JUTEKS - JURNAL TEKNIK SIPIL
Vol. VIII No. I, Halaman: 09 - 18
April 2023

MAPPING GROUNDWATER POTENTIAL ZONE BASED ON REMOTE SENSING AND GIS USING ANALYTICAL HIERARCHY PROCESS (AHP) IN TANA RIGHU, WEST SUMBA, INDONESIA

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Abstrak

This study aims to delineate groundwater potential zones in Tana Righu. Multiple thematic maps were prepared using RS and GIS techniques and was assigned suitable weights on the Saaty's scale. The assigned weights of the thematic maps were then normalized using the AHP technique. Ultimately, these thematic maps were integrated with a weighted overlay technique in GIS. The results showed that about 42% of the study area has "moderate" potential; 35.86% of the study area has "high" potential; 28,82% of the study area has "low" potential. 3.57.1% of the study area has "very high" potential; and 1.56.1% of the study area The "very low" potential. Overall, this study provides more efficient approach to mapping the potential groundwater availability. The results of this study are expected to assist in the planning, management and better utilization of groundwater resources.

Keywords: Groundwater Potential Zone, Remote Sensing, GIS, AHP.

INTRODUCTION

The climate of the island of Sumba categorized as climate type E (Schmidth-Fergudon climate classification), which was a semi-arid climate with a large area of savanna. Same as other semi-arid areas, rainfall in this island was very low, with an average annual rainfall of 1.200 mm. The eastern part of the island of Sumba has lowest rainfall. In the west, the average annual rainfall was 2.500 mm, while along the east coast, the average annual rainfall was only 800 mm (Nuri, 1985). With low rainfall, generally semi-arid areas have limited water resources, especially surface water.

The increase in population has implications for an increase in the amount of domestic and agricultural water demand. The availability of surface water in Tana Righu is limited, so subsurface water sources can be utilized. Groundwater is water that is found in layers of soil or rock below the ground surface (Anonym, 2017). Due to its existence below the ground surface, the presence of groundwater cannot be observed directly. To determine the exact location of groundwater drilling, a preliminary investigation is carried out first. Determining the location of groundwater drilling at random and unscientific can reduce the success rate of a wellbore. Appropriate investigative techniques must precede any groundwater drilling project to increase the chances of successful groundwater drilling.

The conventional methods used to prepare groundwater potential zones are mainly based on ground surveys**,** such as geological, geophysical, and hydrogeological drilling (Ahmed R. and Sajjad H., 2018). These groundwater investigation method is time consuming and costly. In addition, these method requires experts and skilled workers (Moes, Jr. Roscoe., Moss, E. George, 1990). Remote sensing (RS) and geographic information systems (GIS) can be used for groundwater investigations. These geospatial approach has become one of the most contemporary methods (Engman & Ggurney, 1991) and has provided cost and time effective means of assessing and managing groundwater resources (Meijerink, A., 2007).

The integration of RS and GIS has proven to be an efficient tool in mapping water potential using various techniques such as Multi-criteria decision analysis (MCDA). The use of RS and GIS for mapping groundwater potential has been carried out by several other studies in various parts of the world (Nampak, H., et. all., 2014; Mandal, P., et. al., 2021; Saravanan, S., et. al., 2021; R, Rajith., et. all., 2021; Murasingha, S., et. al., 2018; Ibrahim-Bathis, K. & Ahmed, S.A., 2016). MCDA for groundwater resource assessment has been carried out by many researchers. Various studies have shown that the Analytical Hierarchy Process (AHP) model, as an MCDA-based approach, is very effective in calculating the weight factor of groundwater (Sapkota, A. et.al., 2021; . Sutradhar, S., et.al., 2021; Bourjila, A., et.al., 2021; Raju, R. S., et.al., 2019). The main objective of this research is to determine the groundwater potential zone in Tana Righu, West Sumba Regency, Indonesia, based on hospital and GIS using AHP. The present study is helpful in better development, management planning and better utilization of groundwater resources.

RESEARCH METHOD

In this study, the methodology developed to determine groundwater potential zone consists of six main steps (Fig. 2). The first step starts with the identification of factor that affect the groundwater potential. Based on a review of several relevant literatures on groundwater potential from various regions around the world, seven parameters of the influence of groundwater potential i.e. lineament density (LD), geology (GL), land use/land cover (LULC), soil composition (S), slope (SL), geomorphology (GM), and drainage density (DD) were selected for use. The second step is preparing and commutation the thematic maps of groundwater potential parameters, using GIS environment; the third step is assigning weight and rank using AHP technique; the fifth step is integrated all thematic map with weighted overlay technique on GIS, and the last step is reclassifying integrated map to classifying ground water potential zone.

Study Area

This study was conducted in the Tana Righu area, West Sumba Regency, East Nusa Tenggara Province, Indonesia (Figure 1). Tana Righu is a semi-arid area with low rainfall (Nuri, 1985). Due to the low amount of rain, this area is dominated by savanna.

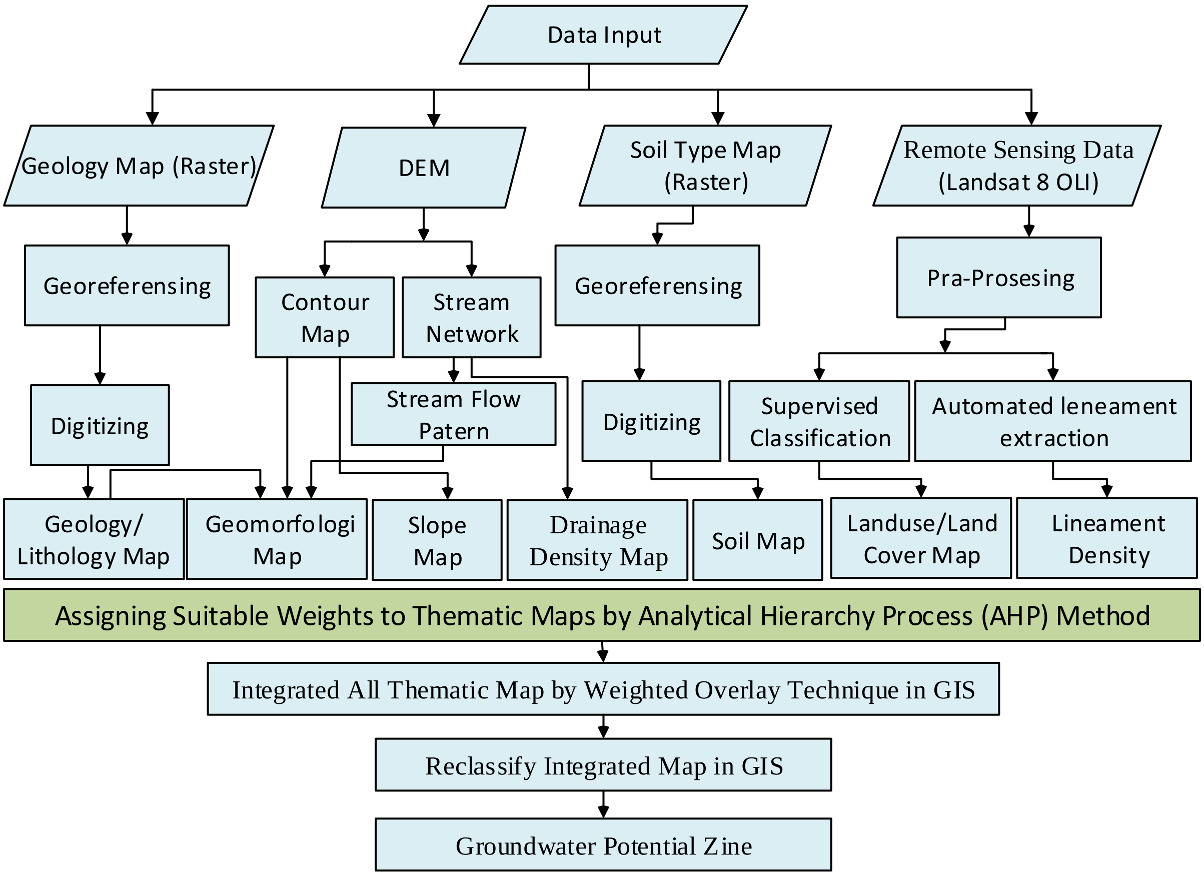

Fig. 2: Methodological Flow Chart

Table 1. Data collected and Sources.

No.	Data collected	Sources of data	Data propose
1	Geological map	Geological Research and Development Center of Indonesia	Geology and geomorphology thematic map
2	Soil type map	Soil and Agroclimate Research Center of Agricultural Research and Development Agency of Indonesia	Soil composition thematic map
3	DEM (30m x 30 m)	Geospatial Information Agency of Indonesia (https://tanahair.indonesia.go.id/portal-web)	Slope, drainage density, geomorphology thematic map
4	Remote Sensing Image (Landsat 8 OLI/TRS)	United States Geological Survey (https://earthexplorer.usgs.gov/), acquired on April 25, 2022	Lineament density and LULC thematic map

Based on the hydrogeological aspect, Tana Righu area is part of the Waikabubak groundwater basin (GWB) (Anonymous, 2017). The groundwater potential in Waikabubak GWB consists of Karst groundwater in the southern part (Waikabubak geological formation), and Unconfined aquifer in the northern part (Herawan W., et al, 2014). Aquifer productivity in the Waikabubak GWB shows that generally is dominated by very low productivity aquifers with a discharge of around 0.1 L/s. In some places where there are underground rivers or Karst springs, the discharge is about 5 L/s (Meiser et al., 1965).

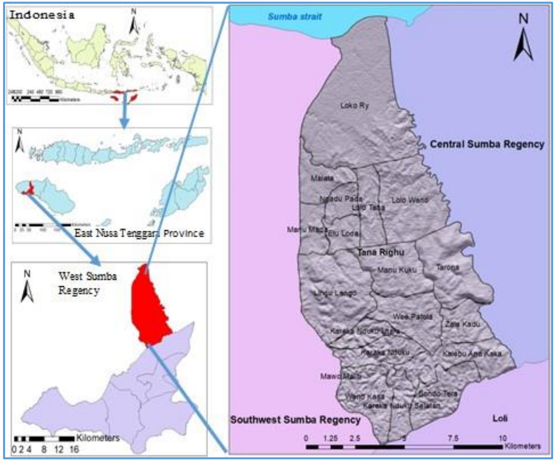

Fig 1. Study area map

Data and Sources

The different types of spatial data have been used in the present study: (a) Geological map (Waikabubak and waingapu Sheets) sourced from the Geological Research and Development Center of Indonesia (raster file, scale 1: 250.000);; (b) digital elevation model (DEM) sourced from the Geospatial Information Agency of Indonesia (30m × 30m raster file); (c) Soil Type Map (Denpasar sheet) sourced from Soil and Agroclimate Research Center of Agricultural Research and Development Agency of Indonesia (raster file , scale 1: 1.000.000); (d) Multispectral Remote Sensing Image, Landsat 8 OLI (Operational Land Imager) recorded April 25, 2022, sourced from the USGS (United States Geological Survey). Data and source of data are presented in Table 1.

RESULT AND DISCUSSION

Preparation and Computation of Thematic Maps

Seven thematic maps were prepared using GIS. The geological and soil type map has been prepared in a GIS environment after rectifying conventional raster map, and digitizing the different characteristics of geology and type of soil.

Remote sensing data (Landsat 8 OLI) was used to prepare LULC map and lineament line. Raw remote sensing data contains distortion, therefore, before the image is processed into LULC map, the pre-processing technique must be apply to image (radiometric and atmospheric correction). Pre-processing is processing of image performed prior to analysis to correct or minimize image distortion from, for example, image systems, sensors and environmental conditions. Radiometric and atmospheric correction of the image was performed with ENVI 4.5. Furthermore, the image is classified using a supervised classification technique by GIS environment. LULC classification results consist of 5 classes, namely, forest, urban area, grasslands, shrubs, water body, and rice fields. Lineament lines are extracted automatically from Landsat 8 OLI images with PCI Geomatics. The lineament line is then reclassified to obtain a lineament density map to five classes i.e. very high, high, medium, low, and very low.

DEM data is used to generate slope by slope function on ArcGIS, and reclassified according to the guidelines from the Indonesian Ministry of Forestry (Anonymous, 2009) (Table 7). DEM is also used to generate the stream network. The process of creating stream network involves the functions of fill, flow direction, flow accumulation, cont, and raster to polylines on ArcGIS. By using line density function on ArcGIS, then the drainage density per square km is created. Drainage density is reclassified into four classes according to Suwarno's clasifikation (Soewarno, 1991), i.e. very high, high, medium, and low (Table 8).

Geomorphological map was prepared by interpretation of several data such as lithology, drainage patterns, elevation, and slope. Each landform unit on the geomorphological map is made based on three aspects, i.e. morphology (morphography and morphometry), morphogenesis, and lithology. The morphological conditions of the landform units were made based on the elevation and slope maps, and the morphogenesis was determined based on the drainage pattern. The geomorphology of the study area consists of two landforms, i.e. plain karst and hill karst (Fig. 8).

Assigning Weight and Rank

The AHP method (Saaty, 1980) was used to assign weights to each factor influencing the potential for groundwater. AHP is a method for identifying the most influential factors for a complex system such as groundwater based on qualitative expert judgment. This is an easy way to compare decision elements that are difficult to measure. This method relies on building a hierarchy of decision elements and then making pairwise comparisons in the form of a matrix (Equation 1). This method is also used as a decision-making tool in cases where adequate and good quality data are not available (Saaty, 2014).

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & a_{23} & \cdots & a_{2n} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & 1 & \cdots & a_{3n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \frac{1}{a_{3n}} & \cdots & \frac{1}{a_{1n}} \end{bmatrix} \quad (1)$$

Where A is the n x n comparison matrix; a_{ij} are alternatives with respect to the given criteria; $a_{ij} > 0$; $1 < i < n$; $1 < j < n$; and n is the number of compared parameters.

A pairwise comparison matrix has been created (Table 2). The importance level for each influence factor is given according to Santy's scale (1-9) (Table 3). Based on a review of several literatures and input from hydrogeologists, the least influential factor is DD therefore it's scale is 1; the importance level of GM is between "Equal importance" to "moderate importance" compared to DD, therefor it's scale is 2; the importance level of SL is "moderate importance" compare to DD, therefore it's scale is 3; the importance level of S is between "Essential" to "very strong importance" compared to DD, therefore it's scale is 6; the importance level of the LULC factor is "Very strong importance" compared to DD, therefor it's scale is 7; the importance level of GL is between "very strong importance" to "extreme importance" compared with DD, therefore it's scale is 8; and the last, the importance level of the LD is "extreme importance" compared with DD, therefore it's scale is 9. After that, a new normalized matrix has been created to obtain the weight of each influencing factor (Table 4).

Table 2. AHP Pairwise Comparison Matrix (Seven Thematic Map)

Influencing factor	DD	GM	SL	S	LULC	GL	LD
DD	1	2	3	6	7	8	9
LULC	0.50	1.00	1.50	3.00	3.50	4.00	4.50
LD	0.33	0.67	1.00	2.00	2.33	2.67	3.00
SL	0.17	0.33	0.50	1.50	1.17	1.33	1.50
S	0.14	0.29	0.43	0.86	1.40	1.14	1.29
GL	0.13	0.25	0.38	0.75	0.88	1.00	1.13
GM	0.11	0.22	0.33	0.67	0.78	0.89	1.00

Table 3. Saaty's 1-9 scale of Relative Importance (Saaty, 1980)

Intensity of importance	Interpretation
1	Equal importance
3	Moderate importance
5	Essential
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate value between adjacent scale values

Assessing Matrix Consistency

To assess the calculated normalized weights are acceptable or require improvement, the consistency test must be carried out on the pairwise comparison matrix. Inconsistency in pairwise comparisons increases with increasing number of parameters (Saaty, 1980). Consistency ratio (CR) is used in AHP to assess the consistency of the pairwise comparison matrix that has been built. In AHP, the pairwise comparison matrix is consistent when the CR value is less than 0.1 (10 %). The pairwise comparison matrix requires improvement or revision if the CR value is greater than 10%. CR is calculated by the formula:

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

Table 4. Normalized comparison matrix for weighting factors influence

Parameter	DD	GM	Slope	Soil	LULC	Geology	LD	Sum	Normalize weight	Eigen value
DD	0.0278	0.0270	0.0256	0.0185	0.0213	0.0286	0.0278	0.1766	0.0252	0.9082
LULC	0.0556	0.0541	0.0513	0.0370	0.0426	0.0571	0.0556	0.3532	0.0505	0.9334
LD	0.0833	0.1081	0.0769	0.0556	0.0638	0.0857	0.0833	0.5568	0.0795	1.0341
Soil	0.1667	0.1622	0.1538	0.1111	0.1277	0.1714	0.1667	1.0595	0.1514	1.3623
Slope	0.1944	0.1622	0.1538	0.2222	0.1489	0.2000	0.1944	1.2761	0.1823	1.2240
Geology	0.2222	0.2162	0.2308	0.2222	0.2979	0.2286	0.2222	1.6401	0.2343	1.0251
GM	0.2500	0.2703	0.3077	0.3333	0.2979	0.2286	0.2500	1.9377	0.2768	1.1073
Principal Eigen value (λ_{max})										7.5942

Where, CI is the consistency index; RI is the Ratio Index (RI values for different numbers of parameter are presented in Table 5). CI is calculated by the formula:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (3)$$

Where, λ_{max} is the principal Eigen value (Table 4) and n is the number of parameters. The value of λ_{max} must be greater than n. λ_{max} has been calculated and its value is 7.5942; the number of parameters (n) is 7, then the CI is 0.099. Consistency Ratio = CI / RI = 0.099 / 1.32 = 0.0661 = 6.61 %. The value of CR is less than 10%, therefore, normalized weights (Table 4) are accepted, and then can be used for weighted overlays on GIS.

Table 5: Saaty's ratio index (RI) for different n values

n	3	4	5	6	7	8	9	10
RI	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49

Lineament Density (LD) of Study Area

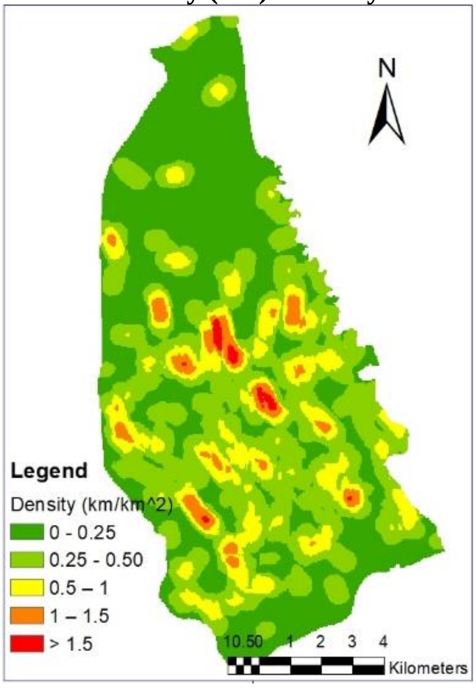

Fig 3. Lineament density map

Lineaments are surface terrains that express joints, fractures, and other linear or curvilinear structures that occur on the surface and beneath the earth's surface (Hung et al., 2005). Lineaments may be used to infer groundwater movement and storage (Hsin Y-F., et.all., 2016). Lineaments provide clues to groundwater movement and storage and are therefore an important guide for groundwater exploration (Nur, A. A., 2017). The higher LD indicates that the groundwater potential is high. Figure 3 is the LD map of the study area. In this map, the LD is higher in the middle of the study area, while in the north and south of the study area has a lower LD. LD was classified into five classes, i.e. Very Low (0 - 0.25 km/km^2), Low (0.25 - 0.50 km/km^2), Medium (0.5 – 1 km/km^2), High (1 – 1.5 km/km^2) and very high (> 1.5 km/km^2). Classes with low density are zones of low potential, therefore their scores are low, whereas classes with high density are zones of high potential, hence their scores are high. Table 9 shows the scores for each LD classes.

Geology of the Study Area

The study location consists of 3 geological formations, i,e, Waikabubak formation, Kaliangga formation, and Jaawila formation (Figure 4). Most of the study area are the Waikabubak formation with an area of 108.9 km2 (84.35%). The second largest formation is the Kaliangga formation with an area of 19.67 km^2 (15.23%). Only a small part of the area included in the Jawila formation is 0.54 km^2 (0.42%).

According to the geological map information from the Geological Research and Development Center, the geological composition of the Waikabubak formation consists of: limestone, clay, sandy marl composition, and tuffaceous marl. The geological composition of the Kaliangga formation is Reef limestone. Meanwhile, the geological composition of the Jawila formation is Grewake sandstone, calcareous, siltstone and clay inserts. Based on a review of some literature and input from hydrogeologists, it was determined that the most influential formations, respectively, were the Waikabubak Formation, the Jawila Formation, and the Kaliangga Formation (Table 9).

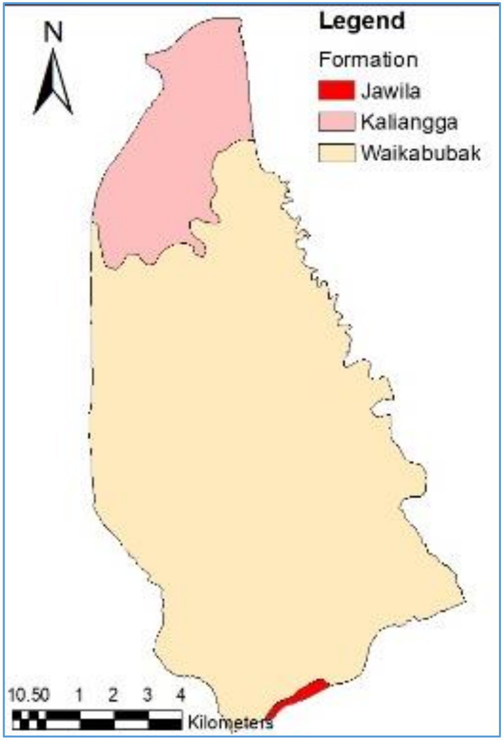

Fig 4. Geology map

Land Use / Land Cover (LULC) of Study Area

Land use of the study location was generated from remote sensing imagery (Landsat 8 OLI) with supervised classification techniques by ENVI 4.5 and ArcGIS 10.5. Land use is divided into five classes e.i. forest, urban area, grasslands, shrubs and paddy fields (Figure 5). Determination of the level of influence of each class is based on the effect of land use class on the runoff coefficient (C). C is defined as the ratio of the volume of water that flows as runoff during rain to the total volume of rainfall during a certain period (Bedient et al., 2013; Júnior, 2015).

The greater value of C, it's mean the greater the amount of rainwater that becomes surface runoff; Thus, the less rainwater infiltrated. C can be estimated by using a table of the relationship between C and land surface properties (Machado, R. E., et.al., 2022). The value of C for the Rational formula can be determined based on land use in an area (Cleveland, T. G., et.al., 2011). The scores for each land use class (except for paddy fields) were determined according to the value of C for rational formula (Table 6). The highest score was given to the land class with the lowest C value, while the land class with the highest C value has lowest score (Table 9).

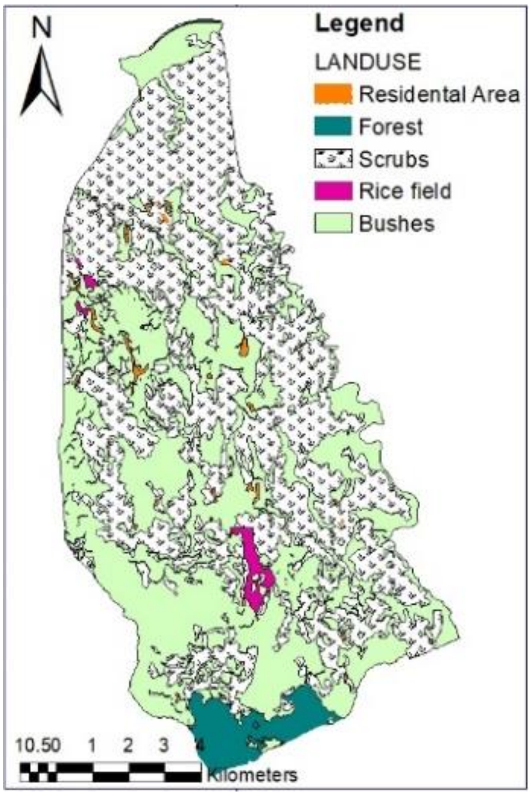

Fig 5. Land use/land cover map

Table 6. Rational method runoff coefficients for various land use (Cleveland, T. G., et.al., 2011)

Land use	Runoff coefficients
Suburban	0.35-0.40
Forest	0,05-0,25
Meadow	0,10-0,25
Grassland	0,15-0,45

Soil Composition

There are 4 types of soil at the study site (Figure 6), i.e. durinodic ustorthents with an area of 24.62 km^2, andics haplustepts covering an area of 52.35 km^2, fluventic eutrudepts covering an area of 31.35 km^2, and vitritorrandic ustorthents covering an area of 20.62 km^2. The soil composition of Durinodic Ustorthents is mostly Pumicelike fragments; the largest composition of andics haplustepts is pumice; fluventic eutrudepts soil is mostly containing coarse to fine sand; and the soil of the vitritorrandic ustorthents is mostly containing of Sinder (Soil Survey Staff, 2014a; Soil Survey Staff, 2014b). Soil with sand content is the most influence on groundwater infiltration and soil with cinder content has the least effect on groundwater infiltration. The scores for each soil type from the highest to the lowest were Fluventic Eutrudepts = 5; Durinodic Ustorthens = 4; Andics Haplustepts = 3; and Vitritorrandic Ustorthents = 2 (Table 9).

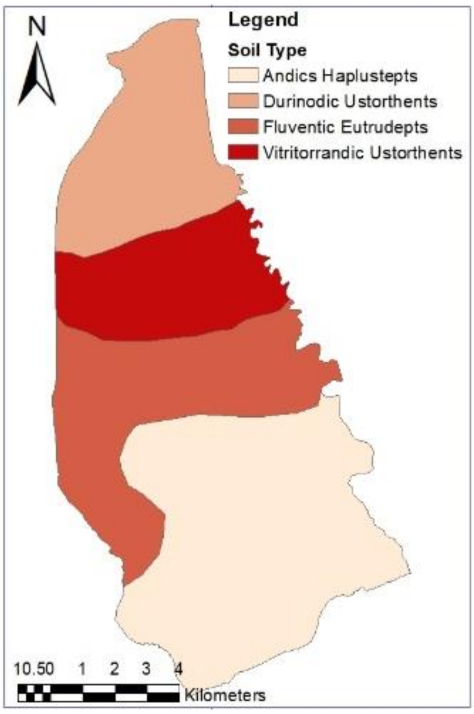

Fig 6. Soil map

Land Slope of the Study Area

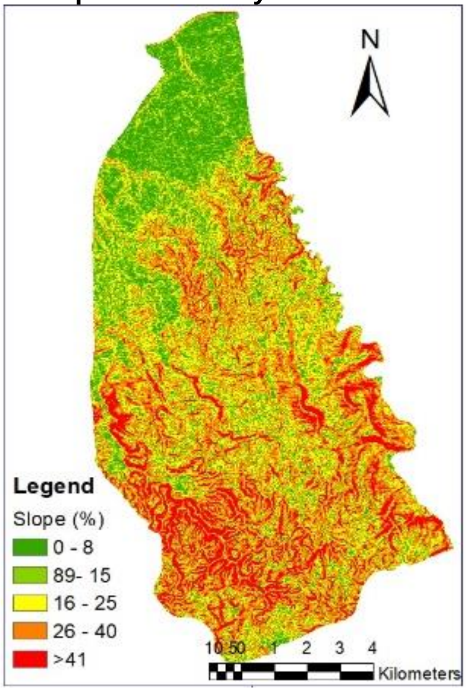

Fig 7. Slope map

Slope is a factor that affects the infiltration rate. The relationship between the slope and the infiltration rate is a non-linear relationship. If the slope increases, the infiltration rate will decrease, and thus will increase the surface runoff (Fox, D.M., et.al., 1997). The slopes of the study location are classified into five classes (Table 5), according to the slope classification propose by the Indonesian Ministry of Forestry (Anonym, 2009). The score for each class of slope is given according to its effect on the infiltration rate. Steeper slopes are given the lowest score, while flat slopes are given the highest score (Table 9).

Table 7. Slope classification propose by Indonesian Ministry of Forestry

Classes	Description	Slope
1	Flat	> 8 %
2	Sloping	8 – 15%
3	A bit steep	16 - 25%
4	Steep	26 – 40%
5	Very steep	< 40%

Geomorphology (GM) of the Study Area

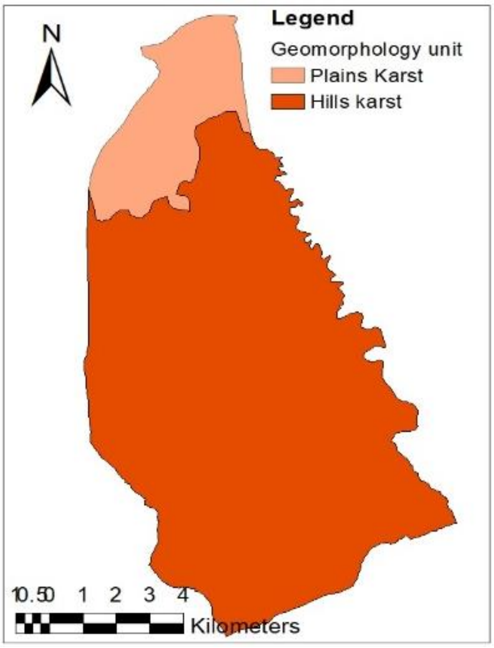

Fig 8. Geomorphology map

GM is the science of landforms on the earth's surface, both above and below sea level, and emphasizes the origin of formation (genesis) and future development, and the relationship with the environment (Verstappen, 1983). Geomorphology also describes various landforms associated with groundwater occurrences and structural features (Ramu and Vinay, 2010). Geomorphology controls the movement of subsurface groundwater. This is one of the most important features in evaluating groundwater potential and prospects. Therefore, geomorphology can be utilized for the management of groundwater resources (Valliammai et al., 2013). Geomorpho-logical maps describe the formation of the earth's surface, along with its geological content, as well as the form of origin of the formation (genesis). The geomorphology of the study area consists of two landforms, i.e. plain karst and hill karst (Fig. 8). Plain karst landform is located in the north region with an area of 10 km^2, while the hill karst is located in the south, with an area of 50 km^2. Table 8 shows the scores for each GM classes

Drainage Density

DD has a significant effect on the peak of flooding in a watershed. The large river network in the river basin will shorten the time of concentration (t_c), because the flow velocity is higher in the channel than in the land surface. t_c is a factor that affects the peak flood discharge. A high DD implies a shorter t_c and increases the peak flood discharge (Pallard, B., et.al., 2009).

Table 8. DD classification propose by Soewarno (Soewarno, 1991)

DD (km/km^2)	Density class
<0.25	Low
0.25-10	Moderate
10-25	High
>25	Very high

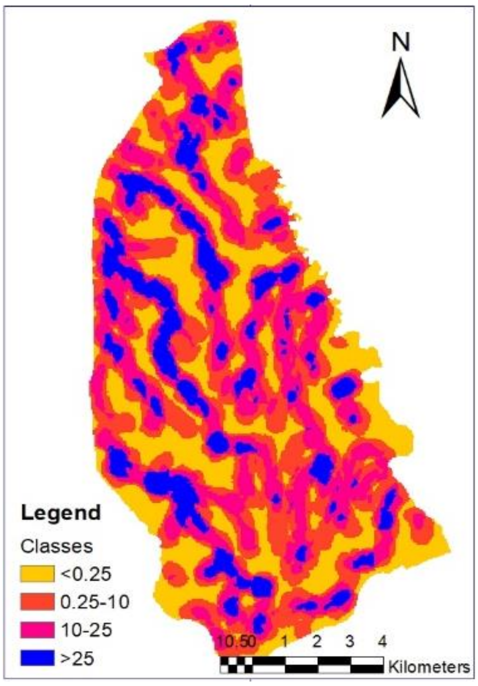

Fig 9. Drainage density map

High peak flood discharge indicates that only a small amount of rainwater is infiltrated (and percolated for groundwater recharge), most of rainwater becomes runoff. In this study, DD is divided into four classes (Figure 9) according to the DD classification suggested by Soewarno (Table 8) (Soewarno, 1991). Scores for each class are given according to their effect on peak flood discharge. High drainage density was given the lowest score, while the lowest drainage density was given the highest score (Table 9).

Table 9. Normalize weights and assigned rank for the sub-parameters

Influencing Factor	Classes	Normalize Weight	Influence (%)	Rank
LD (km/km^2)	Very high	0,2768	27,68	5
	high			4
	Moderate			3
	Low			2
	Very low			1
GL	Jawila formation	0,2343	23,43	3
	Waikabubak formation			4
	Kaliangga formation			2
LULC	Residential Area	0,1823	18,23	1
	Rice field			5
	Forest			4
	Pasture			2
	Scrubs			3
S	Haplustolls Ustorthens	0,1514	15,14	4
	Haplusterts Haplustepts			4
	Hapludolls Eutrudepts			2
	Haplustepts Ustorthents			3
SL (%)	0-8	0,0795	7,95	5
	9-15			4
	16-25			3
	26-40			2
	>40			1
GM	Plains Karst land unit	0,050454	5,05	4
	Hills karst land unit			2
DD (km/km^2)	<0.25	0,025227	2,52	4
	0.25-10			3
	10-25			2
	>25			1

Groundwater Potential Zone (GWPZ)

GWPZ are obtained by combining all raster maps with a weighted overlay technique on ArcGIS. After the overlay process, the next step is reclassify the new raster with natural break interval to obtain a map of the GWPZ (Fig 10). GWPZ zones in study location are classified into 5 i.e. very low, low, moderate, high, and very high. Figure 10 shows that most of the study areas have "moderate" GWPZ (approximately 54.57 km^2 or 42% of the total area). The second largest area of GWPZ is "high" potential zone (approximately 39.87 km^2 or 30.68% of the total area); the third largest area of GWPZ is "low" potential zone (approximately 28.82 km^2 or 22.18% of the total area); the fourth largest area of GWPZ is "very high" potential zone (approximately 4.64 km^2 or 3.57% of the total area), and the smallest area of GWPZ is "very low" potential zone (approximately 2.03 km^2 or 1.56% of the total area).

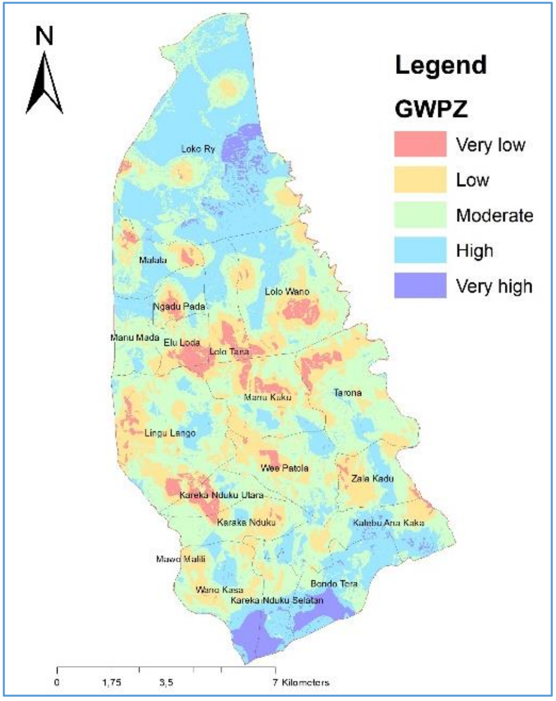

Fig 10. GWPZ of the study area

Zones of "moderate" groundwater potential are generally found in all villages in Tana Riguh, even though most are located in the central part of Tana Righu including Tarona Village, Manu Kuku Village, Lingu Lango Village, Wee Patola Village, and Manu Mada Village. Zones of "high" groundwater potential are found in all villages in Tana Righu, even though mostly found in the northern part of Tana Righu including Loko Ry Village, Malata Village, Lolo Wano Village, and Lolo Tana Village; and a small part is found in the southern part of Tana Righu including Kalebu Ana Kaka Village, Bondo Tera Village, and South Kareka Nduku Village. Zones of "low" groundwater potential are found in all villages in Tana Righu, even though most are found in the central part of Tana Righu including the Lolo Wano Village, Lolo Tana Village, Elu Loda Village, Lingu Lango Village, Wee Patola Village and Tarona Village. Zones of "very low" groundwater potential are found in all villages in Tana Righu, even though most are found in the central part of Tana Righu including Ngadu Pada Village, Elu Loda Village, Lolo Tana Village, Lolo Wano Village, Manu Kuku Village, Tarona Village, and North Kareka Nduku Village. Zones of "very high" groundwater potential are located in the northern part of Tana Righ, located in Loko Ry Village, and in the southern part of Tana Righu covering Bondo Tera Village, South Kareka Nduku Village, and Wano Kasa Village.

CONCLUSION

Potential of GWPZ in the Tana Righu area, West Sumba Regency, Indonesia has been identified. In this study, the factors that are considered as factors that influence GWPZ are Lineament Density, geology, Landuse/land cover, soil composition, slope, geomorphology, and drainage density. Based on a review of several relevant literatures on groundwater potential from various regions around the world and input from hydrogeologist, these factors are weighted based on their level of influence on groundwater using the AHP method. The results are used to create a map of the GWPZ which is classified into very low, medium, and high and very high potential zones. The GWPZ with the largest area is medium potential zone (approximately 54.57 km^2 or 42% of the total area); the GWPZ with the second largest area is high potential zone (approximately 39.87 km^2 or 30.68% of the total area); the GWPZ with the third largest area is low potential zone (approximately 28.82 km^2 or 22.18% of the total area); the GWPZ with the fourth largest area is very high potential zone (approximately 4.64 km^2 or 3.57% of the total area), and the GWPZ with the smallest area is very low potential zone (approximately 2.03 km^2 or 1.56% of the total area).

ACKNOWLEDGEMENTS

This research was funded by the DIPA of the State Polytechnic of Kupang, therefore the leading author of this paper would like to thank to State Polytechnic of Kupang for all the support on this research

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