DPSIR Assessment on Ecosystem Services

Subjects: Environmental Sciences

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The ***DPSIR framework*** (Driver – Pressure – State – Impact – Response) is a useful tool to assess and investigate the cause-effect within an ecosystem to aid better systems - thinking approach for stakeholders, policymakers and governance managers to draft response measures. The DPSIR framework helps to identify and analyse the different effects of human activities over the ecosystem services and human well-being in the different ecosystems such as estuarine, delta, river, coastal, etc. The varied human activities involves mining, construction, fishing, infrastructure development, etc. The DPSIR study shows a holistic view on several interlinked pressures and state changes in the ecosystems, also supporting the development of some potential responses to form systematic, sustainable approaches for mitigating and adapting the impacts caused by human activities.

This contribution describes the application of DPSIR framework to study the impacts of sand mining and sand consumption in the Vietnam's Mekong Delta ecosystem services,

Keywords: DPSIR ; Mekong ; Delta ; Ecosystem Services ; Sand Mining ; 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][6][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].

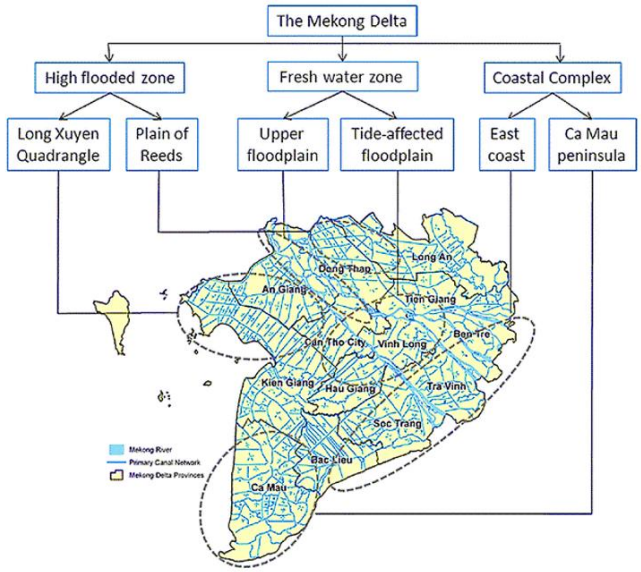

Figure 1. Different landforms across the Mekong delta region, Vietnam [7].

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][11][12][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. 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 2. 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. Thus, the approach will help to broaden the decision-making and implementation by considering more than one issue within the system.

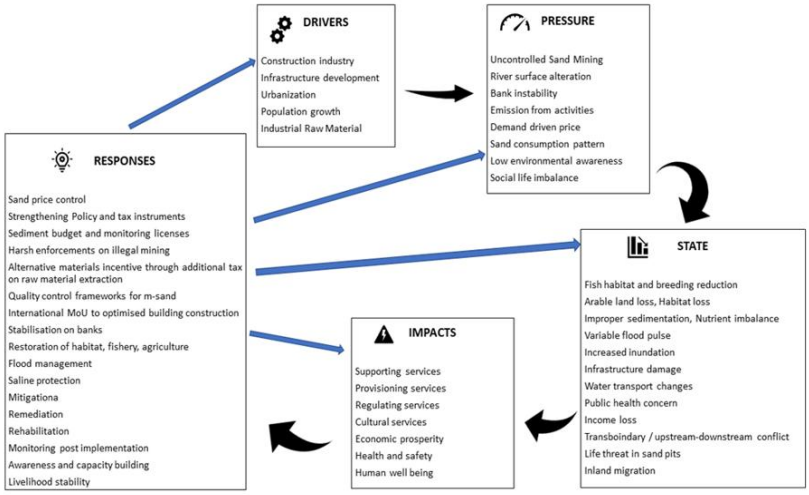

Figure 2. DPSIR model describing the interaction of cause–effect and sand extraction and consumption in the Mekong delta (created by the author).

2.1. 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" [21]. 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 3).

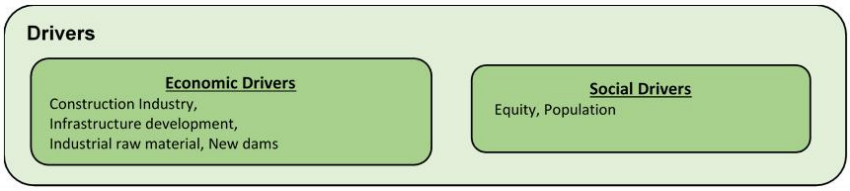

Figure 3. A different set of indicators for economic and social drivers (created by author).

2.2. Pressures

Pressures can be defined as the changes induced in the environment or influences in 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 over the ecosystem transports and transforms into a variety of natural processes to manifest changes in environmental conditions [21]. Pressures are classified as Environmental pressures and Human behaviour pressures with several indicators, as shown in Figure 4.

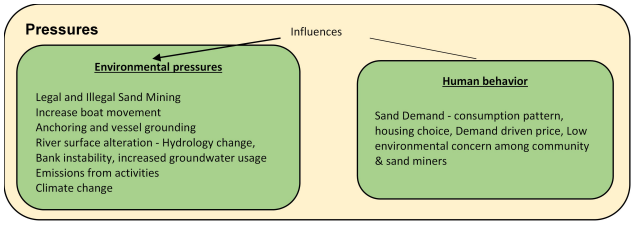

Figure 4. Different pressure indicators influencing the environment and human behaviour (created by the author)

2.3. State

The pressures result in affecting the State of the natural and built environment and human systems. State of the environment is combined interactions of physical, chemical and biological phenomena (temperature, fish stock, CO_2 level etc.) to affect different ecosystem components, that can be measured by their quantity or quality. The state includes 1) environmental state – biotic and abiotic 2) human systems state. The human system state covers complete physical, mental, and social well-being and not merely the absence of disease or deformity [22]. This section discusses the conditions (quality and quantity) of environmental compartments in the Mekong delta that were exposed to the pressures from sand mining. The aim is to show (Figure 5) where the environmental changes are significant and how they are exacerbated by sand mining and urban metabolism.

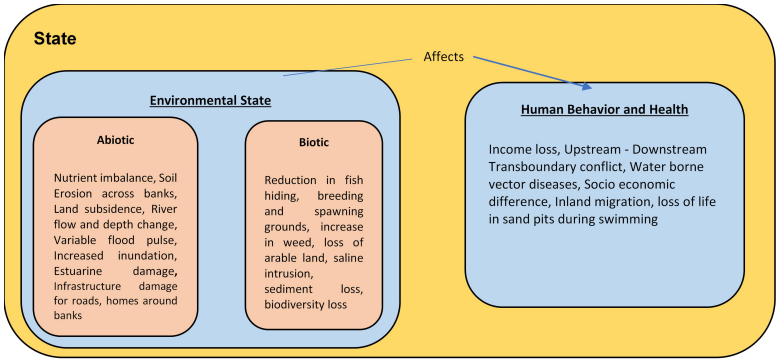

Figure 5. Classification of different change of state undergone by sand consumption (created by author)

2.4. Impacts

The state of the environment and human health changes their quality and functioning due to pressure. These changes occur at 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, resources availability, losses of manufactured capital, biodiversity, safety, etc. [23]. 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; Forests based timber and other products range such as fibres, wild foods and medicines. However, there has been a significant loss in overall natural capital, as resources often were 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 [24]. The impact on different ecosystems categories by environmental damage or changes over the social and economic scenario of the Mekong basin were discussed in this section. The consequences of sand mining and consumption on the different services of the ecosystem are the focus (Figure 6).

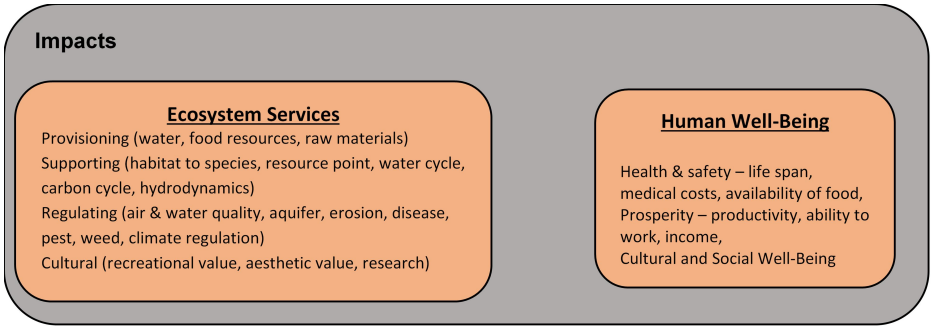

Figure 6. Classification of different eco-services impact categories in the Mekong delta region (created by the author).

Ecosystem services are the indirect and direct benefits obtained from the ecosystem by humans directly or indirectly for survival and quality of life [24][25][26]. River ecosystems are highly biodiverse, influence global biogeochemical cycles through dynamic river flow regime and provide valued services sustaining terrestrial, riverine and marine biodiversity [27]. However, increasing human interventions are degrading fluvial ecosystems by altering their stream flows. Impacts over the benefits of Mekong river and delta region are the consequences of changes in natural, social and anthropogenic states. Impacts often stand as an indicator to develop responses and monitoring support to evaluate the changes caused by the response. The ecosystem services of delta consist of varied four services such as provisioning services, supporting services, regulating services and cultural services, that faces impacts by sand mining shown in Figure 7 [27].

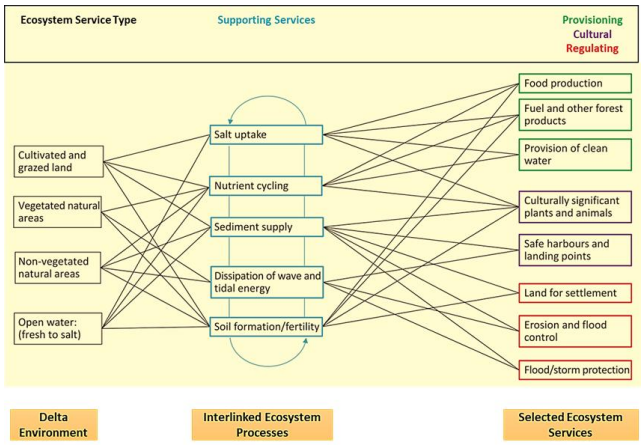

Figure 7. Principle ecosystem services provided by the delta ecosystem that faces impacts

2.5. Responses

Drivers and Pressures will lead to adverse State Changes unless society agrees to impacts and adopts Responses. Response element of the DPSIR is the crucial benefit of the framework, which applies specific actions over other elements DPSIR network. Actions are nothing but protective and corrective responses taken by individuals or group within the society and government to mitigate, prevent, compensate, adapt or correct the changes happened in the environmental and human health state through the chain between drivers and impacts [28]. 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 policymakers, institutions and governance managers. The political and societal responses to overcome or mitigate the effects of previous category indicators with relevance to the Mekong basin can be 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 shows 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 construction industry and infrastructures. These developments remain unavoidable and therefore requires responses addressing improved governance in the resource management. The responses for elements Drivers, Pressures, State and Impacts are provided with an aspect of 1) Immediate attention and 2) Long term attention.

3.Limitation

The DPSIR framework, as the whole, was a beneficial tool for studying over the Mekong River and delta ecosystem, providing a view over systemic inter-relation among several causes and impacts by sand mining across multiple sectors and disciplines. The DPSIR supported specific response framework development for specific problems, still could remain only as a meta-outline of actions or 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 as a challenge in this study on applying DPSIR methodology because the level of stakeholders involved and requirement of their engagement on considering a systemic approach at multi-level (local, regional, national & international) requires enormous coordination. For example, the Mekong River passes across various countries, and delta covers some provinces within Vietnam. The framework identified common causes and issues, but the response application requires roles of multiple authorities, administrative hierarchies and different stakeholders. Therefore, a further assessment would be 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 from a policy level, which involves the higher-level governmental process.

4. Conclusion

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, helping as an aid for 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. The factors such as economic integration, bludgeoning population, integration of economy with global markets, and increase in the purchasing capacity of the people of Vietnam, has made a rapid increase in construction activity not only for commercial activities but also for the human dwellings. Rivers and their associated ecosystems are vital assets of human society, which generate a wide range of eco-service benefits, including values for ecological habitat, fisheries, agriculture, and recreation. The DPSIR framework analysis findings provide an overview of the increasing ecosystem and socio-economic disturbance in the Mekong delta through alteration of river morphology. The main drivers and pressures were identified, and the state of changes clearly indicates that the existing capacities would not be sufficient in the long run for sustainable management. The discussed response framework has to be applied over post-identification and quantification of the change of state on the regions or communities lying in the impact zone. A further refinement of responses, implementation and monitoring measures have to be executed across different level of authorities in Vietnam in a coordinated manner. The public awareness on the impacts of river sand mining and the presence of different alternatives and their quality credibility is very much important. Community-level planning and their engagement could become a powerful instrument if pursued effectively. Further leading to coordination and cooperation between 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 capacity to work diversely across the different disciplines and organisations inclusively government, community, NGO's and academic plays a key role for future resource management and governance.

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