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Review

A DPSIR Assessment on Ecosystem Services Challenges in the Mekong Delta, Vietnam: Coping with the Impacts of Sand Mining

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Abstract: River sand mining has been a concerning problem for the southern Asian developing nations. The rampant growth of urbanisation in developing countries has led to an extensive need for and consumption of sand. The Mekong River and its delta are an essential part of southern Vietnam, and also a global biodiversity hub that is currently being exhausted by intensive sand mining. The understanding of the cause–effect of the sand mining over the Mekong delta region and river, from a systems-thinking perspective, is lacking, not only with Vietnam but also with other countries along the Mekong River. The DPSIR framework (Driver–Pressure–State–Impact–Response) is a useful tool to assess and describe the cause–effect within an ecosystem to aid in a better systems-thinking approach for stakeholders, policy makers, and governance managers to draft response measures. This study used the DPSIR framework to assess the different effects of sand mining on the ecosystem services and human well-being in the Mekong River and delta region of Vietnam. Rapid population growth, urbanisation, and infrastructure development needs remain as primary drivers for the sand consumption. The DPSIR study showed a holistic view of several interlinked pressures and state changes in Vietnam's Mekong, along with some potential responses, to form systematic, sustainable approaches for mitigating and adapting the impacts caused by extensive river sand mining.

Keywords: DPSIR framework assessment; sand mining; Mekong delta; estuarine ecosystem services; sustainable consumption; environmental governance

1. Introduction

The Mekong River is one of the longest rivers in the world, running 4800 km from the Tibetan plateau, passing through six countries: China, Myanmar, Thailand, Lao PDR, Cambodia, and Vietnam [1]. The river delta basin is vast, rich in biodiversity, hugely productive to the regions it occupies by supporting social, ecological, and economic aspects. The population living in the Mekong basin depends on the river and its ecosystem services for livelihood and well-being [2]. In Vietnam, the Mekong delta, also known as Cuu Long or Nine Dragons, covers a small area in the south of the country, around 60,000 km^2 [3,4]. The Mekong delta includes three broad landforms: (i) a floodplain in the northern and central part containing wetlands and grasslands; (ii) eastern and southern coastal ridges consisting of mangroves and mudflats; (iii) low-lying regions of the Ca Mau peninsula with scattered swamps and limestone outcrops (Figure 1) [5–7]. Despite covering the smaller region, about one-fifth of Vietnam's population and a quarter of its overall gross domestic product is represented by the Mekong delta [8]. The agricultural area in the Mekong covers roughly 2.4 million

hectares [9], and is often referred to as the "rice bowl" of Vietnam [3,4]. The functioning of the delta depends on the sediment that the Mekong carries along its course. However, in recent times the sediment load in the Mekong delta region of Vietnam has been reduced through dams, intensive sand mining, hydropower growth, and climate change, intensively affecting the flow regime and hydro morphology of the river [5].

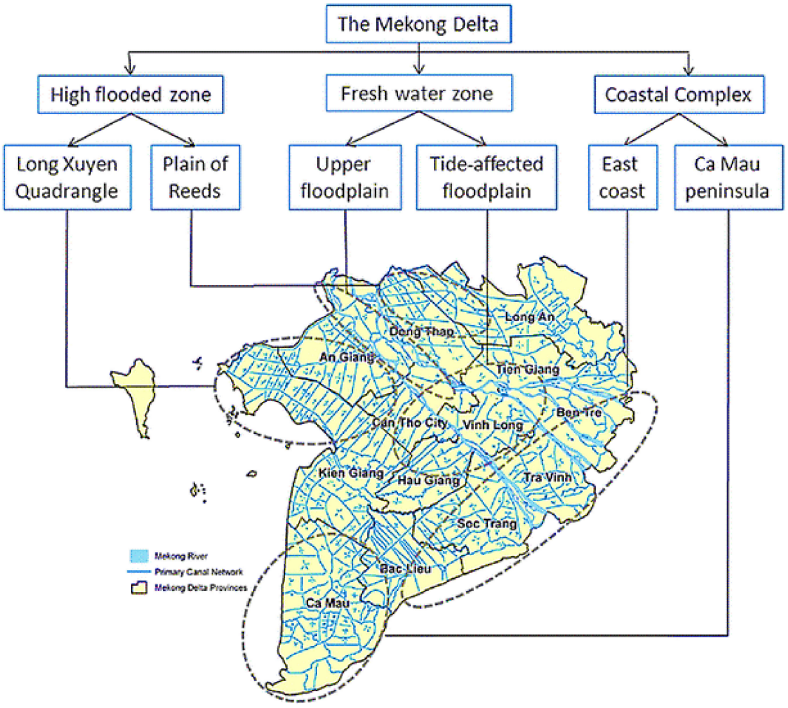

Figure 1. Different landforms across the Mekong delta region, Vietnam [7].

The primary goals of the Vietnamese government have been promoting industrialisation and modernisation, and they have gone through a fast urban growth initiated through the "Doi Moi" reform since 1986 [10]. The urbanisation directly influences the demand for building materials such as sand, clay, coarse aggregates, and gravel, which make up about 94% of global stocks of building and infrastructure materials [11]. According to the Vietnam urban development vision of 2020–2025 [12], the urban population is expected to grow from 38% in 2015 to 45% by 2020 and 50% by 2025. The main driving forces behind fast urbanisation are a public investment in infrastructure and the opening up of land for leasehold entitlements [10]. One of the critical resources from the Mekong sedimentation is sand, which forms the primary resource for economic development among entire Mekong basin countries [10]. Sand mining is a rapidly growing activity in many rivers in South-East Asia, and the regional governments are struggling to cope with the devastating consequences of mining activities [10–13], such as diverted river courses, an increase in suspended sediments, and erosion. River sand in Vietnam has so far been extensively exploited from the past through dredging. These activities have led to enormous ecological and social impacts for the delta region in recent years. Licensed companies often exceed the legal extraction limits, and illegal mining practices are happening at a rate threatening the ecosystem [14]. According to the Department of Construction Materials under Vietnam's Ministry of Construction [15], between 2016 and 2020, the domestic demand for sand was estimated to be around 2.1–2.3 billion m^3, while the total sand reserves of Vietnam were at just over 2 billion m^3. A bathymetric study [16] of a branch of the Mekong–Tien Giang River estimated sand extraction at a rate of 4.64 ± 0.31 million m^3/year over a 20 km length, highlighting an unsustainable practice and also indicating insufficient sediment supply from the upper reaches of the river.

The complex nature of the Mekong delta and the interaction of its various socio-ecological systems have been poorly understood [17]. Thus, this creates the need to analyse the multiple causes and

effects on the ecosystem services of the river and delta by river sand mining and consumption from the Mekong delta of Vietnam. The DPSIR (Driver–Pressure–State–Impact–Response) methodology provides a framework tool for an overview on river sand mining's interaction in the Mekong delta's socioeconomic system by addressing the main driving forces, the resulting pressures, and associated impacts on the system in the past and future, thus providing information to target the response mechanisms to address the consequences. The DPSIR framework was applied to this study as an innovative tool to aid better governance through summarising dynamic interlinkages between the different sources of multiple stressors caused by sand mining and consumption within the Mekong delta of Vietnam. The consequences of sand and gravel mining have long been underestimated in resource planning and management. The study [18] discussed the anthropogenic changes significantly affecting the sediment dependence of the Mekong basin ecosystems services and the threat to the sediment budget for lower Mekong floodplains. Annual instream mining of about 34 Mm^3 of aggregate happens in the lower Mekong River, where 90% is sand [10]. Apart from delta erosion, downstream parts of the river face severe changes in morpho-dynamics and biophysical functioning, which are contributed majorly by sand mining activities [4,19].

Recently, there have been a dramatic shortage of building materials in fast-growing economies [13] and an awareness of massive interventions in the ecosystem balance due to mining activities. To have a more sustainable exploitation of natural resources and consumption for the future, a better understanding of the cause–effect relationships between anthropogenic activity impacts and environmental components is fundamental. The DPSIR framework is a useful methodology to describe and visualise these links in a meaningful way to people, industries, and policy makers. Despite its potential, the application of DPSIR is virtually lacking in developing countries. The DPSIR framework interlinks any adverse effects of human *Driven* activities on the essential ecosystem services, the *Pressures* caused in the system, followed by unfavourable consequences of *State Change* on societal benefits, which could be reflected as *Impact* [20]. Hence, the chain of causes is addressed by having *Responses* to ensure that the benefits of the ecosystem will be delivered sustainably.

The DPSIR framework was used in this study to comprehensively describe the available knowledge and management needs in the Mekong delta as in the following steps:

- to analyse the main economic drivers of sand mining;
- to analyse the pressures derived from associated anthropogenic activities;
- to assess the ecological and social state of the Mekong River and delta region;
- to assess the ecological and social eco-services impacts on the region;
- to suggest the entities responsible for possible management measures and responses to mitigate the effects of sand mining and growing sand demand;
- to present tools and a framework to support sustainable resource consumption.

2. Methodology

The assessment of the different cause and effect scenarios of sand consumption over the river and delta ecosystems was performed using the DPSIR framework [20–41]. The qualitative study involved data and information collected from Vietnamese statistics, previous scientific works, and other internet information available.

2.1. Search Strategy and Documentation

Structured literature research was conducted on the existing DPSIR assessment on different ecosystems such as deltas, rivers, and estuarines. The study applied a specific focus to the Mekong River and delta, as shown in Figure 2. An organised search within several scientific peer-reviewed article databases, such as Web of Science, Science Direct, Scopus and MDPI, was carried out. These databases were chosen based on several similar studies highlighting their diverse quality and comprehensiveness [26,34,35]. The targeted sources were peer-reviewed journal articles, books,

book sections, reports, and news articles that were only in English. The following keywords were used for the search: "DPSIR" or "Driver–Pressure–State–Impact–Response" and "Delta ecosystem services" or "Mekong delta" and "Sand mining". From the keyword DPSIR several combinations were followed such as "Pressure–State–Response", "PSR", "PSIR", "Driver–Pressure–State–Effect–Action", "State change", and "Pressure-Response framework". The primary database search involved a thorough screening of titles and abstracts based on keywords, which was then narrowed down. In addition, the preliminary investigation was complemented by Google search, Google Scholar, the World Wildlife Fund (WWF), the Mekong River Commission, the United Nations Developmental Programme (UNDP), and the statistics office of Vietnam, for further information. The works of literature were initially considered relevant if they matched with any one of the keywords. The documents were stored and handled using Mendeley Reference Manager for efficient bibliography recording. Mendeley is a free desktop application with web importer and plug-ins helping to simplify the storage, organisation, and search of references within a single library (https://www.mendeley.com/). After retaining the documents in the Mendeley library, a thematic screening was carried out, where the documents went through a detailed manual examination and grouped according to their relevance to the study. The manual thematic screening involved a detailed review to obtain data relevant to DPSIR for delta, estuarine and river ecosystems; sand mining impacts over a river; Mekong delta socioeconomic conditions, and other Vietnamese regional coverage. The irrelevant documents were discarded, and similar thematic documents were sorted and grouped as folders within Mendeley. The content of documents that was relevant for assessment preparation was carefully reviewed and validated. During the review, several factors of DPSIR were noted. The noted different factors influencing the ecosystem of the Mekong delta were mapped under relevant DPSIR categories using the yEd Graph editor. yEd is a freely available application aiding in the creation of quality diagrams and flowcharts. The mapped flowchart was utilised for further brainstorming, discussions, and assessment (see Supplementary files).

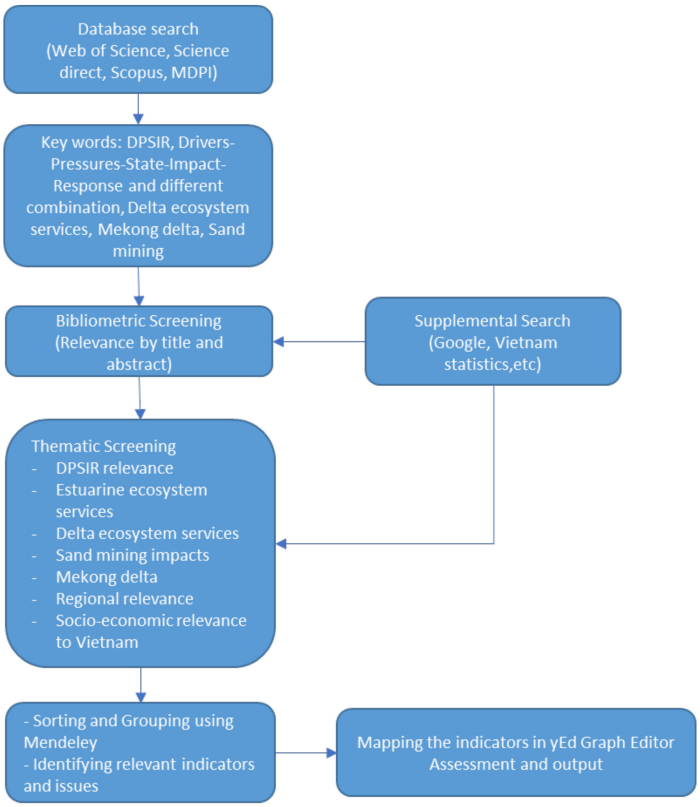

Figure 2. Structured approach for document collection and screening process.

2.2. DPSIR Framework

The DPSIR (Driver–Pressure–State–Impact–Response) framework is a systems-thinking approach-based framework that assumes cause–effect relationships between interacting components of social, economic, and environmental systems (Figure 3). The framework was initially developed by the OECD (Organisation for Economic Co-operation and Development) in 1993, further developed and established by the EEA (European Environment Agency) in 1999, and has been used by the United Nations, as well [36]. The DPSIR framework is a proper tool to aid good governance, and it has been used for many environmental resource management applications, such as water and mineral resources, land and soil resources, agricultural systems, biodiversity and marine resources, etc. This model systemises a cause–effect relationship, describing how *Drivers*, which may be social, economic or environmental developments, exert *Pressures* on the environment. The *State* of the environment changes as a result of *Pressures*. This then leads to *Impacts* (social, economic or environmental), which may lead to requiring societal *Responses* acting as feedback to *Drivers, Pressures, States or Impacts* [33]. DPSIR frameworks provide the possibility for multi-species analyses and multi-sector approaches by considering different indicators from different ecological species, disciplines, and sectors [37]. Thus, the framework provides a holistic view of various happenings in the ecosystem to understand and communicate among scientists, specialists, policy makers and other stakeholders within or outside the subject [38].

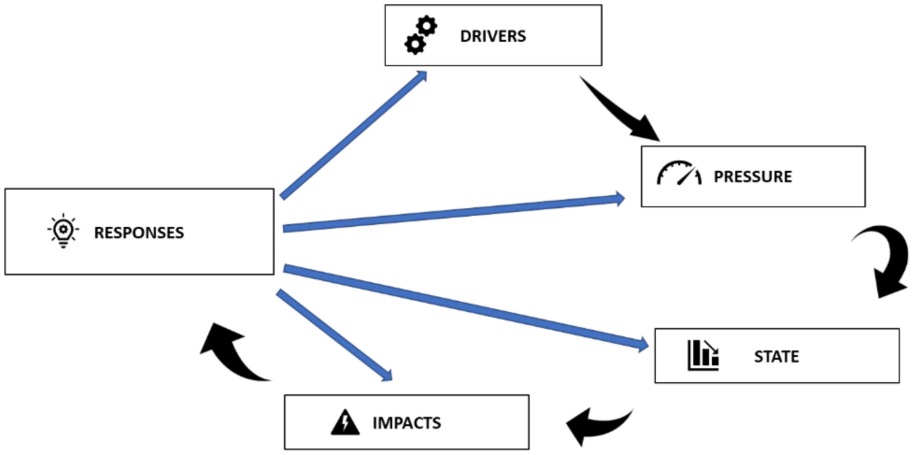

Figure 3. Driver–Pressure–State–Impact–Response (DPSIR) framework (created by the author, source: [36]).

The DPSIR framework is useful in assessing the relationships between the origins and consequences of environmental and social problems [2]. The DPSIR framework involves a variety of indicators based on each of the five elements of DPSIR for analysis (Figure 3) and communicates the outcome. The indicators for causes and effects vary according to the nature of the study. The framework helps the stakeholders to obtain a structure to apply response actions across varied issues under each element of DPSIR. The response measure might require further refinement to adapt its application to the area or region. The DPSIR framework has been used in a few aquatic and marine ecosystem assessments to bridge the gap between science and decision-making. One such study [39] involved assessment of sustainable fisheries management in Lake Tana, Ethiopia, and another study [40] dealt with socioeconomic conditions of small-scale Hilsa fishing in Bangladesh. The DPSIR framework has been useful in determining economic drivers and other various activities contributing to coastal erosion and vulnerabilities [26,33,34,41]. The river ecosystems have undergone few DPSIR-based assessments focussing on bank erosion, water resource management, and biodiversity management [2,23–25,28]. Still, there is a lack of application of the DPSIR framework on the impacts of sand mining on the river ecosystem. This study can be a step towards applying the framework to summarise the causes and

effects associated with sand mining on the river and delta ecosystem, along with defining responses that have to be addressed by multiple stakeholders at different elements of the network.

3. Results and Discussion

The application of the DPSIR model for the Mekong delta region to the cause–effect of sand mining and consumption presents the general situation and the relation between environmental impacts, environmental as well as socioeconomic measures as shown in Figure 4. The socioeconomic developments and their associated effects are always complicated. Addressing the impacts and providing a proper response measure to the impacts were frequently limited, and they were considered only for a particular aspect of the problem with insufficient understanding. System-level thinking of the impacts using the DPSIR framework, including the short- and long-term consequences of the more extensive system and coordinated management action, is required for improved sustainable systems. The systems-thinking approach has to be applied as an approach to problem-solving that incorporates the perspective of understanding the relationships and interactions of several components within the system and also among systems [30]. Thus, the approach will help to broaden the decision-making and implementation by considering more than one issue within the system.

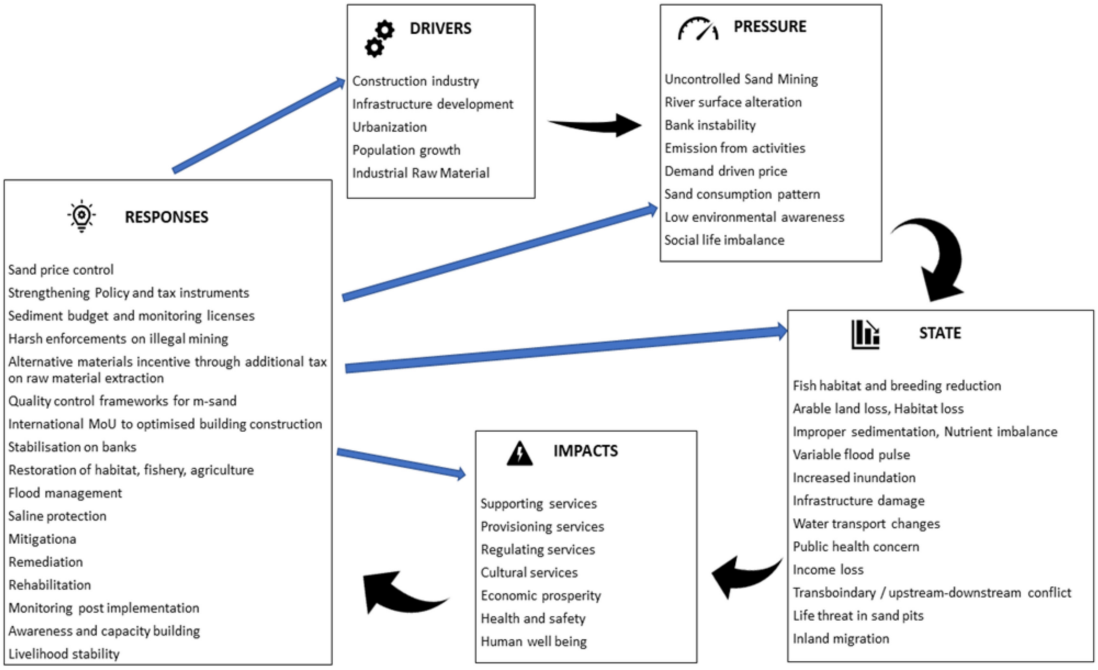

Figure 4. DPSIR framework describing the interaction of cause–effect and sand extraction and consumption in the Mekong delta (created by the author).

3.1. Drivers

Driving forces-Drivers are the processes and anthropogenic activities that fulfil basic human needs leading to pressures on the environment. The intensity and distribution of drivers originate and act globally, regionally, or locally. Driving Forces-Drivers describe "the social, demographic, and economic developments in societies by human activities" [42]. Drivers are divided into Economic Sectors and Social Drivers. The DPSIR framework segregates several causes that act as drivers affecting the ecosystem into these two categories. The main drivers for sand mining and consumption are the construction industry, infrastructure development projects, urbanisation, population growth, and social equity growth. These economic and social drivers are interrelated, where the significant influence is caused by population growth, with most people increasingly preferring to live in cities (Figure 5).

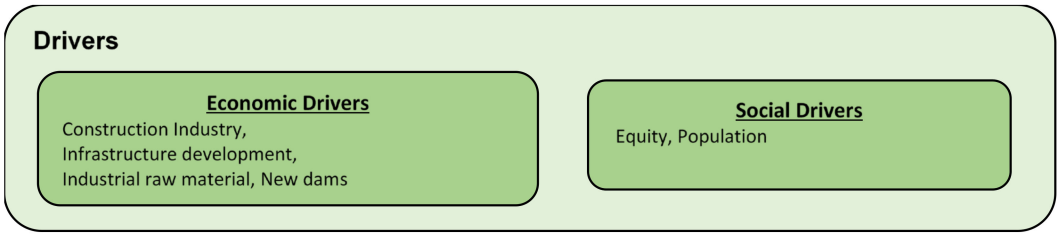

Figure 5. A different set of indicators for economic and social drivers (created by author).

3.1.1. Population

Population growth is a major factor in the socioeconomic system, which makes it priority information to advance services and developmental agendas by governments and businesses. The growing population leads to increased demand for food, water, energy, and other amenities, thus determining the consumption of the natural resources within a system. Vietnam is one of the fast-developing countries in South-East Asia and has a population of about 94 million [43]. Figure 6 shows the population growth between 2000 and 2018 for the Mekong delta region, Ho Chi Minh City (HCMC), and An Giang province, which remain the main focus area of sand mining activities [44]. HCMC is undergoing rapid urbanisation, which was reflected in the increasing population during the period 2000–2018 at an average rate of 2.1–2.2% [43]. The population growth rate in the Mekong region as a whole and An Giang province is meagre and slow in comparison to HCMC. This reduced rate might indicate the status of increasing urbanisation in HCMC, driving the sand requirement in future years. Also, the current rate of sand consumption in HCMC can hinder the future urban agglomeration in the Mekong delta region through a shortage of mineral resources. Most of the sand dredged in the Mekong goes to meet the demand in HCMC megacity. The population growth driving the GDP also demands new public infrastructure, industrial infrastructure, tourism infrastructure, housing constructions, roads, and industrial raw materials, etc. For these developments, the sand is a backbone resource, influencing the pressure for extensive dredging. Thus, population leads to pressures such as urbanisation, increased sand demand, and demand-driven prices.

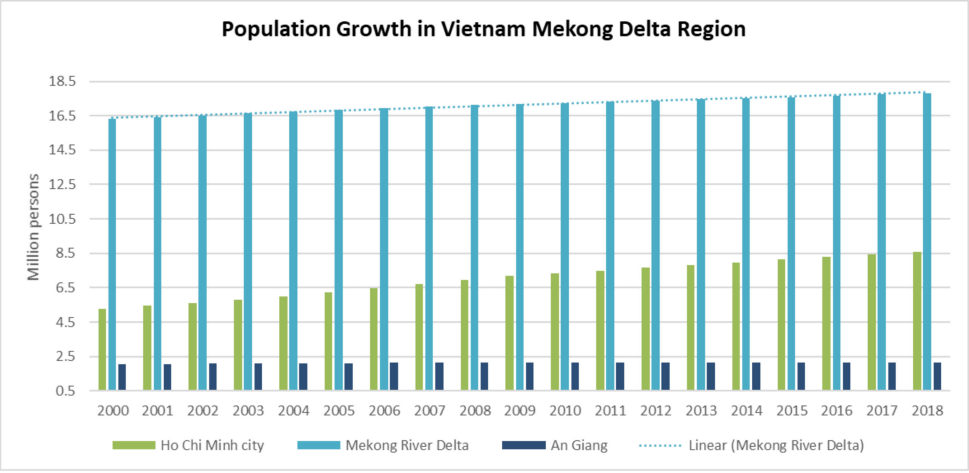

Figure 6. Population growth in Vietnam's Mekong delta region, Ho Chi Minh City, and An Giang province (data source: [44]).

3.1.2. Economic and Infrastructure Development

The Doi Moi policy in 1986 and its follow-up reforms in 1995 and 2003 have rapidly boosted the real estate market in Vietnam [45–47]. Since the reform period, the real estate and associated businesses have progressed and contributed hugely to the country's economic prosperity. Figure 7 depicts the

yearly investments in the sectors of construction and real estate, which have grown exponentially between 2005–2018 [44]. The construction industry of Vietnam is growing at an average of 9–9.2% per year, comprising 5.94% of national GDP structure [48]. The urbanisation of Vietnam reached 39.2% in 2019, which was 0.8% higher than in the year 2018.

Figure 7. Investments in Vietnam's construction and real estate sectors over the years (conversion factor dollar/Vietnamese dong-VND is around 1:23,200; data source: [44]).

The Mekong delta has broader economic importance for Vietnam, as it accounts for 18% of national GDP, 90% of rice exports, and 73% of farmed aquatic products [49]. The social data on living conditions such as housing in the Mekong delta region have not been as good, despite economic and agriculture growth. The percentages of different housings such as permanent, semipermanent, less temporary, and simple permanent housing are less in the Mekong delta region than in other regions and the national average. As of 2018 [43], permanent-type housing corresponds only to 8.9%, which was the least when compared with other areas. The Mekong region housing pattern shows semipermanent-type at 74.7%, while the less temporary and simple permanent housing percentage remains higher than in the other areas. These housing conditions reveal the potential for future demand in the construction sector, thus influencing the consumption of sand and need for sand mining.

The regional economic development of the neighbouring countries influences the sand sedimentation in the Mekong delta of Vietnam through their new dam development projects. Despite the economic value of dam construction across the South-East Asian region, it has often led to a depletion of sediment flux from the lower Mekong basin deltas [4,50], with increased land and coastal erosion and water flow regime variation becoming widespread consequences [51–53]. The study [50] underlined that the recent decade of damming in the Mekong led to change in sediment flux in the lower delta regions from 99 Mt/year to 43 Mt/year by 2020–2029 (57% decrease). Apart from other consequences, it also causes downstream transfer of pollutants, fish population flux, changes in water navigability and transboundary conflict [54]. Several dams have been planned for the future, along with the current operational dams in the Mekong River alone comprising 10 dams in China and two dams in Laos, which could aggravate the river ecosystem state and potential transboundary conflict, as well (Figure 8). This study on using the DPSIR framework underlined the interconnection between dam construction and follow-up transboundary conflicts that cause social unrest (human state).

Figure 8. Planned and operational dams across the mainstream of the Mekong River (Recreated: [55]).

3.2. *Pressures*

Pressures can be defined as the changes induced in the environment or influences on human health that are caused by human activities from *Drivers*. These human activities exert pressures on the environment as a result of production or consumption. Pressure indicators describe developments in the release of substances (chemicals, waste, noise, etc.) or emissions, physical and biological agents, the use of resources and land by human activities. The pressures on the ecosystem transport and transform into a variety of natural processes to manifest changes in environmental conditions [42]. Pressures are classified as Environmental pressures and Human behaviour pressures with several indicators, as shown in Figure 9.

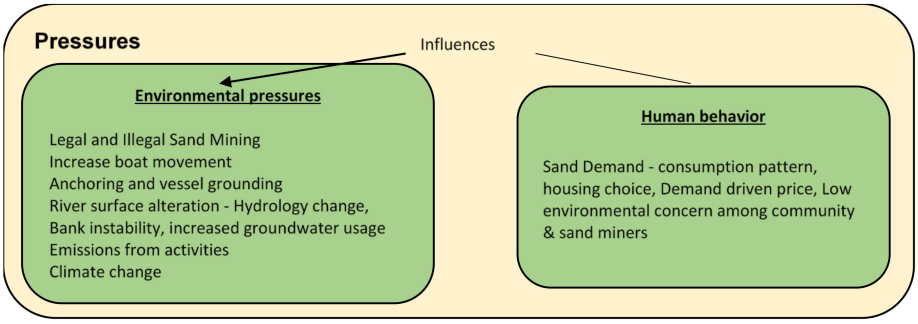

Figure 9. Different pressure indicators influencing the environment and human behaviour (created by the author).

3.2.1. Environmental Pressures

Sand is the second most-consumed resource after water [56,57]. The consumption of sand is driven by population growth, the construction industry, and social infrastructure needs; thus, their growth pressures the extraction processes. Sand mining and dredging in rivers, lakes, and oceans are the only extraction processes followed. These processes take place as legally licensed operations and vastly as illegal operations that dominate the sector. This extraction of sand has effects directly and indirectly on the river/lake/ocean ecosystem and human health, despite the need for development.

The extraction alters the characteristics of the river, such as channel geometry, bed elevation, substrate composition and stability, instream roughness elements (large woody debris, boulders, etc.) depth, velocity, turbidity, sediment transport, stream discharge, and temperature, impacting both instream biota and associated habitat [5]. The sand mining in the riverine areas is mainly through open pit excavation and bar skimming and riverbed dredging. The process causes bed degradation when done uncontrolled and unplanned, causing streambed lowering, channel slope steepening, increased flow depth and width [58]. These conditions have an effect on the equilibrium between the inflow and outflow of sediments across the river channel until the balance is re-established. In a Mekong delta study [59], a deepening of about 1.5 m and irregular deepening were documented over 10 years.

The illegal mining poses a significant threat and puts enormous pressure on the environment, through its unregulated and extensive activities. The illegal mining activities are more localised, involving small boats, barges, and trucks, where the miners haul the sand using shovels, buckets, baskets, and small-scale hydraulic pumps. A documented case study [60] in northern Vietnam revealed that illegal mining activities have persisted, even though they violate public regulations concerning extraction levels and threaten public safety. Even licensed companies often exceed the legal extraction limits. The mining activities cause increased boat movements across the river areas (Figure 10), thus contributing to increased release of toxic materials either in association with actual mining or from machinery and materials used for mining [61]. The large vessel operation involves anchoring, which in turn creates the surface damage and disturbance. These activities increase the sediment and particle movement, further affecting the nutrient balance. The sand mining activities alter the river hydrology entirely in the long run, changing the hydro morphological structure and leading to (a) a higher flow velocity and thus an increased risk of erosion in water bodies, and (b) massive geotechnical problems affecting the slope stability of water bodies and surrounding infrastructures. The consumption of groundwater has also increased in recent years because of a growing population, a growing economy, and agricultural needs, giving rise to land subsistence in the delta region. Subsidence is mainly relevant, as it is further affected by reduced water flow and sediments caused by growing upstream water use, dams, and sand extraction [62,63]. Sand extraction also further reduces groundwater recharge, depleting aquifers and possibly resulting in premature failure of irrigation wells and associated farming problems [61,64].

(**a**) (**b**)

Figure 10. (**a**) Barge carrying sand in the Mekong. (**b**) Sand depot alongside the bank of the Mekong (created by author).

Apart from these factors, climate change adds pressures to the delta's ecosystem through rising sea level, varied monsoon, storm surges, and short or extreme rainfall flooding. Globally, the Mekong delta has been one of the critical hotspots of climate-change-related risks due to its exposure to floods, salinisation, and potential sea level rise [65]. The framework provided the overview that changing the river hydrology by sand mining activities, the proliferation of dams, and climate-change-induced sea level rise is contributing to the devastating state of the Mekong delta.

3.2.2. Human Behaviour Pressures

The human behaviour pressure is driven by social forces, which in turn influence the environmental pressures and human state, as well. According to the DPSIR framework, the main drivers for human behaviour are urbanisation and population growth. Despite the two drivers being interdependent, they act as precursors for human behavioural change. Population growth forces people to opt for improved quality of life and needs, further forcing them to migrate towards the city, causing urbanisation. The people's choice of housing from permanent or semipermanent types develops pressure for the construction industry's sand requirement, e.g., Figure 11 shows increased semipermanent and permanent housing in Ho Chi Minh City. Urbanisation causes the sand demand to increase for housing as well as for infrastructure construction purposes, causing a skyrocketing surge in the sand prices. According to [66], the sand prices rose about 50–200% between March and April in the year 2017, as a result of growing demand. The illegal mining benefits from this demand-driven price through uncontrolled price margins.

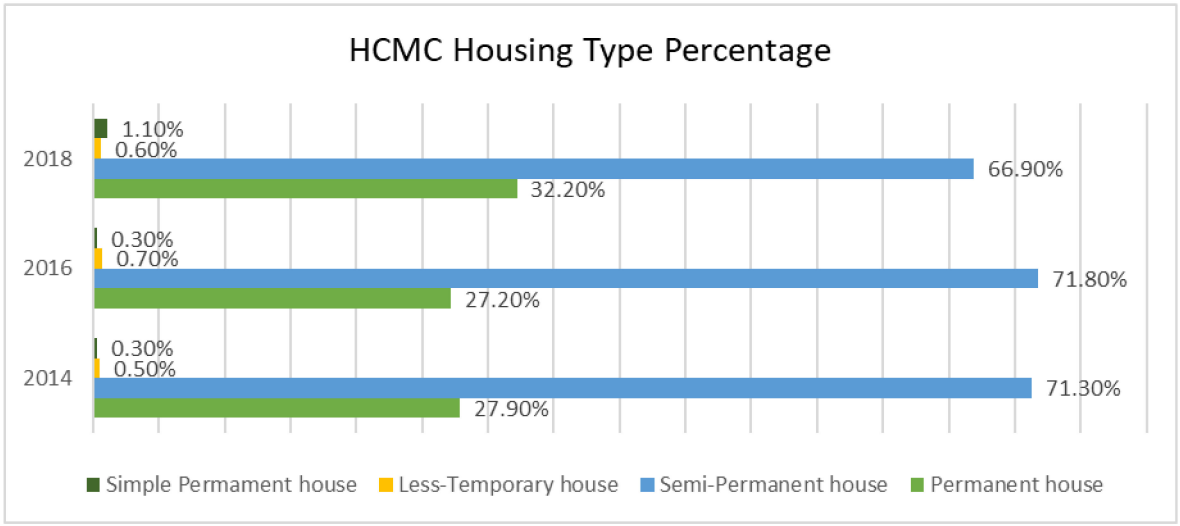

Figure 11. Different housing type percentage distribution in Ho Chi Minh City (data source: [44]).

Previously, there was a lack of worldwide data on sand and gravel extraction, and their impacts, and this has resulted in a lack of awareness among the public and decision-makers. In recent years, the area has attained much public notice as a result of the vast impacts caused by the extraction activities in the delta zones and material scarcity on the supply market. According to [67], within the last five years, there was an increase in papers published on the impacts of sand mining on the riverine ecosystem as an environmental issue, with less scientific studies of the Asian region. There is a lack of data in Vietnam and a lack of transparency of existing data associated with extraction and construction activities. The awareness among the public at the community level plays a significant role in the change of behaviour towards sand consumption and demand. This study on the Mekong region showed that a behaviour change among the population is required to promote public acceptance of using alternative materials in construction, fighting against illegal mining, and knowledge about mitigation activities and their effects on the unforeseen changes caused across river banks. The sand miners are also not completely aware of the safety and future impacts. The dependence of the workers making a living through illegal mining shows a behavioural issue pressured by socioeconomic employment issues. This framework-based analysis highlights the need to identify how the socioeconomic factors influencing the miners working in illegal mining play a vital role in order to initiate a shift.

3.3. State

The pressures result in affecting the state of the natural and built environment and human systems. The state of the environment is the combined interactions of physical, chemical, and biological phenomena (temperature, fish stock, CO_2 level, etc.) that affect different ecosystem components, and that can be measured by their quantity or quality. The state includes (1) environmental state—biotic and abiotic, and (2) human systems state. The human systems state covers the complete physical, mental, and social well-being, and not merely the absence of disease or deformity [30]. This section discusses the conditions (quality and quantity) of environmental compartments in the Mekong delta that have been exposed to the pressures from sand mining. The aim is to show (Figure 12) where the environmental changes are significant and how they are exacerbated by sand mining and urban metabolism.

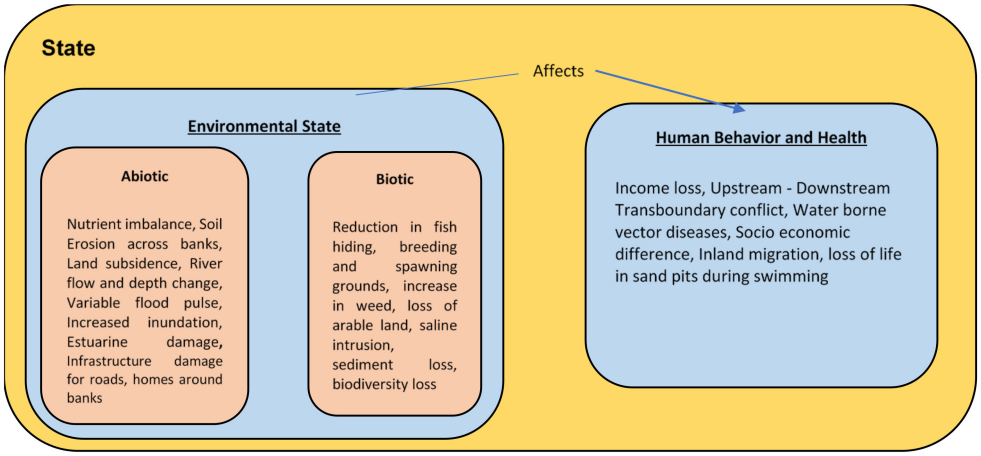

Figure 12. Classification of different changes of state by sand consumption (created by author).

3.3.1. Environmental State

The leading indicators for the current environmental state of the Mekong delta consist of the river ecosystem, estuarine ecosystem, fish stocks, water flow quantity and quality. Ecosystem attributes affected are macro-invertebrate drift, fish movements, species abundance and community structures, and food web dynamics [67]. The sand and gravel mining causes nutrient imbalance through increased suspended matter and turbidity from boat movement, anchoring, and sand mining, causing underwater surface material dispersion and dilutions. The increased turbidity reduces sunlight penetration and results in nutrient degradation, along with eutrophication in canals [68], further altering the quality of water and pH, along with the material emissions from the activities [69].

The species living in a site are forced to be displaced or destroyed, leading to reduced biodiversity triggered by sand mining and various pressures [70], resulting in favourable conditions for invasive species establishment, which affects the native species' survival (e.g., increased water weeds and parasites, benthic invertebrates reduction, etc.) [71]. According to [72], 70% of fishes are migratory in the Mekong; thus, sand mining, along with other drivers such as dams, affects the fish migration routes. This further destroys migratory routes, making fishes lay eggs at unsuitable places and resulting in declining wild fish stocks [73,74]. The Mekong delta region is the most productive fishing region in Vietnam, forming the most extensive offshore fishing sector in Vietnam with a 66% aquaculture fishery output [75]. Therefore, the environmental *state* change of the Mekong with a focus on fishery resources has to be considered as one of the priority indicators. The delta hosts habitats for a large number of bird species, not only native to the region but also a vast proportion of migratory population, constituting a global significance [76]. The study [6] indicated the decline of several species, and the delta damage poses a real danger of several species' global extinction. The application of the DPSIR methodology indicated that the main biotic components change as a result of pressure from sand mining activities.

The key driver of a river's structure and functioning is the flow regime or pattern of flow variation [77]. This DPSIR-applied approach of assessment revealed that the morphological changes induced by the sand extraction and upstream hydropower dams are deemed to be interrelated causes for riverbank and delta shoreline instability and erosion [78]. The studies of [43,64] reported widespread river channel instability, with field observations showing lateral channel mobility threatening settlements, infrastructure, and farms, leading to a spiral of dyke and embankment constructions. The erosion of land in the Mekong delta is happening at an alarming rate; on average, about 5 km^2 of land is being lost each year [4,59]. This loss of land also includes arable land involved in agriculture, thus impacting the food security.

The DPSIR analysis showed that, apart from the erosion impact on production, agriculture also suffers from a lack of freshwater due to saline intrusion within the delta region. The Mekong River flow changes in the wet and dry periods, with low flow in the dry period, cause saline intrusion [78]. Climate change is complex and evolving, pressuring several systems of the Mekong delta. The estuarine erosion and sea level rise fluctuate with the saline intrusion, in the low flow dry season. The main factor affecting the ratio of water flow distribution in the Mekong in the dry season is the unsteady semidiurnal-type tide regime of the East Sea [9]. The study [79] highlighted the impact of climate change in the Mekong; if the sea level rose by 1 meter, about 15,000–20,000 km^2 of the Mekong delta would be flooded, 2500 km^2 of mangrove would be decimated, and 1000 km^2 of cultivated farmland and sea product cultural area would become salt marshes. The lack of freshwater in the dry season of the year 2020 damaged around 41,900 hectares of rice and 6650 hectares of fruit orchards, and 96,000 families struggled to get water for their daily needs [80]. In recent years, only a narrow 20–25 km area of land adjacent to the Hau Giang and Tien Giang tributaries were expected to be mostly saline-free, but in recent years there was a sudden increase [79,80]. The issue of salinity is not a single primary issue, but it is a result of the severe effects of *Drivers* and *Pressures* from sand mining in the Mekong.

A satellite image study [4] between 2003 and 2012 stated erosion was consistent with a significant decrease in coastal surface suspended sediment flow from the river, resulting from dam retention and riverbed sand mining in the river and delta channels, combined with subsidence due to excessive groundwater extraction and sea level rise. Erosion induced by river flow variation has been an acute problem in the Mekong delta over the last decade, frequently occurring and claiming hundreds of houses and other infrastructures (Figure 13) [81,82]. A report [83] stated that six provinces in the Mekong delta of Vietnam had declared an emergency requiring urgent measures for severe erosion areas, directly affecting residential areas, administrative areas, education and healthcare facilities.

Figure 13. Section of National Highway in An Giang eroded into the Hau River, August 2019 (Source: Author Anh).

The Mekong delta has a network of channels that act as a vital gateway for the economy through freight and passenger transport. The land transport infrastructures of the inundated areas are underdeveloped [9], where most roads and their sections have been damaged and inundated

during flooding. It is a necessary mode of transport for the communities in the delta, who are without another alternative because the road network does not reach many communities in the region [1]. Between 2014 and 2015, 9.4 million tonnes of goods were transported through the delta channels, accounting for 20–25% of the total volume of dispatched goods by waterways in the region. There was a reduction in volume traffic in later years with a volume of 6.5–8.5 million tonnes a year [84]. The river channel siltation and low water flow have made many channels non-navigable, with boats aground often. This collective literature, along with the DPSIR method, showed the changes happening in the abiotic environmental elements of the Mekong River and delta.

The hydrogeology of the Mekong delta of Vietnam is a very heterogeneous structure of intersecting aquicludes and aquifers [85]. The increased groundwater withdrawal for freshwater by private and unregulated operations [9] results in land subsidence [63] in the Mekong delta at rates of 10–40 mm/year, outpacing sea level rise by a factor of 10 [86]. This land subsidence can be further connected to the increase in the state of inundation of low-lying areas in the floodplains, based on DPSIR. Each year 3.9 million hectares of the delta are inundated by floods, providing valuable ecosystem services to support the livelihoods that depend on the floodplains. It has been estimated that every year flooding delivers about 79 Mt nutrient-rich sediments to the delta and also enlarges the delta, e.g., the delta near the Ca Mau peninsula is growing seawards by 150 m yearly (World Wildlife Fund, 2016). The comparison with various subsystems of the Mekong delta in Vietnam shows that the floodplains are much more sensitive. The delta region may face a slightly greater extent of intense, prolonged, and increased inundation periods, with a risk of permanent inundation and also a 40% sediment load reduction [62,87]. These ecosystem changes in the Mekong delta will seriously affect the tourism sector and the livelihoods of millions of people who depend on it.

3.3.2. Human Behaviour and Health

Sand mining not only directly affects the equilibrium of the river/lake system environmentally, but also socially and economically through affecting the livelihoods of people, food security, agriculture, health, and safety. The environmental state as described in Section 3.3.1 affects human behaviour and health to a great extent as the Mekong delta plays a major role in the forms of fishery, agriculture, and aquaculture, serving as a source of nutrition, employment, and income to a large population in the region [1]. The fishery depletion affects the fishing by reduced catch, thus making income less stable [88]. This leads the community to poverty, migration towards urban centres for alternative livelihoods, possibly hampering the access to education and better healthcare. In another scenario, farmers face economic loss because of saline intrusion, which costs about (Vietnamese dong) VND 10 to 20 million ($427 to $854) that is spent on each cage for food [89].

The heavily diminished harvest in the fall of 2019 raised fears among many farmers in the delta region who were unable to plant their main crop, particularly rice [90]. Such scenarios lead to poverty, malnutrition, social tensions, stakeholder conflicts, and debt cycles amongst more impoverished fishing communities [40]. The [91] study indicated that the livelihoods of the majority of people in rural regions of Vietnam were closely linked to agriculture, thus resulting in direct losses in gross revenue, total economic output, as indicated in the research [92]. The DPSIR framework related the interlinks among different environmental state changes and helped to highlight that agriculture and aquaculture would continue to be a critical source of income for millions of people in the delta.

The depletion of freshwater and groundwater resources adds up to impacts on the water security for people in the region during the dry season, for the community as well as for agricultural purposes. The prolonged inundation creates an environment for increased water-borne diseases in the local communities, posing a significant health risk. The illegal sand mining leaves sand pits underwater and varied water flows, which have been a hazard for miners and also a reason for the loss of life of many swimmers, particularly kids whose numbers are high in South-East Asia [93]. The study [94] stated that the material loss from sediment dynamics of the upper Mekong is not only related to loss of sand and pebbles, nutrients and water for farming, but also, most importantly, to the protection

of the southern delta. Flooding and erosion cause fatal difficulties for permanent settlements and development of infrastructure, and they lead to vulnerable and unstable living conditions [9]. The delta erosion significantly limits housing safety, mobility, healthcare, and school enrolment among the local communities, causing further social pressure (Figure 14) [95,96].

(**a**) (**b**) (**c**)

Figure 14. (**a**) A section of urban settlement affected by landslide in An Giang province. (**b**,**c**) Collapsed houses damaged by erosion on the Mekong riverbank in An Giang (Source: Author Anh).

The DPSIR framework visualised the vulnerable environmental state of the delta region as a result of the combined effects of sand extraction, hydropower installation, and intensive groundwater usage, causing land to shrink and sink. All these factors influence the local communities' internal migration at a higher rate in the Mekong region [97,98]. In future this situation will amplify along with climate change, forcing migration as environmental refugees.

Sand mining—mostly illegal mining—triggers social collapses such as struggles and fights against miners and sand mafia, often with violent encounters resulting in murders or death, dependence and unemployment, loss of control and social order conflicts [99]. The conflict among the upstream and downstream parties across the river is common and intense. The Mekong has been growing as a centre of transboundary conflict, where it has been claimed that major dams operated by China and a few in Laos in the main stem of the river have been playing a vital role in the sediment depletion, with less water flow in the dry season, varied flood pulse and fish resources in the lower Mekong region [90]. Mekong River Commission studies have shown that mainstream dams can damage downstream farms by impeding the flow of sediment into the delta and blocking fish migration [100]. Cambodia and Vietnam mainly share the Mekong delta, and a lack of planning for sustainable transboundary water and resources management and other issues has been identified in the study [101]. There is a need for effective collaboration between the two countries for the sustainable development of the delta region. The decreasing water resource, biodiversity loss, and delta productivity impact negatively on the local communities. This study under the DPSIR methodology highlighted the need for the governments in these regions to be aware of the socio-political situation to mitigate social unrest possibilities caused by collective issues from sand mining.

3.4. Impacts

The state of the environment and human health change their quality and functioning due to pressure. These changes occur in the physical, chemical, or biological state of the environment, affecting the quality of the ecosystem and human welfare. Impacts can be described as parameters for changes of state, such as human and ecosystem health, resource availability, losses of manufactured capital, biodiversity, safety, etc. [29]. In other words, impacts are the overall implications of state changes in

the eco-services of an ecosystem [20]. The Mekong River and delta provide various services such as water resources support for productive fisheries and hydropower energy production; nutrient-rich soils for abundant agricultural yields; extraction of mineral resources; forest-based timber and other products such as fibres, wild foods, and medicines. However, there has been a significant loss in overall natural capital, as resources often have been exploited in an unsustainable way. Additionally, economic benefits derived from these resources are rarely distributed equitably, and the broad benefits of these rich resources are not effectively realised [102]. The impact on different ecosystem categories by environmental damage or changes in the social and economic scenario of the Mekong basin are discussed in this section. The consequences of sand mining and consumption on the different services of the ecosystem are the focus (Figure 15).

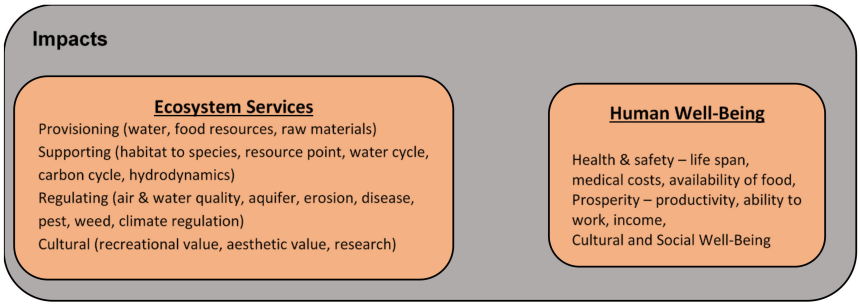

Figure 15. Classification of different eco-service impact categories in the Mekong delta region (created by the author).

3.4.1. Ecosystem Services

Ecosystem services are the indirect and direct benefits obtained from the ecosystem by humans for survival and quality of life [102–105]. River ecosystems are highly biodiverse, influence global biogeochemical cycles through dynamic river flow regime, and provide valued services sustaining terrestrial, riverine, and marine biodiversity [106]. However, increasing human interventions are degrading fluvial ecosystems by altering their stream flows. Impacts to the benefits of the Mekong River and delta region are the consequences of changes in natural, social, and anthropogenic states. Impacts often stand as indicators to develop responses and monitoring support to evaluate the changes caused by the response. The ecosystem services of the delta consist of four varied services: provisioning services, supporting services, regulating services, and cultural services, which face the impacts of sand mining (Figure 16) [107].

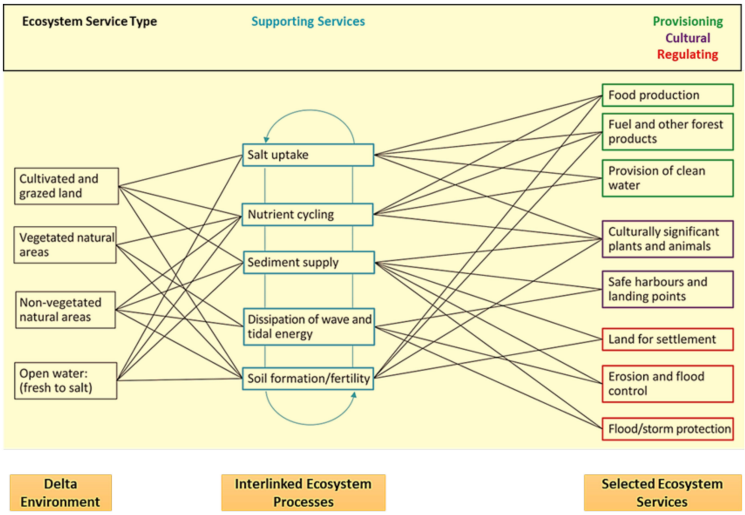

Figure 16. Principle services provided by the delta ecosystem that face impacts (created by author [108]).

The human well-being category covers the social impacts, often interrelated with the ecosystem services. The benefits of the various services provided by the Mekong River and delta ecosystem, which undergoes severe impacts because of sand mining activities, were classified using the DPSIR framework and listed below:

Supporting Services

This service forms a basis for all other ecosystem services. It provides living spaces for plants and animals, thus supporting their life maintenance. In general, habitat as a whole acts as an essential factor supporting all ecosystem functions [109]. The impacted eco-services of the Mekong River and delta include maintenance of floodplain fertility through sedimentation, nutrient cycle, carbon cycle, primary production, soil structure stabilisation, and habitat for several species. The sand mining activities, along with climate change and dam interventions, affect the river flow and sedimentation in the Mekong River, thus affecting the supporting services.

Provisioning Services

These include materials or tangible outputs from ecosystems for basic human needs such as food, fresh water, minerals, shelter, and fuel. Among the other ecosystem services, the provisioning services are greatly sensitive and vulnerable to the changes caused by environmental state degradation and, therefore, act as an essential indicator [110]. In the context of the Mekong delta region, various impacted provisioning services of the river ecosystem include

- Fresh water for individual, aquaculture, and agricultural consumption;
- Sand and gravel as sedimentation;
- Waterway transportation;
- Food resource such as fishes, water plants, herbs, medicinal species, etc.;
- Non-food resources such as wood, jute, shells, biochemicals, etc.;
- Biomass fuel or power production.

The sand as raw material from the provisioning services supports the economic growth of the region and nation, but it also significantly impacts the river and delta region, causing a general reduction in natural capital [111]. The impact on provisioning services in the Mekong River and delta through sand mining activities disturbs the economy of the region and nation because of the economic importance of the products obtained.

Regulating Services

These involve the ecosystem services capacity of the Mekong on their regulating processes. The river, in general, has a substantial regulating role in the ecosystem, covering the delta region eco-services to contribute a huge benefit for the people. The regulating ecosystem services from the river delta also cover the roles of wetlands, floodplains, and coastal ecosystems [112]. Regulative services can involve mitigative and preventive functions for the issues that arise from the sand extraction [113]. The regulative processes provided by the Mekong River facing impacts include

- Water resource regulation–water quality and nutrient regulation, groundwater balance across the delta region, aquifer recharge, counteraction acidification, natural filtration and water treatment;
- Erosion regulation–soil retention through natural water and land interactions, vegetative cover;
- Climate regulation–storm protection by estuary ecosystem, mitigating the saline intrusion, sea level rise, ph balance at the estuary with a natural flow, regulating temperature and precipitation, carbon, or greenhouse gas (GHG) sequestration and air quality;
- Disease regulation–changes in ecosystem services causing unchecked pests, weeds, disease-carrying vectors, etc.;

- Flood regulation–nutrient-rich sediment deposit, inundation, buffering of flood flows, erosion control through water/land interactions, and flood control infrastructure.

Cultural Services

These are the non-material benefits people obtain from ecosystems through cognitive development, spiritual enrichment, recreation, psychological and aesthetic experiences. The cultural services do not represent purely ecological phenomena, but rather are the outcome of complex and dynamic relationships between ecosystems and humans in landscapes over long periods [114]. Cultural services of ecosystems are tightly bound to human values and behaviour; thus, perceptions of services are more likely to differ among individuals and communities, for example, the designation of sacred species or places, development of social rules concerning ecosystem use and inspirational experiences [115]. The associated cultural service values related to the Mekong River and delta that are being impacted include

- Recreational activities like kayaking, rafting, fishing, and swimming through affected river flow change;
- Aesthetic values, tourism, wildlife;
- Cultural heritage–temples, pagodas, etc., alongside the bank facing landslides or erosion;
- Social relations among communities such as fishing, agricultural, aquaculture, etc.;
- Spiritual value and cultural diversity;
- Educational value, such as formal and informal knowledge within society.

3.4.2. Human Well-Being

Human well-being is a high value-based, multidimensional, and context-dependant category comprising physical, emotional, and social well-being (Figure 17). Human well-being is affected by various ecosystem service factors such as access to food, water, shelter, and physical, energy, and material prosperity [105]. These factors are influenced through the impact on supporting, provisional, and regulating services. The category involves values among communities or individuals such as health, education, good social relationships, livelihood security, equity, cultural identity, spiritual satisfaction, freedom of choice, action, and participation in society [116]. Therefore, critical components of human well-being are dependent on well-functioning ecosystems and the biosphere [117]. According to [115], impact on the human well-being category is not limited to the current period, but also may affect the people in future decades. The term human well-being is commonly more associated with poverty. The impact of sand mining and consumption from the Mekong delta is reflected in human well-being through the depletion of all ecosystem service benefits, which include as below.

Physical Well-Being

Quality and quantity of nutritious food (fish, rice, etc.), clean water, clean air, protective shelter (non-erosion zones, flood protection), adequate health protection from diseases and uncertain scenarios, primary resources, energy, stable income (fishers, farmers, etc.), work–life balance.

Social and Emotional Well-Being

Integrated communities, healthy social interactions, non-prevalence of poverty and diseases in communities, affordable healthcare, happy families, social equity, education, freedom and choice, preservation of ecology, recreation time and space.

The vast ecosystem services of the river and delta play a role in poverty and well-being through direct provision of goods and services, by acting as a safety net for the poor, and potentially as a route to alleviate poverty and other social goals [108]. Therefore, impacts on the Mekong River and its delta region create adverse effects on the lives and livelihoods of the communities living directly or indirectly around the region.

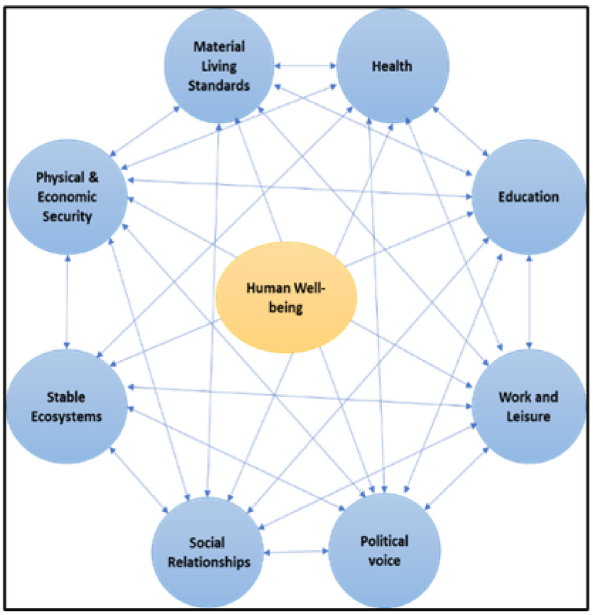

Figure 17. Multidimensional interactions among human well-being indicators (Recreated -source: [117]).

3.5. Responses

Drivers and Pressures will lead to adverse State Changes unless society agrees to impacts and adopts Responses. The Response element of the DPSIR is the crucial benefit of the framework, which applies specific actions to other elements in the DPSIR network. Actions are nothing but protective and corrective responses taken by individuals or groups within the society and government to mitigate, prevent, compensate, adapt, or correct the changes happening in the environmental and human health states through the chain between drivers and impacts [31]. Responses are targeted and linked to drivers, pressures, state changes, and associated impacts. In the DPSIR framework, responses are a human-oriented set of actions adopted by the policy makers, institutions, and governance managers. The political and societal responses to overcome or mitigate the effects of the previous category indicators with relevance to the Mekong basin were assessed. The objectives are the compliance actions, regulatory rules, elimination, reduction, monitoring, and prevention of environmental impacts, along with the mitigation and compensation effects caused by sand mining and unsustainable consumption. In the case of Vietnam's Mekong River and delta, the assessment so far showed that the problems in the study areas have grown as a result of increasing anthropogenic drivers and pressures related directly or indirectly to the development of the construction industry and infrastructures. These developments remain unavoidable and therefore require responses addressing improved governance in the resource management. Sections 3.5.1–3.5.4 describe varied responses derived and developed from scientific literature and reports as a basis. These responses were intended to target several causes and issues across Drivers, Pressures, State and Impacts.

3.5.1. Driver-Based Responses

Vietnam, being a developing country, is undergoing rapid urbanisation and industrialisation, and demanding increased resource consumption. Aggregates are highly desirable among material consumption. Apart from industrial applications, aggregates are mainly used for buildings and infrastructure construction as well as for maintenance activities. Addressing responses targeted towards the drivers requires caution in order not to compensate the developmental needs, i.e., a sustainable development for the human needs. The increased consumption of sand is mainly influenced by demand caused by a growing population that requires further development of housing and infrastructures. The sand and gravel resources obtained from the natural sedimentation process

are also being reduced through upstream dams, resulting in a gap between demand (input) and supply (output). Some proposed responses targeted towards the specified drivers in the Mekong are as follows in Table 1 [10,56,96,115,117].

Table 1. Responses to address the Drivers influencing sand mining

Driver-Responses ([10,56,96,115,117])	Priority Requirement
Strengthening of existing mining policies and streamlining to avoid inconsistencies.	Immediate attention
Strengthening the regulatory and quality control frameworks for manufactured sand (m-sand), in order to boost its wide prevalence of production and usage among the stakeholders.	Immediate attention
Guiding markets toward responsible production and consumption behaviour through the pricing mechanism, with strong government regulations and support from relevant civil societies to ensure harmful impacts are mitigated.	Immediate attention
Policy and tax instruments to make m-sand and other river sand alternatives competitive in the market. Strict actions and regular monitoring of sand price control within the market.	Long-term attention
Additional or increased tax on river sand, aggregates, or mining operations to create incentives or internalise the cost for alternative materials market support.	Long-term attention
Setting up international memorandum of understanding (MoU) for the development of optimised building construction, green infrastructures, and circular economy practices involving reduced materials and alternative secondary waste materials.	Long-term attention

3.5.2. Pressure-Based Responses

The Mekong River and delta of Vietnam are undergoing pressures at various levels majorly driven by sand consumption and sediment imbalance. The environmental pressures have been influenced by human behaviour despite the driver's influence. The pressures concerning the material or resource consumption have always been overexploitation and discharge. Pressures that are endogenic can be addressed with the responses to manage both causes and consequences, while for exogenic pressures the response is only about managing consequences [20]. According to [12], aggregates have been perceived as having a low-unit value and abundant commodity, and, therefore, less monitoring is happening. In Vietnam the aggregates fall under the responsibility of two authorities: the Ministry of Construction—looking after minerals for construction and urban development; the Ministry of Natural Resources and Environment—responsible for planning land use and regulating the environmental and socioeconomic impacts of mining activities. The suggested responses addressing the various pressures on the delta and Mekong River are as follows in Table 2 [12,13,30,48,56,90,116,117].

Table 2. Responses to address several *Pressures* caused by *Drivers* of sand mining.

Pressure-Responses ([12,13,30,48,56,90,116,117])	Priority Requirement
Stringent enforcement of the existing measures to curb illegal sand mining. Further, strengthening the laws to support the closure of illegal mining.	Immediate attention
Regular supervision over the licensed mining sites.	Immediate attention
Awareness among the public and stakeholders of the benefits and quality standards of m-sand/crushed sand, to promote the shift in consumption.	Starting immediate attention with prolonged long-term attention
Public awareness and perception of the impacts of the excessive consumption of river sand have to be further bolstered via outreach and education. Involvement of NGOs and communities, along with possible support from the local authorities.	Starting immediate attention with prolonged long-term attention
Collaborations at local, provincial, national, and international levels to have updated production quality standards for secondary building material substitutes.	Immediate attention

Table 2. *Cont.*

Pressure-Responses ([12,13,30,48,56,90,116,117])	Priority Requirement
Improved coordination between the authorities involved in planning and regulation, which lags at the moment.	Immediate attention
Government focus on investing in assessing the quantity and quality of aggregates must increase. (i.e., Constant sediment budget monitoring at regular intervals.)	Long-term attention
Regular river morphology monitoring in a two to five-year term to pre-plan the mitigation and restoration activities.	Long-term attention
Workshops and capacity-building program for stakeholders involved in the construction sector on the possible utilisation of alternative materials in various applications. Knowledge sharing and obtaining ground-level suggestion for better quality control methods and process.	Long-term attention
Promoting responsible production and consumption of aggregates among communities.	Long-term attention

3.5.3. State-Based Responses

Drivers and Pressures in the Mekong delta are mainly associated with obtaining aggregate to supplement land-based sources for the construction industry and infrastructure. In general, the ecosystem can absorb pressures to some extent, but once the limit is exceeded, it gives rise to ecosystem state changes. Currently, the Mekong River and delta ecosystem is undergoing a change of state at an alarming rate on diverse levels, as discussed in Section 3.3. The responses to the state change are more important, as they focus more on mitigation and repair of the damage caused or arising within the system. In the Mekong River and delta, the change of state is drastic among fisheries, agriculture, and biodiversity, causing a severe threat to the livelihood of communities. With concern over the change of state across the Mekong River and delta, multiple responses that are restoration- and mitigation-oriented towards biotic, abiotic, and human state changes, are as follows in Table 3 [2,23,39,49,69,94,108,116].

Table 3. Responses to address the changes in ecosystem and human health caused by sand mining.

State-Responses ([2,23,39,49,69,94,108,116])	Priority Requirement
Identifying weak zones along the riverbanks to reinforce embankments and flood gates. Identifying communities lying in the impact zones. Identifying infrastructures and roads in prone zones, providing reinforcement of old structures if required.	Immediate attention
Reinforcement or modern structures for flood control, saline intrusion control, water and irrigation supply.	Immediate attention
Saline intrusion prevention in dry season through safe check dams or dykes, without drastic effect on the river hydrology.	Immediate attention
Regular checking and desilting across the Mekong River and check dams.	Immediate attention
Best practices for the restoration of aquatic diversity to optimise fisheries production. Creating hotspot zones over spawning and breeding grounds along the Mekong River.	Immediate attention
Enhanced cooperation of the governments within Mekong River Commision (MRC) for better Mekong River management and illegal sand trading. Dialogues initiated and headed by Vietnam with concern for lower stream issues and transboundary conflicts.	Immediate attention
Awareness among communities of the impacts of sand mining and capacity-building for local communities to report and help in enforcing anti-illegal mining measures.	Long-term attention
Modernising and affordable improvements in fishing and farming according to current scenarios.	Long-term attention
Promoting localised business utilising secondary waste-materials-based construction products.	Long-term attention
Empowering local communities and local governments to interact. Frequent community discussions to identify state changes in the surroundings.	Long-term attention

3.5.4. Impact-Based Responses

The prolonged change of state in the Mekong River and delta should be addressed as necessary, as it leads to cumulative effects over a while, causing impacts that affect society. Impacts on ecosystem services are more challenging to assess but comprise the adverse effects from state degradation on biota and on human health, as well as changes in the functioning of ecosystems, such as biological, geochemical, and physical processes and components of the system [27,32]. The impacts in DPSIR are more like feedback indicators, indicating the attention to address the damage, adapt, and monitor the progress of responses applied as feedback. The impact-based responses are more adaptation- and prevention-oriented, and are shown in Table 4 [30,56,107].

Table 4. Responses to mitigate, monitor, and remediate the impacts of sand mining.

Impact-Responses ([30,56,107])	**Priority Requirement**
Evaluation of impacts in the delta region to target the responses to drivers, pressure, and state elements issues.	Immediate attention
Developing mitigation responses for different issues across DPSIR elements.	Immediate attention
Supportive compensation and livelihood setup for people who lose land by erosion or in erosion-prone areas.	Immediate attention
Restoring the ecosystem services in the various hotspots over the Mekong delta.	Long-term attention
Constant monitoring of the changes caused in ecosystem services.	Long-term attention
Remediation measures of the various state changes that cause impacts on ecosystem services and human well-being.	Long-term attention
Monitoring the post-remediation and restoration responses.	Long-term attention

3.6. Study Limitations

The DPSIR framework, on the whole, was a beneficial tool in this study of the Mekong River and delta ecosystem, providing a view of systemic interrelations among several causes and impacts caused by sand mining across multiple sectors and disciplines. The DPSIR supported a specific response framework development for specific problems, but still could remain only as a meta-outline of actions or a tool to aid or initiate significant changes, (i.e., decision support). The utilisation of the framework methodology needs follow-up activities to draft detailed decisions. The response actions require further assessment by the specific or relevant authorities and stakeholders of the region or sector or discipline to create an adaptive measure relevant to the ground-level scenario of the location or community. The further assessment requirement poses a challenge to this study on applying DPSIR methodology because the level of stakeholders involved and the requirement of their engagement in considering a systemic approach at multiple levels (local, regional, national and international) require enormous coordination. For example, the Mekong River passes through various countries, and the delta covers some provinces within Vietnam. The framework identified common causes and issues, but the response application requires the roles of multiple authorities, administrative hierarchies, and different stakeholders. Therefore, a further assessment is required, along with another challenge of requiring a central authority to channel and implement the post-assessment responses. This study on sand mining impacts requires responses on a policy level, which involves the higher-level governmental process.

4. Conclusions

The qualitative study demonstrates the potential of the DPSIR framework for analysing and mapping the leading causes and effects of excessive sand extraction in Vietnam's Mekong delta. Thus, it is an aid to sustainable governance through developing strategies and policies targeted towards a

systems thinking approach. The findings of the study show that there is a lack of driver-oriented and pressure-oriented response measures involving stringent monitoring, enforcement, alternative material market development, and environmental communication. Factors such as economic integration, burgeoning population, integration of the economy with global markets, and the increase in the purchasing capacity of the people of Vietnam have caused a rapid increase in construction activity, not only for commercial activities but also for human dwellings. Rivers and their associated ecosystems are vital assets of human society, which generate a wide range of eco-service benefits, including those for ecological habitat, fisheries, agriculture, and recreation. The DPSIR framework analysis findings provide an overview of the increasing ecosystem and socioeconomic disturbances in the Mekong delta through alteration of the river morphology. The main drivers and pressures were identified, and the state of changes clearly indicates that the existing capacities will not be sufficient in the long run for sustainable management. The discussed response framework has to be applied to post-identification and quantification of the change of state in the regions or communities lying in the impact zone. A further refinement of responses, implementation, and monitoring measures have to be executed across different levels of authority in Vietnam in a coordinated manner. The public awareness of the impacts of river sand mining and the presence of different alternatives and their quality credibility is very much important. Community-level planning and engagement can become a powerful instrument if pursued effectively, further leading to coordination and cooperation among stakeholders with different interests. The DPSIR assessment obtained outcomes can be used as decision-making inputs in developing proactive strategies for responsible sand consumption with proper enforcement, public outreach, and ecosystem monitoring, with a focus towards preserving the natural ecosystem and supporting local communities. Given the mounting pressures on the Mekong delta ecosystem, enhancing further research and the capacity to work diversely across the different disciplines and organisations including government, community, NGOs and academia plays a key role for future resource management and governance.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/12/22/9323/s1, Figure S1: DPSIR Model—Mekong Sandmining, mapped flowchart: DPSIR Model—Mekong Sandmining.

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