

Placement Location Mapping for Nature-based Solutions in Flood Vulnerable Areas as a Disaster Management Alternative in Bantul Regency

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Abstract. The purpose of this study is to determine potential locations around flood-vulnerable areas for developing the concept of Nature-based Solutions (NbS) in Bantul Regency-Yogyakarta, Indonesia. The data utilized includes rainfall, slope, elevation, land use, soil type, landform, distance from the river, actual flood data, and historical flood data. This data was obtained from the Climate Hazards Group InfraRed Precipitation with Station, National Digital Elevation Model, Bantul Regional Development Planning Agency, and Bantul Regional Disaster Management Agency. The data were overlaid between the flood vulnerability maps processed using the Spatial Multi-Criteria Analysis method and Hydromorphological Landscape Unit Floodplain maps. Results of data processing and analysis for floodplain-based NbS indicate several locations for the implementation of NbS in the pilot project area, particularly at the confluence of the Opak and Oyo rivers. In the intersection of the Opak and Oyo River, various NbS types can be identified and applied. The suggested NbS includes porous pavements, riparian zones, detention basins, and inland wetlands. The placement of the four NbS is based on environmental conditions and the characteristics of each NbS object to prevent flooding.

Keywords. Flood vulnerability, Nature-based Solution (NbS), Geographic Information System (GIS), Spatial Multi-Criteria Evaluation (SMCE), Hydromorphological Landscape Unit (HLU)

1 Introduction

Floods are an annual problem and have a significant impact on the condition of the community both economically, socially, and environmentally. Floods generally occur due to overflowing river water or rivers' inability to accommodate excess river water due to high rainfall. The inundation caused by overflowing or increasing river discharge has unfortunately resulted in significant damage, affecting both the natural environment and man-made structures. Over the 16-year period from 2000 to 2015, a staggering 2.3 billion people were impacted by floods, leading to mortality and damage rates of 20.4% and 19.3%, respectively. The economic consequences of these events translated to a loss of \$70.1 billion. [1].

Floods occur in almost all parts of Indonesia, especially during the rainy season and even during the dry season. Some areas are flooded due to the influence of extreme weather and tropical cyclones in northern Indonesia. Areas with topographical forms in the form of basins or lowlands with small slope values often become flood-vulnerable areas, one of which is the Bantul Regency.



Fig. 1. Bantul Regency Administrative Map (Source: data processing, 2023)

Bantul Regency is one of the administrative areas in the Special Region of Yogyakarta. Bantul Regency is geomorphologically included in the fluvio-volcanic plain zone of Mount Merapi, so it has a high potential for flood vulnerability. Based on data from the Department of Agriculture, Food, Maritime Affairs and Fisheries of Bantul Regency, floods often threaten the agricultural sector which is the leading sector in Bantul Regency. As a result of the flood, floodwaters

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submerged agricultural land in multiple sub-districts of Bantul Regency, covering an area of approximately 10 hectares [2]. If not addressed immediately, the flood disaster will harm farmers and make agriculture production in Bantul decrease.

The application of nature-based solutions is an action to protect, sustainably manage and restore natural and modified ecosystems that effectively and adaptively address community challenges, such as a decrease in agriculture production while providing benefits to humans and nature. A key element signaling an intelligent environment involves employing technology-driven approaches to manage the environment effectively, enabling the implementation of solutions rooted in nature to address environmental challenges [3]. Furthermore, the utilization of Nature-based Solutions (NbS) implementation offers substantiation for the advantages and risk-mitigation capabilities associated with floodplain-based NbS, such as the restoration and safeguarding of floodplains [4]. Floodplains, for example, can have the capacity to manage infiltration, and overland flow, improve hydrological connectivity, regulate water supply, serve as biodiversity hotspots, and provide countless other benefits. However, the ability of floodplains to fulfill these functions depends on the presence and interaction of a range of diverse biophysical factors. [5].

The emergence of the smart city concept is a result of the progression of increasingly sophisticated information technology [6]. Various information about good governance can be accessed quickly by the community through a program called a smart city. The concept of smart cities is not confined solely to urban settings only. Rather, it can be thoughtfully implemented to address challenges or potentials in rural areas and at the provincial level [7]. Based on its dimensions, smart cities are divided into several parts, one of which is the smart environment. A smart environment is an environment that can provide comfort, sustainability of resources, and the beauty of both physical and non-physical beauty, for the community and the public [3]. Through the application of the smart environment dimension, the problem of flooding in the Bantul district can be resolved thereby creating a sustainable environment for the public.

To implement a nature-based solution, a practical method is needed so that it can be implemented by the community around the river. Therefore, prior identification and planning are required before the implementation of a nature-based solution. A suitable site selection for the nature-based solution can be conducted by utilizing functional unit delineation. Determination can be conducted by use in the field of landscape planning and hydrological modeling. The feasibility of nature-based solutions in establishing spatial units that can be effectively planned is yet to be examined [8].

Determining the location of nature-based solutions in flood-vulnerable areas is very necessary for making smart environment-based development planning decisions. This endeavor is undertaken with the aim of ensuring that the ongoing developmental initiatives conscientiously prioritize environmental considerations

and sustainability, thereby mitigating any adverse impact on the natural ecosystem. Therefore, it is necessary for mapping the location of the placement of nature-based solutions in flood-vulnerable areas in the Bantul Regency so that the dimensions of the smart environment in the smart city concept can be achieved. Site selection plan for a nature-based solution can be determined based on the Geographic Information System model. The Geographic Information System can map the spatial potential locations by using the analysis of various spatial data so that it can produce various potential points for the application of nature-based solutions. This study aims to determine the potential locations around the flood-vulnerable area for the development of a nature-based solution concept in Bantul Regency.

Table 1. Data Parameters and Source

Data	Source		
Precipitation	Climate Hazards Group	InfraRed	
	Precipitation with Station (CHIRPS)		
Slope	National Digital Elevation Model (DEMNAS)		
Elevation	National Digital Elevation Model (DEMNAS)		
Landuse	Bantul Development Agency	Planning	
Soil type	Bantul Development Agency	Planning	
Landform	Bantul Development Agency	Planning	
Distance to River	Bantul Development Agency	Planning	
Flood Disaster	Bantul Regional Management Agency	Disaster	

2 Methods

The study's research framework comprised a natural functional reference unit delineated by biophysical spatial criteria, serving as the foundational framework for situating nature-based solutions (NbS). Within the context of the Bantul Regency case study, these units were meticulously examined to delineate regions conducive to the implementation of NbS. These units were explored in mapping the case study area in Bantul Regency to identify areas suitable for the application of nature-based solutions (NbS). The first step of analysis is conducted to identify the flood vulnerability using the Spatial Multi-Criteria Evaluation (SMCE) method. The SMCE method can be described as both a decision support tool and a mathematical instrument that facilitates the comparison of diverse alternatives based on numerous criteria, often with conflicting considerations. Its purpose is to assist decision-makers in making informed and prudent choices [12]. The data is processed using The Integrated Land and Water Information System (ILWIS) software. The parameters, including precipitation, slope, elevation, land use, soil type, landform, and distance to river were obtained (Table 1) from Bantul Regional Development Planning Agency's publication data. The Hydromorphological landscape units (HLU) is determined to represent the

similar hydrological characteristics in each land unit. This data is obtained from Bantul Regional Disaster Management Agency (BPBD)'s data publication. The above results were overlaid using ArcGIS so that it could be determined the location of the application of the nature-based solution in the appropriate area.

3 Results and Discussion

3.1 Flood Vulnerability Modeling

based on the results of SMCE analysis, it was found that rainfall was the dominant parameter dalam hal apa. This was because high rainfall in an area would increase the flooding potential. The next most important parameter was the distance to the river. Floods are more likely to occur when an area is close to a river because the closer an area is to a river, the greater the chance of flooding [9]. In addition, the parameter that had the smallest weight was the geological condition. These geological conditions have little effect on surface water conditions but are very influential on groundwater conditions in an area.

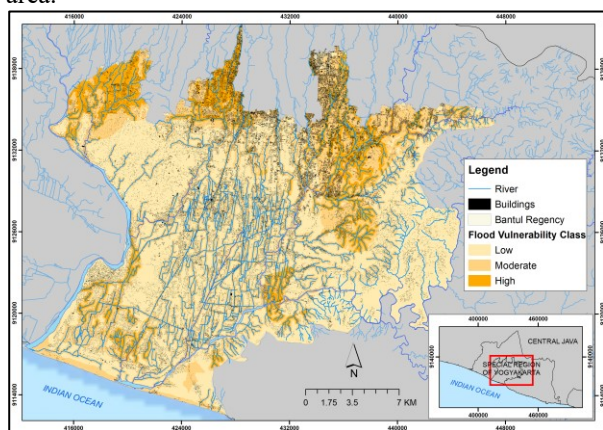


Fig. 2. Flood Vulnerability Map in Bantul Regency (Source: data processing, 2023)

Based on the results of overlaying on several parameters determining flood vulnerability using ILWIS software, that the spatial aspect of the flood vulnerability was obtained. The analysis process was carried out using scoring and then weighting of each parameter. The overlay results were classified into three vulnerability classes: high, medium, and low.

3.2 Modeling the Floodplain Area Using HLUs

By utilizing the concept of hydro-morphological land units, the results of the analysis showed that the area of floodplain HLU in Bantul Regency is 3,233.63 hectares. The floodplain HLU is spread around the major rivers such as the Progo River, Opak River, and Oyo River. The combination of sedimentary, topographic, and hydrological parameters facilitated the discernment and depiction of these inherent functional units within the

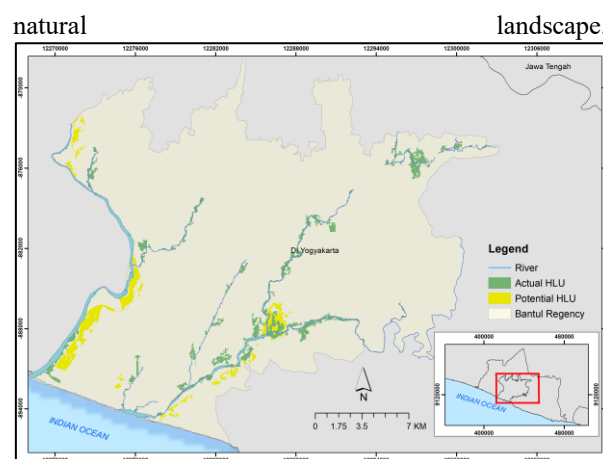


Fig. 3. Actual and Potential HLU Map in Bantul Regency (Source: data processing, 2023)

Based on the analysis and visualization of the HLU parameters in the Bantul Regency area, the resulting HLU area was an actual and potential floodplain HLU. The actual floodplain HLU has a total area of approximately 2,570.14 hectares while the area has a smaller potential area, approximately 1,046.76 hectares. Actual and potential HLUs also have high variability in size and location. However, there is a decrease in the presence of both types of HLUs downstream of the river stretch, with small HLU areas. The area is a river terrace area, or a low-elevation area adjacent to a river where topographic conditions limit the existence of a connected floodplain [10]. While actual HLU dominates in all parts of the river basin, potential HLU is mostly found in the confluence between the Opak River and the Oyo River.

3.3 Site Selection of Nature-based Solution

Flood vulnerability assessment was conducted by referencing the flood risk map, employing a specific region as a representative sample, as illustrated in Figure 3. Upon comparing actual and potential flood Hazardous Land Use (HLU) occurrences, it was observed that the majority of both actual and potential HLU sites were situated within the modeled region characterized by a heightened likelihood of flooding. Nevertheless, distinctive patterns emerged in certain areas. Notably, there existed potential HLU zones outside regions classified as high to moderate flood risk areas. This discrepancy underscored the impediment to natural flood processes in the identified potential floodplain revitalization area, attributable to the presence of human-made infrastructure, such as settlements, which constrained the natural biophysical functionality of floodplains. Hence, it is imperative to undertake restoration efforts on the existing HLU areas to ensure that the potential benefits of HLUs, anticipated with the implementation of Nature-based Solutions (NbS) development, can have a significant impact in minimizing flooding in the area [11].

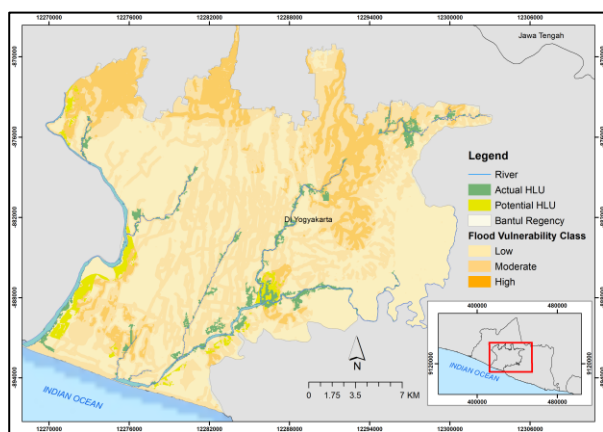


Fig. 4. Actual and Potential HLU in Comparison to Flood Vulnerability Area (Source: data processing, 2023)

Based on the observation of the sampling sites, several applications of NbS could be made to prevent flooding by the characteristics of the applied NbS. Four examples of NbS could be applied in the pilot project area, such as porous pavements, riparian zones, detention basins, and inland wetlands. The four NbS have their characteristics in their application, so they need to be placed in appropriate locations to prevent flooding. The placement of the NbS could be seen in Figure 4 below.

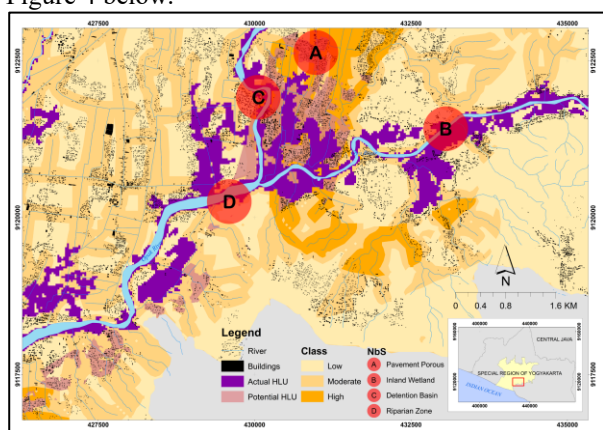


Fig. 5. Nature-based Solution Location Recommendation Map in Bantul Regency (Source: data processing, 2023)

Porous pavements are permeable paving that can drain rainwater. Porous pavements are usually made in urban areas as pedestrian areas. The application of porous pavements has been widely applied because it can control flooding [12]. Porous pavements can drain rainwater into the ground so as not to cause runoff in impermeable areas. In areas characterized by a low infiltration rate, the consequence is an extended period for infiltration. Conversely, elevated infiltration rates can lead to flooding. The deployment of Nature-based Solutions (NbS) porous pavements in the designated pilot project area is situated within a region highly susceptible to flooding, albeit predominantly occupied by built-up infrastructure. With the use of porous pavements, it is expected to accelerate the infiltration rate compared to built-up land using paving blocks. Thus, it can reduce the risk of runoff which can cause flooding.

The second application of NbS in the pilot project area was the implementation of the riparian zone. The zone is a transitional area between dry plains and air bodies which are usually floodplains and riparian buffers adjacent to floodplains. Riparian areas were further identified by the emergence of various types of water-tolerant plants. The application of the riparian zone in the area around the river is expected to reduce flood vulnerability. Positioning riparian vegetation along riverbanks can mitigate flood vulnerability by decreasing floodwater velocity, retaining floodwater in floodplains and wetlands, and lowering floodwater levels downstream [13]. The soil in this area absorbs water during the rainy season and slowly releases moisture into the rivers. This buffers the peak runoff effect and keeps the stream flowing longer.

The third application of NbS was detention basins. Detention basins are basins created around built-up land to collect water. Detention basins are usually in the downstream area and close to the river basin [12]. NbS detention basins are applied to built-up riverside areas that have high flood vulnerability, are in actual flood plains, and are potential floodplains. The utilization of detention basins in the area involves the capture and storage of surplus runoff from both rainfall and river overflow. Subsequently, controlled releases of smaller quantities are executed, thereby mitigating the risk of flooding in developed land areas along the riverbanks [14].

The last application of NbS in the area was inland wetlands. Inland wetlands are areas of vacant land dominated by grass, shrubs, and trees. The application of inland wetlands NbS was placed in areas located on undeveloped land or vacant land around rivers with high flood vulnerability, in actual areas of floodplain HLU, and in potential floodplain HLU areas. The application of NbS inland wetlands can be used to reduce the risk of flooding. Inland wetlands play a pivotal role in mitigating flood risk through the NbS of retaining water during wet periods and gradually releasing it during dry intervals. The storage capacity of wetlands varies depending on the type and location, with some capable of storing as much as 9,400 to 14,000 cubic meters of floodwater per hectare [15]. The inland wetlands at the confluence of the Opak and Oyo rivers can reduce the overflow of water. Considering that these two rivers are the main river with high discharge, the location where the two meet will result in high-volume flooding.

The implementation of the NbS is based on the areas that are in high vulnerability, have the potential for flooding (located in a potential floodplain area), and are in actual floodplains. The NbS is based on consideration of flood vulnerability which has been analyzed environmentally and historical flood data so that an overlay is made on the two maps in the previous step. The application of NbS is not always around the river but can also be in areas far from the river. Through an examination of the environment and historical data, the region can be identified as a priority area for implementation, as determined by the outcomes of the map overlay analysis [16].

4 Conclusion

Based on the results of processing and analysis of floodplain-based NbS data, several locations for placing nature-based solutions were found in the pilot project area at the confluence of the Opak and Oyo rivers. Four types of NbS can be applied in the area, such as porous pavements, riparian zone, detention basins, and inland wetlands. The placement of the four NbS is based on the characteristics of the NbS object and in terms of the environment, which is in a highly vulnerable area, actual HLU, and Potential HLU. Based on the NbS site selection, the NbS not always associated with the riverside. In the case of porous pavements, it can be applied far from the river. This is because the characteristics of the area can affect the environment that determines the location of the NbS placement. GIS can be used as the basis for analyzing NbS selection plans within this NbS. However, several supporting data that can enhance the accuracy of the analysis of the appropriate Nbs implementation are required. Using the SMCE method requires a deep understanding of the problem domain, careful consideration of spatial and non-spatial criteria, and collaboration with experts and stakeholders to ensure the analysis accurately reflects the real-world context. Enhancing the accusation of the implementation of NbS can be done by ensuring the spatial data used for the analysis are accurate, up-to-date, and reliable. Implementing NbS is crucial to recognize and respect local knowledge and practices related to natural resources and ecosystems.

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