

Original Article

Analysis of Coastal Environmental Dynamic Using the DPSIR Framework (Driving Force, Pressures, State, Impacts, and Responses) in Subang Regency, West Java, Indonesia

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ABSTRACT: *The coastal area of Subang Regency is an ecologically and economically important region, yet it is simultaneously exposed to pressures arising from land-use change, pond development, mangrove degradation, coastal development, and shoreline dynamics. This study aims to analyse the coastal environmental dynamics of Subang Regency using the Drivers, Pressures, State, Impacts, Responses (DPSIR) framework based on secondary data. The data were obtained from the Geospatial Information Agency (BIG), scientific journals, and official government reports. The data were analysed using a descriptive-spatial approach by grouping information into the five DPSIR components. Drivers include changes in spatial utilisation and socio-economic activities, while pressures comprise land-use change, mangrove conversion, pond development, and coastal development. State is represented by mangrove conditions and shoreline dynamics, whereas impacts include coastal erosion, land loss, tidal flooding, and declining coastal ecological functions. Responses include mangrove rehabilitation, silvofishery, coastal protection, and spatial management. The results indicate that coastal changes in Subang are spatially heterogeneous. Previous studies reported shoreline changes of 8.17 km during 1988–2013, with the highest sedimentation occurring in Pusakanagara and Blanakan and the highest erosion in Legonkulon. More recent research has also documented extreme dynamics in Pusakanagara, with a maximum accretion rate of 123.49 m/year and a maximum erosion rate of 126.84 m/year. Meanwhile, the mangrove area reportedly declined from 639 ha in 1992 to 261 ha in 2025. These findings indicate that coastal problems in Subang result from interactions between anthropogenic pressures and natural processes. Therefore, management requires a spatial approach that takes into account the characteristics of individual coastal segments.*

KEYWORDS: DPSIR, Coastal, Environmental, Dynamics, Mangrove, Shoreline Change, Erosion, Accretion.

1. INTRODUCTION

Coastal areas are among the spaces where natural processes and human activities interact particularly strongly. This dynamic gives coastal regions high economic value through fisheries, agriculture, aquaculture, settlements, transportation, and various other economic activities [1]. However, the intensity of spatial utilisation can also increase pressure on coastal ecosystems when regional development does not remain balanced with ecological capacity. This condition is evident in Subang Regency, West Java. The coastal area of Subang is located on the north coast of Java and consists of mangrove ecosystems, estuaries, aquaculture ponds seaweed, agricultural land and settlements. The development of these environments is documented in many studies, especially for shoreline change between estuarine and coastal areas, mangrove loss (Land Use/Land Cover Change), sedimentation and erosion.

Shoreline changes in Subang Regency reached about 8.17 km during the observation period [6], and sedimentation and erosion are two of the main forms of change. The highest sedimentation was reported in Pusakanagara and Blanakan, whereas the greatest erosion occurred in Legonkulon. These dynamics cannot be separated from changes in mangrove ecosystems. Mangroves provide ecological functions as coastal protection, habitat for biota, sediment traps, and carbon storage [2, 4]. When these ecosystems change, their coastal protection functions may also be altered. [5] A relationship was identified between changes in mangrove cover, shoreline dynamics, and seawater intrusion in the downstream areas of the Ciasem and Cipunegara watersheds.

include land-use change, mangrove conversion, aquaculture development, and coastal development; while state is represented by mangrove condition, shoreline change, erosion, accretion, sedimentation, and environmental quality.

The analysis was conducted descriptively and spatially by comparing the distribution of changes in land use, mangroves, shorelines, aquaculture ponds, settlements, rivers, and infrastructure. The Impacts section was assessed according to the impacts of changes in coastal conditions (e.g., land loss and erosion, tidal flooding or damage and degradation or loss of ecosystem functions). Marine moratoriums were also identified from desk-based management actions for coastal protection and spatial planning. Relationships among the DPSIR components were then analysed to explain the links between driving forces, pressures, changes in environmental conditions, impacts, and management responses.

The results were presented in the form of a DPSIR synthesis table, graphs of changes in indicators for which temporal data were available, and spatial descriptions. Graphs were used only for numerical data that could be traced to scientific journals or official reports, whereas geospatial data were used to illustrate patterns and distributions of environmental change. Through this approach, the coastal environmental dynamics of Subang Regency could be analysed in an integrated manner using BIG data, scientific publications, and official documents without relying on primary data.

3. RESULTS AND DISCUSSION

3.1. CHARACTERISTICS OF COASTAL DYNAMICS IN SUBANG REGENCY FROM A DPSIR PERSPECTIVE

The coastal area of Subang Regency exhibits dynamic environmental characteristics because it represents an interface between terrestrial and marine processes while simultaneously serving as a setting for various resource-utilisation activities. The presence of aquaculture ponds, rice fields, settlements, mangrove areas, river mouths, and developing infrastructure creates different pressures along different coastal segments. This condition is reflected in shoreline changes occurring through both erosion and accretion. Shoreline changes in Subang over decades, and their relation to a combination of anthropogenic as well as natural processes, have been extensively studied on Landsat-based data [9]. According to the DPSIR framework, these dynamics are captured as a chain of events consisting of drivers, the establishment or development of socio-economic processes and activities associated with spatial utilisation, leading to pressures, especially land-use change, comprising four main categories: mangrove conversion; aquaculture expansion; coastal developments. These pressures are subsequently reflected in changes in state, such as changes in mangrove cover and shoreline position. Such changes generate Impacts, including erosion, land loss, habitat degradation, and increasing coastal vulnerability. Various Responses have subsequently been developed through mangrove rehabilitation, coastal protection, silvofishery, and spatial management.

TABLE 1 DPSIR Synthesis of the Coastal Environment of Subang Regency

Component	Main indicators	Identified conditions
Drivers	Spatial utilisation and economic activities	Aquaculture ponds, agriculture, settlements, and infrastructure development
Pressures	Mangrove conversion and land-use change	Conversion of mangroves to aquaculture ponds and other uses
Pressures	Coastal development	Changes in land function and intensity of spatial utilisation
State	Mangroves	Changes in ecosystem extent and structure
State	Shoreline	Erosion and accretion occur simultaneously
Impacts	Erosion and land loss	Shoreline retreat in several coastal segments
Impacts	Ecosystem degradation	Reduced coastal protection functions and ecosystem services
Responses	Rehabilitation and protection	Mangrove planting, silvofishery, and coastal protection

3.2. DRIVERS: DEVELOPMENT OF ACTIVITIES AND COASTAL SPATIAL UTILIZATION

The Drivers component in the Subang coastal system is primarily associated with increasing demand for space for economic activities and development. Coastal areas are economically attractive because they provide space for agriculture, fisheries, aquaculture, settlements, transportation, and infrastructure. Consequently, changes in spatial utilisation are an important factor in understanding coastal dynamics. [9] Identified settlement development and the conversion of mangrove areas into aquaculture ponds and rice fields as activities associated with shoreline changes. This finding indicates that coastal environmental change does not result solely from oceanographic processes but is also related to changes in land utilisation within the coastal zone. Infrastructure development is another component of these dynamics. In Subang Regency, the presence of the Patimban Port area has increased the strategic importance of the coastal zone from transportation and economic perspectives. This does not, by itself, indicate that development causes environmental degradation; rather, it indicates an increase in the intensity of spatial utilisation that needs to be considered within an environmental management framework [10]. Thus, within the DPSIR model, development should be positioned as a driver, while environmental impacts should be traced through changes in land use and ecosystem conditions. This distinction is important to avoid automatically concluding that every development activity constitutes an environmental cause of degradation.

3.3. PRESSURES: LAND-USE CHANGE AND MANGROVE DEGRADATION

Among organisational definitions of environmental pressures, mangrove ecosystem transformation in relation to aquaculture development constitutes the most evident ecological burden along the Subang coast. Between 1989 and 2013, the area of mangrove-integrated aquaculture ponds decreased from 3,402.6 ha to about 2,384.9 ha [5]. The analogue of ponds without mangroves rose to 8,741.5 ha as of October from 5,745 ha during the corresponding period. This modification signifies a separate development between pond frameworks that prepared plant segments and ponds that do not include mangroves. This modification is significant as it addresses an aspect of the relationship between mangroves and ecology outside that focus specifically on coverage. Mangroves attenuate wave energy, trap sediments and provide habitat to biota supporting coastal stability [11]. If mangrove cover declines, these functions may also decline. Changes in mangrove and shoreline dynamics are also shown in the study [12]. In Blanakan District, almost all areas in the study experienced accretion (Average Change: 360.57 m), while Legonkulon District was more strongly influenced by erosion (average change: 350.18 over a period of 15 years). Changes in mangrove damage were also influenced by shoreline change, with the study estimating this influence at 41% and 68 % at Blanakan and Legonkulon, respectively [12]. Mangroves are not the sole factor in coastal change at Subang, but they do appear to be an important driver of ecological processes within this system. The changes are also influenced by sedimentation, waves, currents, tides, estuarine characteristics, and other oceanographic factors.

3.4. STATE: SHORELINE CHANGE AS A KEY INDICATOR OF COASTAL CONDITIONS

Shoreline change is one of the clearest indicators for describing the coastal State of Subang Regency. Handiani et al. [6] used Landsat data to identify shoreline and coastal ecosystem changes. Their results indicated an inland shoreline change of 8.17 km, with both deposition and erosion covering the entire coastal zone. The most sedimentation was in Pusakanagara 869.9 ha and then Blanakan (725.4 ha). Conversely, Legonkulon experienced the most extensive erosion with an area of 885.8 ha [6].

TABLE 2 Shoreline-Change Dynamics in Subang Regency

Area	Process	Reported value	Source
Pusakanagara	Sedimentation	869.9 ha	[6]
Blanakan	Sedimentation	725.4 ha	[6]
Legonkulon	Erosion	885.8 ha	[6]
Ujung Pamanukan	Erosion	±1.2 km	[5]
Ciasem Bay	Erosion	±1.2 km	[5]
Blanakan Bay	Accretion	±1.3 km	[5]
Cipunagara Estuary	Accretion	±1.7 km	[5]

These data demonstrate that shoreline change in Subang Regency has high spatial heterogeneity. Erosion does not occur uniformly along the coast, and accretion likewise varies in intensity. This condition highlights the importance of analysing the coast by individual segments. More recent findings reinforce this pattern. Using DSAS analysis and Sentinel-2A imagery over the period from 2016 in [8] to assess 2024, the results showed extreme rates of both erosion and accretion occurred in the very high atmosphere at Subang coast. Accretion and erosion were identified in Pusakanagara, with a maximum of 1,021.08 m (123.49 m/year) for the accreted area, while the maximum value for erosion was 1,048.74 m(126.84m/year). Mangroves vs shoreline change (DPSIR) [12] showed that mangrove degradation was associated with shoreline changes in Blanakan and Legonkulon. Most of Blanakan experienced accretion, whereas Legonkulon was more strongly characterised by erosion. Results that link mangrove change with shoreline change show that vegetation reinforces the physical mechanisms operating in coastal areas. Erosion has also been shown to extend about 1.2 km inland at Ujung Pamanukan and Ciasem Bay [5]. At some sites, the maximum accretion was about 1.3 km in Blanakan Bay and approximately 1.7 km at Cipunagara Estuary [37]. However, the association between mangroves and shoreline change should not be considered a unidirectional causal relationship. Shoreline changes in Subang studied by [8] show the same as sedimentation, wind, currents, waves, bathymetry and tides. Consequently, shoreline change (loss or gain of land) is caused through a combination of human impacts and natural processes. The DPSIR framework is relevant because it accommodates both groups of factors within a single analytical framework without assuming that all coastal changes are caused solely by human activities.

3.5. IMPACTS: EROSION, LAND LOSS, AND DEGRADATION OF ECOSYSTEM FUNCTIONS

Changes in coastal conditions subsequently generate various impacts. The most apparent impacts are erosion and land loss in coastal segments experiencing shoreline retreat. [5] Approximately 1.2 km of erosion was recorded at Ujung Pamanukan and Ciasem Bay during 1989–2013. At the same time, other areas experienced accretion. This pattern indicates that the impacts of shoreline change cannot be evaluated solely from aggregate land-loss figures; they must also be assessed according to the location and function of the affected land. When erosion occurs in mangrove areas, the impacts may include habitat loss and reduced coastal protection functions [13]. When it occurs in aquaculture areas, the impact may involve a reduction in productive land. When it occurs near settlements or infrastructure, the consequences may include an increased risk of asset damage. Mangrove degradation also has implications for the ecological functions of coastal areas. Recent research indicates that Subang mangroves contain substantial carbon stocks, with an estimated average of approximately 183.73 Mg C/ha. This finding indicates that mangrove loss is associated not only with changes in the physical form of the coastline but may also

reduce the capacity of the ecosystem to store carbon [7]. Therefore, mangrove protection can be considered part of both coastal adaptation and climate-change mitigation strategies.

3.6. RESPONSES: MANGROVE REHABILITATION AND ECOSYSTEM-BASED MANAGEMENT

Responses to environmental change along the Subang coast can be viewed through two principal approaches: ecosystem-based responses and infrastructure-based responses. Mangrove rehabilitation is one relevant ecosystem-based response because pressure on mangrove ecosystems has persisted over a long period. Rehabilitation should not focus solely on increasing vegetation area, but also on restoring coastal protection, habitat, and carbon-storage functions. Another relevant approach is silvofishery, particularly in areas with a history of aquaculture use. This approach allows productive activities to continue while retaining part of the mangrove cover [14]. Infrastructure-based responses can also be found in coastal management. However, research on shoreline dynamics indicates that protective structures must be carefully planned because coastal systems are interconnected. An intervention at one location may affect sedimentation patterns elsewhere. Therefore, management responses should not be directed only toward locations experiencing the greatest erosion, but should also consider sediment sources, mangrove conditions, estuarine characteristics, land use, and surrounding human activities. Based on the overall findings, the DPSIR relationships along the Subang coast can be formulated as follows.

TABLE 3 Synthesis of DPSIR Relationships

Component	Process	Main indicator	Implication
Drivers	Development of activities and spatial utilisation	Aquaculture ponds, settlements, agriculture, infrastructure	Increasing demand for space
Pressures	Land conversion and land-use change	Mangrove loss, aquaculture expansion	Pressure on ecosystems
State	Changes in coastal conditions	Mangroves, erosion, accretion, sedimentation	Changes in physical and ecological characteristics
Impacts	Consequences of changing conditions	Loss of land, habitat, and ecosystem functions	Increasing vulnerability
Responses	Management actions	Rehabilitation, silvofishery, coastal protection	Reduction of pressure and ecosystem recovery

Overall, the analysis shows that coastal problems in Subang are not a single issue but rather a sequence of interconnected changes. Land-use change and pressure on mangroves form part of the anthropogenic pressures, while erosion, accretion, and sedimentation demonstrate the strong influence of natural processes. Another important finding is the high degree of spatial heterogeneity. Recent research has documented very strong erosion and accretion dynamics in Pusakanagara, while earlier studies reported high sedimentation in Pusakanagara and Blanakan and pronounced erosion in Legonkulon [6,8]. These conditions indicate that coastal management in Subang Regency should not rely on a uniform approach. Each coastal segment needs to be considered based on the combination of anthropogenic pressures, mangrove condition, shoreline dynamics, sedimentation characteristics, and the function of the affected land. Thus, the DPSIR framework provides a useful basis for linking BIG geospatial data with scientific evidence from previous studies.

4. CONCLUSION

Based on the analysis using the Drivers Pressures State Impacts Responses (DPSIR) framework, the coastal environmental dynamics of Subang Regency result from interactions among the development of socio-economic activities, spatial utilisation, pressure on mangrove ecosystems, and natural coastal processes. The development of aquaculture ponds, settlements, agriculture, and infrastructure has increased the intensity of coastal spatial utilisation, which in turn places pressure on ecosystems through land-use change and mangrove conversion. Coastal environmental conditions are very dynamic, especially in mangrove ecosystems and shoreline position. Erosion and accretion both contribute to shoreline changes, which vary in nature across locations. This condition illustrates that the subang coastal zone is not a single system, and environmental changes should be understood based on the characteristics of individual coasts. The impacts of these dynamics include land loss or landform change, erosion, potential tidal flooding, habitat degradation, and reduced mangrove ecological functions. The magnitude of these impacts varies according to the characteristics of the affected areas, including mangroves, aquaculture ponds, agricultural land, settlements, and infrastructure. Management responses that have developed include mangrove rehabilitation, coastal vegetation planting, pond management through silvofishery approaches, coastal protection, and spatial planning. However, the different characteristics of coastal change among locations indicate that management cannot be implemented through a uniform approach. Management efforts need to be adapted to the level of pressure, ecosystem condition, shoreline dynamics, and spatial functions of each coastal segment.

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