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WATERSHED MANAGEMENT APPROACH AS AN ALTERNATIVE SOLUTION FOR FLOOD PROBLEM IN NORTHERN PART OF CENTRAL JAVA

(*Pendekatan Pengelolaan DAS Sebagai Alternatif Solusi Masalah Banjir di Jawa Tengah Utara*)

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ABSTRACT

The flood disaster in northern Central Java was caused by rainfall, the influence of tidal surges, and ground subsidence in various sites. This study aims to give alternative solutions to flood control in Central Java watersheds draining to the north coast. By identifying the flood water discharge areas, the amount of runoff causing flooding can be reduced. By overlaying maps of floodwater discharge, land cover, degraded land, and forest functions, 12 recommendations of forests and land rehabilitation (RHL) are obtained, suited to the area's concerns. The recommendations are planned only for the areas with vulnerable and highly vulnerable to floodwater discharge, so priority is given to activities that incorporate runoff into the ground as much as possible to reduce the flood volume. The RHL is grouped into the enrichment of plants in open areas with the function of forest areas, enhancing terraces to reduce erosion, increasing soil fertility, and constructing infiltration wells or bio pores. Of the 31 regencies/cities whose rivers flow into the north coast, there are 5 (five) regencies/cities whose RHL recommendations are applied to more than 50% of the area, namely Salatiga City (99%), Semarang district/city (76%), Jepara Regency (71%), Pekalongan Regency (55%), and Brebes Regency (51%).

Keywords: Flood vulnerability, land rehabilitation activities, flood disaster

ABSTRAK

Bencana banjir di Jawa Tengah bagian utara disebabkan oleh curah hujan, pengaruh gelombang pasang, dan penurunan muka tanah di berbagai lokasi. Penelitian ini bertujuan untuk memberikan alternatif solusi pengendalian banjir di DAS Jawa Tengah yang bermuara di pantai utara. Dengan mengidentifikasi daerah debit air banjir, jumlah limpasan yang menyebabkan banjir dapat dikurangi. Dengan overlay peta debit air banjir, tutupan lahan, lahan terdegradasi, dan fungsi hutan, diperoleh 12 rekomendasi rehabilitasi hutan dan lahan

(RHL) yang sesuai dengan kepentingan kawasan. Rekomendasi RHL hanya direncanakan untuk daerah yang rawan dan sangat rentan terhadap debit air banjir, sehingga prioritas diberikan pada kegiatan yang sedapat mungkin memasukkan limpasan ke dalam tanah untuk mengurangi volume banjir. RHL dikelompokkan menjadi pengayaan tanaman di areal terbuka dengan fungsi kawasan hutan, peninggian terasering untuk mengurangi erosi, peningkatan kesuburan tanah, dan pembuatan sumur resapan atau biopori. Dari 31 kabupaten/kota yang sungainya bermuara di pantai utara, terdapat 5 (lima) kabupaten/kota yang rekomendasi RHL diterapkan lebih dari 50% wilayahnya, yaitu Kota Salatiga (99%), Kabupaten/Kota Semarang (76%), Kabupaten Jepara (71%), Kabupaten Pekalongan(55%), Kabupaten Brebes (51%).

Kata kunci: Kerentanan banjir, kegiatan rehabilitasi lahan, bencana banjir

I. INTRODUCTION

Flooding has been a problem on Java Island for generations, especially after heavy rainstorms (Asdak et al., 2018). The mass media and institutional website reported 2,123 flood events on the northern coast of Central Java from 2009 to 2018 (Handayani et al., 2020). A mix of factors usually causes floods in cities. Both rural and urban settlements are susceptible to the same forces of nature, but urban settlements are worsened (Handayani et al., 2020; Pramono, 2021; Rudiarto et al., 2018). When the drainage or artificial system fails, coastal high tides, fluvial and groundwater flows can cause flooding in urban areas (Jha et al., 2012). Flood conditions in urban areas are caused by heavy rainfall (i.e., climate change effect), exacerbated by tidal flooding (Rudiarto et al., 2018), and land subsidence along the northern coast of Java (Abidin et al., 2013; Andreas et al., 2017; Gumilar et al., 2013).

Flood control policies have been issued to reduce the flood risk on the northern coast of Central Java (Handayani et al., 2019). For example, in Semarang coastal area, structural and non-structural methods for controlling coastal flooding have been implemented, including dykes, drainage systems, pump stations, polder systems, coastal-land reclamations, coastal planning and management, public education, and the establishment of an institutional framework for disaster management (Marfai & King, 2008). In Pemalang, mitigation of non-structural river overflows in the downstream Comal Watershed includes spatial planning following land use management in the Comal Watershed, detection and prediction of the Comal River's discharge conditions through recording and observing hydrometeorological data, riverbank area management planning, disaster literacy in schools and communities, and improvement of the Comal River's discharge conditions (Wibowo et al., 2019).

Water flows regardless of administrative jurisdictions; however, the use of spatial planning (i.e., land use policy) to regulate urbanization is analyzed in terms of administrative jurisdiction. In Indonesia, a river basin frequently encompasses many administrative boundaries or local government agencies.

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This implies that multiple parties may manage a river basin. Such conditions make land-use planning and developing river management control systems difficult (Handayani et al., 2020). Flood risk reduction for cities as political or economic units must consider a variety of sizes, including the river and water catchment as a whole. This is because the source of flooding may be some distance away from the impacted receptor, for example, a town or city. As a result, the best solution may be to address the flooding before entering the urban environment (Jha et al., 2012). Because flooding is caused, among other things, by surface runoff, flood reduction can be done by suppressing the occurrence of surface runoff (Ahiablame & Shakya, 2016). One way to reduce runoff is to introduce as much water into the soil as possible through soil and water conservation measures such as beaver dams, woody debris or riparian (Paimin et al., 2012; Wilkinson et al., 2010).

This paper is a desk study that aims to provide some alternative solutions for reducing flood risk through soil and water conservation activities in accordance with the physical conditions of the existing land. The analysis is based on the watershed as the unit analysis that depends on its typology (Paimin et al., 2012; Pramono & Putra, 2017). However, the land rehabilitation recommendations are presented by the village so that each village will find it easier to plan and implement them.

II. METHODS

A. Study Site

We conducted our study from January to June 2021. Our research area is in the northern part of Central Java Province (see Figure 1), and it comprises four river basins. The presence of arterial and toll roads in the northern corridor is a significant infrastructural boost that has aided the region's rapid economic development (Marpaung et al., 2021). As a result, several developing challenges to river basin functions are mostly caused by unrestrained population increase (Handayani et al., 2020). As forest and agricultural lands are converted to population and industrial zones, such growth leads to a loss in non-built-up areas.

The river basins of Pemali-Comal, Bodri-Kuto, Wiso-Gelis, and Jratunseluna have a combined area of 1,690,708 ha and cut through four cities (Tegal, Pekalongan, Semarang, and Salatiga), and 17 regencies (Brebes, Tegal, Pemalang, Pekalongan, Batang, Kendal, Temanggung, Demak, Jepara, Kudus, Pati, Rembang, Blora, Grobogan, Sragen, Boyolali, and Semarang) (Figure 2). Each of those river basins consists of more than one watershed, some are large, but most of them are small watersheds. Pemali-Comal river basin consists of 35 watersheds, Bodri-Kuto 9 watersheds, Wiso-Gelis 20 watersheds, and the largest one, Jratunseluana, consists of 42 watersheds.

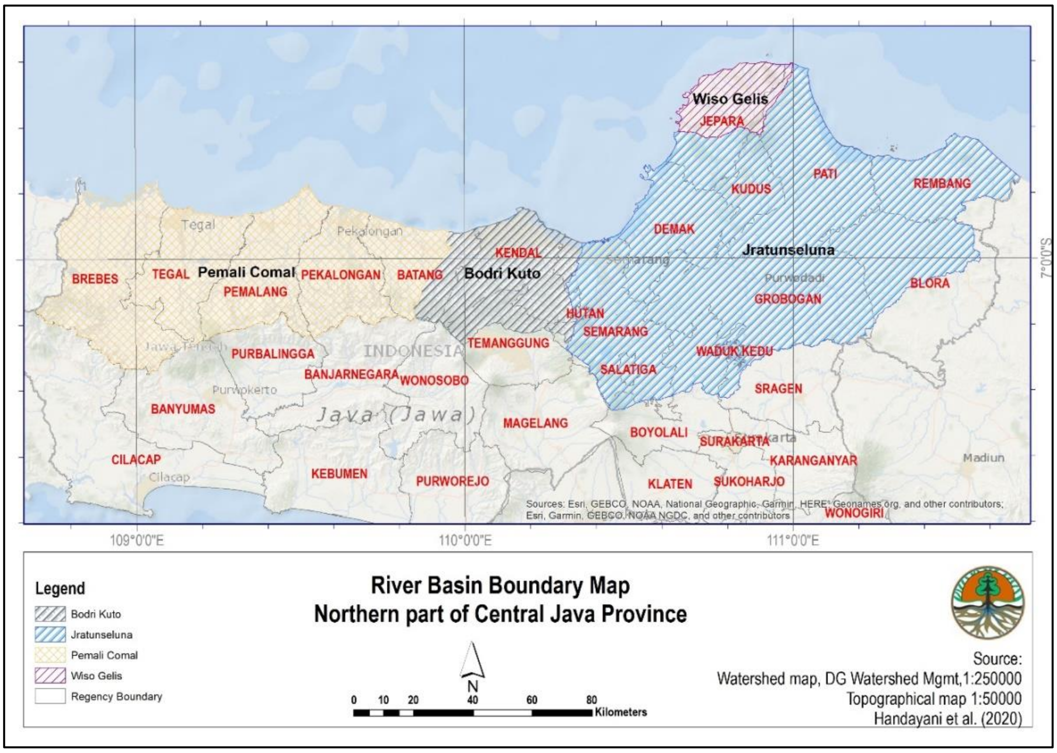

Figure 1. Study area

B. Materials

The material used in this study was daily rainfall data which is satellite-based precipitation, downloaded from CHIRPS (Climate Hazards Group InfraRed Precipitation with Station https://www.chc.ucsb.edu/data/chirps) from 2000 – 2019. We use data provided by CHIRPS because some studies showed that precipitation data provided by CHIRPS is reliable for Java Island (Faisol et al., 2020; Wahyuni et al., 2021). Based on the rainfall data, the average maximum daily rainfall was determined for 20 years, which was used to determine the distribution of flood supplies. The maps used for this study can be seen in Table 1.

Table 1. Information about maps and data used in this study

Thematic map	Map owner	Year produced	Scale
Land cover	Directorate General of Forestry Planning and Environmental Management, MoEF	2018	1:250.000
Designated forest function	Directorate General of Forestry Planning and Environmental Management, MoEF	2018	1:250.000
Degraded land	Directorate General of Watershed Control and Protected Forest, MoEF	2018	1:250.000
Land system	Geospatial Information Agency	1988	1:250.000
Land Use Capability	Watershed Management Technology Center, MoEF	2000	1:250.000
Topography	Geospatial Information Agency	2014	1:250.000

C. Method

This research was a desk study carried out in all watersheds that flow towards the north coast in Central Java Province. Areas that cause flooding downstream are called floodwater discharge areas (Nurlina et al., 2014; Paimin et al., 2012; Pramono & Putra, 2017). The criteria for floodwater discharge vulnerability areas were land with high erosion vulnerability and precipitation (Paimin et al., 2012). The spatial distribution of floodwater discharge was done by overlaying land systems, land cover, and the maximum daily average rainfall maps (The details of how to determine the floodwater discharge vulnerability is presented in Appendix 1-3). The floodwater discharge was divided into 5 (five) vulnerability classes (see Appendix 3), ranging from "not vulnerable" to "very vulnerable." The "not vulnerable" class indicates that the location does not produce surface runoff that can contribute to flooding in the downstream watershed area, while the "highly vulnerable" location, usually in the upstream watershed, has large runoff and open land cover. This "very vulnerable" location contributes to the large flow that causes flooding. On the other hand, areas that always experience flooding are floodplain areas, so drainage maintenance becomes a mandatory activity. Floodplain areas are usually located downstream of the watershed and are affected by tidal waves.

The land vulnerability map was obtained by overlaying land cover and land system. A new code resulting from the overlay process is given for each land unit according to Appendix 2. The same method is also used to determine the floodwater discharge vulnerability (see Appendix 3).

Determination of vulnerability to floodwater discharge obtained from Paimin et al. (2012), while the recommendations are based on the availability of thematic maps, namely: current land cover, land use capability, designated forest function, degraded land, and vulnerability to floodwater discharge. Each thematic map shows the limiting factors that were important in the selection of RHL. Land degradation maps are used to prioritize areas to be rehabilitated, while land use capability map was used to select RHL activities according to their capability classes. Maps of land cover and forest function are used to determine the type of RHL that is in line with current conditions. In general, the recommendation of RHL is to put as much water as possible into the soil through soil and water conservation measures. Some of these provisions are: enrichment planting that will be carried out in the forest area with high land capability class and the current land use is not a plantation forest, and infiltration wells in residential areas. The flowchart to determine the forest and land rehabilitation recommendation is presented in Figure 2.

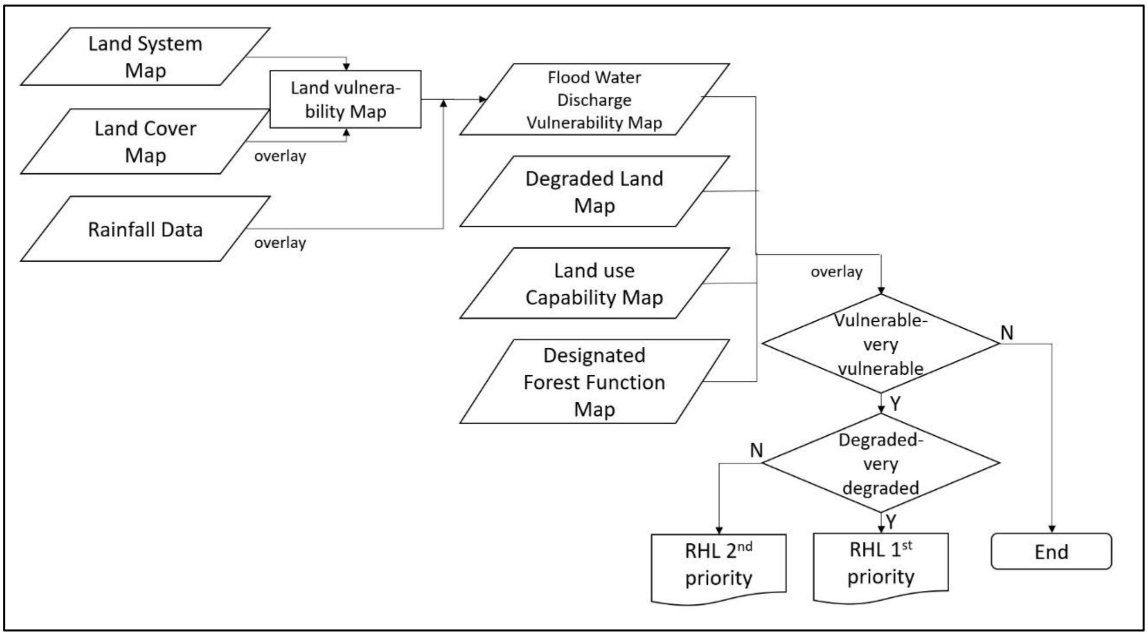

Figure 2. The determination of forest and land rehabilitation/*Rehabilitasi Hutan dan Lahan* (RHL) recommendations
Source: Modified from Paimin et al. (2012)

III. RESULTS AND DISCUSSION

A. Flood-Prone Area

The flood-prone area is often called a flood plain and is determined by the land system (Paimin et al., 2012), which is swamps, beaches, and meanders. Based on the criteria made by Paimin et al. (2012), flood-prone areas are generally located downstream of the watershed, so the mitigation that can be done is by improving drainage. In addition, flooding that occurs in floodplains can be exacerbated when exposed to tidal waves or inundation. The distribution of the flood-prone areas is presented in Table 2 and Figure 3.

Table 2. Distribution of flood-prone areas (flood plains) in the northern part of Central Java

Vulnerability Class	Area (ha)	Percentage (%)
Not vulnerable	453,605	26.8
Slightly vulnerable	92,783	5.5
Moderately vulnerable	587,624	34.8
Vulnerable	34,364	2.0
Very vulnerable	522,332	30.9

Source: Data analysis, 2021

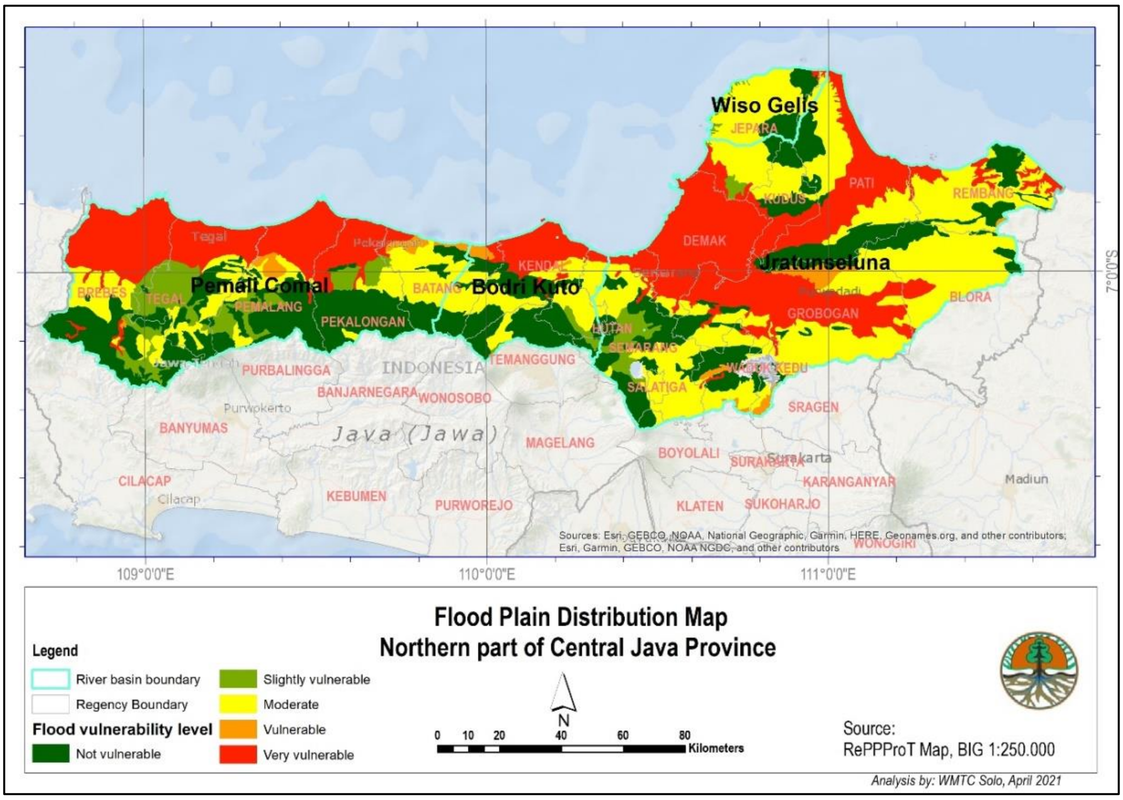

Figure 3. Flood prone area in the northern part of Central Java
Source: Data analysis, 2021

The flood-prone areas with "very vulnerable" criteria are 522,332 ha (30.9% of the total area) spread mainly along the plains in the north of Central Java Province. These areas are plains with flat slopes, which are mainly located in coastal and swamps land systems. In addition, alluvial plains and alluvial valleys are also prone to flooding. Flood-prone areas with very vulnerable criteria are located in the watersheds of Pemali-Comal, Bodri-Kuto, and Jratunseluna river basins. However, due to the relatively hilly land system with few plains, "very vulnerable" and "vulnerable" classes are not found in Wiso Gelis river basin. The lowest class of Wiso Gelis river basin is "moderately vulnerable" in the coastal area. In coastal areas, flood-prone conditions are also exacerbated by soil subsidence (Abidin et al., 2013; Andreas et al., 2017) and high rainfall due to climate change (Rudiarto et al., 2018). The flood-prone area determined in this study is relatively less detailed than that studied by Setyani and Saputra (2016) because our study is for a regional scale (Central Java Province).

B. Flood water Discharge Area

Flooding that occurred in the research area was caused by the combination of rain and the land condition (Paimin et al., 2012). A flood discharge area is an upstream water catchment area that provides a floodwater supply to the downstream. With the same land cover and rainfall intensity, upstream will produce a larger surface runoff than downstream area.

Parameters that determine vulnerability to floodwater discharge area are land systems (i.e., representing landscape and land cover that can describe the possibility of erosion) and maximum daily rainfall (Paimin et al., 2012). The results of the overlaying of the three maps show the areas that have potential as floodwater discharge areas. This information is needed to determine the locations with flood discharges potential throughout the Northern Central Java Province, which requires forest and land rehabilitation activities (Table 3).

Regarding the reduction of floodwater discharge, Pramono et al. (2001) analyzed the effectiveness of various water conservation measures in the upstream and middle watershed areas such as water traps in forest areas, check dam and retaining dam on agricultural areas, infiltration wells in settlements and infiltration ponds in industrial and office areas. Table 4 shows the construction of infiltration wells, biopore, water traps, retaining and check dams as well as intensifying the existing infiltration ponds in the upper and middle part of Ciliwung that reduce the flood volume of Jakarta by 34.39%, and the funds required (11 trillion rupiahs)

Table 3. Area for land and forest rehabilitation to reduce surface runoff (in ha)

Regency/City	Not vulnerable	Slightly vulnerable	Moderately vulnerable	Vulnerable	Very vulnerable
1. Banjarnegara			89.5	431.3	5.6
2. Banyumas			87.3	77.5	15.1
3. Batang	429.9	26,410.6	26,707.8	28,856.0	3,851.3
4. Blora	266.9	26,161.2	44,731.1	25,948.5	973.7
5. Boyolali	3,061.7	6,194.9	8,655.8	27,088.6	2,172.2
6. Brebes	14,399.9	64,117.0	26,605.8	57,654.7	7,241.5
7. Cilacap			11.0	197.1	
8. Demak	12,662.6	85,224.7	541.1	1,945.8	101.4
9. Grobogan	9,747.5	144,559.9	23,953.4	25,272.4	2,066.7
10. Jepara	2,305.4	18,343.3	12,648.1	56,234.4	8,121.2
11. Karanganyar					
12. Kebumen					
13. Kendal	6,079.0	44,102.7	15,268.7	34,451.9	1,397.4
14. Klaten					
15. Kudus	2.5	14,104.5	5,072.6	15,697.3	8,818.2
16. Magelang			14.3	45.6	
17. Pati	13,783.6	57,734.5	23,367.7	52,409.5	10,900.2
18. Pekalongan	1,812.7	28,447.6	21,792.8	38,931.2	3,236.0
19. Pemalang	3,618.1	38,525.7	8,612.3	52,000.3	10,986.2
20. Purbalingga			21.8	472.7	125.7
21. Purworejo					
22. Rembang	2,435.3	21,288.8	40,975.7	26,625.4	1,523.0
23. Salatiga		86.2	2,480.4	6,328.6	33.4
24. Semarang	5,519.6	20,023.9	32,590.1	66,860.7	10,332.1
25. Sragen	1,890.6	279.3	4,139.2	5,433.5	103.4
26. Sukoharjo					
27. Surakarta					
28. Tegal	1,860.7	34,455.9	7,580.8	45,803.5	3,732.4
29. Temanggung	18.9	4,380.4	2,037.4	23,026.9	653.0
30. Wonogiri					
31. Wonosobo				10.6	

Source: Data Analysis, 2021

Table 4. Type, volume, effectiveness and cost of water conservation measures in upper and middle part of Ciliwung Watershed

Water conservation measures	Volume (unit)	Effectiveness (%)	Cost (x Rp. million)
1. Infiltration well	3,719,148.0	32.3	11,157,444.0
2. Infiltration ponds (Bogor and Depok cities, Bogor regency)	60.0	1.5	-
3. Biopore	53,131,000.0	0.4	531,310.0
4. Check dam	101.0	0.1	19,761.8
5. Water traps	84,251.0	0.0	379.1
6. Ponds in agricultural area	18,270.0	0.0	13,340.7
7. Retaining dam	250.0	0.0	4,737.5
Total		34.4	11,726,973.1

Source: Pramono et al. (2001)

C. Forest and Land Rehabilitation (RHL)

The priority RHL activities are tree planting in the open forest areas and choosing activities that maximize water infiltration. Some of the conditions used are: residential areas will implement the construction of infiltration wells and biopores, and enrichment planting is carried out on forest land or open land that should function as forest. Besides, the enrichment planting will be carried out in areas with steep slopes. The first priority of RHL activities is on land areas that are degraded and very degraded and categorized as vulnerable to flood discharges. Similarly, the second priority of RHL activities is also located in areas that are vulnerable to flooding discharge (vulnerable and very vulnerable classes) but outside the degraded and very degraded lands. These 2 (two) priorities allow the local government to carry out RHL planning according to the available budget efficiently.

By overlaying maps of floodwater discharge, land cover, degraded land, and forest functions, 12 recommendations for RHL are generated tailored to the local community's concerns. The RHL suggestion is only intended for regions categorized as "vulnerable" or "very vulnerable" to floodwater discharge; therefore, priority is given to the actions that absorb runoff into the ground as much as feasible to limit the flood volume as much as possible. There are four categories of RHL: the enrichment of planting in the open areas with the function as forest areas, improving terraces to reduce erosion, boosting soil fertility, and the construction of infiltration wells or biopores. The RHL recommendations for the Northern Part of Central Java Province are presented in Table 4. Spatially, the first and second priority of RHL activities are presented in Figures 4 and 5, while the detailed area of RHL activities for each regency/city is presented in Table 5.

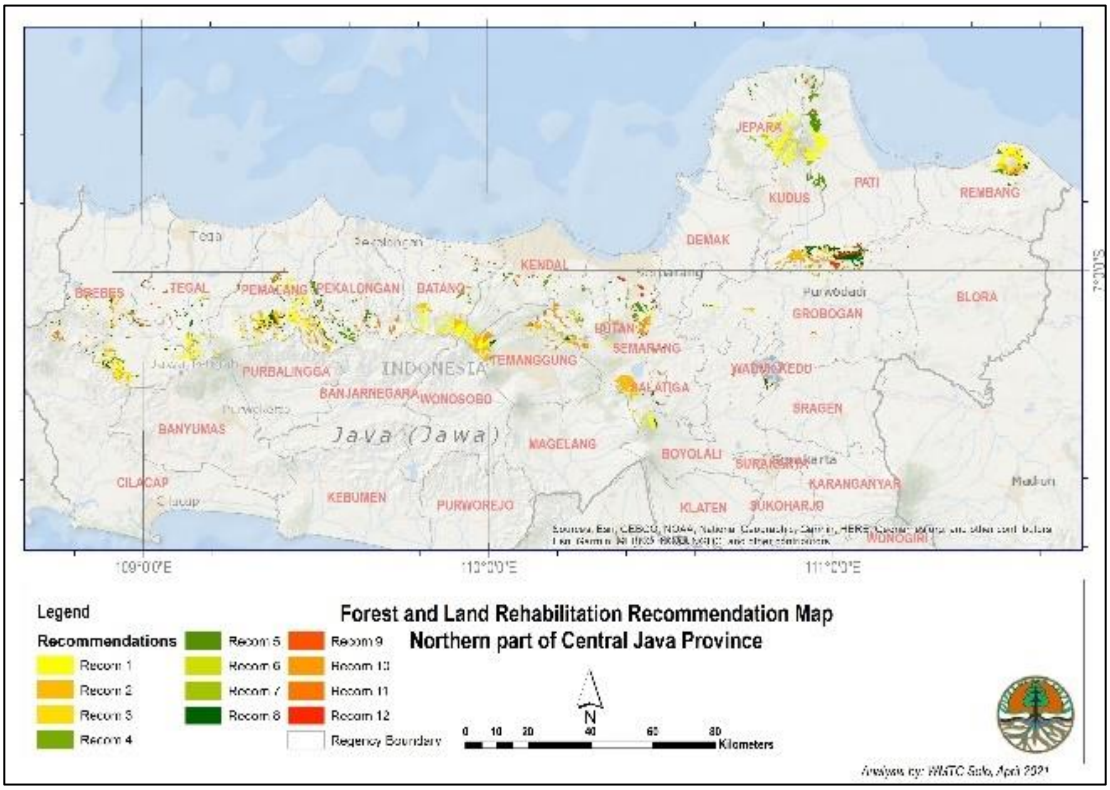

Figure 4. Recommendation for the first priority forest and land rehabilitation in the northern part of Central Java Province

Source: Data Analysis, 2021

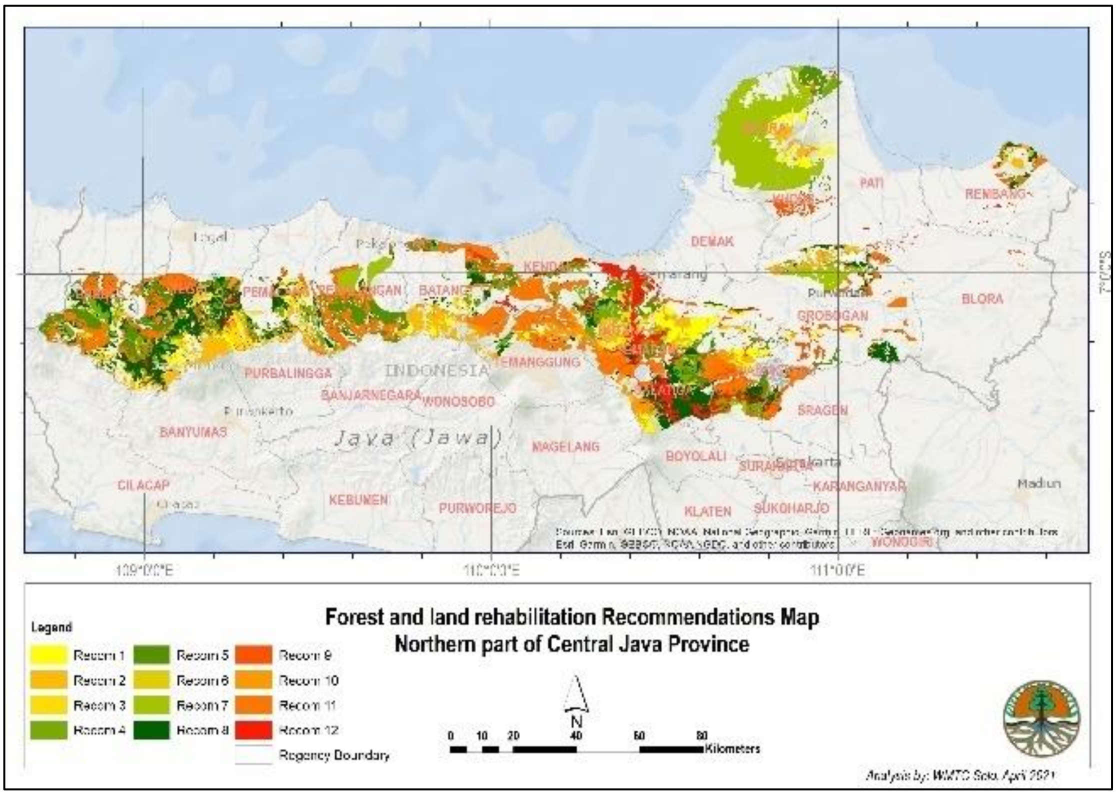

Figure 5. Recommendation for the second priority forest and land rehabilitation in the northern part of Central Java Province

Source: Data Analysis, 2021

Table 5. Forest and land rehabilitation for the northern part of Central Java Province

	Recommendations	First priority (ha)	Second priority (ha)
1	Enrichment planting (landslide control, bioengineering) + terrace improvement	25,865	44,371.4
2	Enrichment planting (landslide control, bioengineering) + terrace repair	20,833	52,682
3	Enrichment planting (agroforestry), terrace improvement	75	15,414
4	Enrichment planting, agroforestry	4,228	53,112
5	Enrichment planting+ mulching, ground cover, compost	8,856	64,758
6	Enrichment planting, terrace improvement	432	310
7	Planting of plants adapted to dry/wet weather	2,042	84,313
8	Planting of road protection trees in paddy fields, drainage system improvement	8,180	82,791
9	Planting of protective trees roads, improvement of soil fertility	314	24,836
10	Terrace improvement, terrace strengthening plants	6,574	35,309
11	Application of mulch, ground cover, compost	4,022	129,836
12	Infiltration wells, biopore	3,091	44,197

Source: Data Analysis, 2021

Tree selection suitable for enrichment planting in the degraded land can be based on the previous studies. For example, Pratiwi et al. (2012), in their study in Juwana Watershed recommended some tree species for land rehabilitation, including *Vitex* sp. (laban), *Pterocarpus indicus* Wild. (angsana), *Sandoricum koetjape* Merr. (kecapi), *Canarium* sp. (kenari), *Dracontomelon dao* (Blanco) Merr.&Rd. (dao*), Anthocephalus chinensis* (Lamk.)A.Ric. (jabon), *Artocarpus heterophyllus* Lamm. (nangka), *Cananga odorata* Hook f.et T. (kenanga), *Dalbergia latifolia* Roxb. (sonokeling), *Albizia lebbeck* Benth (tekik*), Quercus* sp. (pasang), *Lagerstroemia speciosa* Pers. (bungur), *Pterospermum javanicum* Jungh. (bayur). In the steep slope area, one of the potential trees recommended for landslide control is Sumatran pine (*Pinus merkusii* Jungh. & Vriese ex Vriese) (Indrajaya & Handayani, 2008).

The agroforestry system is another model of enrichment planting for RHL to control runoff (Setyowati, 2007) and to overcome the lack of agricultural land while maintaining forest and environmental functions (Supriadi & Pranowo, 2015). Budiastuti et al. (2020) stated that in the prioritized sub-watersheds in the Muria Region, sengon trees were dominated in the agroforestry system, followed by mahogany, coffee, and teak. This research shows that combining sengon trees and coffee is ideal because coffee reduces rain-induced erosion but requires shade, while sengon trees can provide shade while increasing soil fertility. This combination can control surface runoff and soil erosion during the rainy season. A sengon/ coffee-tree-based agroforestry system is ecologically friendly and appropriate for development in the prioritized sub-watersheds.

Furthermore, Fitri et al. (2020) stated that the agroforestry system affects the quality of watershed landscape management, erosion, soil properties, and potential water retention. Based on this study, various types of agroforestry in Upper Ciliwung show that the soil hydrological group is dominated by group B (i.e., hydrological soil group based on United States Department of Agriculutre/USDA)(USDA, 2007), which indicates that the infiltration capacity is at a moderate level while the CN value varies between 44-78[1]. Another study by Udawatta et al. (2002) found that the contour strip and agroforestry treatments reduced runoff by 10% in the agroforestry sites compared to 1% in the control watershed. The runoff reductions most occurred in the second and third years after the treatment was established in both treatments.

Table 6. Distribution of forest and land rehabilitation recommendations for each regency in the Northern Part of Central Java Province (in ha)

Regency/City	Total area (ha)*	Recommended area for rehabilitation (ha)**	Forest and land rehabilitation recommendations (ha)			
			First priority	%	Second priority	%
Salatiga	8,929	8,929	230	2.58%	8,612	96.45%
Semarang	142,711	135,326	8,541	5.98%	99,897	70.00%
Jepara	102,408	97,652	5,238	5.11%	67,640	66.05%
Pekalongan	94,480	94,220	6,005	6.36%	46,113	48.81%
Brebes	175,582	170,019	8,644	4.92%	80,487	45.84%
Kendal	101,320	101,300	4,414	4.36%	46,704	46.10%
Tegal	103,469	93,433	2,982	2.88%	49,013	47.37%
Pemalang	114,148	113,743	10,861	9.51%	43,194	37.84%
Batang	86,475	86,256	5,598	6.47%	32,809	37.94%
Kudus	43,695	43,695	1,634	3.74%	16,862	38.59%
Boyolali	108,778	47,173	1,163	1.07%	36,611	33.66%
Temanggung	87,781	30,117	6,304	7.18%	19,413	22.12%
Grobogan	206,541	205,600	3,378	1.64%	45,255	21.91%
Pati	158,196	158,196	13,274	8.39%	14,642	9.26%
Rembang	103,762	92,848	5,384	5.19%	9,700	9.35%
Sragen	97,886	11,846	547	0.56%	9,129	9.33%
Demak	100,476	100,476	69	0.07%	2,464	2.45%
Blora	195,729	98,081	76	0.04%	1,947	0.99%
Purbalingga	80,797	620	73	0.09%	548	0.68%
Banjarnegara	114,942	526	60	0.05%	467	0.41%
Banyumas	139,009	180	1	0.00%	179	0.13%
Cilacap	234,641	208	24	0.01%	185	0.08%
Magelang	114,842	60	0	0.00%	60	0.05%
Wonosobo	99,342	11	11	0.01%	0	0.00%

Note: *) Data obtained from Geospatial Information Agency (Table 1) might be different from the official area

**) The areas included in the watersheds that emptied to the northern part of Central Java

Source: Data Analysis, 2021

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Table 6 shows that out of 31 regencies/cities with rivers flowing into the north coast, 5 (five) regencies/cities have RHL recommendations that are applied to more than 50% of the area, namely Salatiga City (99%), Semarang district/city (76%), Jepara Regency (71%), Pekalongan Regency (55%), and Brebes Regency (51%). Information on the extent of areas to implement the RHL recommendations will assist the provincial and local governments in budget allocation.

This study reveals that practically all watersheds that significantly flow the water to the Java Sea are "vulnerable" and "very vulnerable" to floodwater discharge; hence, it is recommended that the 12 forest and land rehabilitation recommendations be put into effect. Our study showed that in the Jratunseluna River Basin area, RHL should be conducted, especially in Jragung, Tuntang, Juwana, Serang (including Salatiga, Kudus, and some of Semarang Regency). While in the Pemali-Comal River Basin the RHL should be conducted in Comal, Sragi (more specifically in Pemalang Regency). In Bodri-Kuto River Basin, the RHL should be conducted in Blorong Bodri (mostly Semarang City). In addition, in Wiso-Gelis River Basin consisting of small watersheds and covering the whole area of Jepara Regency, the RHL activities are recommended for 71% of its total area.

IV. CONCLUSION

Rainfall, tidal surges, and ground subsidence in various locations contributed to the flood disaster in Northern Central Java. This research intends to provide alternative flood management strategies in the Central Java Watersheds that flow into the north shore. The amount of runoff that causes floods can be minimized by identifying floodwater discharge areas. Twelve RHL suggestions are derived by overlaying maps of floodwater discharge, land cover, degraded land, and area functions tailored to the area's issues. The RHL suggestion is only for regions that are "vulnerable" or "very vulnerable" to floodwater discharge; thus, efforts to absorb runoff into the ground as much as possible to limit flood volume are prioritized. The RHL is divided into four categories: boosting open areas with forest-like plants, enhancing terraces to decrease erosion, increasing soil fertility, and building infiltration wells or biopores. Based on our analysis, Salatiga City (99%), Semarang district/city (76%), Jepara Regency (71%), Pekalongan Regency (55%), and Brebes Regency (51%) are among the 31 regencies/cities with most of their area needs to apply the RHL. Our research revealed the need for RHL activities in the Jratunseluna River Basin, particularly in Jragung, Tuntang, Juwana, and Serang (including Salatiga, Kudus, and some of Semarang Regency). Sragi and Comal are the two rivers in the Pemali-Comal Basin (more specifically in Pemalang Regency). It is recommended that RHL be conducted in Blorong Bodri (mostly Semarang City). The RHL are also recommended for 71 percent of the Wiso-Gelis River Basin, which is made up of small watersheds and covers the entire Jepara Regency.

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CONTRIBUTION

All authors had an equal role as main contributors in discussing the conceptual ideas and the outline, providing critical feedback for each section, and writing the manuscript. All authors have read and agreed to the published version of the manuscript.

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Appendix 1. The vulnerability class of floodwater discharge

Land system	Class	Land Cover	Class
Tidal swamps, Beaches	very low	Water bodies, building	very low
		Protected forest, conservation forest	very low
Alluvial plains, Alluvial valleys	low	Production forest, estate	low
Plains	moderate	Rice field, savanna, shrubs	moderate
Fans, lahars, and terraces	high	Settlements	high
Hills and mountains	very high	Dry land, open areas	very high

Source: Pamin et al., (2012).
Notes: Land system is associated to surface runoff that causes erosion. At the steeper land system cause more runoff and soil erosion.

Appendix 2. Land vulnerability classes based on land system and land cover

		Land cover class					
		very low	very low	low	moderate	high	very high
Land system class	Very low	Very Low	Very Low	Very Low	Very Low	Very Low	Very Low
	low	Very Low	Very Low	Very Low	Low	Low	Low
	moderate	Very Low	Low	Low	Moderate	High	High
	high	Very Low	Low	Moderate	High	High	Very high
	Very high	Very Low	Moderate	High	High	Very high	Very high

Appendix 3. Floodwater discharge vulnerability class

Maximum daily rainfall (mm)	Land vulnerability				
	Very low	Low	Moderate	High	Very high
< 20 (very low)	Not vulnerable	Not vulnerable	Slightly ulnerable	Slightly vulnerable	Moderately vulnerable
21-40 (low)	Slightly vulnerable	Slightly vulnerable	Slightly vulnerable	Moderately vulnerable	Moderately vulnerable
41-75 (moderate)	Slightly vulnerable	Moderately vulnerable	Moderately vulnerable	Moderately vulnerable	Vulnerable
76-150 (high)	Moderately vulnerable	Moderately vulnerable	Vulnerable	Vulnerable	Vulnerable
>150 (very high)	Moderately vulnerable	Vulnerable	Vulnerable	Very vulnerable	Very vulnerable

Source: Modified from Paimin et al (2012)

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