Developing a groundwater conservation area using analytical hierarchy process in Randublatung groundwater basin

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Abstract. Randublatung Groundwater Basin is a cross-regional Groundwater Basin located in Central Java with an area of 203 Km². The increase of population in this area led to the increasing need for groundwater not only for freshwater sources and consumption but also for agriculture and industrial needs. The rise of uncontrolled groundwater usage can result in pollution and degradation in the quality and quantity of groundwater. There need to be conservation efforts to maintain the sustainability of groundwater utilization. This study aims to determine conservation zones and management priorities in the Randublatung groundwater basin area. Conservation zones are determined based on the value of their parameters: (a) availability and potential of groundwater, (b) groundwater depletion, (c) changes in groundwater quality, (d) land use, (e) aquifer characteristics, (f) prioritization of groundwater protection areas, and (g) water use. Those parameters are weighed using the Analytic Hierarchy Process (AHP) method and then overlaid corresponding to the weight of the parameter to acquire the matrix of conservation zones. The results indicate the type of lithology in the research area was an alluvial deposit—the development of the data processing presented in the form of a map of groundwater. There are four types of conservation zones in a confined aquifer, i.e., secured, vulnerable, and critical.

1. Introduction
Groundwater is water found in layers of soil or rocks below the soil surface [1]. All water below the ground surface is called underground water (or subsurface water), where groundwater occurs in two different zones, namely the unsaturated zone and the saturated zone [2].

The groundwater basin is bounded by hydrogeological boundaries, where all hydrogeological processes such as recharge, flow, and groundwater discharge occurred [1]. Groundwater Basin Randublatung is a trans-provincial Groundwater Basin located in the Central Java area. The Randublatung groundwater basin was found in two provinces divided into three regencies, namely Central Java Province with Grobogan Regency and Blora Regency and East Java Province with Bojonegoro Regency. The area of the Randublatung groundwater basin has an area of 203 km² [1]. The increase in population in the Randublatung Basin area causes an increase in the need for groundwater, which causes an increase in groundwater utilization. The demand for groundwater is not only for the
fulfillment of clean water sources but also for agriculture and industry. In addition to meeting the needs of raw water, utilization of groundwater has also using to meet irrigation needs.

Several areas in the Randublatung groundwater basin are prone to drought, including Jati District, Randublatung District, Kedungtuban District, and Cepu District [3]. The condition of the agricultural area in the Randublatung groundwater basin mainly relies on groundwater to meet the needs of the irrigation network. Currently, there are 119 production wells for groundwater irrigation networks and 128 private drill wells used to meet agricultural water needs in the Randublatung groundwater basin area.[4].

Groundwater conservation is an effort to maintain the existence and sustainability of groundwater conditions, nature, and function. It is always available in sufficient quantity and quality to meet the needs of living things, both now and in the future [5]. A groundwater conservation zone is a zone or area determined based on the similarity of the groundwater carrying capacity, the same level of damage to groundwater, and its management [6].

Unrestricted use of groundwater in drought-prone areas can lead to reduced aquifer rechargeability and decreased groundwater quality. Protecting the groundwater environment and groundwater availability needs groundwater conservation. Groundwater conservation can consider several parameters such as the amount of groundwater utilization, groundwater level decline, changes in groundwater quality, and negative impacts on the environment arising from groundwater damage.

The method for determining groundwater conservation can predict using the Analytic Hierarchy Process (AHP). AHP is a decision-making method obtained from the decomposition of perceptions and judgments in a multi-level hierarchical structure that explains the components that control decisions by assessing several factors [7]. Hierarchy defines as a representation of a complex problem in a multi-level system where the first level is the goal, followed by the level of factors, criteria, sub-criteria, and so on down to the last level of alternatives [8].

The Randublatung groundwater basin is physiographically including in the Randublatung Zone, where this zone borders the Rembang Zone in the north and Kendeng Hills in the south [9]. This zone is a depression formed during the Pleistocene and occupy by fine elastic sediments from the Quaternary Lidah Formation and sometimes marl from the Mundu Formation [10][11]. The Randublatung Zone is a low zone consisting of Alluvium deposits composed of 2 parts, namely at the top consisting of Alluvium deposits of silt-sand-clay size, while at the bottom consisting of Alluvium deposits of sand-gravel size [4].

Based on the physical properties of the constituent rocks, groundwater availability, and aquifer productivity in the Randublatung groundwater basin, there are three aquifer units, namely aquifers with high productivity and wide distribution, aquifers with average productivity with wide distribution, and local aquifers with moderate production [12]. This research aims to develop a groundwater conservation area in Randublatung groundwater basin. In addition, to provided insights for sustainable water resource development and planning area.

2. Methodology
The study area is in the Randublatung groundwater basin. Randublatung groundwater basin is a cross-provincial groundwater basin with number 125 and coordinates 07°9’17.55” - 07°15’57.66” South Latitude and 111°11’23.39” - 111°36’26.12” East Longitude [1]. Randublatung groundwater basin is located in 2 provinces divided into three regencies, namely Central Java Province with Grobogan Regency and Blora Regency and East Java Province with Bojonegoro Regency with an area of 203 Km². The study area is presented in figure 1.
In the methodology of determining the Groundwater Conservation Zone of the Randublatung Groundwater Basin, the first thing to collect is the data needed as a parameter for groundwater conservation. After that, the Analytic Hierarchy Process (AHP) method is weighted according to the management priority of the groundwater conservation zone. Finally, patching is carried out to obtain groundwater conservation zones and maps of groundwater conservation zones.

The value of the parameter class is determined based on the aquifer susceptibility aspect. Aspects of Aquifer susceptibility are utilizing groundwater and the risk of damage to the quantity and quality of groundwater. Therefore, the main idea is the parameter which has less impacted by the groundwater quantity and quality damage, has the smaller value on the necessity to be conserved.

In this case, the parameter class with the lowest vulnerability value for the occurrence of damage to the quantity and or quality of groundwater due to natural conditions and aspects of groundwater utilization neither nor pollution is determined to be 1. The higher vulnerability class is 2, 3, and so on, following the class division of each parameter used.

Preparation of weighting parameters for groundwater conservation zones using AHP method [13]:

1. Identifying recharge and groundwater discharge areas;
2. Determining the parameters of the groundwater level;
3. Identifying groundwater quality;
4. Identify land risk classes for the degradation of quality and quantity of groundwater;
5. Identify potential characteristics of aquifers;
6. Identifying the spring protection zone;
7. Identify the groundwater use class.
The process of using the AHP method is carried out with the following steps [16]:

1. Identify problems and factors that influence decision-making.
   For the first step of AHP, each factor that influences decision-making is given a score from 1 to 9. The score depends on the ratio of its influence to other factors in the pairwise comparison shown in Table 1. In this case, the Saaty standard scale is used to describe the relative impact of the parameters. A score is 1 shows the same effect of the parameters, and a score of 9 indicates the extreme result of a decision-making parameter compared to other parameters.

   **Table 1. Analytic Hierarchy Process (AHP) relative class scale value [8].**

   | Influence | Same as | Weak | Moderate | Strong | Strong | Very Strong | Very Important | Very – very Important | Absolute |
   |-----------|---------|------|----------|--------|--------|-------------|------------------|----------------------|---------|
   | Scale     | 1/9     | 1/8  | 1/7      | 2/5    | 1/4    | 1/3         | 1/2             | 1        | 2       | 3       | 4       | 5       | 6       | 7       | 8       | 9       |
   |           |         |      |          |        |        |             |                 |          |         |         |         |         |         |         |         |         |         |
   | Less Important |         |      |          |        |        |             |                 |          |         |         |         |         |         |         |         |         |         |
   | More Important |         |      |          |        |        |             |                 |          |         |         |         |         |         |         |         |         |         |

2. Arrange the decision-determining criteria with a paired comparison matrix.

   $A = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & X_{nn} \end{bmatrix}$

3. Add the element values of each column from the element values of the criteria matrix above. and then getting the number of elements in each column.

4. Divide each element in the column by the appropriate number of columns elements from the matrix element in step (2) and add up each column in step (3), to obtain a normalized matrix.

5. The next step is to add up each row in the step matrix (4). The next step is to calculate the priority value of the criteria by dividing each number of rows by the number of criteria. The priority value of each measure is obtained.

6. Test the consistency by calculating $(A) \times (WT)$ by multiplying the pairwise comparison matrix with the priority weight of the criteria, then calculating the value of max. The sum of these eigenvalues is called the principal eigenvalue ($\lambda_{\text{max}}$), which measures the matrix’s deviation from consistency.

   $\lambda = \sum (CijXij)$

7. Calculating the consistency index

   $CI = \frac{\lambda_{\text{max}} \ - \ n}{n \ - \ 1}$

   $CR = \frac{CI}{RI}$

Dimana

- $CI$ : consistency index
- $\lambda_{\text{max}}$ : eigenvalue the highest value matrix
- $n$ : the amount number of parameter
- $CR$ : consistency ratio
- $RI$ : Random Index value depending on the number of parameters.
(8) Calculate the consistency ratio with the CR = CI/IR, where IR is a random index in table 2.

Tabel 2. The value of Random Index for n = 15 [7].

| n   | RI  |
|-----|-----|
| 1   | 0.00|
| 2   | 0.00|
| 3   | 0.58|
| 4   | 0.90|
| 5   | 1.12|
| 6   | 1.24|
| 7   | 1.32|
| 8   | 1.41|
| 9   | 1.45|
| 10  | 1.49|
| 11  | 1.51|
| 12  | 1.48|
| 13  | 1.56|
| 14  | 1.57|
| 15  | 1.58|

The expected consistency index (CI) is close to perfect CI = 0 to produce a decision that is close to valid. Although it is difficult to achieve perfection, the consistency ratio (CR) is expected to be 0.1. If the consistency ratio (CR) > 0.1, then the decision comparison assessment must be recalculated.

3. Result and Discussion
3.1 Conservation Zone Parameters
3.1.1 Groundwater recharge and discharge area. A water supply area is a water infiltration area that can add groundwater naturally to a groundwater basin [6]. A groundwater discharge area is a groundwater discharge area that occurs naturally in a groundwater basin [6]. Determining the boundary between the groundwater recharge area and the groundwater discharge district is important in compiling the groundwater basin determination plan. Infiltration areas and compensation are related to the availability of groundwater in the Groundwater Basin that is interconnected. If the infiltration area system is disturbed, its balance will damage the existing system in the groundwater discharge area [13]. The compensation area has a relatively closer groundwater elevation contour line than the release area, which has a sparse groundwater elevation contour line. Figure 2(a) The distribution of groundwater reclamation areas is in the western and southern parts of the Randublatung Groundwater Basin. The release area is in the middle of the groundwater basin.

3.1.2 Groundwater depletion. The position of the water table has an essential effect on the land surface and the utilization of water from free aquifers [2]. Groundwater degradation includes overexploitation of groundwater where the groundwater level drops too fast or more than the allowable level [14].

Changes in the groundwater table depth generally depend on the size of the existing utilization in an area. Excessive use of groundwater that does not pay attention to the quantity of available groundwater will cause an increase in the position of the groundwater level in the Randublatung Groundwater Basin. Figure 2(b) shows that, in general, the depth of the groundwater table in the Groundwater Basin is at 0-5 m from the surface. However, it was found locally in Cepu and Kradenan sub-districts with a groundwater level of more than 10 m.

3.1.3 Groundwater quality. Electrical conductivity is one of the parameters of groundwater's chemical quality, which shows the electrical conductivity of water [13]. Water that contains many salts has a higher electrical conductivity value. Figure 2(c) shows that based on the value of electrical conductivity, a classification of groundwater quality in the Randublatung Groundwater Basin is generally classified as Safe and Very Safe. However, it was found locally in Cepu and Kradenan Districts which are included in the vulnerable zone.

3.1.4 Land use effect in quantity and quality degradation. Use factors include the type of land use, including information on water sources used, drainage systems, sanitation, waste quality, and wastewater disposal [5]. Groundwater utilization will be closely related to land use that develops in an area [13]. Land use in human life is an aspect that cannot be ruled out because humans use the land for different purposes to fulfill various needs and necessities of life. The difference used is based on human needs, their abilities, and land-use suitability. Each land use has a value and weight for its impact on conservation priorities. Figure 2(d) shows the Randublatung Groundwater Basin; in general, the land use is used as moor, shrubs, rice fields, gardens, and settlements.
3.1.5. Aquifer Potential Characteristics. Groundwater conditions are the state of groundwater, which includes the quantity and quality of groundwater in an aquifer system [6]. A groundwater environment is a physical environment that is affected by groundwater conditions [6]. Aquifers and aquitards are distinguished by their geometry and the magnitude of representative hydraulic parameters [15]. In contrast to hydraulic conductivity, the transmissivity coefficient is defined as a parameter that expresses the property of the entire thickness of the aquifer [15].

The aquifer potential is related to a large amount of groundwater utilized in the Randublatung Groundwater Basin. The parameters of the potential characteristics of the aquifer were obtained from the regional hydrogeological map of the study area [12]. Based on the physical properties of the constituent rocks, groundwater availability, and aquifer productivity in the Randublatung groundwater basin. Figure 2(e) shows three aquifer units: aquifers with high productivity and wide distribution found in the Districts of Kradenan, Randublatung, Kedungtuban, and Cepu. Aquifer units with average productivity and wide distribution are found in Randublatung, Kedungtuban, Cepu, Margomulyo, Ngraho, and Padang. Local aquifer units with moderate production in the Districts of Gabus, Jati, and Ngraho.

3.1.6. Spring protection zone. The spring protection zone is a pseudo area with a radius of 1000 meters determined by the distribution of springs in the Groundwater Basin related to strategic water sources for the public interest [6]. This area is needed to protect the sustainable use of groundwater in springs. Figure 2(f) shows that in the Randublatung Groundwater Basin, there are no springs with a significant discharge, so the parameters of the spring protection zone have no effect in this area.

3.1.7. Groundwater utilization. Assessment of the amount of groundwater is intended to determine the relationship between changes in groundwater entering and leaving a container within the basin (intra-basin) and between basins (inter-basin) within a specific time limit (water balance) [5]. Groundwater pumping decreases the pore water pressure, increasing the overlying layer's effective stress on the aquifer's bedding plane [14].

The use of groundwater is closely related to the condition of the existing aquifer. In its development, the condition of the aquifer will change as the amount of groundwater utilization changes. The utilization of groundwater must be considered and adjusted to the needs not to damage the existing aquifer conditions. Figure 2(g) shows the potential for degradation of groundwater quantity in the Randublatung Groundwater Basin seen from the use of groundwater at high, medium, and low levels. With the highest utilization in Cepu District. At the same time, the lowest utilization is in Margomulyo District.
AHP Matrix
In determining the priority of groundwater conservation zone management, weighting becomes very important because one parameter will have a higher priority in the conservation framework. Groundwater recharge-discharge area parameters are the main parameters in conservation because the sustainability of groundwater use is very dependent on the sustainability of the recharge zone.

By using the AHP (Analytical Hierarchy Process) method, the weights of each of the above parameters are calculated, and the weights are obtained, as shown in Table 3. These weights have a consistency value (CI) close to 0 (≈ 0), and a consistency value that can be accepted in the theory of AHP is < 0.1, so these weights can be used.

Table 3. Pairwise comparison matrix for AHP method.

| Parameters       | Recharge area | Groundwater depletion | Electric conductivity | Land use | Aquifer characteristics | Springs protection | Water use |
|------------------|---------------|-----------------------|-----------------------|---------|-------------------------|-------------------|----------|
| Recharge area    | 1             | 1.20                  | 1.20                  | 1.50    | 2.00                    | 3.00              | 3.00     |
| Groundwater depletion | 0.83          | 1                     | 1                     | 1.25    | 1.67                    | 2.50              | 2.50     |
| Electric conductivity | 0.83          | 1                     | 1                     | 1.25    | 1.67                    | 2.50              | 2.50     |
| Land use         | 0.67          | 0.80                  | 0.80                  | 1       | 1.33                    | 2.00              | 2.00     |
| Aquifer characteristics | 0.50          | 0.60                  | 0.60                  | 0.80    | 1                       | 1.50              | 1.50     |
| Springs protection | 0.33          | 0.40                  | 0.40                  | 0.50    | 0.67                    | 1                 | 1        |
| Water use        | 0.33          | 0.40                  | 0.40                  | 0.50    | 0.67                    | 1                 | 1        |

Table 4. Pairwise comparison matrix for AHP method.

| Parameters       | Classification | Rank | Normalized Weight |
|------------------|----------------|------|-------------------|
| Recharge Area    | Discharge area | 1    | 0.222             |
|                  | Recharge area  | 2    |                   |
| Groundwater depletion | <5.00 m      | 1    | 0.185             |
|                  | 5.00 – 10.00 m | 2    |                   |
### groundwater conservation zone

By patching the above parameters, the Randublatung Groundwater Basin is divided into four zones, namely Safe Zone I, Safe Zone II, Vulnerable Zone, and Critical Zone (see Figure 3).

#### 3.3.1. Safe Zone I

The groundwater potential is good; generally, the position of the groundwater level at the groundwater level is less than 5 m from the ground surface. Groundwater quality is outstanding, with a DHL value < 750 μS/cm. Aquifer unit with high productivity and wide distribution. In this zone, conservation and control of groundwater use are required.

#### 3.3.2. Safe Zone II

The groundwater potential is good; generally, the groundwater level is at a depth of fewer than 5 m from the ground surface. Groundwater quality is good, with a DHL value of 750 – 1500 μS/cm. Aquifer unit with average productivity and wide distribution [17]. In this zone, it is necessary to take conservation and control measures for groundwater use, considering the possibility of groundwater quality degradation due to land use.

#### 3.3.3. Vulnerable Zone

Medium groundwater potential, generally the groundwater level is at a depth of more than 10 m from the ground surface. Groundwater quality is excellent, with a DHL value of 750 - 1500 μS/cm. Local aquifer unit with moderate production. In this zone, it is necessary to take conservation and control of groundwater use because it generally has a small transmissivity value, and groundwater utilization exceeds the aquifer's ability to meet various needs.

#### 3.3.4. Critical Zone

Medium groundwater potential, generally the groundwater level is at a depth of more than 10 m from the ground surface. Groundwater quality is outstanding, with a DHL value > 1500 μS/cm. In this zone, it is necessary to take conservation and control of groundwater use due to the degradation of groundwater quality.
4. Conclusions
The present study is an attempt to developing a groundwater conservation area in Randublatung groundwater basin. A total of 7 thematic layers: Recharge area, Groundwater depletion, Electric conductivity, Land use, Aquifer characteristics, Springs protection, and Water use. According to the final output map, the conservation zone in Randublatung groundwater basin could be classified into four areas: secure I, secure II, vulnerable, and critical. Safe Zone 1 is primarily located in Kradenan and Kedungtuban Districts. Safe Zone II is located in most areas of the Randublatung Groundwater Basin. The vulnerable zones are located in the Districts of Gabus, Jati, Randublatung, and Padangan, recharge areas. Critical zones are located locally at several points in the Kedungtuban, Cepu, and Padangan sub-districts. The groundwater conservation area map of the present study provides insights for decision makers for proper groundwater management.

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