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Disaster mapping as decision support system to decrease abrasion impact due to climate change in Bantul Coastal Area

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Disaster mapping as decision support system to decrease abrasion impact due to climate change in Bantul Coastal Area

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Abstract. Global climate change affects the physical condition of coastal areas, one of which is the rise in wave height. The increase in wave height allows higher volume of carried substrate on the swash and backwash motions. These events have an impact on increasing the abrasion intensity, specifically on the coastal areas which consist of sand material (beaches). Coastal area of Bantul Regency is one of the areas exposed to abrasion because it is directly facing the Indian Ocean. Application of atmospheric science and technology is needed to reduce the impact of losses caused by abrasion. Disaster mapping is an effort to reach that expectation. This research aimed (1) to identify abrasion susceptibility, and (2) to analyse social vulnerability due to abrasion in Bantul coastal area. The assessment was done by GIS-based spatial-multi criteria analysis to process physical and socio-cultural aspects in regards of abrasion, which the analytical unit was the coastal area between Opak and Progo River estuaries. This research resulted in susceptibility map and social vulnerability map as references for coastal mitigation directives supporting the resilience of region and community towards climate change.

Keywords : climate change, abrasion, susceptibility, vulnerability.

1. Introduction

The coastal area is defined as the area between highest tide shoreline and the boundary of landform genesis change. Coastal dynamics can be caused by natural and artificial factors. One of the natural causes of coastal dynamics is the abrasion phenomenon. Abrasion is a destructive process that is affected by sea waves and currents.

Global climate change is hypothesized as a factor in the emergence of various coastal disasters [1], one of which causes a rise in wave height [2] and further causes intensive coastal abrasion. Hydrodynamic factors of coastal genesis in the form of sea waves, tidal waves, and sea currents would practically be intensified due to global warming, thus affect the swash and backwash cycles on the shore. It consequently leads to the more eroded substrate and following shoreline changes.

The coastal area of Bantul Regency is covered by sand substrate. It geographically faces Indian Ocean, which allows continuous accumulation of sandy materials on the beach. As seen from the coastal typology, the coastal area with such conditions could be classified as marine depositional coast [3]. As an exposed area, Bantul coastal is basically susceptible to coastal hazards, and thus the regions' elements would be vulnerable. Reference [4] has studied Depok Coastal as a sample of Bantul coastal area and stated that the coastal is relatively susceptible to disasters in the form of tsunami, abrasion, landslide, and mass movement.

Beside from the shore hydrodynamic factors, abrasion in coastal area of Bantul is also influenced by the reduction of sand deposit transported by Opak River and Progo River. Reference [5] stated that the sand mining activities along those rivers cause the deposition process on the beach part of Bantul coastal. Therefore, this research is focussing on the coastal area bounded by Opak and Progo River estuaries, which are Samas, Pandansari, Goa Cemara, Kwaru, Baru, and Pandansimo. The coastal area is located in the southern part of the districts of Sanden and Srandakan. These regions have the most severe abrasion impacts, which can be seen from its building damages, specifically food stalls and settlements [6]. The abrasion susceptibility is caused by the geophysical aspect of the coastal area, which consists of morphodynamic and hydrodynamic sub-aspects. The morphodynamic factors causing to abrasion are elevation, the area distance to shoreline, morphology, and slope; while the hydrodynamic factors are wave height, tidal wave height, and sea current intensity.

Abrasion poses a serious threat to the area including the people who live there, as the coastal area had become a space to settle and do economic activities to its various resources [7]. The response of social environment in experiencing hazards or disasters could be defined as social vulnerability. Social vulnerability is conditions that are determined by social factors or processes that can increase the vulnerability of a community on the impacts of harm [8]. The Asian Disaster Preparedness Center (ADPC) stated that the social vulnerability assessment is based on its factors including perceptions of the risks and views of the cultural aspects in community, religion, ethnicity, social interaction, age, gender, and poverty [9]. Factors causing to social vulnerability of abrasion are population density, sex ratio, poverty ratio, disability ratio, and dependency ratio [10].

An effort of coastal mitigation is needed to support appropriate policy-making of conserving coastal environment including geophysical and socio-economic aspects. Along with that urgency, this research was conducted to identify the coastal area susceptibility and social vulnerability to abrasion, as the phenomenon has massively damaged the coastal ecosystem in Bantul Regency. Construction of susceptibility and social vulnerability maps based on multi-criteria analysis is the exact attempt to understand the levels of possibility to survive from coastal hazards and disasters. The maps would consequently allow deciding actions to mitigate based on the regional status in terms of abrasion or other coastal hazards. The assessment then followed up by alternatives of attempts to rehabilitate as well as to conserve coastal environment towards the irresistible abrasion impacts, by the applicable efforts to improve the coastal area both geo-physically and socially.

2. Data and Method

The susceptibility and social vulnerability mapping of this research were conducted based on quantitative design. The studied area is the coastal area of Bantul Regency, Daerah Istimewa Yogyakarta Province, Indonesia. The specific area was then selected based on the worst existing condition caused by abrasion, so to construct the analysis unit, i.e. (1) the beach in the whole coastal area between Opak River Estuary and Progo River Estuary for the susceptibility assessment, and (2) each coastal area of Samas, Pandansari, Goa Cemara, Kwaru, Baru, and Pandansimofor the social vulnerability assessment. Figure 1 shows the study area.

2.1. Data Collection

The data consist of main spatial data attributes and also supporting data of coastal characteristics as evidence. Primary data were collected from (1) geomorphological survey, (2) spatial data interpretation, and (3) structured interview to people who live in research area; while secondary data were collected from institutional sources, such as Meteorological, Climatological, and Geophysical Agency and Alaska Satellite Facility.

The main data used to construct susceptibility map were adapted from the Underlying Physical Susceptibility Model (UPSM), which had been applied in to the coastal area of Scotland [11]. The parameters were then sorted to be applied in this research, considering the local coastal characteristics in Bantul Regency. The susceptibility assessment was mainly based on elevation and proximity to open coast (area distance from shoreline) parameters, and supported by coastal morphodynamic (morphology and slope) and hydrodynamic (sea wave height and current intensity) aspects.

The social vulnerability is based on parameters of population density, sex ratio, poverty ratio, disability ratio, and dependency ratio [10], thus the main data were total population, area, total men and women, impoverished people, disabled people, children under-15-years-old and elderly people above-65 years old; and were supported by people's perception of abrasion phenomenon. Those were collected by structured interview census to 35 heads of household as respondents. All the collected data for this research are shown in table 1.

Table 1. Data Source, Place, and Year

Data	Source	Place	Year
Area Susceptibility			
Elevation[a]	DEM processing	Study area	2010
Distance to shoreline[a]	DEM processing	Study area	2010
Morphology[b]	DEM processing and field survey	Study area	2018
Slope[b]	DEM processing and field survey	Study area	2018
Wave height[b]	Meteorological, Climatological, and Geophysical Agency	Bantul Shore	2016
Sea current intensity[b]	Meteorological, Climatological, and Geophysical Agency	Bantul Shore	2016
Social Vulnerability			
Total population[a]	Census	Study area	2018
Men and women[a]	Census	Study area	2018
Impoverished people[a]	Census	Study area	2018
Disabled people[a]	Census	Study area	2018
Elderly people (>65 y.o.)[a]	Census	Study area	2018
Children (0-14 y.o.)[a]	Census	Study area	2018
Perception to abrasion[b]	Census	Study area	2018

[a]Main data.
[b]Additional-supporting data.

2.2. *Data Processing*

The collected data were put into geodatabase. Both susceptibility and social vulnerability maps were constructed by GIS-based spatial multi-criteria analysis as provided by ArcMap 10.3software. The multi-criteria analysis is basically done by weighting the main spatial data attributes according to their influences on coastal abrasion. The parameters' influence was determined based on literature study.

2.3. *Data Analysis*

The data were analyzed by descriptive quantitative method. As for the susceptibility map, both elevation and distance parameters were considered to have an equal influence to abrasion; while as for the social vulnerability map, the different weights were applied in parameters of social vulnerability which was based on the agreed national reference of Indonesian National Agency for Disaster Management. The research procedure is showed by a workflow diagram in figure 3.

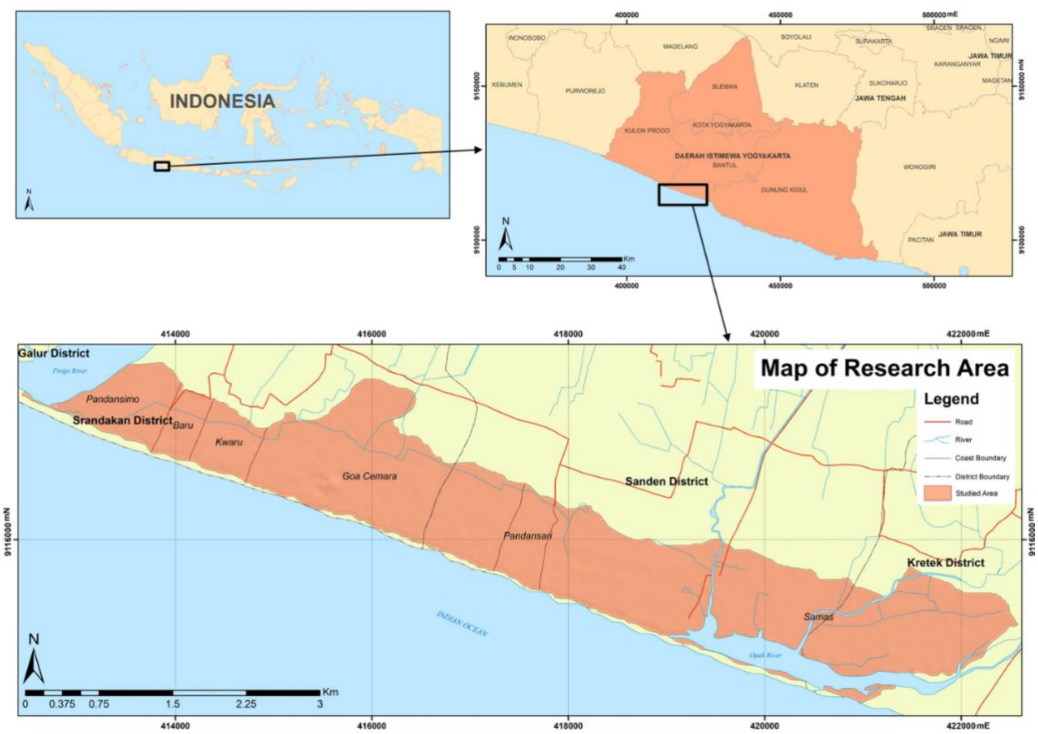

Figure 1. Map of research area

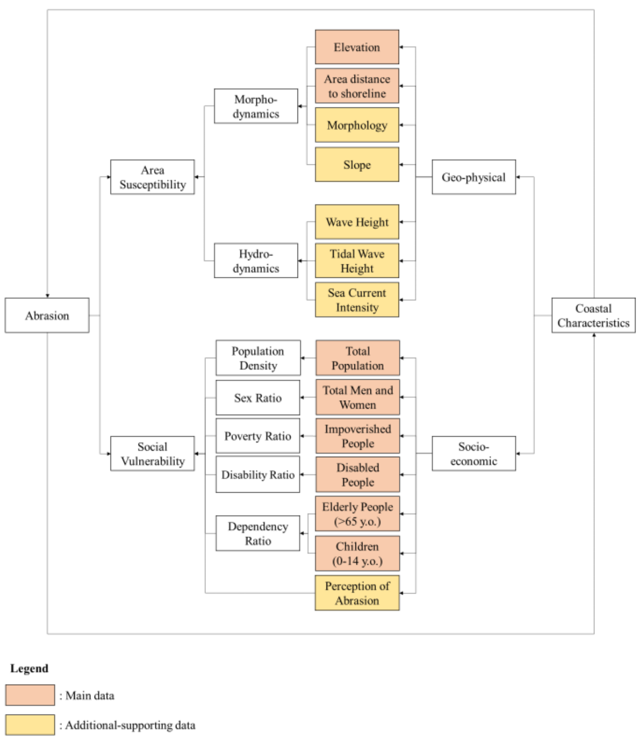

Figure 2. Collected data of coastal characteristics

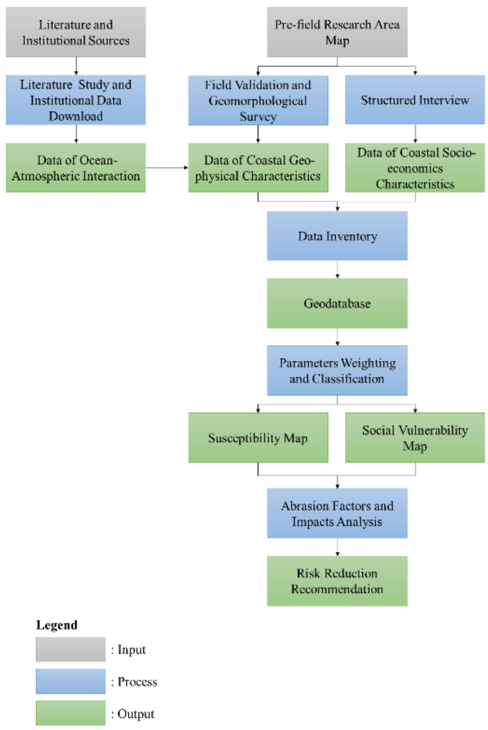

Figure 3. Research procedure

3. Result and Discussion

3.1. Abrasion as an Impact of Coastal Dynamics

Reference [12] stated that coastal area development could be influenced by complex geomorphic processes. Bantul coastal area is classified as marine depositional coastal typology which is characterized by flat to undulating reliefs, sandy material, and marine processes (near the sea) and aeolian processes (near land) [13]. The coastal typology thus causing coastal erosion and sedimentation as dominant geomorphic processes that works in Bantul coastal area. The coastal area of Bantul Regency, specifically the area that is bordered by Opak River and Progo River estuaries has the main substrate in the form of sand materials (sandy shore), so that it has a large beach.

Coastal area is associated with morphodynamic, hydrodynamic, and aeolian processes [14]. Furthermore, the broader factors that affect coastal dynamics has been described, including astrodynamic, aerodynamic, hydrodynamic, morphodynamic, geodynamic, ecodynamic, and anthropodynamic [15]. There are interactions between those processes that affect coastal conditions [5].

Sandy substrate could easily be carried away through geomorphic processes by water energy (forming beach) or wind energy (forming sand dunes). Hydrodynamic factors on the shore in the form of extreme sea waves and currents at certain times could affect the coastal ecosystem. The sea wave dynamics in Bantul in 2016 is shown in figure 4, with the highest wave reaching 5 meters in June while the lowest waves in between 1 and 1.5 meters from December to February. Wave height fluctuation is influenced by wave generator factors such as the velocity, duration, and direction of wind; and fetch length [16]. The extreme weather condition would increase the region's threat to abrasion damages, along with the morphodynamic factors.

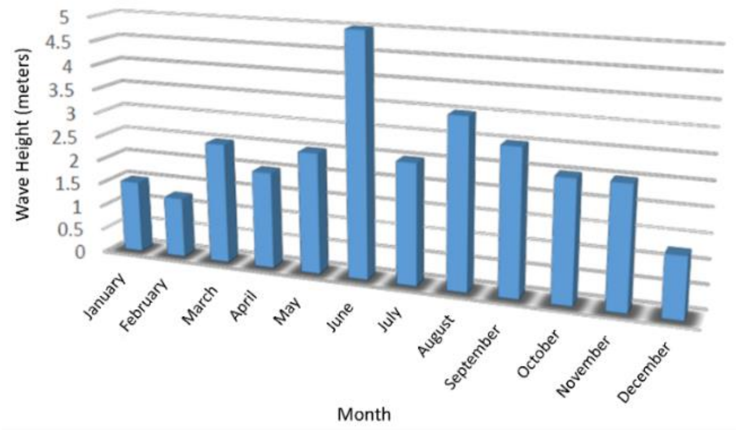

Figure 4. Wave height dynamics in Bantul shore, 2016 (Meteorological, Climatological, and Geophysical Agency, 2016 as quoted in [18])

Global climate change that occurs has increased hydrodynamic intensity in coastal areas. Air temperature on land and sea that has increased due to global warming affects to rising wind velocity and practically followed by wave height [5]. The situation causes intensive abrasion in the study area.

In terms of geomorphology, sand deposits in the beach area of Bantul come from transported volcanic eruption materials from Mount Merapi by Opak River and from Mount Sumbing by Progo River. However, sand mining activities that continue until 2017 in the middle part of Opak River and Progo River cause the reduction in sediment supply of beach. Thus, increasing abrasion intensity in the coastal area of Bantul is an accumulation of suppressing factors in the upstream, middle, and downstream parts of Opak and Progo River.

Abrasion as a result of the coastal dynamics causes damages. Physically, the damages could be seen from worst level in coastal areas of Kwaru, Pandansimo, Samas, and Goa Cemara respectively, including disturbed building structure and land cover pattern. Those coastal areas experienced shoreline retreat due to intensive abrasion until 2013. Table 2 describes the risk elements that were damaged by abrasion.

Table 2. Physical Damages Caused by Abrasion[18]

Coastal Area	Year	Damages
Kwaru	2009	Infrastructure facilities, SAR viewing post, shrimp ponds
	2010	Tourism infrastructure
	2011	Public infrastructure and tourism facilities
	2012	*Casuarina equisetifolia* vegetation
	2013	51 buildings were lost, 25 houses were exposed, *Casuarina equisetifolia* vegetation
Pandansimo	2006	6 houses, 2 stalls, 1 market stall
	2010	Infrastructure facilities owned by fishermen
Samas	2013	20 damaged/missing buildings including houses and public infrastructure
Goa Cemara	2013	*Casuarina equisetifolia* vegetation

3.2 Area Susceptibility to Abrasion

The beach in coastal area of Bantul Regency basically has a high level of susceptibility to shoreline changes, because it contains deposits of unravelled/unconsolidated sandy material and is directly facing high energy of sea wave and current from Indian Ocean [19]. The abrasion susceptibility assessment shows that the lower elevation and distance values would affect the higher level of susceptibility to abrasion, or it could be stated that abrasion susceptibility is inversely proportional to the parameters of elevation and distance from shoreline. The condition causes the graded level of susceptibility as follows: (1) shore area (at elevation of 0-25 meters above sea level (m.a.s.l.) and distance of 0-100 meters from shoreline) is highly susceptible to abrasion; (2) beach area at elevation of 26-35 m.a.s.l.and distance of >100-400 meters from shoreline is moderately susceptible to abrasion; and (3) beach area at elevation of >35 m.a.s.l.and distance of >400-500 meters from shoreline is lowly susceptible. The spatial pattern of susceptibility level to abrasion on shore to beach area in Bantul coastal is shown in figure 5.

Figure 5. Map of area susceptibility to abrasion in part of coastal area of Bantul Regency

Abrasion is a geomorphic process in the form of erosion in coastal areas that could cause shoreline changes. Changes to the coastline have greater susceptibility if the slope condition is steeper [20]. Relief condition in each coastal area indicates the susceptibility to abrasion horizontally among all the coastal areas, as it contains its certain material and geomorphic process. As seen from beach relief, the coastal areas of Samas and Kwaru are considered to have higher abrasion susceptibility than other coastal areas. It is based on their shore areas that are relatively steeper and wider than other coastal areas.

3.3. Social Vulnerability to Abrasion

Social vulnerability is the level of social inability to the face any forms of hazard [17], which indicates the condition of population that potentially experiencing disadvantages due to hazards that may occur [20]. The level of social vulnerability is determined based on the parameters of population density, sex ratio, age ratio, disability ratio, and poverty ratio [10]. The analysis is focused on the coastal areas of Samas and Kwaru, as only the two coastal areas that have domiciled residents. Thus, the coastal areas of Pandansari, Goa Cemara, Baru, and Pandansimo are practically have zero-value of social vulnerability or classified as not socially vulnerable to abrasion.

Kwaru Coastal Area is categorized in high level of social vulnerability while Samas Coastal Area is categorized in moderate level (figure 6). The assessment result (table 3) shows that the parameters of population density and poverty ratio are the ones that highly influencing social vulnerability differences in the coastal areas of Samas and Kwaru. Samas Coastal Area has a population density of 13 people per square kilometre, while the Kwaru Coastal Area has 86 people per square kilometre. Samas Coastal Area has larger population but larger area, and thus the lower population density than Kwaru Coastal Area. On the contrary, Kwaru Coastal Area certainly the densest coastal area, and thus have the highest level of social vulnerability because the population density parameter is considered to be the most influencing factor. Kwaru Coastal Area experienced narrowing 150 meters of its area in 2013, which the continuation may increase the social vulnerability index for various coastal hazards and disasters.

Figure 6. Map of social vulnerability to abrasion in part of coastal area of Bantul Regency

The poverty condition of the population is assessed based on variable of individual income per month. Between the two compared coastal areas, Samas has the worst condition, as the poverty ratio reaches 195.24. It means that there will be 195 poor people if there were 100 non-poor people, thus there might be 95 people who become dependency expenses to the coastal area. The main livelihoods in Samas Coastal Area are fishermen, merchants, and dry land farmers; those are the activities which commodities are seasonally fluctuate. Meanwhile, the residents in Kwaru Coastal Area are in middle social class, which main economic activities are more diversified from traditional farming (including fishing), such as processed seafood seller, shrimp pond farmers, and civil servants.

Table 3. Social Vulnerability Levels of Abrasion Phenomenon.

Coastal Area	Parameter					Social Vulnerability Index	Social Vulnerability Class
	Population Density	Sex Ratio	Poverty Ratio	Disability Ratio	Dependency Ratio		
Samas	0.6	0.3	0.3	0	0.3	1.5	Moderate
Pandansari	0.6	0.1	0.1	0	0.1	0.9	Low
Goa Cemara	0.6	0.1	0.1	0	0.1	0.9	Low
Kwaru	1.8	0.3	0.1	0	0.3	2.5	High
Baru	0.6	0.1	0.1	0	0.1	0.9	Low
Pandansimo	0.6	0.1	0.1	0	0.1	0.9	Low

The gap of tourism development among coastal areas is the main issue causing social inequalities. Kwaru Beach is considered to have greater appeal in terms of tourism than Samas Beach, thus affecting the local people's preference to build up a small business (usually in the form of food stalls) or become tour guides. Those kinds of business have become the main sources of income for most people in the area, as well as the additional sources of income for the existing fishermen and shrimp farmer communities.

3.4. Coastal Defence Recommendation as Disaster Risk Reduction

The analysis of susceptibility and social vulnerability to abrasion in part of Bantul coastal area is the basis for mitigation efforts in the area due to abrasion or any coastal hazards that triggered by extreme hydrodynamic. Thus, it is important to plan the applicable mitigation as an attempt to reduce the potential risks. Based on the results of susceptibility and social vulnerability analysis, the recommended mitigation is consequently need to be area-specific, as each coastal area has different urgency in terms of abrasion phenomenon.

3.4.1. Highly Susceptible Coast to Abrasion.

The susceptibility to abrasion in part Bantul coastal is assessed based on coastal topographic condition. The highly susceptible area requires structural defence efforts, as it is the most effective one. The area mitigation requires retaining wave buildings to decrease the higher wave impacts. This effort certainly requires further studies related to the engineering aspects of wave-retaining buildings. Otherwise, beach reclamation could be done to recover the lost deposit that is eroded by sea wave and current.

The non-structural effort that might be done as coastal abrasion mitigation is renewing the coastal conservation zones periodically, based on the repetition of sea wave and current cycle that affects coastal area of Bantul; so as to evaluate the ecological function of the area. As the follow up to the zonation renewal, reforestation of *Casuarina equisetifolia* vegetation as natural breakwater should also be done, specifically at the nearest exposed area to sea wave and current (shore and front beach).

3.4.2. High-Socially Vulnerable Coast to Abrasion.

The main social problems faced by coastal areas of Samas and Kwaru are respectively poverty and population density. The effort to handle social vulnerability in both coastal areas is focused on the two strategic issues. The empowerment of coastal communities can be aimed in prior to people who live in Samas Coastal Area which are relatively underdeveloped as seen from a whole development perspective. The program that can be implemented is training for workforce and opening local small business that funded by government as an opportunity to promote local coastal commodities. The program is expected to improve the perception of community towards tourism conduciveness in Samas Coastal Area. Coastal commodities such as shrimp ponds, salt ponds, and seafood stalls could be great sources of income, as it is proven in Kwaru Coastal Area. Furthermore, the development of tourism sector towards ecotourism is also recommended to develop an environment-responsive activity as well as to improve regional economy.

Meanwhile, Kwaru Coastal Area has its potential human resource, with higher level in life quality so that the region develops more rapidly. The progress of tourism sector still needs to be balanced with community awareness of abrasion threat, especially with the condition of Kwaru Coastal Area which has historically been the worst affected. Tourists in Kwaru Coastal Area could also be given the responsibility to monitor the coastal ecosystems in line with governmental acts. Thus, the preservation of coastal function could be carried out in a participatory manner by utilizing the human resource potential in Kwaru Coastal Area.

One of the main issues related to intensive abrasion of the beach area is the massive sand mining along the rivers. Thus, the area rehabilitation in each coastal should include programs of sand mining restriction along the strategic line of beach deposit transportation. The strict enforcement, restriction, and periodical monitoring of sand mining activities along the river to the coastal are urgent to be implemented, as the sand mining is consistently done with less consideration of the environment threshold. The proposal could be applied initially along Opak River and Progo River lines, as the routes of beach sediment of Samas, Pandansari, Goa Cemara, Kwaru, Baru, and Pandansimo Coastal Areas. Thus, the proper management involving multi-institutions and multi-administrative regional governments needs to be optimized.

4. Conclusion

The findings in this research could be concluded as follows. Abrasion susceptibility is inversely proportional to the parameters of elevation and distance from shoreline, as in the studied area it resulted in three sub-areas with graded susceptibility levels: (1) shore area at elevation of 0-25 m.a.s.l. and distance of 0-100 meters from shoreline is highly susceptible to abrasion; (2) beach area at elevation of 26-35 m.a.s.l. and distance of >100-400 meters from shoreline is moderately susceptible to abrasion; and (3) beach area at elevation of >35 m.a.s.l. and distance of >400-500 meters from shoreline is lowly susceptible. The social vulnerability to abrasion is primarily influenced by population density and poverty ratio. The coastal area of Kwaru and Samas are respectively have high and moderate level of social vulnerability, as Kwaru Coastal Area is the densest area among the studied area while Samas Coastal Area has dependency expenses; while coastal areas of Pandansari, Goa Cemara, Baru, and Pandansimo are not socially vulnerable to abrasion as there are no domiciled people.

The mitigation to coastal abrasion could be done by structural and non-structural efforts. Structurally, the highly susceptible area requires retaining wave buildings to decrease the higher wave impacts, and also reclamation to recover the beach part as to rehabilitate its function in facing the front shore hydrodynamic. The non-structural effort could be in the form of conservation zones renewal of coastal area periodically, following up the local sea waves and currents cycle; and completed by reforestation of *Casuarina equisetifolia* to optimize its function as a natural breakwater.

Attempting to improve the coastal community capacity to abrasion, it requires the empowerment of people in underdeveloped coastal areas, with some alternatives programs related to workforce training and developing small business which highlights the local coastal commodities, so that they would be stable under the threats of abrasion damages. The coastal areas which have population density problem could use its potential human and economic resources to balance the development of tourism with community awareness of abrasion threat, in actions that involve community, government, and tourists to monitor the coastal ecosystem as well as the river ecosystem which carries out deposit supply for it.

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