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DOI
10.1080/02626667.2022.2030865

Publication date
2022

Document Version
Final published version

Published in
Hydrological Sciences Journal

Hydrological Sciences Journal

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/thsj20

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HYDROLOGICAL SCIENCES JOURNAL
https://doi.org/10.1080/02626667.2022.2030865

SPECIAL ISSUE: ADVANCING SOCIO-HYDROLOGY

Socio-hydrological approach for farmer adaptability to hydrological changes: a case study in salinity-controlled areas of the Vietnamese Mekong Delta

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ABSTRACT
The Vietnamese Mekong Delta (VMD) is an example of a complex dynamic socio-hydrological system in which societies and hydrology interact and co-evolve. The dominant engineering approach in the VMD has enhanced the dynamics of society and hydrology. This study looks at the implications of socio-hydrological dynamics in the coastal VMD where saline water is controlled by various infrastructures. In the first phase, key informant interviews and focus group discussions were used to explore socio-hydrological dynamics in the study area. The results show divergence in livelihood strategies inside the freshwater-projected area, shaping a heterogeneous agricultural landscape of fresh- and brackish-water livelihoods manifested by four socio-hydrological groups. Next, the Motivation and Ability (MOTA) framework and household surveys were used to assess the adaptability in the agricultural development pathway advocated by the freshwater policy. The result revealed differentiations among these socio-hydrological groups. The findings suggest other practices may be required to help the area navigate towards future adaptations to socio-hydrological changes.

ARTICLE HISTORY
Received 26 December 2020
Accepted 25 November 2021

EDITOR
S. Archfield

GUEST EDITOR
D. Yu

KEYWORDS
hydrological dynamics; Motivation and Ability (MOTA) framework; salinity-control measures; socio-hydrology; Vietnamese Mekong Delta

1 Introduction

Global deltas, such as the Nile, Ganges-Brahmaputra, and Mekong, provide land and water resources that are crucial for both food production and economic development in societies around the world (Renaud *et al.* 2016). However, these deltas are increasingly impacted by both environmental pressures and human activities (Ericson *et al.* 2006, Syvitski *et al.* 2009, Park *et al.* 2020, Loc *et al.* 2021). The Vietnamese Mekong Delta (VMD) has seen multiple changes in hydrological regimes throughout its development history. As pointed out by Huu Nguyen *et al.* (2016) and Vo *et al.* (2019), the hydrological changes in the VMD are aligned with the country's political agenda, focusing first on rice farming to ensure food security and rice exportation and, later, on higher value crops. In the upstream of VMD, which is affected by yearly floods, the rice-first agenda resulted in the expansion of high dike systems for flood protection which enabled rice intensification by triple-rice farming (Biggs *et al.* 2009, Vo *et al.* 2019, Nguyen *et al.* 2020a), while in the coastal area, construction of river dikes and sluice gates facilitated rice farming in salinity-intrusion zones (Biggs *et al.* 2009, Renaud *et al.* 2015, Loc *et al.* 2017, 2018, 2021).

These historical changes in the VMD water systems reflect an engineering mindset in delta planning aimed at removing or controlling natural predicaments to further economic development and settlement opportunities. However, more recently, this approach has been subject to closer scrutiny and criticisms related to its environmental and social impacts. The dike heightening in the upstream of VMD, for instance, changed natural functions of flood plains to intensive farming, causing multiscale impacts on the delta's ecosystems and on community livelihoods (Duc *et al.* 2018, Tong 2017, Park *et al.* 2020, Loc *et al.* 2017, 2018, 2021). Similarly, the construction of sluice gates to prevent salinity intrusion in coastal areas transformed aquatic habitats and hindered brackish-water livelihoods (Renaud *et al.* 2015). It was noted that although the aim of these infrastructures, in the beginning, was to improve the livelihoods of the delta's inhabitants, the current reality in the delta shows that these aims have not been successfully realized. These projects have been initiated and developed mostly based on technical and financial information but often fail to integrate the relevant social and institutional aspects (Korbee *et al.* 2019, Loc *et al.* 2018, 2021). As suggested by Käkönen (2008) and Renaud *et al.* (2015), uneven distribution of social costs and benefits of these

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megastructures, rooted in a simplification of social heterogeneity, limits their success and sustainability. Phi *et al.* (2015) reaffirmed this point by emphasizing the roles of multiple actors in water management and emphasized the need to assess the motivation and ability of local actors to adapt megastructures and their associated changes to local practices. In addition, the preference for control measures in planning for VMD (van Staveren *et al.* 2018) implied the adoption of a linear perspective about delta futures, ignoring the dynamics of social and hydrological processes and their mutual interaction (Di Baldassarre *et al.* 1969). Such ignorance means the planning cannot capture the full spectrum of dramatic socio-hydrological changes in the delta (Sivapalan *et al.* 2012), steering the delta on a reactive pathway, which implies high vulnerability (Di Baldassarre *et al.* 1969). Yu *et al.* (2020) also suggested a robustness–fragility trade-off as a result of the interplay between self-organization of social factors and engineering designs.

A socio-hydrological approach was proposed by Sivapalan *et al.* (2012) to address many challenges that arise from the complexity of human and water systems and the interactions between them. The approach embraces the notion that hydrological regimes are governed not only by physical but also by social structures that are dependent on changes in human culture, such as norms and values (Sivapalan *et al.* 2012). On the other hand, human decision making on water management is likely to be influenced by both cultural factors and natural system dynamics (Sanderson *et al.* 2017, Roobavannan *et al.* 2018). Together with the inclusion of two-way feedbacks, the inclusion of changing norms and values into the socio-hydrological models will help us to better understand the system and generate predictions that are closer to reality (Kandasamy *et al.* 2014, Roobavannan *et al.* 2018). Several case studies have included changing values and norms in the models, e.g. Roobavannan *et al.* (2018) and Van Emmerik *et al.* (2014). Lastly, the approach facilitates a more accurate perspective on the plurality and diversity of social elements as part of socio-hydrological systems, as it favours the amalgamation of homogeneous individuals into groups with distinct social and hydrological attributes and, hence, with different behaviours in a changing environment.

The VMD is an example of a delta system where the changing of hydrological regimes by infrastructure alone may not match the socio-hydrological complexity. The interplay between social and hydrological systems proposed an unparalleled pattern of development that deviated from the master design for the delta. In this research, we seek to unravel this divergence using a case study in coastal areas of VMD that underwent shifting hydrological regimes caused by a large freshwater infrastructure intervention of dikes, sluices and canals. The research aim was twofold. Firstly, using a qualitative approach, we explored the interplay between livelihood strategies (the social part) and hydrological conditions (the ecological part). Later, we unravelled the impacts of this interplay on shaping the heterogeneous livelihood strategies in the freshwater-projected area. Lastly, using a quantitative approach, we analysed the adaptability of freshwater planning and possibilities for deviation from the development pathway advocated by the freshwater policy.

2 Methodology

2.1 Study area

Ben Tre province is situated in the coastal area of VMD. The province experiences yearly salinity intrusion, frequently lasting from November to April (SWIRP 2018). According to F. G. Renaud *et al.* (2015), salinity intrusion threatens freshwater supply for irrigation and domestic use but also provides opportunities for brackish aquaculture. In 2000, the project North Ben Tre (NBT) was initiated with the aim to control salinity intrusion in the area (Fig. 1). The Ba Lai sluice gate installed on Ba Lai River was the key construction element in the NBT project intended to turn the river into a freshwater reservoir for the area.

The increased availability of freshwater since the Ba Lai sluice gate came into operation in September 2002 (Huy *et al.* 2009) facilitated triple rice cultivation in the coastal area, with three harvests per year, especially in Ba Tri district. Other important changes included a conversion to cash crops (especially coconut) from seasonal rice and an expansion of aquaculture. The expansion of brackish aquaculture (mostly shrimp farming) followed a noteworthy spatial pattern, as it happened both in freshwater and brackish-water areas. Illegal shrimp farming in the freshwater zone is a major concern as it disturbs irrigation planning for Ben Tre province to 2030 (SWIRP 2018). Some previous studies, such as those by Di Giusto *et al.* (2021) or Lan (2011), mentioned similar phenomena in VMD but few discussed it through the lens of socio-hydrological dynamics.

2.2 Socio-hydrological dynamics of the area

The first part of our study adopted a qualitative approach to unravel the socio-hydrological dynamics of the study area. Key informant interviews (KIIs) combined with focus group discussions (FGDs) were conducted to understand the history of the area before and after the initiation of the NBT freshwater project.

KIIs and FGDs were carried out in two coastal districts, Ba Tri and Binh Dai, where agricultural livelihoods have largely been reshaped since Ba Lai sluice gate came into operation. Two KIIs with semi-structured questionnaires were designed to include officials working in the Office of Agriculture and Rural Development (OARD) of the two districts. The aim of these interviews was to get a broad overview of agricultural and irrigation conditions in the area, so the questionnaires included a wide range of related topics. Table 1 presents the topics and their relations to socio-hydrological dynamics in the area.

The FGDs focused on three main themes: (1) history of agricultural and irrigation development in the area; (2) advantages and disadvantages of agricultural livelihoods since the initiation of the NBT project; (3) challenges to agricultural livelihoods on pathways advocated by the NBT project. Participatory mapping with sketched maps was applied in FGDs to bring a sense of space into the discussions. FGDs were conducted in the four communes Phu Long and Tan My of Ba Tri district and Tan Xuan and Thanh Tri of Binh Dai

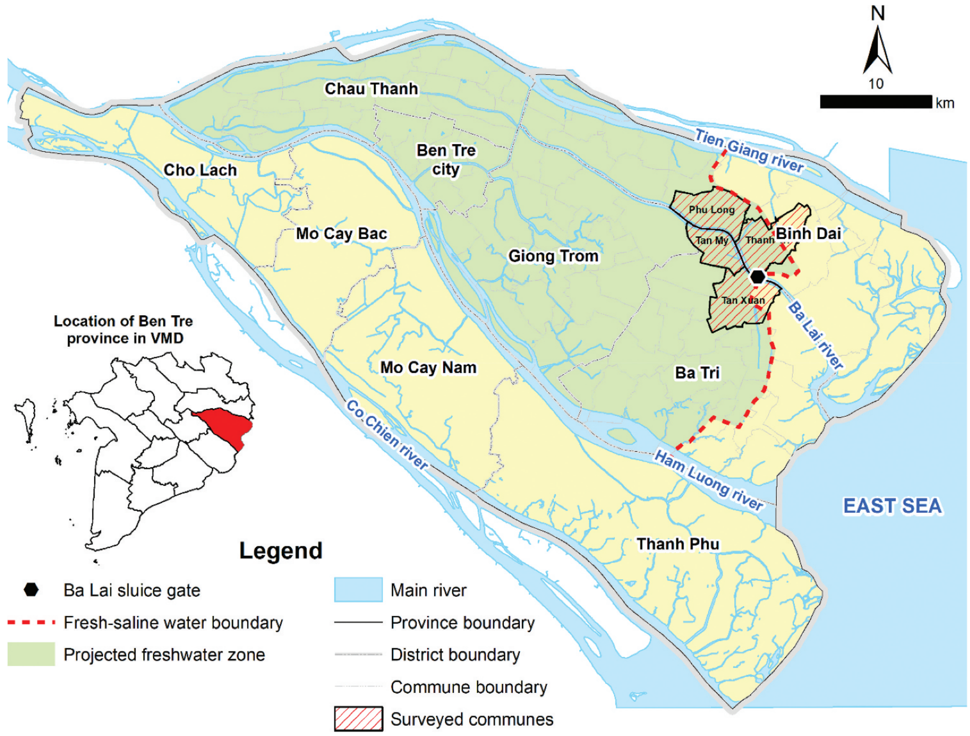

Figure 1. Map of study area and boundary of North Ben Tre freshwater project.

Table 1. Topics of KIIs and their relevance to socio-hydrological dynamics.

Topic	Relations to socio-hydrological dynamics
Role of respondents in their organizations	To assess the extent to which respondents are aware of the agriculture and irrigation situation in the area through the decision making process
Participation level of local communities in planning and operating items of North Ben Tre project	Social actors shaped the socio-hydrological dynamics in the area
Conditions of agriculture and hydrology before and after project initiation	Sociological (reflected by agricultural livelihoods) and hydrology dynamics
Future agriculture and hydrological planning	Unravelling pathways advocated by current socio-hydrological complexity

district (Fig. 1), with around 5–10 farmers per commune. These four communes were selected based on two criteria: (1) their locations near Ba Lai sluice gate; and (2) their mix of freshwater and brackish-water crops. Farmers growing rice, coconut and shrimp were selected to represent prevalent agricultural livelihood strategies in the area.

2.3 Farmers' adaptability to the pathway advocated by the NBT project

To assess farmers' motivation and ability to adopt the freshwater orientation for agriculture prescribed in the NBT project, we applied the Motivation and Ability (MOTA) framework (Phi *et al.* 2015). This framework was developed based on Fogg's behaviour model (Fogg 2009), which centres on triggers, motivations and abilities. The model of human behaviour in the MOTA framework was founded on Ajzen's theory of planned behaviour (TPB) (Icek 2019) and the rational choice theory (RCT) which underwent a long history of development through the work of Blau (1964), Cook *et al.* (1978), Homans (1961) and Coleman (1990), to name a few researchers, presuming that humans act to maximize their benefits and minimize the costs. This feature marked a departure from the classic stimulus–response model in which human behaviour is the result of accumulated pressure. The MOTA framework also differs from emotional models of behaviour such as Beliefs, Desires and Intentions (BID) or Physical, Emotion, Cognitive and Social Factors (PECS), in which the links between emotion and rational behaviours are still under debate. The reliability of the MOTA framework has been tested through its application in case studies on human behaviours to support policy analysis in VMD and Vietnam (see Phi *et al.* 2015, Nguyen *et al.* 2019a, 2019b, 2020) and in Bangladesh (Kulsum 2020).

Figure 2 presents four main components of the MOTA framework – trigger, motivation, ability, action – and the relations among them. The action component is the rational behaviour of the subject. The course of action is normally assumed to be known under RCT (Kennedy 2012). Motivation and ability are two pre-conditions for action (Phi *et al.* 2015). The MOTA framework recognizes three dimensions of ability: financial, technical and institutional. The motivation component consists of perceptions of threats (negative) and opportunities (positive). The motivation and ability elements are the core elements of the RCT, and the trigger component reflects the stimulus mechanism in the classic stimulus–response model. It is worth noticing that triggers in the original MOTA framework are characterized as fast events that have immediate impacts on social systems. However, in

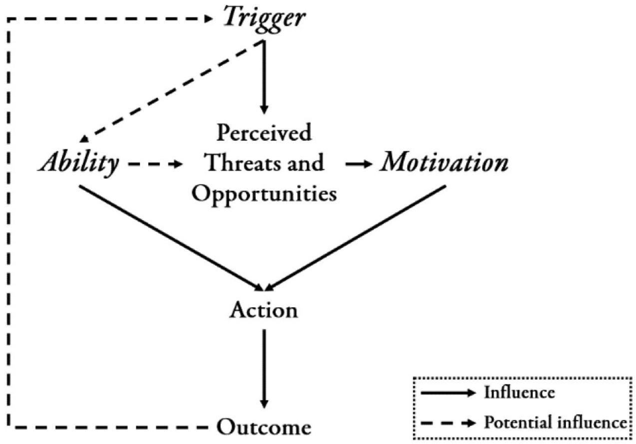

Figure 2. MOTA framework: from trigger to action (adapted from Phi *et al.* 2015).

this study, to legitimize the application of the framework in the context of socio-hydrological dynamics, we shifted our focus to triggers as slow events with accumulating impacts.

In this study, a structured questionnaire was developed to quantify the MOTA components. Table 2 presents a list of indicators for each component. The ability of farmers to adapt to freshwater planning was studied through three scenarios – (1) change crop, (2) maintain current crop and (3) diversify crops – in a hypothetical context in which freshwater policy was fully enforced. The indicators applied were based on previous studies such as Nguyen *et al.* (2019a, 2019b), complemented by indicators based on the results of the FGDs. An assumption made in collecting the data is that farmers are fully

Table 2. Indicators for MOTA components.

MOTA components	Indicators
Triggers	Road conditions in the last five years
	Electricity supply in the last five years
	Irrigation in the last five years
	Access to freshwater/saline-water resource after construction of Ba Lai sluice gate
	Credit (opportunity to obtain a loan) in the last five years
	Agricultural extension in the last five years
	Market condition in the last five years
	Income in the last five years
Motivation	Income from selected option
	Threat to selected option
Ability	Ability to cover seasonal crop expenses
	Ability to cover expense of converting to new crops, partly or completely
	Current accessibility of freshwater/saline-water resource
	Accessibility of freshwater/saline-water resource when freshwater policy is fully enforced
	Current sufficiency of freshwater/saline water
	Sufficiency of freshwater/saline water when freshwater policy is fully enforced
	Suitability of current irrigation system
	Suitability of current electritricity system
	Suitability of soil
	Suitability of road
	Suitability of seedlings
	Suitability of agro-material
	Suitability of farming equipment
	Suitability of farming techniquue
	Accessibility to information
	Chance of joining cooperative
	Chance of attending tranining
	Cooperation with middlemen

Table 3. Surveyed household cropping systems by districts and communes.

District	Commune	Current cropping system			Total
		Coconut	Rice	Shrimp	
Ba Tri	Tan My	22	6	0	28
	Tan Xuan	2	28	0	30
	Sub-total	24	34	0	58
Binh Dai	Phu Long	11	0	11	22
	Thanh Tri	17	0	15	32
	Sub-total	28	0	26	54
Total		**52**	**34**	**26**	**112**

aware of their own ability and their socio-environmental context (Jones and Tanner 2017). The indicators are measured on an equivalent bipolar rating scale, ranging from −1 to +1.

The sampling scheme for the survey combined stratified and non-probabilistic sampling. More specifically, the definition of socio-hydrological groups from FGDs was used as sampling strata and convenient sampling with support from a local guide was conducted to select households for the survey. The reason to adopt non-probabilistic sampling was that, to our best knowledge, unlike known population size in sampling by administrative or by agricultural production strata, there was no data summarized by socio-hydrological groups to support random stratified sampling. The method of convenient sampling with a local guide (usually local officials) was adopted to increase the chance of response from interviewees (in the Vietnamese context, local farmers are reluctant to talk to strangers without the prior approval of local officials). Table 3 presents sampling sizes divided by communal administrative boundaries and types of crops. To analyse the implications of the socio-hydrological complexity for farmers' adaptability to the projected freshwater pathway, beside descriptive statistics, inferential statistics using Kruskal-Wallis test (Kruskal *et al.* 1952) were applied. We tested the null hypothesis that all socio-hydrological groups had the same median perception levels of trigger, motivation and ability at significance levels of .01 and .05. If the derived p value is less than the significance level, we can infer that there was differentiation between groups in term of their perceptions. This non-parametric test holds no assumption about the data's normal distribution compared to one-way analysis of variance (Kruskal *et al.* 1952), so it is useful in assessing differences between more than two groups of samples when the sample cannot guarantee randomness.

3 Results

3.1 Interplay in the socio-hydrological system and its shaping of socio-hydrological heterogeneity

Assimilation of the information collected from KIIs and FGDs revealed the emergent dynamics driven by co-evolution of social and hydrological spheres and the socio-hydrological heterogeneity as a result of these dynamics. The Appendix Figure A1, A2, A3 and A4 presents the results of participatory mapping in FGDs.

Subsistence agriculture was the only livelihood strategy in the area up to 1975. In all four surveyed communes, one-season rice and salt farming was the only cropping practice. Due to the absence of sea dikes and sluice gates, farmers were exposed to extreme hydrological events. They therefore practiced a cropping system adapted to the hydrological conditions. Rice was cultivated from July to December each year to avoid threats of salinity intrusion (from December to April) and tidal inundation. Fishing and wood collection from the nearby mangrove were other subsistence practices of migrants in the area unfit for rice cultivation due to acidic soil. The key informant from Binh Dai OARD called the area "dong co nang" (*Eleocharis* field – an indigenous plant that can endure acidic soil) to emphasize its level of under-development.

In the period between 1975 and 2002 (the benchmark year for initiation of the NBT project), gradual and divergent developments occurred that shaped a heterogeneous agricultural landscape. Major differences can be observed between the Ba Tri and Binh Dai districts. In Ba Tri district, irrigation facilities, such as river dikes and tidal sluice gates, were constructed as of 1981. These facilities supported the conversion from one-season rice to double rice in the Tan Xuan commune. Closing the tidal sluice gate system supported the intensification to triple rice in the inland area of the Tan Xuan commune. In the Tan My commune, the controlled environment paved the way for the cultivation of freshwater cash crops like sugarcane and coconuts. Salt farms were located in the seaside areas, creating a clear boundary between zones for freshwater and saltwater crops. Shrimp farming was introduced into Tan Xuan around 2002, in areas that were previously occupied by salt farms.

In Binh Dai district, the river dike system was not built until 1990. As a result, one-season rice was still widely practised up to the early introduction of shrimp farming from nearby Tien Giang province in 1986. As a result, high-profit shrimp farming was introduced in an area predominantly used for subsistent one-season rice farming. This conversion from subsistence farming to a high-profit crop was supported by the national political and economic reform in 1986 (the *Doi Moi* reform) that encouraged agricultural diversification to high-value crops. Whereas extensive shrimp farming was common in the years after its introduction, in 1990 this was gradually replaced by industrial shrimp farming which has become common since 1990. Nonetheless, one-season rice was still the dominant crop in the area.

The operation of Ba Lai sluice gate in 2002 marked the divergence in the agricultural landscape of the area. In Ba Tri, the freshwater agenda was strictly followed, manifested by rice intensification to triple crops in Tan Xuan commune and expansion of freshwater cash crops like fruits and coconuts in Tan My commune. Major infrastructures were constructed to fortify freshwater planning for the area; for instance, the completion of the freshwater reservoir Kenh Lap in 2018 in Tan Xuan commune. On the contrary, the situation in Binh Dai district showed diversification away from the freshwater projection. Brackish shrimp farming moved landwards into the zone projected as a freshwater zone. As a result, the Phu Long commune forms a vast area of mixed saline and freshwater livelihoods.

Discussion with farmers in the Phu Long commune revealed that complicated hydrological conditions of Binh Dai hampered the forging of freshwater policy. Binh Dai district is located between two main rivers, Ba Lai and Tien Giang (Fig. 1). After the Ba Lai sluice gate came into operation, saline water was prevented from entering via the Ba Lai River. However, saline water from the Tien Giang River can still reach inland areas. As a result of the changing hydrological condition, new farming practices emerged. To continue shrimp farming, farmers developed multiple strategies such as the reuse of saline water, pumping saline water into the freshwater area and even groundwater extraction. The incomplete sluice systems in Binh Dai caused a freshwater shortage for coconut farmers. Coconut farmers in two communes, Thanh Tri and Phu Long, also mentioned the externalities of brackish shrimp farming and their implications for coconut in the freshwater zone.

The complex dynamics arising from interactions between farmers and hydrological settings shaped a heterogeneous agricultural landscape in the freshwater area defined in the NBT project. Four socio-hydrological groups can be defined: the "proponent" (i.e. committing to freshwater planning), the "opponent" (i.e. opposed to freshwater planning), the "fragile" group (i.e. cultivating freshwater crops in a fresh/saltwater conflict zone) and the "unaffected" group (i.e. cultivating brackish shrimp in the saline area). Figure 3 presents spatial distributions of the three groups in the NBT-projected area.

3.2 Socio-hydrological groups' adaptability to the freshwater pathway

In this section, using the MOTA framework, we analyse the adaptability of the four socio-hydrological groups to the freshwater pathway as advocated by the NBT project. A quantitative survey targeted the four socio-hydrological groups defined in Section 3.1. The rationale for picking a saline group affected by a freshwater project was to pinpoint the contrast between shrimp farmers in fresh- and saltwater areas. The groups can be characterized by the following socio-hydrological features: (1) proponent group: groups of freshwater-crop farmers (rice and coconut) in a freshwater zone; (2) opponent group: groups of brackish shrimp farmers in a freshwater zone; (3) fragile group: groups of freshwater-crop farmers (coconut) in a fresh/saltwater conflict zone; and (4) unaffected group: groups of brackish shrimp farmers in a saltwater zone.

3.2.1 Courses of action towards a freshwater future

Table 4 presents a summary of rational actions taken by farmers on exposure to the hypothetical context of complete freshwater. The ratio of farmers opting for total conversion to new crops was the highest in the "opponent" group (91%). This behaviour reflects the awareness of shrimp farming misconduct in the freshwater area. In contrast, the "proponent" group has the highest ratio of keeping current crops (79%), which shows the influence of the acceptance of hydrological conditions on the behaviour of farmers. The "fragile" and "unaffected" groups were marked for their higher proportions of crop diversification (33% and 40%, respectively).

The analysis of alternative options, as suggested by farmers opting to diversify or convert to new crops (Fig. 4), shows the dominance of freshwater crops. Coconut is the most preferred in the "proponent" and "unaffected" groups. This can be

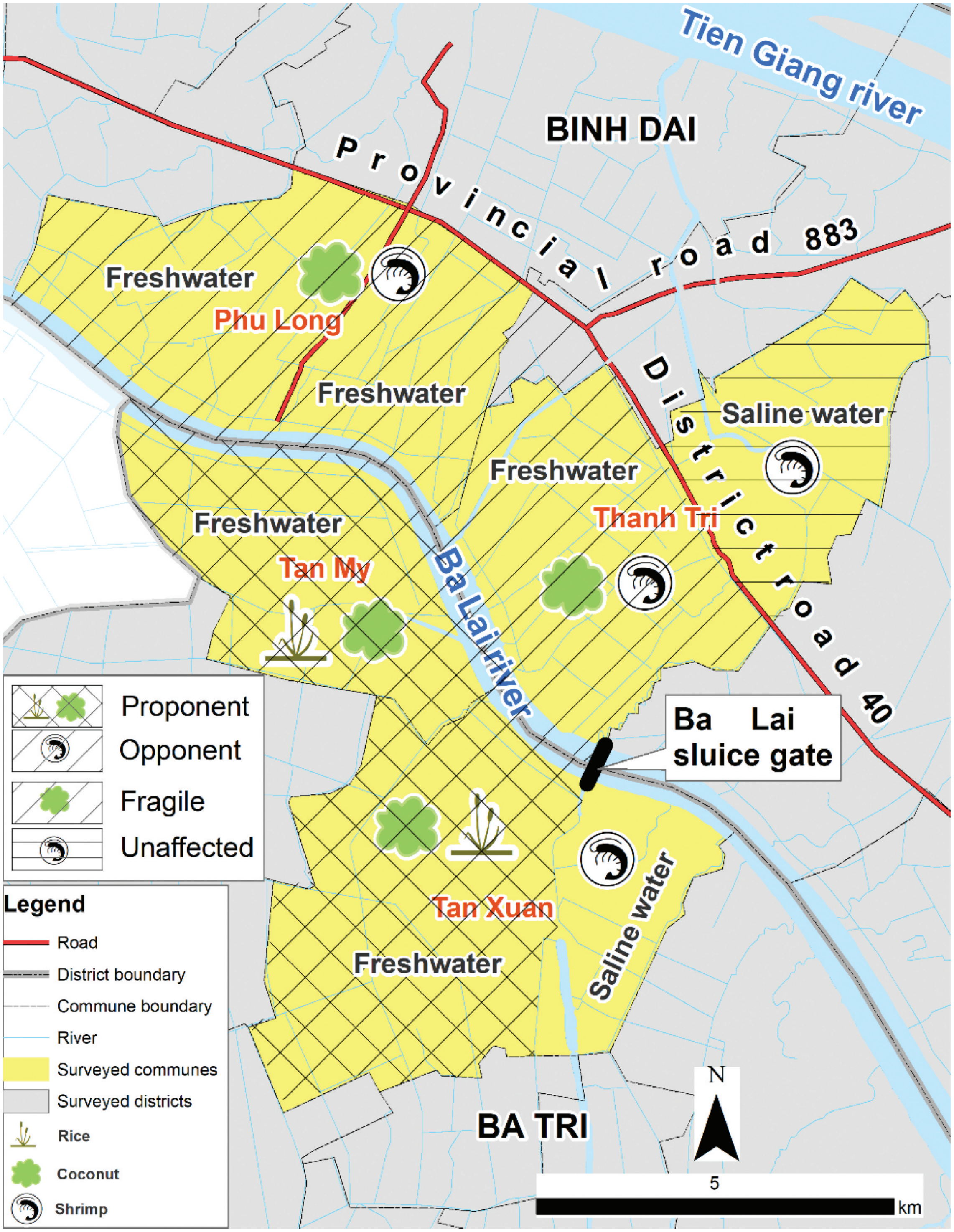

Figure 3. Socio-hydrological heterogeneity in the study areas.

Table 4. Summary of courses of action taken (numbers of farmers) by socio-hydrological groups.

Groups	Keep current crops	Diversify crops	Convert to new crops	Total
Proponent	46	9	3	58
Opponent	0	1	10	11
Fragile	21	7	0	28
Unaffected	10	4	1	15
Total	77	21	14	

explained by the symbolic value attached to the coconut in Ben Tre district. A fruit tree is regarded as another realistic alternative in the "proponent" and "fragile" groups. Fruit trees like guava, pomelo, orange and jackfruit provide opportunities to improve income for farmers in freshwater-stable zones, compared to the current income from rice and coconut. Innovations in agronomy have enabled grafting between high-value and saline-tolerant plants, such as the combination of

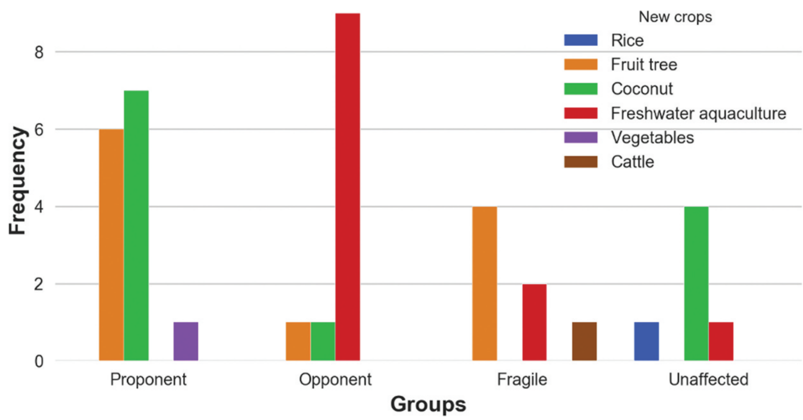

Figure 4. Alternative crops by socio-hydrological group.

Annona muricata (has a high value) with *Annona reticulata* (can tolerate a high salinity level). This innovation supports the adoption of fruticulture in the "fragile" group.

Freshwater aquaculture is the prevalent option in the "opponent" group, which is probably grounded in the fact that current facilities (e.g. ponds) from shrimp farming can be used in freshwater aquaculture as well. According to shrimp farmers in Phu Long commune, conversion from brackish shrimp farming to fruticulture is not a good option. The conversion of shrimp ponds to orchards induces a high cost but does not guarantee success, as land previously used as shrimp ponds needs a long time to recover to an appropriate state for fruticulture. One shrimp farmer revealed that it would cost him 50 million Vietnamese Dong (~2150 USD) and 10 years to restore 5000 m^2 of shrimp land to a normal state for fruit cultivation.

3.2.2 Triggers, motivations, abilities and overall MOTA scores

The trigger component captures perceptions about socio-hydrological conditions: the disparities in water resources, market conditions and income presence among the socio-hydrological groups. Differences in water resources and market conditions are at a significantly high level compared to income. The trigger scores aggregated by groups (Fig. 5) revealed that, on average, positive perceptions of triggers prevailed. The market was the only trigger showing negativity in all groups. A negative perspective of market conditions revealed farmers' financial precariousness in terms of being at the lowest position in the relevant agricultural value chains. Unlike universal difficulties proposed by the market, water resource and income conditions only posed hindrances to the "opponent" and "fragile" group, respectively. A negative perspective about water resources in the "opponent" group revealed the negative influence of the freshwater project on brackish shrimp farming.

The motivation and ability aggregated by groups (Fig. 6) show that, in general, farmers in all groups are positive about their abilities and are motivated to take actions towards a freshwater future. However, the levels of optimism are significantly different between groups, with the exceptions of financial ability and income motivation.

Shrimp farmers of the "opponent" group are least concerned about threats to their livelihood options, reflected by their highest score in the threat perception category. Threat perceptions were almost neutral in the other three groups, revealing their uncertain attitudes towards selected options. The complete opposite situation was observed for technical ability; here the "opponent" group shows the least optimistic view compared to the other three groups. The disparity in technical ability was remarkable in comparison with shrimp farmers in the "unaffected" group. The lowest technical ability score in the "opponent" group pointed to awkwardness in shifting from brackish shrimp farming to freshwater crops (mostly fish farming). It also suggested the likelihood of enduring the status quo of brackish shrimp farming in the freshwater-projected zone.

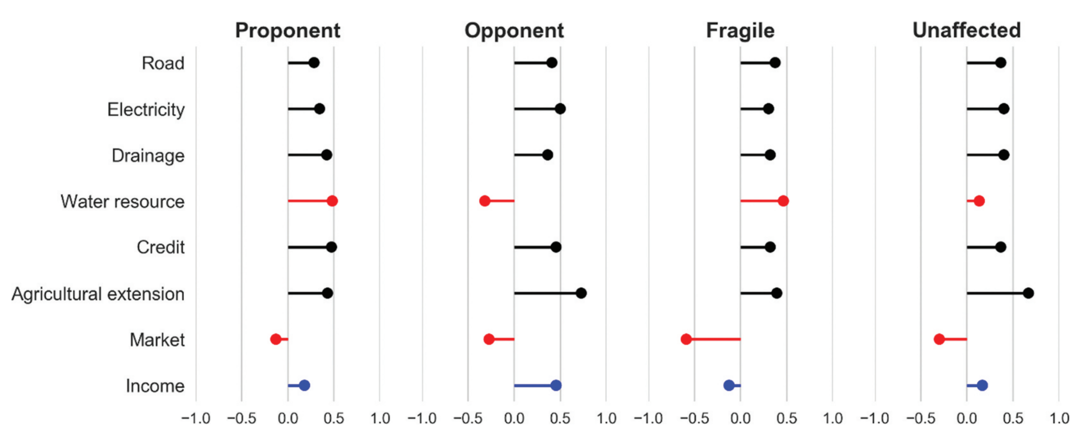

Figure 5. Aggregated scores of trigger indicators by socio-hydrogical groups (red and blue colours highlight differences significant at the .01 and .05 level, respectively). For numerical results refer to Table A1 in the Appendix.

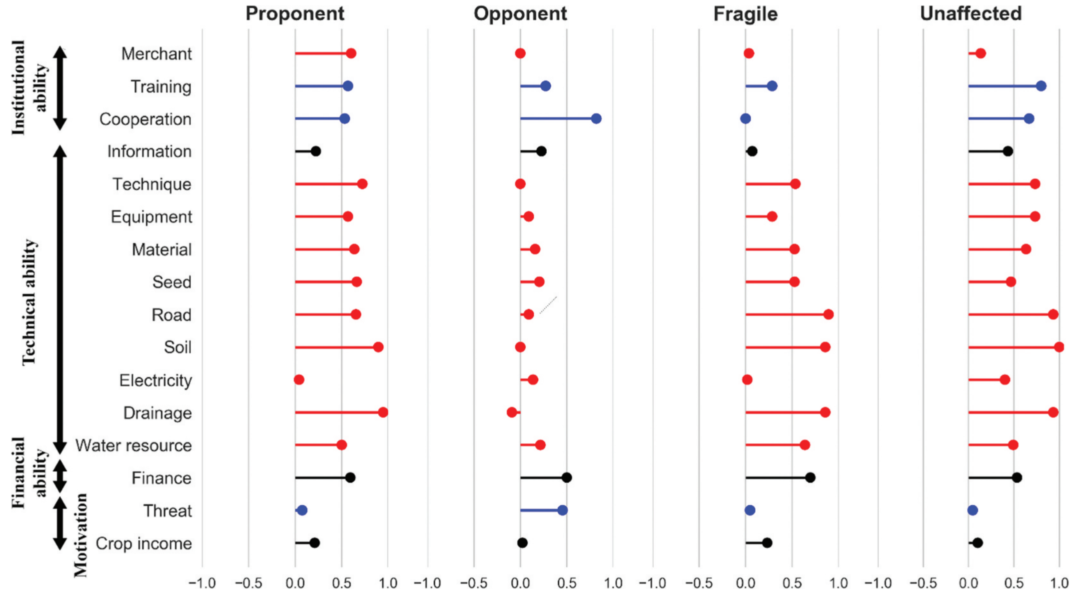

Figure 6. Aggregated scores of motivation and ability indicators by socio-hydrogical groups (red and blue colours highlight differences significant at the .01 and .05 level, respectively).

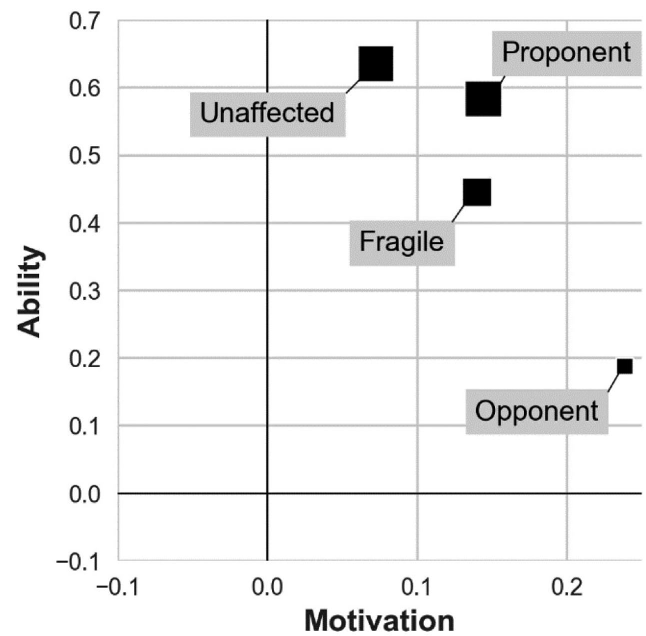

Figure 7. Overall MOTA scores by socio-hydrological group (sizes of squares indicate overall MOTA scores).

The aggregated scores of perception about institutional ability also provided insights into farmers' acceptance of the freshwater project. The training and cooperation dimensions of institutional ability showed differentiation between socio-hydrological groups at a significance level of 5%. Shrimp farmers in the "opponent" group are the most optimistic about the establishment of cooperation, while those in the "unaffected" group show the highest positivity in receiving training. The optimism about cooperative had high weights in shaping farmers' perspectives as the establishment of cooperative means opportunities for offtake and avoiding price squeeze by middlemen. Meanwhile, the reliability of middlemen was the dimension of institutional ability that marked the distinction of the "proponent" group. This high positivity of farmers suggested a more cohesive bond between farmers and middlemen in the freshwater zone in Ba Tri side.

Figure 7 presents the MOTA scores of the four socio-hydrological groups calculated by averaging their motivation and ability scores. All four groups were located on the positive side of the MOTA chart, defining optimistic perspectives towards actions. However, mapping of the MOTA scores revealed that the four groups formed two obvious clusters. One contained the three groups "unaffected," "proponent" and "fragile" and the other included only the "opponent" group. The "opponent" group was characterized by its distinctively higher motivation but the least ability, while the other three groups were less motivated but had significantly higher ability. The "opponent" group had the lowest overall MOTA among the four groups.

4 Discussion

4.1 Interplay between social and hydrological systems and its derivation of socio-hydrological heterogeneity

The local finding in the NBT project area has a universal meaning in that it again emphasizes the importance of considering the interplay between humans and nature in assessing complex systems like deltas. Unravelling the feedback mechanism between social and natural components helps us understand the resilience of socio-ecological systems, as demonstrated in the work of Xu *et al.* (2020) and Ishtiaque *et al.* (2017) or Viero *et al.* (2019) and Carisi *et al.* (2017) on human-induced impacts on such systems. Similarly, in this study, the co-evolution of livelihood strategies (the social part) and hydrological conditions (the ecological part) has shown its effects on the adoption of large-scale irrigation planning.

The findings from the first qualitative research phase illustrate how a dynamic socio-hydrological system that involved multiple social actors and their interactions with hydrological settings shaped a heterogeneous agricultural landscape. The social system continuously evolved as a response to environmental changes, following different pathways in different geographical areas and resulting in two different contrasting zones in Ba Tri and Binh Dai districts. The Ba Tri side was marked for its strict adoption of freshwater planning, while in Binh Dai a mosaic of freshwater and brackish-water livelihoods emerged. Emergent behaviours, which are noted characteristics of a complex system, appeared in brackish shrimp farmers in the freshwater area, manifested by their improvised farming practice, i.e. pumping saline water into the freshwater zone, groundwater abstraction, reuse of saline water, etc.

In applying a socio-hydrological approach with a special focus on the dynamics of the socio-hydrological system, this study also constructed a thesis on the divergence from the officially targeted freshwater pathway in the NBT project area. Specifically, brackish shrimp farming in the NBT freshwater area had a dynamic socio-hydrological driver rather than a purely profit-driven nature in a concurrent perspective. Most importantly, the socio-hydrological approach adopted in this research suggests a reflexive way to typify actors by their socio-hydrological features. As socio-hydrological dynamics and their impacts on the landscape do not fit neatly into administrative boundaries, the development of appropriate socio-hydrological groups for further analysis is essential. This study suggested four socio-hydrological groups – the "proponent," "opponent," "fragile" and "unaffected" groups – distinguished by their social features (livelihood adoptions) and hydrological conditions.

4.2 Farmers' adaptability to freshwater policy

As the socio-hydrological paradigm emerged, an interesting challenge arose in terms of the use of socio-hydrology principles, insights and concepts to support the design of new human–water system solutions and policies. As stated in the introduction of this article, water infrastructure projects are often initiated and developed primarily based on technical and financial information and often fail to integrate the social and institutional aspects. In this study, we focused on social and institutional impacts to measure ongoing policies and to evaluate the degree to which they will be adopted by local people.

The MOTA framework was applied in this research to analyse farmers' ability to adopt the pathway advocated by the NBT freshwater project. The results showed a differentiation between socio-hydrological groups in their perceptions about socio-hydrological contexts and in their motivation and ability to adopt a future with freshwater farming alone.

The aggregated MOTA scores showed the lowest adaptability in the "opponent" group and higher adaptability in the "unaffected" and "proponent" groups. The low MOTA score of the "opponent" group of brackish shrimp farmers in the freshwater zone was largely contributed by low technical ability. The low ability in the "opponent" group suggested technical support in the form of training for new potential crops (i.e. fish farming) is essential to ensure brackish farmers' commitment to freshwater policies. Meanwhile, low motivations in the other three groups were mainly associated with high threat perception. The high threat perception revealed the vulnerability of agricultural livelihoods that can discourage actions and, hence, adaptability. To address multiple risks to agricultural livelihoods, it is essential to have multisector collaboration ranging from entrepreneurs to agronomists and agricultural extension.

5 Conclusion

The implementation of complex water infrastructure projects is fraught with challenges, not only of a technological and hydrological nature but social and institutional as well. Conventional means of assessing such projects, such as cost–benefit analysis and social impact assessment, often rest on faulty or unrealistic expectations about how people in affected areas or communities will respond to such projects and the environmental changes they induce. As a result, large infrastructure projects often falter in the face of unexpected responses by local stakeholders, such as the "failure" to respond to infrastructure in the manner envisioned by planners.

In this paper, we have demonstrated the socio-hydrological dynamics, driven by the interplay between social and hydrological systems, that shaped a heterogeneous agricultural landscape that deviated from the freshwater design for the studied area. The application of the MOTA framework in analysing the adaptability of socio-hydrological groups showed a high degree of variation in the ability and motivation of farmers to change their cropping practices in the manner anticipated by government planners. These findings help to explain the persistence of other forms of production, such as shrimp farming, in the local area. We believe that this study represents a promising step towards the interdisciplinary study and assessment of infrastructure projects in a manner that takes into account the complexity of coupled social and hydrological systems. Given the water management challenges faced by other deltaic zones around the globe and the continuing allure of infrastructural solutions to these challenges, the framework that we have applied and the findings that we have presented should have broader applicability to other global contexts.

Acknowledgements

We thank all key informants for sharing their views and supporting the interviews and focus group discussions.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was funded by the UDW (Urbanizing Deltas of the World) Integrated Project on Strengthening Strategic Delta Planning Processes in Bangladesh, The Netherlands, Vietnam and beyond, of the Netherlands Organization for Scientific Research (NWO) under project number W 07.69.106. The finalization of the paper also benefited from a follow-up grant under the NWO UDW-3 Programme with project number W 07.6919.302. Fieldwork for this research was supported by the project 'Transforming agricultural livelihoods for climate change adaptation in the Vietnamese Mekong Delta: A case study in Ben Tre province' [grant number: KHCN-TNB-DT/14-19/C20].

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References

Biggs, D., *et al.*, 2009. The delta machine: water management in the Vietnamese Mekong Delta in historical and contemporary perspectives. *In*: *Contested waterscapes in the Mekong region: hydropower, livelihoods and governance*, 203–225.

Blau, P.M., 1964. *Exchange and power in social life*. New York: Wiley.

Carisi, F., *et al.*, 2017. Is anthropogenic land subsidence a possible driver of riverine flood-hazard dynamics? A case study in Ravenna, Italy. *Hydrological Sciences Journal*, 62 (15), 2440–2455. doi:10.1080/02626667.2017.1390315

Coleman, J.S., 1990. *Foundations of social theory*. Cambridge: Harvard University Press.

Cook, K.S., *et al.*, 1978. Power, equity and commitment in exchange networks. *American Sociological Association*, 43 (5), 721–739. doi:10.2307/2094546

Di Baldassarre, G., *et al.*, 1969. Debates—perspectives on socio-hydrology: capturing feedbacks between physical and social processes. *Journal of the American Water Resources Association*, 5 (3), 2. doi:10.1111/j.1752-1688.1969.tb04897.x

Di Giusto, B., *et al.*, 2021. Development versus adaptation? Facing climate change in Ca Mau, Vietnam. *Atmosphere*, 12 (9), 1160. doi:10.3390/atmos12091160

Duc, D., *et al.*, 2018. Questioning triple rice intensification on the Vietnamese Mekong delta flood plains: an environmental and economic analysis of current land-use trends and alternatives. *Journal of Environmental Management*, 217, 429–441. doi:10.1016/j.jenvman.2018.03.116

Ericson, J.P., *et al.*, 2006. Effective sea-level rise and deltas: causes of change and human dimension implications. *Global and Planetary Change*, 50, 63–82. doi:10.1016/j.gloplacha.2005.07.004

Fogg, B.J., 2009. A behavior model for persuasive design. *In*: *Proceedings of the 4th international conference on persuasive technology*. doi:10.1145/1541948.1541999

Homans, G., 1961. *Social behaviour: its elementary forms*. London: Routledge and Kegan Paul.

Huu Nguyen, H., *et al.*, 2016. A review of the drivers of 200 years of wetland degradation in the Mekong Delta of Vietnam. *Regional Environmental Change*, 16 (8), 2303–2315. doi:10.1007/s10113-016-0941-3

Huy, Q., *et al.*, 2009. Operation of the Ba Lai irrigation system in the Mekong Delta, Vietnam. *Paddy and Water Environment*, 123–133. doi:10.1007/s10333-009-0155-0

Icek, A., 2019. The theory of planned behavior organizational behavior and human decision processes. *Organizational Behavior and Human Decision Processes*, 50 (2), 179–211. Academic Press, inc.

Ishtiaque, A., Sangwan, N., and Yu, D.J., 2017. Robust-yet-fragile nature of partly engineered social-ecological systems: a case study of coastal Bangladesh. *Ecology and Society*, 22 (3). doi:10.5751/ES-09186-220305

Jones, L. and Tanner, T., 2017. 'Subjective resilience': using perceptions to quantify household resilience to climate extremes and disasters. *Regional Environmental Change*, 17 (1), 229–243. doi:10.1007/s10113-016-0995-2

Käkönen, M., 2008. Mekong Delta at the crossroads: more control or adaptation? *Ambio*, 37 (3), 205–212. doi:10.1579/0044-7447(2008)37[205:MDATCM]2.0.CO;2

Kandasamy, J., *et al.*, 2014. Socio-hydrologic drivers of the pendulum swing between agricultural development and environmental health: a case study from Murrumbidgee river basin, Australia. *Hydrology and Earth System Sciences*, 18 (3), 1027–1041. doi:10.5194/hess-18-1027-2014

Kennedy, W.G., 2012. Modelling human behaviour in agent-based models. *In*: A.J. Heppenstall, A.T. Crooks, L.M. See and M. Batty, eds. *Agent-based models of geographical systems*. Springer, 167–179.

Korbee, D., *et al.*, 2019. Navigating the bureaucracy: an analysis of implementation feasibility for the Mekong Delta Plan, Vietnam. *Journal of Environmental Planning and Management*, 62 (9), 15451561. doi:10.1080/09640568.2019.1623014.

Kruskal, W.H., *et al.*, 1952. Use of ranks in one-criterion variance analysis. *Journal of the American statistical Association*, 47 (260), 583–621.

Kulsum, U., 2020. *Supporting adaptive delta management: systematic exploration of community livelihood adaptation as uncertainty*. Delft, The Netherlands: Delft University of Technology.

Lan, N.T.P., 2011. From rice to shrimp: ecological change and human adaptation in the Mekong Delta of Vietnam. *Environmental Change and Agricultural Sustainability in the Mekong Delta*, 45 (2), 259–270. doi:10.1007/978-94-007-0934-8

Loc, H.H., *et al.*, 2017. Integrated evaluation of ecosystem services in prawn-rice rotational crops. Vietnam. *Ecosystem services*, 26, 377–387.

Loc, H.H., *et al.*, 2018. Socio-geographic Indicators to Evaluate Landscape Cultural Ecosystem Services: A Case of Mekong Delta. Vietnam. *Ecosystem Services*, 31.

Loc, H.H., *et al.*, 2021. How the saline water intrusion has reshaped the agricultural landscape of the Vietnamese Mekong Delta, a review. *Science of The Total Environment*, 794, 148651

Nguyen, H.Q., *et al.*, 2019a. Farmer adoptability for livelihood transformations in the Mekong Delta: a case in Ben Tre province. *Journal of Environmental Planning and Management*, 62 (9), 1603–1618. doi:10.1080/09640568.2019.1568768

Nguyen, H.Q., *et al.*, 2020a. Socio-ecological resilience of mangrove-shrimp models under various threats exacerbated from salinity intrusion in coastal area of the Vietnamese Mekong Delta. *International Journal of Sustainable Development & World Ecology*, 4509, 1–14. doi:10.1080/13504509.2020.1731859

Nguyen, H.Q., *et al.*, 2019b. Evaluation of retrofitting responses on urban flood in Ho Chi Minh City using Motivation and Ability (MOTA) framework. *Sustainable cities and Society*, 47, 101465. doi:10.1016/j.scs.2019.101465.

Nguyen, H.Q., *et al.*, 2020. Land use dynamics in the Mekong delta: from national policy to livelihood sustainability. *Sustainable development*. doi:10.1002/SD.2036.

Park, E., *et al.*, 2020. Dramatic decrease of flood frequency in the Mekong Delta due to river-bed mining and dyke construction. *Science of The Total Environment*, 723, 138066.

Phi, H.L., *et al.*, 2015. A framework to assess plan implementation maturity with an application to flood management in Vietnam. *Water International*, 40 (7), 984–1003. doi:10.1080/02508060.2015.1101528

Renaud, F.G., *et al.*, 2015. Resilience and shifts in agro-ecosystems facing increasing sea-level rise and salinity intrusion in Ben Tre province, Mekong Delta. *Climatic Change*, 133 (1), 69–84. doi:10.1007/s10584-014-1113-4

Renaud, F.G., Szabo, S., and Matthews, Z., 2016. Sustainable deltas: livelihoods, ecosystem services, and policy implications. *Sustainability Science*, 11 (4), 519–523. doi:10.1007/s11625-016-0380-6

Roobavannan, M., *et al.*, 2018. Norms and values in sociohydrological models. *Hydrology and Earth System Sciences*, 22, 1337–1349. doi:10.5194/hess-22-1337-2018

Sanderson, M.R., *et al.*, 2017. Bringing the "social" into sociohydrology: conservation policy support in the Central Great Plains of Kansas, USA. *Water Resources Research*, 53 (8), 6725–6743. doi:10.1002/2017WR020659

Sivapalan, M., Savenije, H.H.G., and Blöschl, G., 2012. Socio-hydrology: a new science of people and water. *Hydrological Processes*, 26 (8), 1270–1276. doi:10.1002/hyp.8426

SWIRP, 2018. *Supplementing irrigation planning for Ben Tre province to 2020 with vision to 2030*. Ho Chi Minh city, Vietnam: Southern Institute for Water Resources Planning (SWIRP).

Syvitski, J.P.M., *et al.*, 2009. Sinking deltas due to human activities. *Nature Geoscience*, 2 (10), 681–686. doi:10.1038/ngeo629

Tong, Y.D., 2017. Rice intensive cropping and balanced cropping in the Mekong Delta, Vietnam — economic and ecological considerations. *Ecological Economics*, 132, 205–212. doi:10.1016/j.ecolecon.2016.10.013

Van Emmerik, T.H.M., *et al.*, 2014. Socio-hydrologic modeling to understand and mediate the competition for water between agriculture development and environmental health: Murrumbidgee river basin, Australia. *Hydrology and Earth System Sciences*, 18 (10), 4239–4259. doi:10.5194/hess-18-4239-2014

van Staveren, M.F., van Tatenhove, J.P.M., and Warner, J.F., 2018. The tenth dragon: controlled seasonal flooding in long-term policy plans for the Vietnamese Mekong delta. *Journal of Environmental Policy and Planning*, 20 (3), 267–281. doi:10.1080/1523908X.2017.1348287

Viero, D.P., *et al.*, 2019. Floods, landscape modifications and population dynamics in anthropogenic coastal lowlands: the Polesine (northern Italy) case study. *Science of the Total Environment*, 651, 1435–1450. doi:10.1016/j.scitotenv.2018.09.121

Vo, H.T.M., *et al.*, 2019. Political agenda-setting for strategic delta planning in the Mekong Delta: converging or diverging agendas of policy actors and the Mekong Delta plan? *Journal of Environmental Planning and Management*, 62 (9), 1454–1474. doi:10.1080/09640568.2019.1571328

Xu, A., *et al.*, 2020. Water conservancy projects enhanced local resilience to floods and droughts over the past 300 years at the Erhai Lake basin, Southwest China. *Environmental Research Letters*, 15 (12), 125009. doi:10.1088/1748-9326/abc588

Yu, D.J., *et al.*, 2020. Socio-hydrology: an interplay of design and self-organization in a multilevel world. *Ecology and Society*, 25 (4), 1–16. doi:10.5751/ES-11887-250422

Appendix.

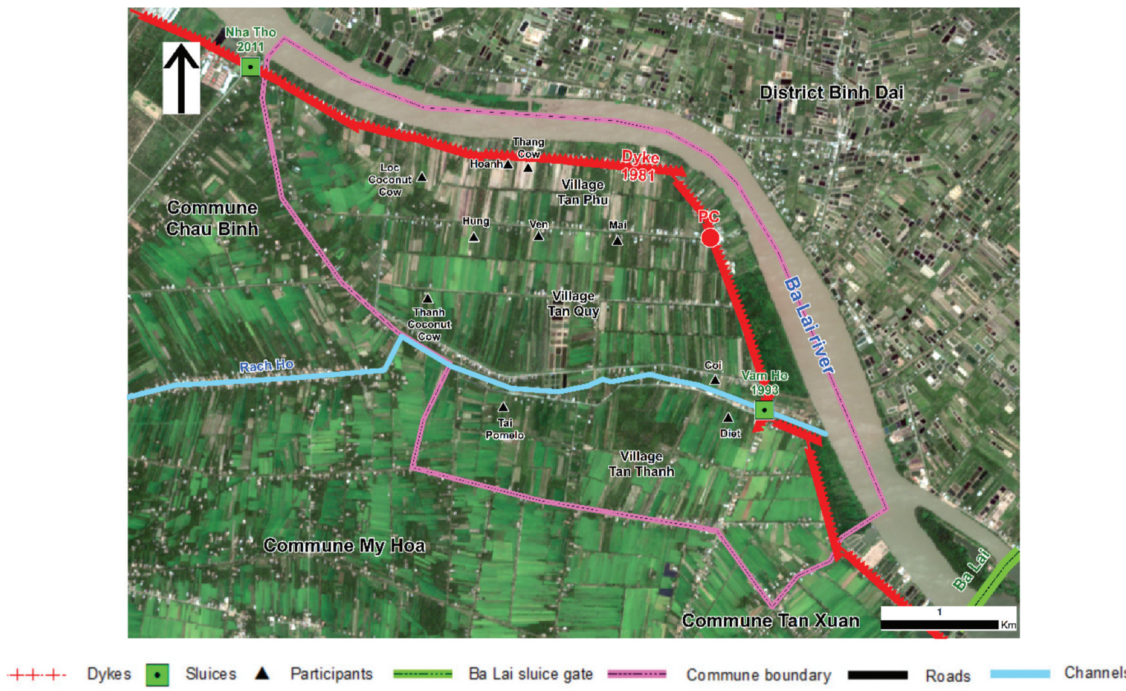

Figure A1. Result of focus group discussion in Tan My commune of Ba Tri district.

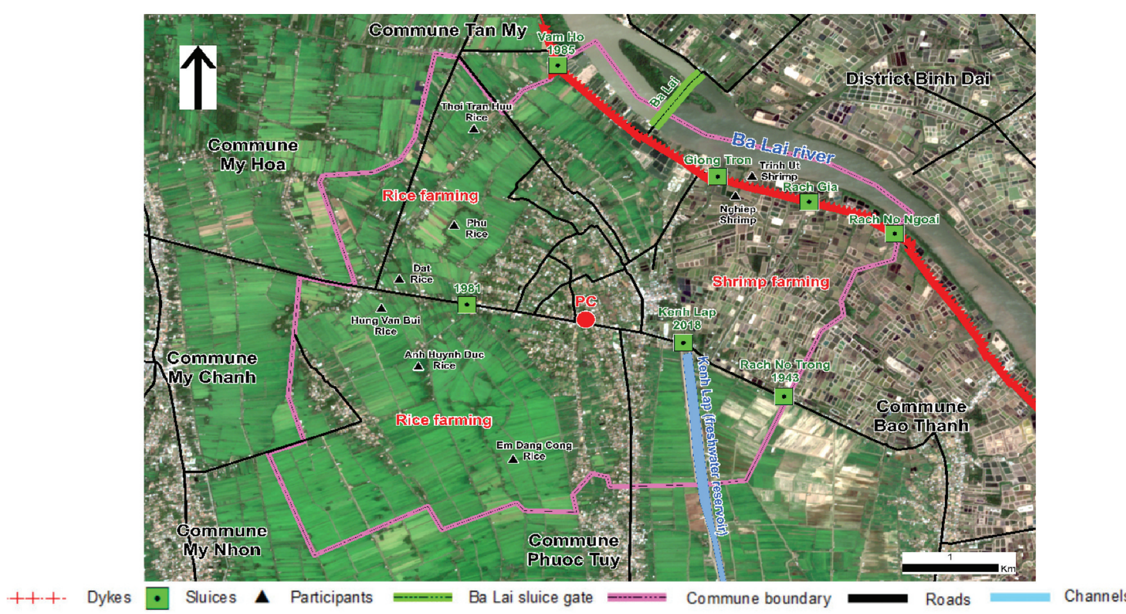

Figure A2. Result of focus group discussion in Tan Xuan commune of Ba Tri district.

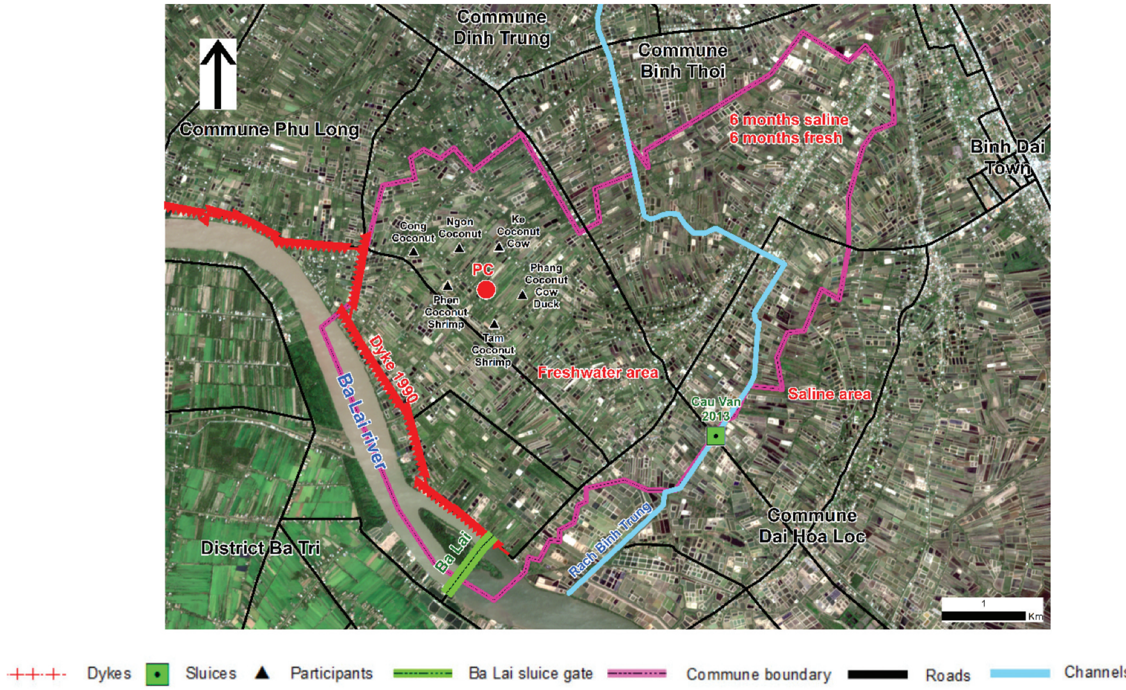

Figure A3. Result of focus group discussion in Thanh Tri commune of Binh Dai district.

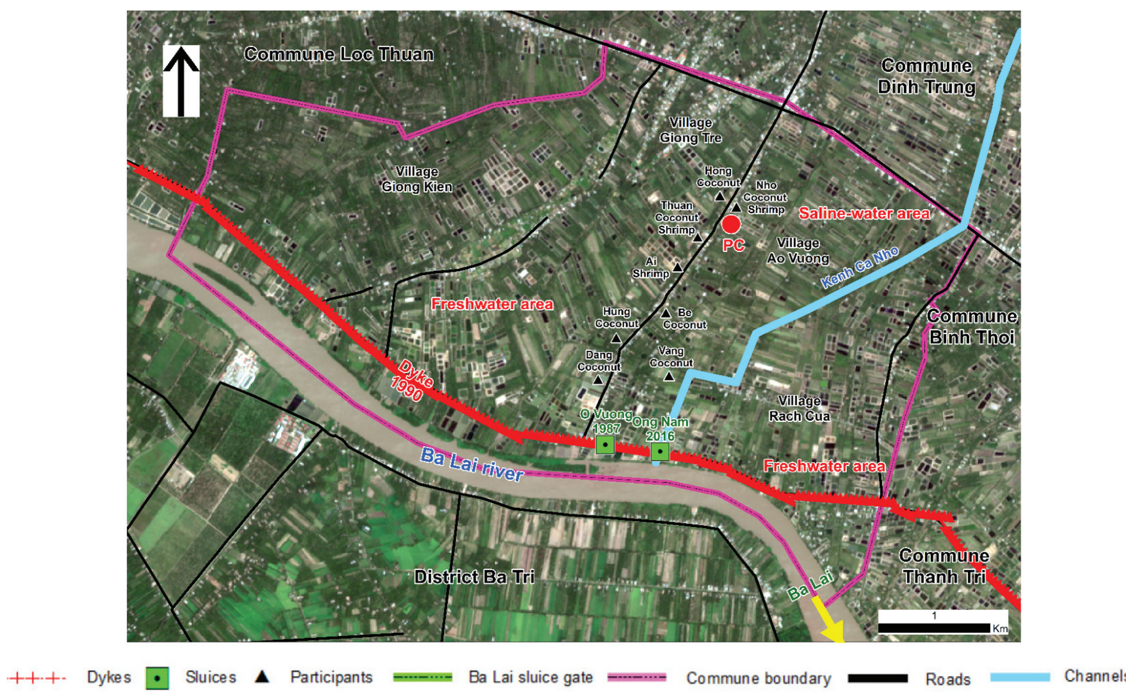

Figure A4. Result of focus group discussion in Phu Long commune of Binh Dai district.

Table A1. Significant difference between groups using the Kruskal-Wallis method.

Trigger		Motivation		Ability	
Road	0.784	Crop income	0.235	Finance	0.578
Electricity	0.440	Threat	**0.049**	Water resource	**0.000**
Drainage	0.943			Drainage	**0.000**
Water resource	**0.000**			Electricity	**0.000**
Credit	0.131			Soil	**0.000**
Agricultural extension	0.372			Road	**0.000**
Market	**0.004**			Seed	**0.001**
Income	**0.015**			Material	**0.000**
				Equipment	**0.004**
				Technique	**0.000**
				Information	0.166
				Cooperative	**0.018**
				Training	**0.023**
				Merchant	**0.000**

Bold and bold underlined numbers indicate significant differences at 0.05 and 0.01 levels, respectively.