Determination of recharge areas to optimize the function of urban protected areas on a small island

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Abstract. The increase in population and economy as a whole has an impact on the urban and regional growth patterns, through the development of settlements, infrastructure, and other supporting activities. The city on the small island also experiences the same pattern, particularly in the city appointed as one of the national strategic areas. Uncontrolled and sporadic growth pattern will cause serious effect on environmental degradation. Sabang, nationally announced as a strategic special zone, located on a small island with land-use dominated by forests, natural topography, mountains, and hills. One effort to maintain the environment due to the development growth is to optimize the catchment areas. The purpose of this study is to determine the recharge area, which would be a consideration in planning the spatial pattern of Sabang. The factors reviewed in this study are rainfall, slope, land-use, and soil conditions. Scoring techniques were used to measure the value of these factors. Furthermore, the Geographic Information System (GIS) was used to identify the recharge areas and to overlay both raster and vector data. The result shows that the potential area as the recharge areas is 63.8% of Sabang (7,873.67 ha), which includes forest areas, mangrove beaches, housing, green open spaces, terrestrial nature reserves, mixed plantations, industrial estates, tourism, trade and services, landslide-prone areas, river areas and beaches, and reservoirs. The finding indicates that there is the need to review the land-use plan to be ecologically compatible, particularly in the so-called eco-sensitive zones where the recharge areas are necessary.

1. Introduction
The increase in population and the economy as a whole has an impact on the development of regions and cities, through massive infrastructure development and utilization of space-optimized for productive activities [1] [2]. Sabang City, an administrative city that is mostly located on the small island of the western tip of Indonesia (Weh Island) is also experienced rapid development. It has various limitations, such as island size, land conditions, water availability, human resources, and other resources.

Based on Law Number 37 of 2000, Sabang has been designed as a free trade and port area. The Aceh Government Law No. 11 of 2006 concerning the Aceh Government also stipulates it to be an area separate from the customs area so that it is free from the trade rules for imposing import duties, value-added tax, and the sales tax on luxury goods. Through the Sabang Area Concession Agency, the Sabang trade area is expected to be the center of regional economic growth through activities in the
fields of trade, services, industry, mining and energy, transportation and maritime affairs, post and telecommunications, banking, insurance, tourism, processing, packaging, and warehouses for agricultural, plantation, fishery, and industrial products from the surrounding area. In the structure of the national space, Sabang is designated as the center for national strategic areas which strengthens the potential for the implementation of international-scale infrastructure provision in this region.

In the perspective of sustainable development, regional development must pay attention to the carrying capacity of the environment, namely the ability of the environment to support the lives of humans and other living things [3][4]. Especially, in the context of Sabang, the Directorate of Special Areas and Disadvantaged Areas of National Development Planning Agency detailed several challenges in developing Sabang area, including limited carrying capacity of the area (land), because Weh Island is mostly mountainous (48%), hills (39%), and bumpy (10%). Land-use in Sabang is still dominated by forests, additionally, there are also cropland, water body, and built-up area. Urban area development in a small islands must consider vulnerability to climate change and natural disasters, because of its location in the middle of a vast ocean [5][6].

The carrying capacity of the environment is the most important consideration in spatial planning, both in the preparation of the Regional Spatial Planning (RSP) and in the evaluation of spatial use. The importance of the RSP is made to improve security, comfort, increase productivity, and create harmony between the natural environment. The carrying capacity of the environment also needs to be evaluated [4][3]. Evaluation of spatial patterns in the Spatial Plan is part of the steps in spatial management which can be drawn up for improvement.

The evaluation of land carrying capacity is part of the evaluation of environmental carrying capacity. One way to evaluate environmental carrying capacity is land-based evaluation. Through this evaluation, the land-use planning can be directed to be used by its capabilities so that the utilization can be directed according to its carrying capacity. Land capability assessments provide information about the constraints of a particular land which becomes an instrument in making decisions for land-use based on their capabilities and potential. Furthermore, land suitability analysis can also be carried out to determine the most suitable land-use [7]. The purpose of this study is to determine the recharge area, which would be a consideration in planning the spatial pattern of Sabang.

2. Materials and Methods

2.1 Study area

This research was conducted in the administrative area of Sabang, Aceh Province, Indonesia (5°46’28”–05°54’28”N and 95°13’02”–95°22’36”E, Fig. 1), covering an area of 153 km². Sabang consists of two sub-districts, Sukakarya (73 km²) and Sukajaya (80 km2) (Figure 1). The average height of urban areas is twenty-eight meters above sea level. The boundaries of the area surrounding Sabang are as follows:

a. the north bordered by Malacca Strait;

b. the south bordered by Samudera Indonesia;

c. the west bordered by Samudera Indonesia; and

d. the east bordered by the Malacca Strait.
Figure 1. Study location
Source: http://portal.ina-sdi.or.id/home/; http://tides.big.go.id/DEMNAS/

2.2 Factors that affect recharge area
The level of infiltration of rainwater into the soil is a very important factor to preserve groundwater deposits (Ministry of Forestry, 1998). Infiltration rates depend on rainfall, slope, land use, and soil type.

a. Rainfall
Some of the rainwater that reaches the surface of the land will seep into the soil (infiltration) and some others flow above the ground (surface runoff), which fills the soil basin, lake, enters the river, and finally flows into the sea. Water that seeps into the ground partly flows vertically is in the soil (percolation), filling groundwater which then comes out like a spring or flows into the river. Finally, the water flow in the river will reach the sea [8].

b. Slope
The angle of the slope determines the equilibrium between surface runoff and infiltration [9]. The slope of the slope is a huge influence on the level of infiltration of water into the soil. The greater the slope of a place, the steeper it will be, so that the greater the surface runoff and the smaller the water
seeps into the ground. Rainwater that falls on a sloping surface will flow down quickly. Water that flows quickly will minimize the chance of water to seep into the soil [10].

c. Land Use
Land use is influenced by several factors, especially humans who use the land excessively so that it can cause unwanted physical symptoms, such as lack of agricultural productivity, floods, erosion, reduced recharge area, and others. Therefore, land use is dynamically following the development of human life and culture. Changes in land use that are not in accordance with their designation are also one of the reasons why the surface of the land becomes watertight which cause the rainwater that falls cannot seep into the soil. Changes in land use can be in the form of forests into settlements, forests into rice fields and so forth. This will cause rainwater to become a surface flow and cause potential flooding or inundation in area.

d. Soil Type
The type of soil has a large influence on the level of water infiltration. Rainwater seeps into the soil through a capillary path that will close or open because the colloid-colloid pressure of the soil is enlarged or reduced. Soils with a sandy texture will have a higher infiltration rate compared to those with texture. Likewise, lands with a wrinkling texture will have a higher infiltration rate compared to clay-textured soils. This can be understood because the texture of the soil is determined by the grain, the rougher the grain size, the greater the space between the grains (soil pores), so the opportunity for the ability of water to sink into the soil is greater.

2.3 Infiltration Level Classification Method
Aspects of determining infiltration are first presented in the form of maps and then classified according to the level of infiltration.

a. Slope
Classification and slope scoring for infiltration level uses Chow’s Classification (1988) applied by the Indonesian Minister of Forestry (Table 1).

| No. | Slope % | Description          | Infiltration | Score | Notation |
|-----|---------|----------------------|--------------|-------|----------|
| 1.  | <8      | Flat                 | Very high    | 5     | a        |
| 2.  | 8-15    | Gently undulating    | High         | 4     | b        |
| 3.  | 15-25   | Undulating           | Medium       | 3     | c        |
| 4.  | 25-40   | Moderately steep     | Low          | 2     | d        |
| 5.  | >40     | Steep                | Very low     | 1     | e        |

Source: Regulation of the Minister of Forestry of the Republic of Indonesia Number: P.32/MENHUT-II / 2009.

b. Soil
The classification of soil types and permeability for infiltration levels also use the Chow’s Classification (1988) applied by the Indonesian Minister of Forestry. While for the classification of soil texture with the classification contained in the Minister of Public Works Regulation No. 02 of 2013 concerning Guidelines for Preparation of Water Resources Management Plans (Table 2) (Table 3) (Table 4).
Table 2. Classification of soil types for infiltration levels

| No. | Soil type      | Infiltration | Score | Notation |
|-----|----------------|--------------|-------|----------|
| 1.  | Black andosol  | Very high    | 5     | a        |
| 2.  | Brown andosol  | High         | 4     | b        |
| 3.  | Regosol        | Medium       | 3     | c        |
| 4.  | Latosol        | Low          | 2     | d        |
| 5.  | Alluvial       | Very low     | 1     | e        |

Source: Regulation of the Minister of Forestry of the Republic of Indonesia Number: P.32/MENHUT-II/2009.

Table 3. Classification of Soil Permeability for Infiltration Levels

| No. | Permeability (cm/hour) | Infiltration | Score |
|-----|------------------------|--------------|-------|
| 1.  | > 12.7                 | Very high    | 5     |
| 2.  | 6.3-12.7               | High         | 4     |
| 3.  | 2.0-6.3                | Medium       | 3     |
| 4.  | 0.5-2.0                | Low          | 2     |
| 5.  | <0.5                   | Very low     | 1     |

Source: Regulation of the Minister of Forestry of the Republic of Indonesia Number: P.32/MENHUT-II/2009.

Table 4. Classification of Soil Textures for Infiltration Levels

| No. | Soil texture | Infiltration value (mm/hour) | Infiltration | Score |
|-----|--------------|------------------------------|--------------|-------|
| 1.  | Sand         | >30                          | Very high    | 5     |
| 2.  | Sandstone    | 20-30                        | High         | 4     |
| 3.  | Sandy clay   | 10-20                        | Medium       | 3     |
| 4.  | Berliat clay | 5-10                         | Low          | 2     |
| 5.  | Clay         | 1-5                          | Very low     | 1     |

Source: Regulation of Civil Works Ministry No. 02/2013.

c. Rainfall

Rainfall with a longer period will have greater infiltration. Thus the rain factor is developed as "infiltration rain" or RD. Where to calculate the average infiltration rainfall formula per year is used:

\[ RD = 0.01 \times P \times Hh \]

Information:

RD = infiltration rain factor
P = annual rainfall
Hh = number of rainy days each year

The results of the calculation of the RD value with the potential infiltration can be classified as follows (Table 5).

Table 5. Rainfall classification based on infiltration level

| No. | RD Value | Infiltration | Score | Notation |
|-----|----------|--------------|-------|----------|
| 1.  | >5,500   | Very high    | 5     | a        |
| 2.  | 4,500-5,500 | High     | 4     | b        |
3. 3,500-4,500 Medium 3 c
4. 2,500-3,500 Low 2 d
5. <2,500 Very low 1 e

Source: Regulation of the Minister of Forestry of the Republic of Indonesia Number: P.32/MENHUT-II/2009.

Land use, especially the cover vegetation type influences infiltration through three forms, namely roots and pores increase soil permeability, vegetation resist runoff and vegetation reduces the amount of percolation water through transpiration (Regulation of the Minister of Forestry of the Republic of Indonesia Number: P.32/MENHUT-II/2009). Given the role of land use, then about the actual infiltration rate values can be classified as follows.

2.4 Infiltration Capability Analysis
Infiltration rates depend on rainfall, percentage of run-off type of land, slope, and land use.

a. Potential Infiltration
Maps of rainfall distribution, soil type, and slope are changed in the form of potential infiltration maps. These three aspects provide a natural potential infiltration level index (Regulation of the Minister of Forestry of the Republic of Indonesia Number: P.32/MENHUT-II/2009).

b. Actual Infiltration
While changes in land use provide an index of the actual infiltration rate. Actual infiltration values are taken directly from the infiltration measurements in the field using infiltrometer double rings based on the type of land use in Sabang (Table 6).

Table 6. Land use classification

| No. | Land use classification     | Infiltration | Score | Notation |
|-----|----------------------------|--------------|-------|----------|
| 1.  | Dense forest               | Very high    | 5     | a        |
| 2.  | Production forest, plantation | High       | 4     | b        |
| 3.  | Shrubs, meadows            | Medium       | 3     | c        |
| 4.  | Horticulture               | Low          | 2     | d        |
| 5.  | The settlement, rice fields | Very low   | 1     | e        |

Source: Regulation of the Minister of Forestry of the Republic of Indonesia Number: P.32/MENHUT-II/2009.

2.5 Classification of Recharge Area
Classification of the recharge area is done by overlaying the potential infiltration capabilities of the actual infiltration. This process uses a recharge area assessment model that is based on the 2009 Procedure for Drafting the Forest and Land Rehabilitation Technical Plan. Information from the classification of recharge area assessment models is as follows:

1. Good condition, which is if the actual infiltration value is greater than the potential infiltration value, for example (eA) or (dB).
2. Natural Normal Conditions, which is if the actual infiltration value is equal to the potential infiltration value, for example (bB) or (cC).
3. Critical Start Condition, which is if the actual infiltration value has dropped by one level from the potential infiltration value, for example (aB) or (cD).
4. Rather Critical Condition, which is if the actual infiltration value has dropped two levels from the potential infiltration value, for example (aC) or (bD).
5. Critical Condition, which is if the actual infiltration value has dropped three levels from the potential infiltration value, for example (aD) or (bE).
6. Very Critical Condition, which is if the actual infiltration value changes from very large to very small from the potential infiltration value, for example (aE).

3. Results and Discussion
The recharge area is an area that is planned for the entry of water from the soil surface into a zone of saturation of water to form a flow of water into the soil. The function of the recharge area is to accommodate the discharge of rainwater that falls in the area. Indirectly recharge areas play an important role in controlling floods and droughts in the dry season. The impact of uncontrolled land use changes is flooding. Floods occur because of the absence of land that holds rainwater. Another impact is the occurrence of drought during the dry season. This happens because the rainwater that falls in the rainy season is not accommodated into the soil which results in a small amount of groundwater, even if it does not exist.

Therefore, the arrangement of Recharge areas is very important to be applied to a city. Every city should plan the recharge areas. Likewise with Sabang, a strategic area as a center of tourism and trade, so that development becomes better by determining the right activities in the recharge areas. The downstream part of the watershed is generally in the form of agricultural cultivation areas, residential areas (urban), and industry, as well as reservoirs for electricity generation, fisheries and others. The upstream watershed area is usually intended for Recharge areas. Thus the success of downstream watershed management depends on the success of watershed management in the upstream section. Watershed damage can be characterized by changes in hydrological behavior, such as high frequency of flood events (peak flow) and increased erosion and sedimentation processes. This condition is due to the inappropriate system of handling and watershed utilization [11] [12].

Determination of recharge areas is very important to maintain the availability and sustainability of water due to changes in land use, in line with population growth. The increasing population will be followed by the increasing need for land. This will have an impact on forests that will turn into agricultural land, and then agricultural land will change into settlements. These changes will have an impact on the extent of Recharge areas [11] [13].

Identification of recharge areas in Sabang based on scores generated from the results of overlaying data on rainfall maps, slope maps, soil types, and land use. The recharge area of an area depends on a number of these factors. The factors of rainfall, slope, soil type, and land use cannot be separated from each other in the analysis of Recharge areas in certain regions. Based on the results of the parameter overlay calculation carried out by summing the total score obtained in determining the category of recharge area, the distribution of the area of the recharge area in Sabang can be seen in Table 7 and Figure 2.

Table 7. Extensive distribution of recharge area conditions

| No. | Recharge area       | Area (ha) |
|-----|---------------------|-----------|
| 1.  | good                | 4,768.37  |
| 2.  | natural normal      | 3,105.30  |
| 3.  | start critically    | 2,457.31  |
| 4.  | rather critically   | 856.42    |
| 5.  | critical            | 868.89    |
| 6.  | very critical       | 279.44    |
| Total|                    | 12,335.73 |

Good recharge conditions and potential as recharge areas are 7,873.67 ha (63.8%), which includes forest areas, mangrove beaches, housing, green open space, terrestrial nature reserves, mixed plantations, industrial estates, tourism, trade and services, areas prone to landslides, river areas and beaches, and reservoirs. The conditions of recharge areas in Sabang are still great. Land use which is categorized as good and normal is naturally spread in protected and cultivation areas. Meanwhile, the
categories of regions began to be critical, somewhat critical, critical, and very critical covering an area of 4,462.06 ha (36.2%).

The spatial use refers to the function of space stipulated in spatial plans implemented by developing land stewardship, water management, air stewardship, and stewardship of other natural resources. In the use of space in a protected function room, the priority is given to the government and regional government to accept the transfer of land rights from holders of land rights if the concerned person will give up his rights. The priority right for the government and regional government is intended so that the government can control the land in the protected function space to ensure that space still has a protected function [14].

Figure 2. Distribution map of the recharge area

According to the National Spatial Planning Plan, the direction of spatial use in Recharge areas is regulated based on zoning regulations. Zoning regulations for Recharge areas are prepared by taking into account the limited use of space for non-built cultivation activities, which have a high ability to withstand rainwater runoff, provision of infiltration wells and/or reservoirs on existing built-up area. The application of the Zero Delta Q Policy to each cultivation activity must be submitted. Infiltration greatly affects the available discharge in an area. Percolation discharge after the water has been infiltrated with appropriate vegetation to be planted in the recharge area. Some of them are bamboo, banyan, bisbul (a type of persimmon), rambutan, jackfruit, mangosteen, and matoa. Besides that, it is also necessary to try to improve soil conditions to easily absorb water. Related to the effectiveness of the entry of water into the soil, two main factors are irregular, namely vegetation cover and soil structure [15].
The groundwater stream and the store structure are significant factors in hydrogeological demonstrating. The fundamental issues in water asset the board are the assessment of the spring framework working and water accessibility. In this examination, to oversee water assets in the bone-dry territory was utilized as a groundwater stream model and Geographic Information System devices. In this examination, to set up a guide demonstrating regions appropriate for groundwater energize, a multi-criteria approach utilizing a weighted-rating procedure has embraced. The recording front of high revive capacity is 45% of the absolute shallow spring augmentation and the medium is just 29%. At that point, the effect of the groundwater revives is assessed by pressure-driven heads recreation and water spending investigation. The model abuse outlines the effect of the water energize on the pressure-driven heads which the situation, the expansion of the misuse of 20% reductions the water-powered heads while in the subsequent situation, the effect of a revives dam expands the piezometric levels with steady misuse and precipitation. To oversee water assets and to help chiefs and organizers, those outcomes are useful. [15] [16].

From the results of the analysis of water infiltration conditions, using variables of population density, accessibility, and supporting facilities, location directives were obtained based on the suitability of the location of the green open space development. The slope criteria are divided into three sub-criteria, namely the slope sub-criteria of 0-8%, the slope sub-criteria of 8-15% and the slope sub-criteria > 15%. Land use is divided into three categories, namely the trading area, residential area, and other use areas. Population density is divided into three sub-criteria, namely areas with high population density, areas with moderate population density and areas with low population density. Accessibility criteria are divided into three sub-criteria, namely 200 m distance from an arterial road, 400 m distance from an arterial road, and distance > 400 m from an arterial road. The criteria for supporting facilities are divided into three sub-criteria, namely a distance of 500 m from the city center, a distance of 1,000 m from the city center and a distance of >1,000 m from the city center.

Overall, the land in Sabang is quite suitable to be developed as green open space, which is equal to 8,260 ha. There is land that is not suitable for the development of green open space of 3,173.98 ha because it is influenced by a relatively extreme slope. The land that is very suitable to be developed into green open space is in the central area of Sabang because there are better-supporting facilities and accessibility compared to other regions, which is 74.20 ha. Current conditions, the development of green open space is carried out in the downtown area because of the relatively more population density there. The land classified as suitable for the development of green open space, which is equal to 765.38 hectares, generally it is in the main road corridor which provides good accessibility to the population.

4. Conclusion
Good recharge conditions that have the potential to be Recharge areas are 7,873.67 ha (63.8%) which includes forest areas, mangrove beaches, housing, green open space, terrestrial nature reserves, mixed plantations, industrial estates, tourism, trade and services, vulnerable areas landslides, river areas and beaches, ponds, reservoirs. Land use which is categorized as good and normal is naturally spread in protected and cultivation areas. Whereas the categories of regions starting to be critical, somewhat critical, critical, and very critical are 4,462.06 ha (36.2%).

From the analysis of water infiltration conditions, which are varied with other variables, such as population density, accessibility, and supporting facilities, location directions are also obtained based on the suitability of the location of the development of green open space. Overall, the land in Sabang is quite suitable to be developed as green open space, which is 8,260 ha. There is land that is not suitable for the development of green open space, which is 3,173.98 ha, which is affected by a relatively extreme slope. The land that is very suitable to be developed into green open space is in the central area of Sabang, with the consideration that there are better-supporting facilities and accessibility compared to other regions is 74.20 ha. Currently, the development of green open space is carried out in the downtown area because of the relatively more population density. The land categories that are suitable for green open space are 765.38 hectares, which are generally located in the
main road corridors which provide good accessibility to the population. Also, the distribution of population settlements that tend to be along the main road corridor affects the results of green space suitability. Directions for use of space in recharge areas can be directed according to zoning regulations.

Zoning regulations for recharge areas are prepared by taking into account the limited use of space for non-built cultivation activities that have a high ability to withstand rainwater runoff, provision of infiltration wells and/or reservoirs on existing built-up area. The application of the Zero Delta Q Policy to each cultivation activity must be submitted. Infiltration greatly affects the available discharge in an area. Percolation discharge after the water has been infiltrated with appropriate vegetation to be planted in the recharge area. Some of them are bamboo, banyan, bisbul (a type of persimmon), jackfruit, mangosteen, and matoa. Improvements to soil conditions need to be done to make it easier to absorb water and increase green open space, such as city parks. In the context of built-up area, to maintain recharge areas in residential areas, infiltration wells should be provided. The provision of infiltration wells can be a rule in developing new settlements.

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