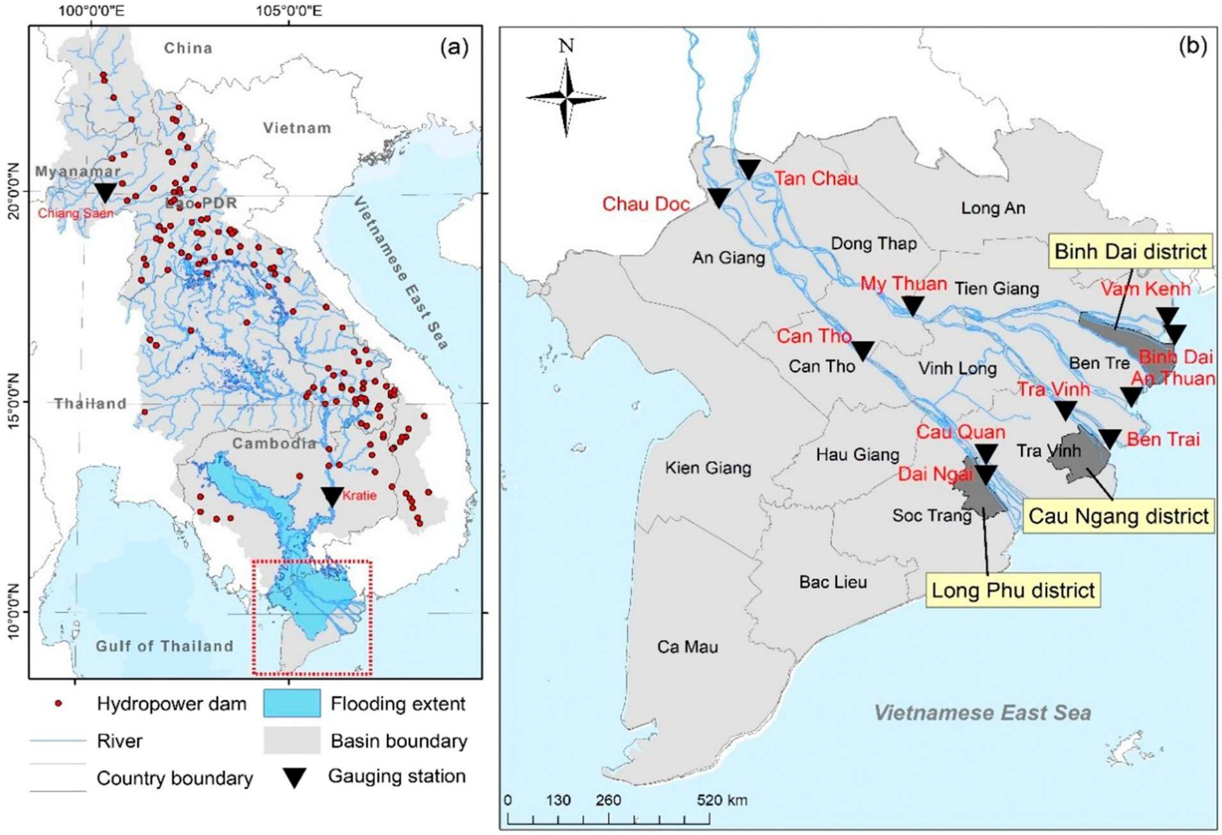


Fig. 1. The VMD in the Mekong River Basin (a) and three selected study areas (Binh Dai, Cau Ngang, and Long Phu districts) and the location of gauging stations used in this study (b).

a dense network of gauging stations, we applied the DHI MIKE 11 model that couples hydrodynamics and water quality processes to examine the spatial variations of salinity. This model was adopted because the Mekong river network was already digitised from the Cambodian town of Kratie to the river estuaries in the VMD (Dang et al., 2018). In this model, local rainfall is modelled by using the NAM (Nedbør-Afstrømnings-Mode) model with rainfall data measured at 39 stations. Rainfall data were obtained from the South Region Hydrology – Meteorology Centre of Vietnam. The advection-dispersion (AD) module of MIKE 11 was used for salinity intrusion simulation. The model also employs the same river network consisting of 3586 natural rivers and artificial canals. Input data, including upstream discharge (at Kratie), downstream water level (at estuaries), salinity and local rainfall, were obtained from the Mekong River Commission (MRC) and the South Region Hydrology – Meteorology Centre of Vietnam. Design specifications of delta-based water infrastructure were collected from the Institute for Water and Environment Research (IWER) and the Southern Institute of Water Resources Research (SIWRR), Vietnam.

For the purpose of this study, the hydrodynamic model is calibrated and validated against water level data measured in 2000, 2002, and 2011 (at multiple water level stations) and discharge data observed in 2005 (at Can Tho and My Thuan stations). Salt concentration levels are calibrated with observed data from 2005 and validated with data from 2009 at Tra Vinh and Cau Quan stations. In general, the Nash-Sutcliffe efficiency coefficients (NSE) ranged from 0.74 to 0.96 for water level stations on the main streams (see Fig. 2; for more information, see Dang et al., 2018). The NSE values for discharges calculated at Can Tho and My Thuan for 2005 are 0.91 and 0.87, respectively. NSE values for salt concentration at Tra Vinh and Cau Quan in 2009 are 0.65 and 0.68. The NSE coefficient was calculated according to the following:

$$NSE = 1 - \frac{\sum_{t=1}^{T} \left(Z_m^t - Z_0^t\right)^2}{\sum_{t=1}^{T} \left(Z_0^t - \overline{Z_0}\right)^2} \quad (1)$$

where $\overline{Z_0}$ is the mean of either observed water levels or discharges; Z_m is modelled water level or discharge; Z_0^t is observed water level or discharge at time t.

In the study, we consider three scenarios to simulate saltwater intrusion in the VMD: (1) baseline, (2) sea level rise, and (3) hydropower development and sea level rise. Dam simulations to study the impact of 110 upstream hydropower dams were undertaken by Lauri et al. (2012) for the period 1982–1992. We used the change in the mean of monthly discharge for the period 1982–1992 to shift the mean of monthly discharge for the period 2000–2010 by using the delta factor method. Since all 110 dams in the basin are considered in this scenario, the effect of their storage variability is reflected by the change in saline boundary between the baseline scenario and the hydropower development scenario.

$$\Delta Q = \frac{\overline{Q}_{series,i}}{\overline{Q}_{ref,i}} \times \left(1 - \frac{S_{sim}}{S_{total}}\right) \quad (2)$$

where $\overline{Q}_{series,i}$ is the (11-year) average discharge for month *i* produced by Lauri et al. (2012); $\overline{Q}_{ref,i}$ is the (11-year) average observed discharge for month *i* in the period 1982–1992; S_{sim} is the mean of the total storage capacity of reservoirs from 2000 to 2010; S_{total} is the total storage capacity of all 110 reservoirs in Lauri et al. (2012). This factor was then used to correct the river flow for the period 2000–2010. Since most of the dams were constructed after 1992 (see Fig. 3), we assumed that the Mekong was still in the unregulated condition before 1992. This method is similar to a study by Pokhrel et al. (2018), who attempted to evaluate change in hydrological regimes driven by large-scale

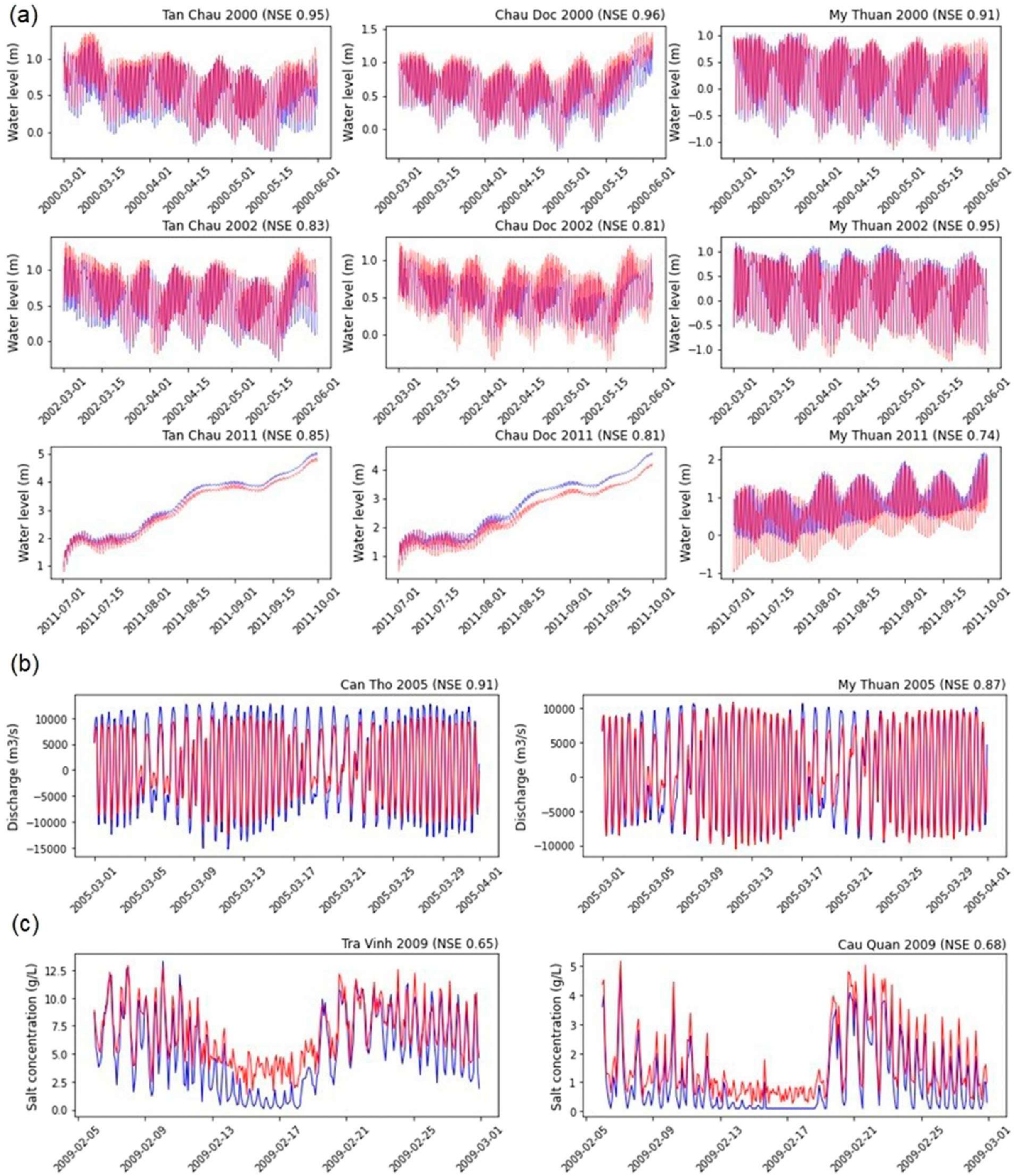


Fig. 2. Presentation of Nash-Sutcliffe efficiency (NSE) values for (a) water level, (b) flow discharge, and (c) salt concentration calculated at stations on the Mekong mainstream (blue = observed; red = modelled). See Dang et al. (2018) for more detail on model calibration and validation.

hydropower dams on the Lower Mekong Basin (LMB). 2000 to 2010 is the period before a series of large dams (Xiaowan 9.9 BCM in 2010, Gongguoquiao 120 MCM in 2012, and Nuozhadu 21.7 BCM in 2014) had been completed on the Upper Mekong Basin (UMB) (known as the Lancang River Basin) in China, which together increase the total water storage (Fig. 3) and have had major hydrological influences on the lower stretch (see Hecht et al., 2019; Wassmann et al., 2019).

Three scenarios provide insightful comparison for saltwater intrusion (Table 1). Here, we seek to identify key drivers of saltwater intrusion in the coastal zones. While previous studies have identified possible hydrological alterations under hydropower development, the expansion of irrigation schemes, infrastructural development, and climate change (Dang et al., 2016; Hecht et al., 2019; Hoang et al., 2019), this study elaborates on how these drivers are responsible for the fluctuations of water flows within the VMD and particularly saltwater intrusion in the coastal areas.

3.2. Qualitative data and analysis

An exploratory multiple case study approach was adopted (Yin, 2014). This approach incorporates multiple sources of studies into analysis, where selected cases are compared and contrasted (Onwuegbuzie

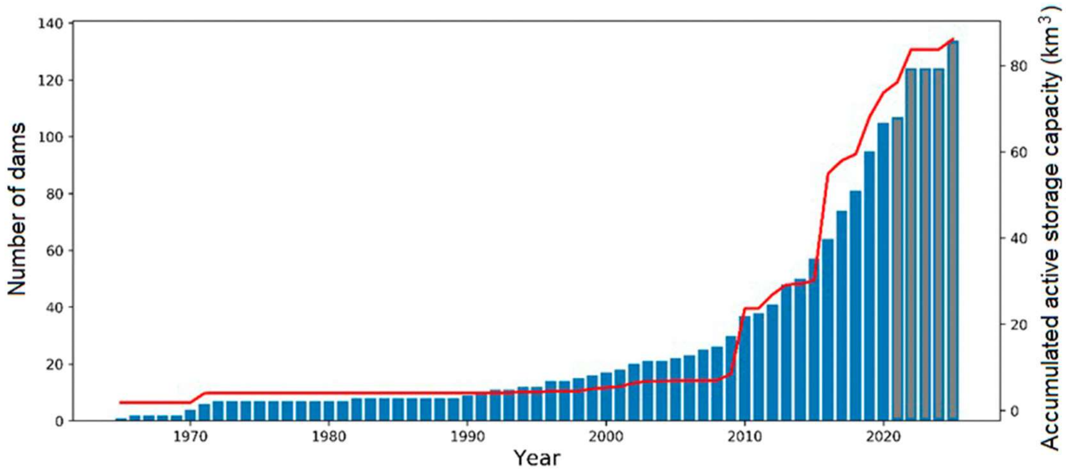


Fig. 3. Increases in the number of hydropower dams (blue) in the Mekong River Basin and reservoir storage capacity (red) over the period 1960–2025 (Data source: MRC). This graph shows that after the year 2010, the accumulative active storage capacity of reservoirs in the Mekong increased significantly due to the construction of Chinese dams.

and Leech, 2007). In light of this approach, the qualitative data collected in three study areas were utilised to comparatively analyse various dimensions of saltwater intrusion (see Table 2 in the Supplementary Section). Trends of saltwater intrusion, its impacts, and adaptation practices to salinity, for instance, are taken into consideration. Together, these analyses help advance empirical understanding of how alterations of hydrological patterns across the LMB are linked to saltwater intrusion dynamics in the coastal delta. The analysis considers upstream and local development-environment relationships as well as their implications for saltwater intrusion processes. In this study, the data collection was undertaken at different points in time, spanning April to June 2019 (Binh Dai District), December 2017 to May 2018 (Cau Ngang District), and November 2014 to June 2015 (Long Phu District).

Narrative and thematic approaches were both adopted to assist the qualitative data analysis. According to Paschen and Ison (2014), considering its application in relation to the social research contexts in this study, narrative research offers an innovative and holistic approach to better understand socio-ecological dynamics and improved design of local adaptation policies. The thematic analysis, as noted by Braun and Clarke (2006), assists in 'thematising meaning' of qualitative data, which involves a multi-step procedure of analysis including open, axial, and selective coding (Neuman, 2011). These analytical processes were assisted with the application of NVivo software (Bazeley and Jackson, 2013).

This study also involves content analysis of a wide range of resources relevant to hydropower development, transboundary environmental impacts, and saltwater intrusion in the Mekong region, including policy documents, scientific reports, books, and journal articles. These secondary sources contribute substantially to contextualising the issues under study and allow for gaining in-depth knowledge of local narratives and policy discourses associated with saltwater intrusion and adaptation in the study areas. Similarly, these resources were also analysed with the use of NVivo.

4. Results and discussion

4.1. Historical analysis and perceptions of saltwater intrusion

The LMB has experienced recurrent droughts and saltwater intrusion over the past few decades, evidenced in the years of 1992–1993, 1998–1999, 2004–2005, 2010–2011, 2015–2016, and 2019–2020 (Guo et al., 2017; Cosslett and Cosslett, 2018; Vietnam News, 2020). These events, when compounded by El Niño effects and the operations of cascading hydropower dams upstream, have led to the significant reduction of water flows in the Mekong River and (dis)tributaries of riparian countries downstream, especially in the VMD (Adamson and Bird, 2010; Kuenzer et al., 2013; Hoang et al., 2019). Extensive impacts of saltwater intrusion correlate positively with significant damage costs, particularly in the agricultural sector (Cosslett and Cosslett, 2018). In the years 2015–2016 and 2019–2020, most coastal provinces in the VMD were seriously affected by saltwater intrusion, with the saltwater encroaching more than 100 km inland (UNDP Vietnam, 2016; VDMA, 2020).

In term of seasonal variability, hydrological regimes in the LMB are driven by the Western North Pacific monsoon with distinct dry and wet seasons. Though the UMB contributes only around 19% of annual flows at Stung Treng, Cambodia (Data: 1960–2004; see Fig. 4.; Source: MRC), its flows in the dry season allow the maintenance of ecological functions and reduce saltwater intrusion in coastal areas. Different from the wet season, snow melt water and rainfall under the Indian monsoon together with the weakened Western North Pacific monsoon bring approximately 34% of the dry season flows (recorded at Stung Treng). Given the large active storage capacity of Chinese reservoirs (~33 billion cubic meters; Data: Hydropower Database of MRC, 2018), the dams in the UMB play a significant role in fostering and regulating water flows downstream. However, apart from low monsoon rainfall, it was observed that drought events have become extreme since the

Table 1
Hydrodynamic simulation scenarios.

Scenarios	Upstream boundary	Downstream boundary		Hydropower development
		Water level	Salt concentration	
Baseline	2000–2010	2000–2010	2000–2010	Before the construction of large dams in China
Sea level rise	2000–2010	2000–2010 (+30 cm)	2000–2010	Before the construction of large dams in China
Hydropower development and sea level rise	2000–2010 (altered by 110 dams)	2000–2010 (+30 cm)	2000–2010	All 110 dams (Lauri et al., 2012), including large dams in China

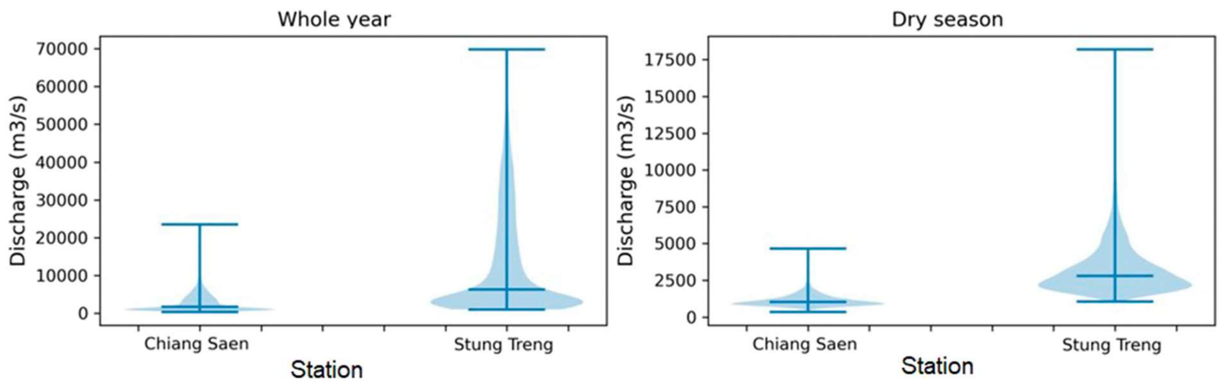


Fig. 4. The variability of discharge observed at Chiang Sean (at the outlet of the UMB) and Stung Treng (at the border between Cambodia and Laos) reveals that the UMB plays an important role in water supply during the dry season (Data used for the analysis: 1960–2004; Source: MRC).

afore-mentioned dams came into operation (Lu et al., 2014; Cochrane et al., 2014). This suggests that the operation of upstream hydropower dams is closely connected to hydrological fluctuations downstream, especially in the VMD.

While El Niño effects can be reasonably well forecast, upstream flow regulations together with sea level rise in the coastal areas make saltwater intrusion highly unpredictable in terms of timing, intensity, and magnitude. In this study, farmers in Binh Dai and Long Phu districts have experienced substantial impacts of salt concentration, especially at the end of the dry season and find it impossible to curb such situations on a large scale. Government officials expressed grave concerns about saltwater intrusion in their locales in recent years. An agricultural expert in Cau Ngang District, for instance, noted that:

> "*Previously in our district, we enjoyed 6 months of freshwater supply and 6 months of saltwater. Since the late 2000s, the saltwater intrusion has come early, and the salinity level has intensified especially in the later months of the dry season. This is very much different from what we have experienced so far.*" (Fieldnote on 23 January 2018).

Our simulation results, as illustrated in Fig. 2, suggest that this phenomenon is largely attributed to the diurnal tidal regimes of the Vietnamese East Sea. Spanning the coastline of the Vietnamese East Sea, the study areas are subject to the immediate effects of tidal systems, thus making it highly exposed to saltwater intrusion. These aspects will be further expounded through local farmers' observations and interpretations of the events that occurred in study areas during the dry season (See Section 4.3.2).

In the following section, we conduct hydrodynamic modelling to gain a better insight into the key drivers of hydrological change in the Mekong River, their characteristics, and how they are linked to saltwater intrusion in the coastal areas.

4.2. Modelling results

As suggested by other studies (Lauri et al., 2012; Hecht et al., 2019), hydropower reservoirs are attenuating seasonal variability by transferring more water from the wet season to the dry season for hydropower production. Although the collaborative operation of dams to increase releases during the dry season can be implemented, hydropower reservoirs could weaken the upstream flood flows that push saltwater back to the estuaries (Smajgl et al., 2015). In this study, we found that the dry-season releases from hydropower dams could theoretically help alleviate salinity in the delta and combat sea level rise (Fig. 5a, b). However, if hydropower reservoirs cannot store enough water at the end of the wet season, they may continue to retain more water in the dry season for the following year, thus exacerbating salinity effects. While dam owners can give more priority to hydropower production for capital interests, the coordinated operations would fail. What is more, during the monsoon season, agricultural activities can be sustained by rainwater supply. In contrast, in case a higher amount of water is needed for irrigation during the dry season and the early wet seasons, water demand can be fulfilled through direct diversions of water from river networks at hand (Hoang et al., 2019). This suggests that there should be a working mechanism in place to regulate the operation of hydropower dams to ensure sufficient water discharge downstream and increasing water demands for irrigated agriculture of riparian countries.

Building on the IPCC's report in 2014 on the gradual change in sea level rise (ranging from 17 to 38 cm), our modelling results suggest that it is a critical driver of saltwater intrusion, apart from their already existing exposure to the delta (Minderhoud et al., 2019; Dang et al., 2019). According to the model (Fig. 5c), the 2 g/l saline boundary will shift about 30 km further inland for a 30 cm of sea level rise compared to the baseline. This finding is consistent with the estimation made by Smajgl et al. (2015). Our interviews with key respondents confirm the assumption that the El Niño effects and hydropower dams, when interacting with pre-existing water-engineering systems in the floodplains of the Mekong Delta, have reduced the water flows downstream, thus worsening saltwater intrusion in the coastal areas.

This study suggests that, given the current situation, it would be challenging to model the impacts of the entire delta-based water infrastructure on saltwater intrusion due to the incomplete studies on operational rules of dyke systems and sustained efforts in structural investment for saltwater prevention in the coastal areas. This implies that, while the VMD in general and the coastal plains in particular are placed at risk of the afore-mentioned drivers, enhancing capacity for water management is critically important. While the mixed policy of water management inclusive of structural and non-structural measures is essential at the delta scale, collaboration among Mekong riparian states should be equally important to warrant the equitable utilisation of Mekong water resources (Fox and Sneddon, 2005). This study therefore suggests that, while the latter effort would involve much politics and policy dialogues among the riparian states, it is imperative to implement delta-based adaptive actions to deal with the situation. In the following sections, we discuss how local governments and farming households have dealt with saltwater intrusion (see Fig. 6).

4.3. Institutional and household responses to saltwater intrusion

Various adaptation pathways have been deployed at the institutional and household levels to deal with saltwater intrusion. Our data suggest that both short-term and long-term measures have been undertaken to alleviate saltwater intrusion. Table 3 presents various adaptation approaches that have been implemented across the study areas in addressing salinity challenges. The following sections will elaborate on these dimensions.

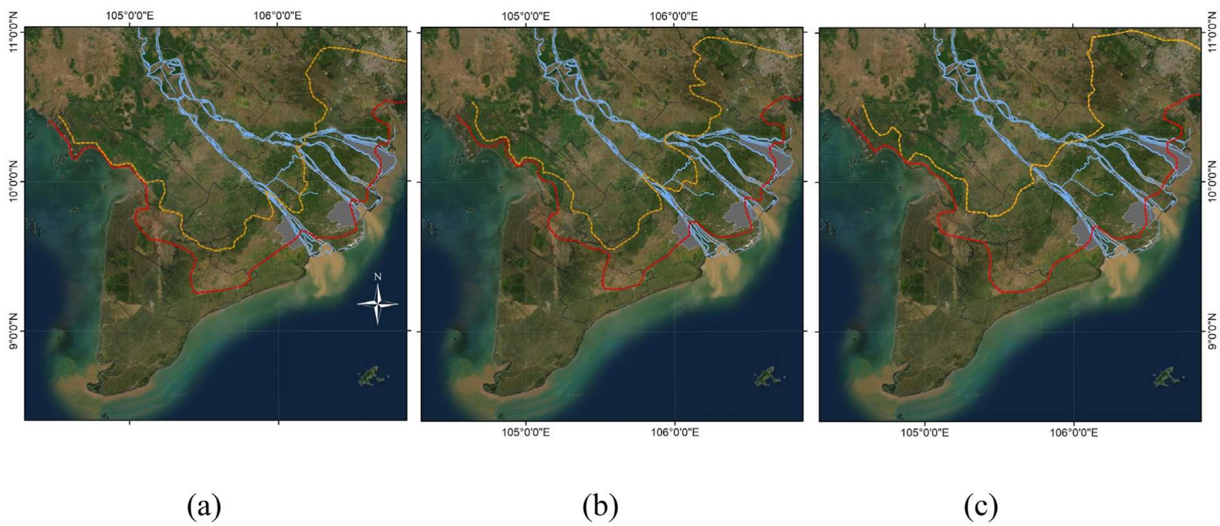


Fig. 5. Maximum saline boundary of three simulation results: (a) Baseline; (b) Hydropower development and sea level rise; and (c) Sea level rise (red line – high salt concentration: 20 g/l; yellow line – low salt concentration: 2 g/l; Background map source: ESRI).

4.3.1. Adaptive responses at the institutional level

Structural measures (e.g., dykes) have been prioritised to support intensive rice production and prevent the infiltration of saltwater inland. The period 1995–2010, for instance, witnessed the extensive development of 'salinity-freshening' projects by installing an array of large-scale irrigation schemes (i.e., canals and sluices) and diverting water from the Tien (Mekong) and Hau (Bassac) rivers to irrigate local agricultural systems (Benedikter, 2014). For instance, financed by World Bank, the Ministry of Agriculture and Rural Development constructed the South Mang Thit irrigation scheme to irrigate some 225,000 ha of rice and regulate saltwater for aquacultural activities in Vinh Long and Tra Vinh provinces (Cosslett and Cosslett, 2014). This period also witnessed the development of the Tiep Nhat irrigation project in Soc Trang to secure freshwater supply for about 53,910 ha in the province (Ho and Ubukata, 2018). In Ben Tre Province, the operation of the Ba Lai irrigation scheme also provides freshwater for agricultural areas (50,800 ha) in its northern areas (Hoang et al., 2009). While comprehensive impact assessments on these operational systems have not yet been implemented,

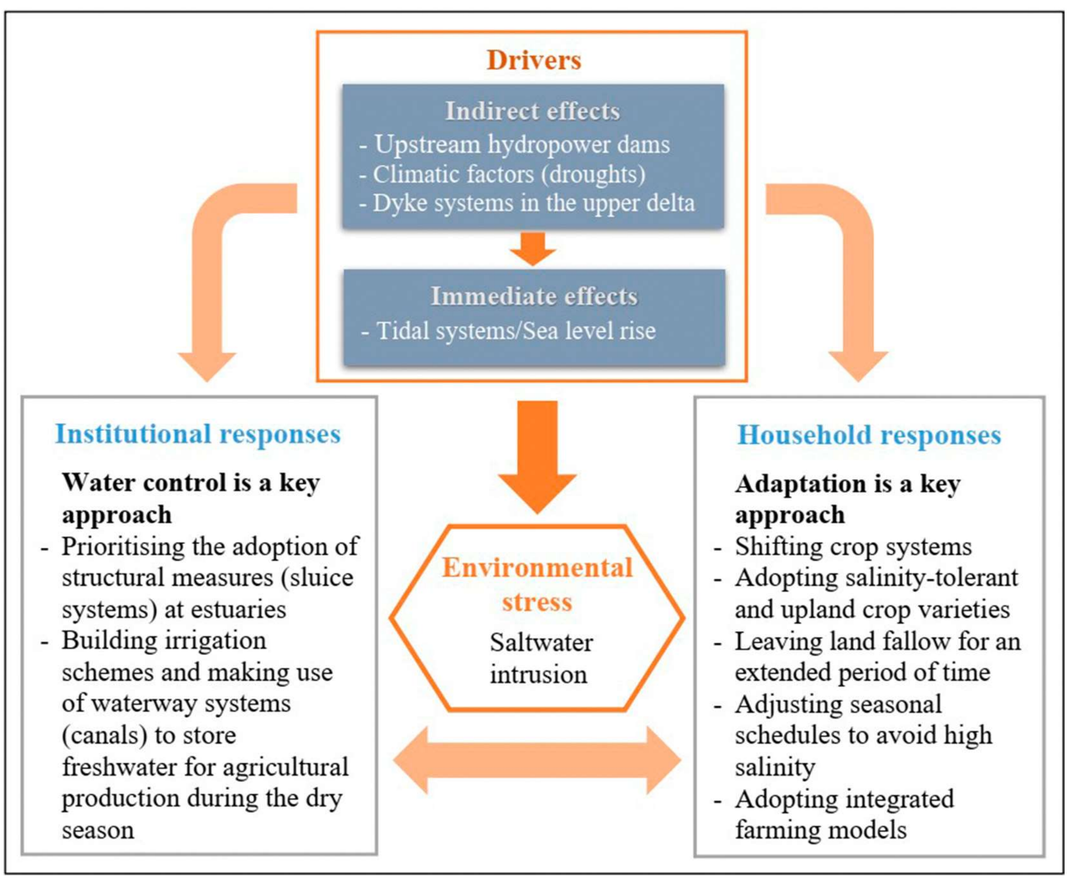


Fig. 6. Illustrations of institutional and household responses to saltwater intrusion.

Table 3
Adaptive responses at household and institutional levels across the study areas.

Adaptive responses	Selected study areas		
	Binh Dai District	Cau Ngang District	Long Phu District
Institutional level	Reorganising production activities in salinity and freshwater zones Harnessing the freshwater supply from Ba Lai reservoir (the Ba Lai irrigation scheme) for diversifying crop production and supplying year-round freshwater for inhabitants living in upstream (freshwater zone) and downstream localities (salinity zone) of Ba Lai River	Improving the performance of local sluices systems (e.g., Thau Rau, Cha Va, and Vinh Kim) that allow freshwater retention for rice cultivation and saltwater intake for shrimp farming when possible Collaboration between the Cau Ngang Office of Agriculture and Rural Development and the local Enterprise for Hydraulics and Agriculture in scheduling rice crops and operating sluice systems Regulating freshwater flows from adjacent localities for local utilisation (i.e., agricultural production activities)	Building sluice systems to prevent the saltwater encroachment into production zones Utilising canals to store freshwater, making it available for crop production Providing precautions about saltwater intrusion at the commune level Providing training for farmers on adaptive responses to saltwater intrusion Selecting suitable crop systems/varieties Shifting seasonal calendar Providing agricultural insurance to local farmers Providing financial support (e.g., micro-credits) to maintain farmers' livelihoods
Household level	Availability of the freshwater resources in the upper part of the Ba Lai River allows farmers to practice multiple crops (e.g., planting rice, bananas, coconuts…) Households in the salinity zone (downstream of the river) remain to practice salinity water-based farming systems (e.g., shrimp farming and other integrated farming models) Mixing freshwater from the Ba Lai irrigation scheme into saltwater for intensive shrimp farming Off-farm/Non-farm activities	Shifting crop activities from rice to shrimp-rice and intensive shrimp farming practices Adopting salinity-tolerant upland crop varieties during the dry season where possible Leaving land fallow for an extended period of time Extracting groundwater for shrimp farming Off-farm/Non-farm activities	Building small ponds to store freshwater during the dry season Shifting from rice-fish farming to rice-shrimp farming practices Adjusting seasonal schedules for fish and rice farming to avoid high-level salinity Adopting alternative crops (e.g., sugarcane) Planting salinity-tolerant rice varieties in high elevation areas Off-farm/Non-farm activities

renewed attempts in building an even larger sluice system on the Ca Mau Peninsula such as Cai Lon-Cai Be mean that the central/provincial governments persistently pursue structural measures as a key approach for water management, although much doubt is cast upon their effectiveness in securing coastal community resilience (e.g., ongoing disruption of salinity agroecosystems that are the basis of local livelihoods).

Interviews with local government officials demonstrate that sustained efforts have been invested to deal with saltwater intrusion, largely based on conventional technical approaches. Monitoring of river salinity was regularly undertaken to keep track of salinity levels and provide warnings for local communities to act upon responses when necessary (Interviews with a government official in Cau Ngang District, January 2018). In Long Phu District for instance, extension officials collected water samples and utilised testing instruments installed at sluice gates to measure salinity (Interview with key informants, April 2015).

4.3.2. Adaptive responses at the household level

Various adaptation strategies suggest that local farmers have adopted their experiential knowledge in addressing saltwater intrusion (see Table 3). Our data suggest that they have flexibly opted for crops and crop varieties that are more tolerant to salinity (e.g., coconut trees) and transformed local farming systems (e.g., the integrated shrimp-rice farming in Cau Ngang District) as well as shifted seasonal calendars to avoid possible risks and accommodate salinity conditions (see Fig. 7 in the Supplementary Section). Aligning with the introduction of novel farming systems, innovative water management has also been practised. In Binh Dai and Cau Ngang districts, for instance, farmers mixed freshwater into saltwater to reduce the salinity level, making it possible for shrimp farming. They also store freshwater in garden ponds or place canvas underneath the ponds to keep freshwater available for use for an extended duration. However, this water storage method is solely adopted by farmers who have backyard gardens. Freshwater can also be stored in canals for irrigated farming within the communities.

While smallholder farmers continue to work their lands to sustain their livelihoods, others (especially the poor) prefer to migrate to urban areas in search of employment. In this regard, out-migration is conceived of as an adaptation approach in the VMD to not only alleviate rural unemployment pressures but also stabilise migrants' incomes (Tran, 2019). As noted by local informants, while out-migration helps alleviate acute poverty, it induces shortages of agricultural labour in rural areas and worsens migrant workers' health in the longer term.

How local farmers perceived saltwater intrusion is closely linked to their ecological knowledge and experiences in interacting with local environments. They observed local natural phenomena to predict the level of water salinity, whereby they take adaptive actions. Farmers involved in a group discussion in Long Phu District shared that the bright reflection of star light on the water surface at night is an indication of high salinity. Together with scientific knowledge (using salinity testing tools), such experiential knowledge is useful in diagnosing the changing salinity conditions, thereby supporting farmers' response to saltwater intrusion.

4.4. Differential perceptions of impacts of hydrological change on the VMD

There is a variation in ways local respondents perceive the transboundary environmental impacts of hydropower dams on the VMD. Our data suggest that most government officials demonstrate relevant knowledge of ongoing hydropower development in the

Mekong basin to its downstream impacts. They claim that these transboundary dynamics, to some extent, are directly associated with altered water flows in the Mekong River, which consequently disrupts water systems in the VMD, engendering saltwater intrusion in coastal areas. However, in response to our questions in interviews, most farmers attribute the situation to locally-situated problems of climatic variability in the dry season. For them, saltwater intrusion is largely associated with changing rainfall patterns, extended drought, and rising temperatures.

4.5. Pathways towards sustainable adaptation in the coastal plains

The VMD has come under critical pressures to address saltwater challenges. The Prime Minister's Decision No. 1397/QD-TTg. on 'Approving hydraulic planning in the VMD from the years 2012-2020 and orientation towards 2050' has sparked efforts to deal with climate change and sea level rise delta-wide (Vietnam Prime Minister, 2012). The past few years have seen increasing efforts in preventing saltwater intrusion (Cosslett and Cosslett, 2014; Smajgl et al., 2015; Pham et al., 2018). Most peripheral zones of the coastal delta have been sealed off by sea dykes or sluice systems (e.g., Ba Lai sluice system in Ben Tre Province). As indicated by most government officials in the study areas, these 'hard' measures could effectively secure local farming practices and tackle extreme saltwater intrusion events in the future.

Adaptation approaches, in contrast, are mainly practised on smaller scales, particularly within the district and commune-level administrations. This study suggested that adverse effects of salinity prompted farmers to change their livelihood strategies and develop innovative adaptation methods. From the social learning perspective, these practices were grounded on farmers' motivations to 'learn to adapt' (Tran et al., 2018). Local narratives suggest that experiential knowledge of 'living with floods' that has been successfully adopted in the upper delta (Tran, 2020) would be beneficial to 'living with salinity' in the coastal areas. From a policy perspective, this study highlights that farmers are important knowledge brokers who mobilise resources and distribute innovative knowledge across the delta. This would make a meaningful contribution to the enforcement of the Government's Resolution No. 120/NQ-CP in enhancing the rural livelihood resilience (The Vietnamese Government, 2017).

Our data suggest that, while the adaptation-oriented policies are exercised at the district and commune levels, greater priority is given to the control approach (i.e., structural measures) at the provincial and delta levels. This dual policy points to the transboundary implications of hydrological alterations that needs to be factored into long-term adaptation strategies in the coastal areas. As Khong et al.'s (2020: 10) argue, "*…as Vietnam can do little to increase flows into the VMD, the only option is to construct sea dykes.*" Concerning this, three critical issues need to be urgently addressed: (1) how the equitable utilisation of water and related resources in the Mekong River can be guaranteed, (2) how the costs and benefits of utilising the Mekong resources can be negotiated between upstream and downstream countries, and (3) to what extent saltwater intrusion can be addressed in the VMD. This study calls for an imperative to establish an ad-hoc institutional structure (e.g., a delta-based steering committee) tasked with coordinating the integrated water management and adaptation as well as steering strategic development visions in the VMD, taking consideration of transboundary implications of hydropower development which are not adequately addressed in the Government's Resolution 120/NQ-CP (The Vietnamese Government, 2017). As such, greater efforts should be made in pushing forward an integrated environment and development agenda at the Mekong region scale that holds the upstream Mekong countries accountable for hydropower-driven transboundary impacts, which would expose critical threats to the VMD in upcoming decades.

This study has some limitations. While saltwater intrusion events propagate across the VMD, this study looks narrowly into three coastal areas of the Vietnamese East Sea. This may fail to provide an overarching assessment of salinity impacts in relation to transboundary implications across the upper zones (flooding zones) of the delta. A promising follow-up to this study would be the focus on the comparative analysis of how transboundary impacts mediate hydrological change in both flooding and salinity zones of the VMD. Another limitation of this study is concerned with the fact we do not directly simulate the impact of hydropower dam operations but adopt the delta factor method to provide input data for the hydrodynamic model. Also, uncertainties in sea level rise were not considered. However, there are no reasons to believe that adding these uncertainty modelling approaches would deeply alter the main findings of this work.

5. Conclusions

The study suggests, while the altering hydrological flows driven by the upstream hydropower dams and localised infrastructure (dykes in the upper delta) cause disturbance to water-related activities in the VMD, saltwater intrusion in the study areas is largely affected by tidal systems. It is largely due to their geographical locations (i.e., stretching along the coastline) that make them highly susceptible to saltwater intrusion. Through the numerical modelling analysis, this study provides a nuanced understanding of the temporal-spatial dimensions of hydrological alterations operating at the regional and delta scales. Further research should focus on how/to what extent the upstream development dynamics interact with in-situ exploitative activities (e.g., sand mining upstream, groundwater extraction) that affect saltwater intrusion and land subsidence in the coastal delta.

Results from the hydrological modelling reveal the complexities of saltwater intrusion in the coastal delta, where various impact factors come into play. Given the contemporary environment-development challenges in the Mekong region, water flows in the Mekong River are contingent on various externalities, including seasonal operations of hydropower dams, climatic effects, and increasing water demands of riparian countries for irrigation purposes. It is deemed more problematic while we lack the mechanism of water data sharing (which vary in time and space) among the Mekong countries. This study suggests that, under the operational mechanism of the newly-formed Lancang-Mekong Cooperation Framework, basin-wide data of seasonal water flows should be shared, and relevant information meaningfully transferred.

The case studies illuminate the substantial efforts by coastal communities to adapt to saltwater intrusion, evidenced by the deployment of various on-the-ground adaptation approaches. From a policy perspective, the study highlights the need to adopt a mixed approach (i.e., control and adaptation) to manage the coastal water environments. While greater priority is put on structural measures at the central and provincial levels to deal with saltwater intrusion, adaptation is predominantly adopted at the household level. The study contributes to informing sustainable adaptation strategies in the delta, suggesting that, while adapting to saltwater intrusion in the coastal plains is essential, it is equally important to articulate the transboundary impacts of upstream hydropower dams, not only for the sake of the coastal areas but also the VMD as a whole.

CRediT authorship contribution statement

Category 1:

Conception and design of study: Thong Anh Tran; Thanh Duc Dang

Acquisition of data: Thong Anh Tran; Thanh Duc Dang; Tri Huu Nguyen; Van Huynh Thanh Pham

Analysis and interpretation of data: Thong Anh Tran; Thanh Duc Dang

Category 2:

Drafting of the manuscript: Thong Anh Tran; Thanh Duc Dang

Revising the manuscript critically for important intellectual content: Thong Anh Tran; Thanh Duc Dang.

Category 3:

Approval of the version of the manuscript to be published:

Thong Anh Tran; Thanh Duc Dang; Tri Huu Nguyen; Van Huynh Thanh Pham

Declaration of competing interest

There are no conflicts of interest among the authors with respect to the research, authorship and publication of this paper.

Acknowledgements

This study was partly funded by the SEARCA's (Southeast Asian Regional Centre for Graduate Study and Research in Agriculture) Seed Fund for Research and Training Program, the Philippines. The authors wish to extend their gratitude to respondents for their provision of information for the study. Lastly, thanks are due to anonymous reviewers for their valuable comments and constructive feedback and Brian Eyler, Kimberley Thomas, and Jonathan Rigg for their assistance in proofreading the paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.145125.

References

Adamson, P., Bird, J., 2010. The Mekong: A drought-prone tropical environment? International Journal of Water Resources Development 26 (4), 579–594.

Apel, H., Khiem, M., Nguyen, H.Q., To, Q.T., 2020. Brief communication: seasonal prediction of salinity intrusion in the Mekong Delta. Nat. Hazards Earth Syst. Sci., 20, 1609–1616.

Arias, M.E., Holtgrieve, G.W., Ngor, P.B., Dang, T.D., Piman, T., 2019. Maintaining perspective of ongoing environmental change in the Mekong floodplains. Curr. Opin. Environ. Sustain. 37, 1–7.

Bazeley, P., Jackson, K., 2013. Qualitative Data Analysis with NVivo. Sage Publications, London.

Ben Tre Statistical Office, 2018. Ben Tre Statistical Yearbook in 2017. Youth Publishing House, Ben Tre.

Benedikter, S., 2014. The Vietnamese Hydrocracy and the Mekong Delta – Water Resources Development from State Socialism to Bureaucratic Capitalism. LIT, Berlin.

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qual. Res. Psychol. 3 (2), 77–101.

Cau Ngang People"s Committee, 2015. Land Use Plan to 2020 in Cau Ngang District. Tra Vinh People's Committee, Tra Vinh Province.

Chu, T.H., Suhardiman, D., Tuan, L.A., 2014. Irrigation development in the Vietnamese Mekong Delta: towards polycentric water governance? International Journal of Water Governance 2 (2), 61–82.

Cochrane, T., Arias, M., Piman, T., 2014. Historical impact of water infrastructure on water levels of the Mekong River and the Tonle Sap system. Hydrol. Earth Syst. Sci. 18 (11), 4529–4541.

Cosslett, T.L., Cosslett, P.D., 2014. Water Resources and Food Security in the Vietnam Mekong Delta. Springer, Switzerland.

Cosslett, T.L., Cosslett, P.D., 2018. Sustainable Development of Rice and Water Resources in Mainland Southeast Asia and Mekong River Basin. Springer, Singapore.

Dang, T.D., Cochrane, T.A., Arias, M.E., Van, P.D.T., de Vries, T.T., 2016. Hydrological alterations from water infrastructure development in the Mekong floodplains. Hydrol. Process. 30 (21), 3824–3838.

Dang, T.D., Cochrane, T.A., Arias, M.E., 2018. Future hydrological alterations in the Mekong Delta under the impact of water resources development, land subsidence and sea level rise. Journal of Hydrology: Regional Studies 15, 119–133.

Dang, V.H., Tran, D.D., Pham, T.B.T., Khoi, D.N., Tran, P.H., Nguyen, N.T., 2019. Exploring freshwater regimes and impact factors in the coastal estuaries of the Vietnamese Mekong Delta. Water 11 (4), 1–17.

Demont, M., Rutsaert, P., 2017. Restructuring the Vietnamese rice sector: towards increasing sustainability. Sustainability 9 (2), 325.

Eckstein, D., Hutfils, M.-L., Winges, M., 2017. Global Climate Risk Index 2019 – Who Suffers Most from Extreme Weather Events? Weather-Related Loss Event in 2017 and 1998 to 2017. Briefing Paper, GermanWatch, Bonn.

Fox, C., Sneddon, C., 2005. Flood pulses, international watercourse laws, and common pool resources – A case study of the Mekong lowlands. Research Paper No. 2005/20. United Nations University.

Gain, A.K., Ashik-Ur-Rahman, M., Vafeidis, A., 2019. Exploring human-nature interaction on the coastal floodplain in the Ganges-Brahmaputra delta through the lens of Ostrom's social-ecological systems framework. Environmental Research Communications 1 (5), 051003.

Grumbine, R.E., Dore, J., Xu, J., 2012. Mekong hydropower: drivers of change and governance challenges. Front. Ecol. Environ. 10 (2), 91–98.

Guo, H., Bao, A., Liu, T., Ndayisaba, F., He, D., Kurban, A., De Maeyer, P., 2017. Meteorological drought analysis in the Lower Mekong Basin using satellite-based long-term CHIRPS product. Sustainability 9 (6), 1–21.

Hecht, J.S., Lacombe, G., Arias, M.E., Dang, T.D., Piman, T., 2019. Hydropower dams of the Mekong River basin: a review of their hydrological impacts. J. Hydrol. 568, 285–300.

Hirsch, P., 2020. Scaling the environmental commons: broadening our frame of reference for transboundary governance in Southeast Asia. Asia Pac. Viewp. 61 (2), 190–202.

Ho, T.T., Ubukata, F., 2018. Climate change in Vietnam's Mekong Delta: Soc Trang rice farmers' perceptions and adaptive behaviours. Journal of Environmental Science for Sustainable Society 8, 1–14.

Hoang, Q.H., Kubo, N., Hoang, N.G., Tanji, H., 2009. Operation of the Ba Lai irrigation system in the Mekong Delta, Vietnam. Paddy Water Environment 7, 123–133.

Hoang, L.P., van Vliet, M.T.H., Kummu, M., Lauri, H., Koponen, J., Supit, I., Leemans, R., Kabat, P., Ludwig, F., 2019. The Mekong's future flows under multiple drivers: how climate change, hydropower developments and irrigation expansions drive hydrological changes. Sci. Total Environ. 649, 601–609.

Hossain, M.A.R., Ahmed, M., Ojea, E., Fernandes, J.A., 2018. Impacts and responses to environmental change in coastal livelihoods of south-west Bangladesh. Sci. Total Environ. 637-638, 954–970.

Khong, T.D., Loch, A., Young, M.D., 2020. Perceptions and responses to rising salinity intrusion in the Mekong River Delta: what drives a long-term community-based strategy? Sci. Total Environ. 711, 134759.

Kuenzer, C., Campbell, I., Roch, M., Leinenkugel, P., Tuan, V.Q., Dech, S., 2013. Understanding the impact of hydropower developments in the context of upstream-downstream relations in the Mekong River Basin. Sustain. Sci. 8 (4), 565–584.

Lauri, H., De Moel, H., Ward, P.J., Räsänen, T.A., Keskinen, M., Kummu, M., 2012. Future changes in Mekong River hydrology: impact of climate change and reservoir operation on discharge. Hydrol. Earth Syst. Sci. 9 (5), 6569–6614.

Li, D., Long, D., Zhao, J., Lu, H., Hong, Y., 2017. Observed changes in flow regimes in the Mekong River basin. J. Hydrol. 551, 217–232.

Lu, X.X., Li, S., Kummu, M., Padawangi, R., Wang, J.J., 2014. Observed changes in the water flow at Chiang Saen in the lower Mekong: impacts of Chinese dams? Quat. Int. 336, 145–157.

Middleton, C., Matthews, N., Mirumachi, N., 2015. Whose risky business? Public-private partnerships, build-operate-transfer and large hydropower dams in the Mekong region. In: Matthews, N., Geheb, K. (Eds.), Hydropower Development in the Mekong Region: Political, Socio-economic and Environmental Perspectives. Routledge, London: pp. 127–152.

Minderhoud, P.S.J., Coumou, L., Erkens, G., Middelkoop, H., Stouthamer, E., 2019. Mekong delta much lower than previously assumed in sea-level rise impact assessments. Nat. Commun. 10 (1), 1–13.

Mukhopadhyay, A., Ghosh, P., Chanda, A., Ghosh, A., Ghosh, S., Das, S., Ghosh, T., Hazra, S., 2018. Threats to coastal communities of Mahanadi delta due to imminent consequences of erosion – present and near future. Sci. Total Environ. 717–729.

Neuman, W.L., 2011. Social Research Methods: Qualitative and Quantitative Approaches. 7th edition. Pearson, Boston.

Nguyen, M.T., Renaud, F.G., Sebesvari, Z., 2019. Drivers of change and adaptation pathways of agricultural systems facing increased salinity intrusion in coastal areas of the Mekong and Red River deltas in Vietnam. Environ Sci Policy 92, 331–348.

Onwuegbuzie, A., Leech, N., 2007. Sampling designs in qualitative research: making the sampling process more public. Qual. Rep. 12 (2), 238–254.

Paschen, J.A., Ison, R., 2014. Narrative research in climate change adaptation – exploring a complementary paradigm for research and governance. Res. Policy 43 (6), 1083–1092.

Perera, M.D.N.D., Ranasinghe, T.K.G.P., Piyadasa, R.U.K., Jayasinghe, G.Y., 2018. Risk of seawater intrusion on coastal community of Bentota river basin Sri Lanka. Procedia Engineering 212, 699–706.

Pham, V.H.T., Febriamansyah, R., Afrizal, Tran, T.A., 2018. Government intervention and farmers' adaptation to saline intrusion: A case study in the Vietnamese Mekong Delta. International Journal on Advanced Science, Engineering and Information Technology, 8(5), 2142–2148.

Pokhrel, Y., Shin, S., Lin, Z., Yamazaki, D., Qi, J., 2018. Potential disruption of flood dynamics in the Lower Mekong River basin due to upstream flow regulation. Sci. Rep. 8 (1), 1–13.

Räsänen, T.A., Koponen, J., Lauri, H., Kummu, M., 2012. Downstream hydrological impacts of hydropower development in the Upper Mekong Basin. Water Resour. Manag. 26 (12), 3495–3513.

Sithirith, M., 2016. Dams and state security: damming the 3S rivers as a threat to Cambodian state security: damming the Mekong tributaries. Asia Pac. Viewp. 57 (1), 60–75.

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. Nat. Clim. Chang. 5 (2), 167–174.

Sneddon, C., Fox, C., 2006. Rethinking transboundary waters: a critical hydropolitics of the Mekong basin. Polit. Geogr. 25 (2), 181–202.

Soc Trang Department of Agriculture and Rural Development, 2019. Integrated Report on Implementation for Socio-Economic Development in 2019. Soc Trang People's Committee, Soc Trang Province.

Soc Trang Statistical Office, 2019. Soc Trang Statistical Yearbook in 2018. Soc Trang Province, Vietnam.

The Vietnamese Government, 2017. Resolution No. 120/NQ-CP on "Sustainable and climate resilient development of the Mekong Delta", dated 17 November 2017. Office of the Government, Hanoi, Vietnam.

To, P.T., Kam, S.P., Chu, T.H., Le, C.D., Nguyen, T.K., Barr, J., Ben, D.C., 2003. Impact of seawater intrusion control on the environment, land use and household incomes in a coastal area. Paddy Water Environ. 1 (2), 65–73.

Tran, T.A., 2019. Land use change driven out-migration: evidence from three flood-prone communities in the Vietnamese Mekong Delta. Land Use Policy 88, 104157.

Tran, T.A., 2020. From free to forced adaptation: A political ecology of the 'state-society-flood' nexus in the Vietnamese Mekong Delta. Asia Pac. Viewp. 61 (1), 162–182.

Tran, T.A., Suhardiman, D., 2020. Laos' hydropower development and cross-border power trade in the Lower Mekong Basin: a discourse analysis. Asia Pac. Viewp. 61 (2), 219–235.

Tran, T.A., James, H., Pittock, J., 2018. Social learning through rural communities of practice: empirical evidence from farming households in the Vietnamese Mekong Delta. Learn. Cult. Soc. Interact. 16, 31–44.

Tran, T.A., Pittock, J., Tuan, L.A., 2019. Adaptive co-management in the Vietnamese Mekong Delta: examining the interface between flood management and adaptation. International Journal of Water Resources Development 35 (2), 326–342.

UNDP Vietnam, 2016. Vietnam drought and saltwater intrusion:Transitioning from emergency to recovery. https://www.vn.undp.org/content/vietnam/en/home/library/environment_climate/viet-nam-drought-and-saltwater-intrusion.html. (Accessed 7 June 2020).

Vietnam Disaster Management Authority (VDMA), 2020. Flash update no. 1 about the Drought and Saltwater Intrusion in the Mekong Delta. Development, Vietnam Ministry of Agriculture and Rural http://phongchongthientai.mard.gov.vn/en/Pages/flash-update-no-1-about-the-drought-and-saltwater-intrusion-in-the-mekong-delta.aspx. (Accessed 5 June 2020).

Vietnam News, 2020. What would Vietnam be without the Mekong Delta? https://vietnamnews.vn/opinion/op-ed/653533/what-would-viet-nam-be-without-the-mekong-delta.html (Assessed 20 March 2020).

Vietnam Prime Minister, 2012. Quyết định Phê duyệt quy hoạch thủy lợi Đồng Bằng Sông Cửu Long giai đoạn 2012-2020 và định hướng đến năm 2050 trong điều kiện biến đổi khí hậu, nước biển dâng, số 1397/QĐ/TTg. ngày 25 tháng 9 năm 2012 [Decision on Approving hydraulic planning in the VMD from 2012–2020 and orientation towards 2050 in the context of climate change and sea level rise, No. 1397/QD/TTg. dated 25 September 2012]. Office of Prime Minister, Hanoi, Vietnam.

Vo, Q.T., Roelvink, D., van der Wegen, M., Reyns, J., Kernkamp, H., Giap, V.V., Vo, T.P.L., 2020. Flooding in the Mekong Delta: the impact of dyke systems on downstream hydrodynamics. Hydrol. Earth Syst. Sci. 24, 189–212.

Wang, W., Lu, H., Yang, D., Sothea, K., Jiao, Y., Gao, B., Peng, X., Pang, Z., 2016. Modelling hydrologic processes in the Mekong River Basin using a distributed model driven by satellite precipitation and rain gauge observations. PLoS One 11 (3), e0152229.

Wassmann, R., Phong, N.D., Tho, T.Q., Hoanh, C.T., Khoi, N.H., Hien, N.X., Vo, T.B.T., Tuong, T.P., 2019. High-resolution mapping of flood and salinity risks for rice production in the Vietnamese Mekong Delta. Field Crop Res. 236, 111–120.

Wong, P.P., Losada, I.J. Gattuso, J.-P., Hinkel, J., Khattabi, A., McInnes, K.L., Saito, Y., Sallenger, A., 2014. Coastal systems and low-lying areas. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Inter-Governmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom: pp. 361–409.

Yin, R., 2014. Case Study Research: Design and Methods. SAGE Publications, Thousand Oaks.