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BUILDING RESILIENCE THROUGH NATURE-BASED SOLUTIONS: EXPLORING THE URBAN-RURAL LINKAGES IN FLOOD MITIGATION STRATEGIES FOR JAYAPURA

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ABSTRACT

Nature-based solutions (NbS) offer flexibility and adaptability to different adoption scales and purposes. NbS adoption is influenced by various factors in the target area, including environmental, socio-cultural, and economic factors. Therefore, the chances of successful NbS adoption vary between locations due to different characteristics of the target area. This study aims to identify various factors influencing the suitability level of NbS adoption, potential locations for NbS adoption, and to assess urban-rural linkage in improving the water resilience of Jayapura. This research paper explores the potential locations for implementing nature-based solutions (NbS) in both urban and rural areas of Jayapura City. The NbS measures assessed in this study are landscape restoration, water storage pond, and multifunction green open space. This study employed the Analytical Hierarchy Process (AHP), a Multi-Criteria Decision Analysis (MCDA), to summarize the influence of six factors on suitability level. The result reveals that 75% of the Jayapura City area is highly suitable for landscape restoration interventions, especially in areas with lower population density. Whereas in urban areas, implementing multifunction green open spaces and water storage ponds can target flood reduction on a local scale. Building a city's resilience requires implementing NbS in both urban and rural areas. The paper highlights the importance of collaboration and coordination between urban and rural areas in enhancing the city's resilience.

Keywords: *AHP; flood; nature-based solutions*

INTRODUCTION

The threat of climate change complicates various urban problems that currently cover many cities worldwide. As a provincial capital located on the coast, Jayapura City plays a vital role as the center of government and economic activity in the easternmost region of Indonesia. The higher level of urbanization marked by increasing economic growth and population (BPS, 2021) has created a positive growth trend in economic areas and new settlements in Jayapura City. However, along with rapid urbanization, the threat of disasters such as landslides and floods is also increasing, especially in the area that was initially a water catchment or swamp. For example, the flash flood incident in the Sentani area in 2019 resulted in the loss of access to Jayapura City (Setyawan, 2022).

Several approaches have been developed to overcome flooding in Jayapura City. Studies related to efforts to increase drainage capacity and develop water storage ponds have been carried out by the Papua River Basin Agency (Balai Wilayah Sungai - BWS). There are also efforts to maintain and protect the Cycloop forest area under the supervision of the Jayapura city government. However, as the risk of flooding in the future increases due to the impact of climate change, alternative solutions that can better adapt to dynamic conditions and provide additional benefits (co-benefits) are required. In its development, alternative approaches using nature, commonly referred to as nature-based solutions (NbS), have been widely adopted to help solve various socio-environmental problems, including flooding.

Various studies related to NbS for flood mitigation found that the opportunity for NbS adoption was strongly influenced by various factors surrounding the adoption destination area, including environmental, socio-cultural, and economic factors. This study aims to identify various factors influencing the suitability level of NbS adoption, and potential locations, and to assess urban-rural linkage in improving the water resilience of Jayapura using Multi Criteria Decision Analysis (MCDA). The result will be visualized to compile a suitability map of NbS adoption locations using a geographic information system tool.

MATERIAL AND METHODS

This study used the Analytical Hierarchy Process (AHP), a Multi-Criteria Decision Analysis (MCDA) approach, to provide an assessment or scoring to each reclassified factor and then rank it according to its level of importance. There are three steps to assess the NbS suitability for flood mitigation in this study. In the first step, the suitable NbS measures are selected based on the study area characteristics.

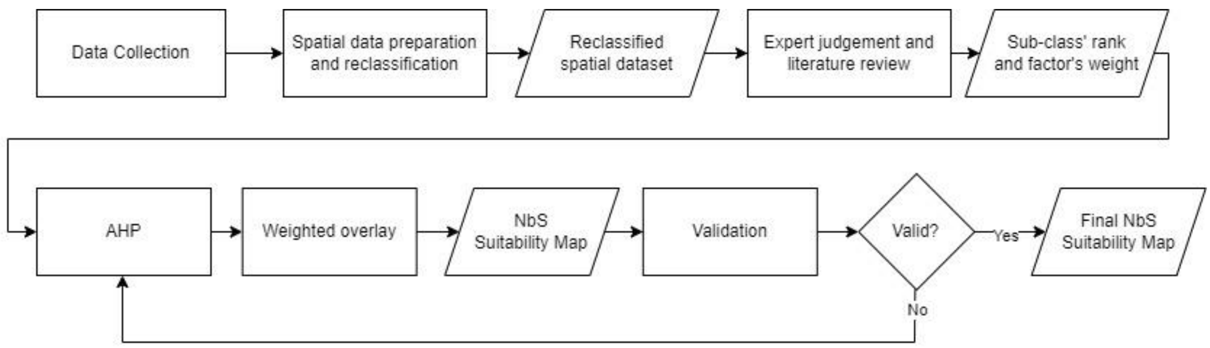

Figure 1. Flowchart of NbS suitability mapping

Second, AHP method is utilized to summarize the NbS measures' influencing factors and suitability level visualization using *weighted overlay* on Geographic Information System (GIS) tools, which in this study is ArcMap 10.8.2. Finally, an analysis is performed on the NbS adoption suitability map results to identify areas with the highest priority level for implementing NbS adoption. The NbS suitability map is generated as described in Figure 1.

Study Area

Jayapura City is the capital of Papua Province. Jayapura occupies an area of 940 km^2 and consists of five districts: North Jayapura, South Jayapura, Heram, Abepura, and Muara Tami (Figure 2). According to the 2020 census, Jayapura is populated by 300,192 people, making the city population density 319 people per square kilometer (Badan Pusat Statistik Kota Jayapura, n.d.). Jayapura city has a varied topography, with extreme slopes next to plains and many swamps. These unique characteristics expose the city to a higher risk of floods, including flash floods and landslides (Gokkon, 2019).

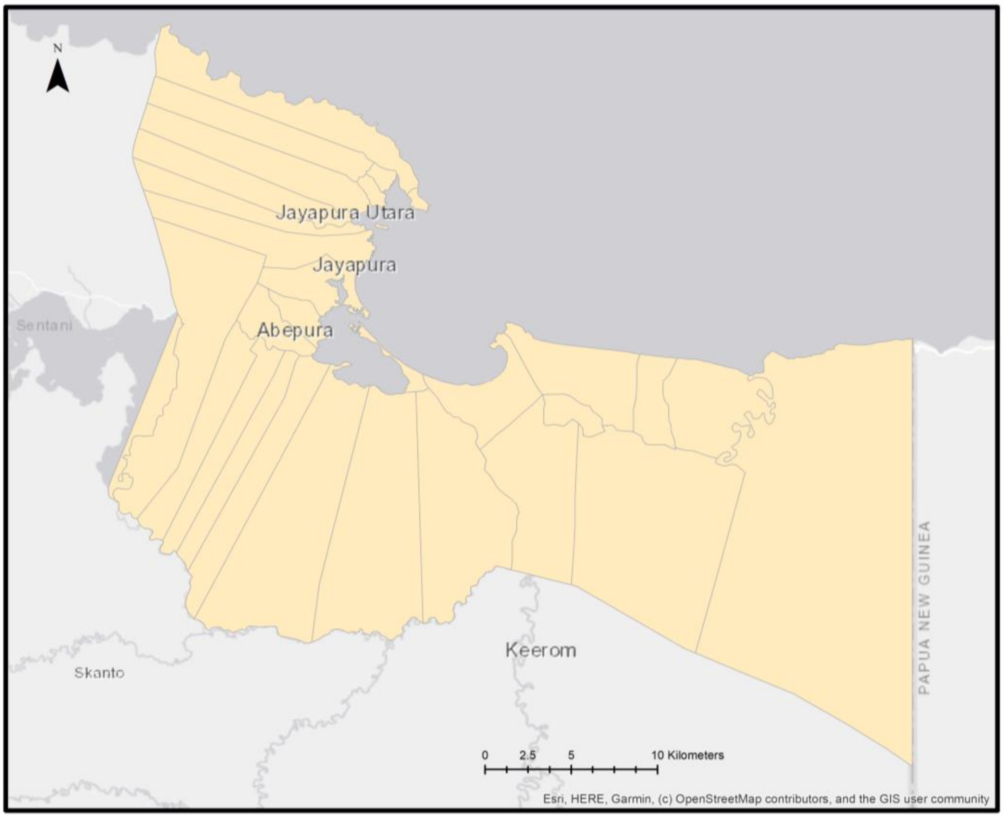

Figure 2. Jayapura City

Land use/ land cover conversion from forests into urban areas increases the flood risk. In Jayapura's case, land clearing and conversion into settlement areas in the Cycloop mountain area, the loss of water catchment areas, and extreme weather have been accused as one of the causes of flood in Jayapura (Martha A. Patoding et al., 2022).

Datasets

Six factors represent various influencing factors in adopting NbS for flood mitigation in Jayapura. Those data were collected and processed to be analyzed based on the rankings resulting from the AHP method. All six data were obtained from various sources, then reclassified, and converted into raster format with a spatial resolution of 10 x 10 meters.

Surface runoff

Surface runoff data was produced through the SCS Curve Number calculation method. This method was based on the assumption that soil types and land use/land covers will affect the amount of generated surface runoff. Therefore, to generate surface runoff data, the land cover and soil type were classified to obtain each data class's curve number value (Cronshey et al., 1985). The second step was carried out by calculating the potential maximum retention value (S) in the study area. In the third step, using the average daily rainfall data (P), the surface runoff (Q) was calculated from rainfall data and the potential retention data. The rainfall data was obtained from the Meteorological, Climatological, and Geophysical Agency.

Slope

In assessing the suitability of a location with the NbS approach, especially one that also involves residents' activities, the slope has an influence that should be considered because of its relation to soil stability. Slopes with extreme slopes are more prone to erosion and landslides and can trigger an increased risk of flooding. DEM data from DEMNAS was processed to produce a slope map.

Land use/ land cover

LULC data was generated from Sentinel-2 imagery from the European Space Agency (ESA) with a spatial resolution of 10 meters and processed on Google Earth Engine. LULC in this study was reclassified into six classes: water body, urban area, forest, open-field high vegetation, open-filed low vegetation, and wetland. Anthropogenic activities can cause land cover conversion, potentially increasing impervious surfaces. The infiltration capacity variability of different land cover features affects their ability to regulate floods (Bett et al., 2021).

Spatial zoning

Spatial zoning in this study represents the existing government's area master plans. This study's spatial zoning data source is the Regional Spatial Plan (*RTRW - Rencana Tata Ruang Wilayah*) 2013 of Jayapura City. The spatial zoning data was reclassified into nine classes: blue zone, green zone, housing zone, protected zone, government zone, industrial zone, public and social service zone, office and trade zone, and mixed zone.

Tree cover

Vegetation provides essential benefits in flood prevention as it enhances infiltration capacity and increases evapotranspiration, and its higher surface roughness reduces flood travel time (Kuriqi and Hysa, 2021). Therefore, including tree cover information is essential in identifying areas with higher flood risk and suitable for NbS adoption. Tree cover ratio data was processed through two main stages. In the first stage, tree cover classification was conducted using remote sensing from Sentinel 2 satellite imagery in 2021. Then, Normalized Difference Vegetation Index (NDVI) was used to identify the density of vegetation in the study area and is classified into five classes.

Building Density

Building density data represents the area's urbanization level or population density that will affect the suitability and effectiveness of NbS elements to be planned (Bona et al., 2022). Information on built-up areas is also important since the NbS implementation as hybrid infrastructure in urban areas requires an existing physical infrastructure. The Normalized Difference Built-Up Index (NDBI) represents building density in this study.

Table 1. NbS characteristic and suitability criteria

NbS measures	Area's characteristic	Intervention scale	Function	Suitability Criteria
Landscape restoration	Upstream, rural to mixed urban-rural area, along river stream	• Bigger area • Long term	• Return the water infiltration area function, reduce runoff potency, and manage groundwater and surface water quality	• High surface runoff • Close to the river • Low tree cover
Water storage pond	Urban area	• Small to medium area • Short to medium term	• Collect water surface with high impermeability and support water infiltration to the ground • Reduce peak flow load in the occurrence of constant rainfall with high-intensity • co-benefits as open space and recreational area	• High surface runoff • High building density • Match to land use zonation
Multifunction green open space	Urban area	• Small to medium area • Short to medium term	• Utilizing the park as an existing space in the urban area with an additional function as a retention area • Co-benefits as open space and recreation	• Existing open space • Match land use zonation • Low tree cover • High population density

NbS Measures

The NbS approach selection used in this study was based on several criteria, namely the characteristics of the target location, the benefits of NbS, and the intervention scale. The location suitability criteria were formulated to obtain the general characteristics of the areas considered suitable for adopting the selected NbS approach. The criteria are based on the relationship between the basic functions of each chosen NbS approach and the various factors identified previously. Table 1 summarizes the basic functions and the suitability criteria for selected NbS measures.

NbS Suitability Mapping using AHP

The AHP approach, as part of a multi-criteria analysis, was used to rank the importance and relative weights of the factors used in the study. The AHP approach involves three main stages: (1) constructing the criteria's hierarchical sequence, (2) pairwise comparison between factors, and (3) evaluating ranking consistency. The process of constructing the criteria's hierarchical sequence was carried out by assigning priority values to each factor sub-class based on the level of influence and suitability for the selected NbS measure from a scale of 1 (very low) to 5 (very high). Secondly, pairwise comparison was done by giving weights between factors that indicate the level of importance between. In the pairwise comparison stage, Fundamental Values (FV) are the final values representing the weighting between factors. In the third stage, the Consistency Index (CI) and Consistency Ratio (CR) were calculated to evaluate the weights and rankings consistency between factors.

$$CI = \frac{(\lambda_{max-n})}{n-1} \quad \text{(Equation 1)}$$

$$CR = \frac{CI}{RI} \quad \text{(Equation 2)}$$

If the CR is lower than 0.1, then the AHP process is considered reasonable. Otherwise, the AHP process needs to be reviewed. All factors given weights and ratings will then be mapped using the help of the weighted overlay tool in ArcGIS Pro software for each of the selected NbS approaches.

Validation

The area under the curve (AUC) is used to assess model prediction accuracy and is commonly used in suitability mapping analysis (Saha et al., 2023). There are 150 random points generated and distributed in the study area for interpretation based on image data. The suitability results' accuracy level is assessed based on the AUC score in the range of 0 (100% of the model predictions are not appropriate) to 1 (100% of the model predictions are appropriate).

RESULTS

Factors Weight in NbS Adoption

Weight between factors was assigned by pairwise comparison method. Each factor has been given a weighting value, which represents the level of importance of that factor over other factors. Consistency Ratio (CR) values were calculated for the three NbS approaches with respective results of 0.06 (landscape restoration), 0.08 (water storage pond), and 0.05 (multifunction GOS). These three CRs indicate that the weighting for each factor is appropriate and remains within reasonable consistency limits. Based on Table 2, the dominant influencing factors of each NbS intervention can be identified.

In landscape restoration result, land use has the highest FV score (32), followed by spatial zoning (24) and surface runoff (16). It was identified by a previous study (Schulz and Scröder, 2017) that existing land use factors, particularly the historical and existing presence of forest areas, are the main factors in determining restoration areas. In other studies related to forest restoration, land use is also a determining factor in filtering the most suitable areas (Chen et al., 2021).

Table 2. Fundamental Values Between Nbs Adoption Suitability Factors

Variable	Fundamental Value		
	Landscape restoration	Water storage pond	Multifunction green open space
Slope	11	10	17
Surface runoff	16	24	24
LULC	32	31	33
Tree cover (NDVI)	12	5	5
Building density	5	7	6
Spatial zoning	24	23	15

The factors with the highest FV scores in water storage ponds are land use (31), surface runoff (24), and spatial zoning (23). Urban areas, open-field, and highly populated areas have a high potential to be selected as water storage pond locations because water storage ponds can also provide additional functions for public activities, such as recreation. Based on its function to collect water in areas with low water absorption, the construction of water storage ponds is prioritized in areas with high surface runoff.

Three factors with the highest weight in multifunction GOS are land use (34), surface runoff (34), and slope (17). Urban areas and open-field low vegetation are suitable location criteria for multifunctional GOS criteria, which prioritizes areas with high building density since it utilizes existing parks in urban areas so that they can provide additional functions, such as recreational functions.

In all three NbS options, land use, surface runoff, spatial zoning, and slope have higher FV scores than other factors, which shows the dominance of biophysical factors in determining the suitability of NbS adoption. In Jayapura City, the slope is an important factor in determining a suitable NbS location since the topography is dominated by steep slopes, even in urban areas. The slope, related to soil stability, is a factor that should be considered, especially in multifunction GOS interventions where community activities are involved, and their safety has to be ensured.

Suitability Map of NbS Measures

The analysis result shows that, in general, the suitable areas of NbS adoption are distributed following the location criteria listed in Table 1. The suitability maps of NbS measures and their suitability class area are shown in Fig. 3 and Table 3, respectively.

Landscape restoration is associated with green areas, either forest or open fields with high vegetation, located relatively far from settlements. As much as 75.75% of the Jayapura City area is highly suitable for landscape restoration interventions, especially in existing forest areas and spatial zoning for green and protected zones. In contrast, areas with low suitability are generally distributed in settlement areas with high building density.

On the water storage pond suitability map, 70.26% of the total area of Jayapura City is included in the moderate suitability class. High and very high suitability only covers 8.31% and 0.04% of the total study area, distributed in urban areas and open fields with low vegetation, which is flat and has high surface runoff. This result fits the purpose of water storage ponds in reducing the inundation potential in areas with high runoff where the surface is impermeable. Its proximity to residential areas allows it to be a recreational facility.

Table 3. Comparison of area for each suitability level

NbS Measure	Suitability class	Total Area	
		Hectare (Ha)	Precentage (%)
Landscape restoration	Very low	9.67	0.01
	Low	3446.81	3.81
	Moderate	18471.42	20.41
	High	68570.63	75.75
	Very high	21.62	0.02
Water storage pond	Very low	0.62	0.00
	Low	19367.09	21.40
	Moderate	63596.21	70.26
	High	7522.73	8.31
	Very high	33.50	0.04
Multifunction GOS	Very low	11.21	0.01
	Low	65279.29	72.12
	Moderate	15580.14	17.21
	High	9539.55	10.54
	Very high	109.96	0.12

Multifunctional GOS is intended to add the benefits of the existing green open spaces to store runoff water. The study area was dominated by low and moderate suitability classes, 72.12% and 17.21% of the total study area. The high and very high suitability classes only cover 10.54% and 0.12% of the total area, spread over urban areas with low tree cover.

Validation

The validation process shows that Area Under the Curve (AUC) for landscape restoration, water storage ponds, and multifunction green open space are 0.893, 0.894, and 0.881, respectively. The validation outcomes, as determined through the AUC, indicate good results achieved in the performed suitability analysis.

DISCUSSION

The suitability maps show the distribution pattern difference for each NbS measure (Figure 3). At the same time, cumulatively, it also shows the distribution of potential locations to implement NbS spread throughout the study area. The high-suitability location of landscape restoration is distributed in non-urban areas, where the building density is considerably low. On the other hand, water storage ponds and multifunction GOS have higher suitability in more densely populated and developed city areas. AUC scores validated the performance of the suitability model to predict and determine the most preferred location to be developed for the selected NbS measures.

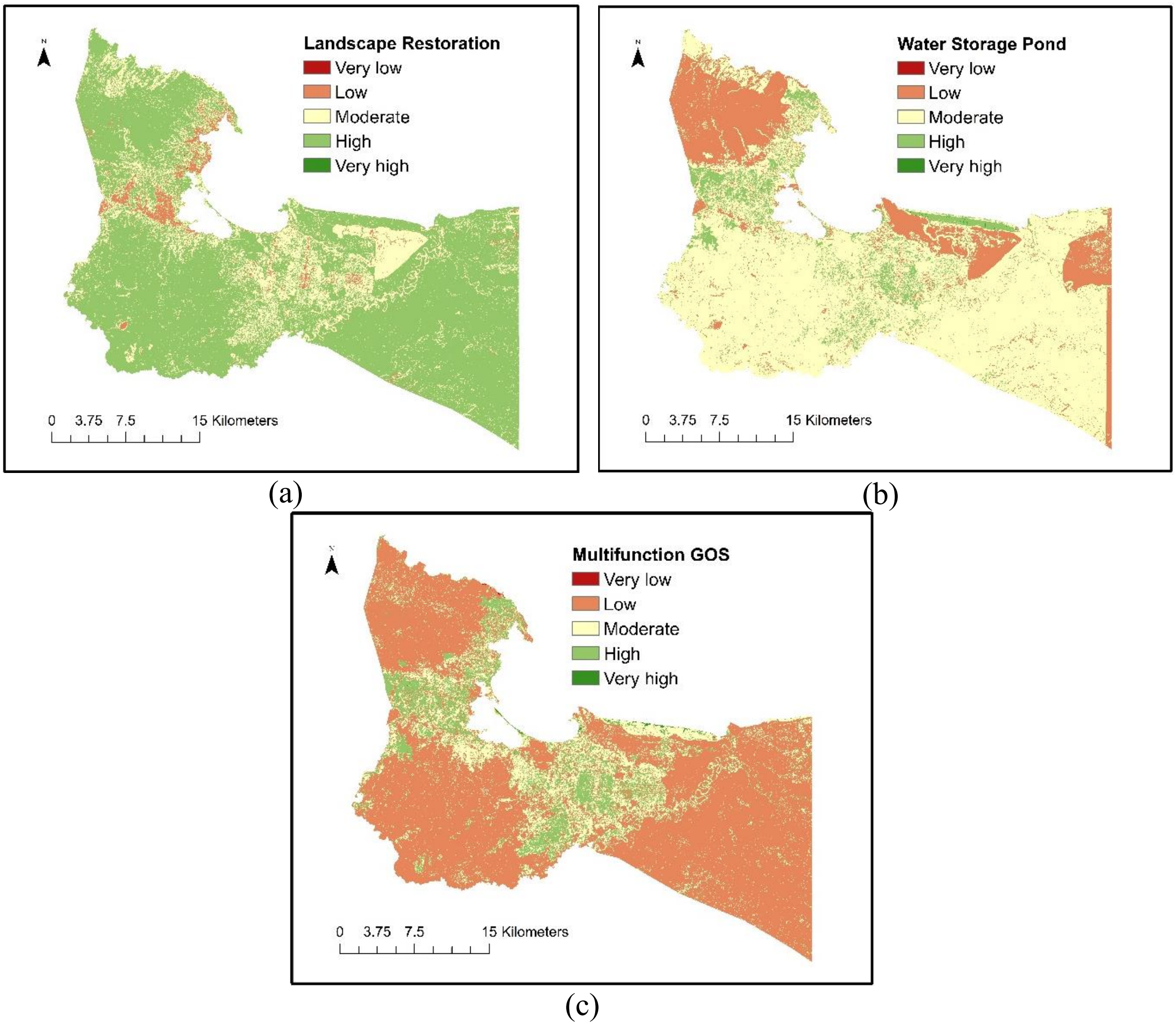

Figure 3. NbS suitability maps

A water storage pond is a small-scale NbS adoption targeted for dense urban areas. The primary function of a water storage pond is to capture and retain runoff during storms. Water storage ponds can be a combination of rainwater harvesting facilities, permeable pavements, rain gardens, etc. It can be designed to be integrated into existing physical or gray infrastructure to increase its water storage capacity in urban areas.

The ideal implementation of multifunction green open space is to add benefit or function to existing public open space in urban areas. It works as small and local scale NbS to retain water temporarily. A multifunction green open space combines different NbS elements, including a water storage pond. Besides reducing flood risk and improving water resource management, multifunction open green space provides other benefits, including improving water quality, removing pollutants in runoff water, and improving the community's well-being (Hamel and Tan, 2021).

Alternatively, landscape restoration is considered a large-scale NbS that can support flood reduction over a longer period. Landscape restoration, such as reforestation and revegetation efforts, will increase water storage capacity to distribute the water more evenly in a watershed. In addition to that, landscape restoration adoption also improves ecological function. The suitable locations for landscape restoration are mainly found in the upstream area, which is considered a rural area (Ruangpan et al., 2020).

In water resources management and flood reduction efforts, urban and rural areas are interconnected through river networks or watersheds (Kabisch et al., 2022). Hence, change in rural areas will affect the urban areas. Rapid development due to population growth and urbanization in Jayapura dominates the coastal or downstream area, heightening the risk of natural disasters such as floods and landslides. With the decreasing available space in the existing urban area, the forests in the upstream area are under threat of being converted into open fields and urban areas to accommodate space demand for development. When this happens, the disaster risk increases even more.

This study shows that Jayapura has potential locations for nature-based solution implementation in urban and rural areas. By restoring natural vegetation and increasing vegetation cover, landscape restoration helps to enhance the infiltration capacity of the soil, reducing the amount of runoff and slowing down the water flow. This process allows for better water storage within the landscape, reducing the risk of floods and improving water availability in the watershed. In urban areas, implementing multifunction green open spaces and water storage ponds targets flood reduction on a local scale. Building a city's resilience is a collective effort encompassing both urban and rural areas.

CONCLUSION

Urban challenges such as floods and landslides in Jayapura require attention and efforts to resolve them according to the city's character. The nature-based solution approach is a more adaptive flood mitigation alternative in facing the threat of flooding. There are various factors influence the selection of NbS measures and suitability identification. Based on the method used in this study, the suitability of NbS is strongly influenced by land cover/ land use, surface runoff, and spatial zoning. Apart from that, the unique topography character of Jayapura City with varying slopes is an essential factor in determining the suitability of NbS due to the threat of landslides in several areas.

The potential locations to develop Nature-based Solutions are distributed in the entire study area, according to the specific role of the applied approach. Water storage ponds and multipurpose green open spaces suit more urbanized areas, while landscape restoration is for less urbanized areas. Therefore, maintaining and restoring the rural areas and improving water storage capacity are crucial to reducing flood risk in Jayapura City. The linkage between NbS in urban and rural areas is significant, highlighting the importance of implementing NbS that is more adaptable and flexible to climate change to improve water resource management and mitigate the impact of natural disasters.

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