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Groundwater Potential Mapping using Geospatial and AHP Techniques in Eastern Province of Rwanda

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Abstract

The article presents an analysis of the potential groundwater recharge zones in the Eastern Province of Rwanda using Geographic Information System (GIS) technology. The groundwater potential zones (GWPZs) in the area are influenced by several factors. To conduct the spatial analysis, seven theme layers were created and integrated, including geology, drainage density, rainfall, slope, soil, land use and land cover (LULC), and normalized difference vegetation index (NDVI). The Analytical Hierarchy Process (AHP), based on multiple criteria, was utilized to assign weights to each layer. By overlaying the theme layers with the prescribed weights, a map of potential groundwater recharge zones was generated. These zones were classified into five categories: poor, fair, medium, good, and excellent, representing 173 km2 (1.9 %), 1002 km2 (11.3%), 5976 km2 (67.2%), 1732 km2 (19.5%), and 12 km2 (0.1%), respectively. The findings revealed that a significant portion of the study area exhibited good to moderate potential zones for groundwater. Among the seven districts in the Eastern Province, Rwamagana district had the highest coverage of good and excellent groundwater potential zones, accounting for 59% and 1% of the area, respectively. The accuracy of the GWPZ map was assessed by comparing it with borehole yield data, demonstrating the reliability of the chosen methodology. These validated results provide valuable support for the sustainable management and strategic utilization of groundwater resources in the study area. The study outcomes can guide decision-makers in making informed choices regarding the conservation of groundwater resources in the research area.

Keywords: Groundwater potential zone, AHP, GIS, sustainable management, Rwanda

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1. Introduction

One of the essential elements for human survival and the fulfillment of all life's needs is water (Ahirwar et *al*., 2020). Groundwater makes up about 99 percent of the world's liquid freshwater, yet it is often overlooked or mismanaged (Nah & Mensah, 2020). Groundwater offers enormous social, economic, and environmental benefits to countries, including potential contributions to climate change adaptation and the achievement of the Sustainable Development Goals (SDGs) (Nah & Mensah, 2020). Groundwater resources are major sources of drinking water in Sub-Saharan Africa (SSA) countries. Data reveals that groundwater is used for residential purposes by 50% of people living in cities and 80% of those in rural areas, this rate is expected to increase in the future (Patle, 2019). Groundwater development has a lot of potential to meet the requirement for rapidly expanding water supply in SSA region, both for human survival and for economic growth (Lapworth et *al*., 2017).

The mapping of groundwater potential zones is critical for the most efficient use and conservation of this valuable resource (Das et *al*., 2019). Therefore, regarding the importance of groundwater resources, there is a need to develop a low-cost, quick-to-implement method for assessing groundwater resources and management techniques (Vasudevan et *al*., 2015). Geographical Information System (GIS) has been shown to be a beneficial tool for groundwater investigations because it provides an ideal foundation for efficiently handling massive and complicated spatial data for natural resource management (Ghosh et *al*., 2016; Shekhar & Pandey, 2015). Rwanda's population is increasing, approximately 12 million people live currently in an area of 26,338 square kilometers, resulting in a population density of 456 inhabitants per square kilometer that depend on natural resources (NISR, 2017). In addition, the National Institute of Statistics of Rwanda (NISR) projects the population to increase by more than 50% to 17.6 million by 2035 and to double to about 22.1 million people by 2050 (GoR, 2008). The expected Increase of population is expected to influence water demand and accessibility to water will be restricted and insufficient to meet demand. Thus, groundwater is one of the important sources to respond to the existing water shortage, especially in rural areas (RWB, 2021).

Due to water scarcity of springs and other water sources within the region, the Eastern province experiences recurring water scarcity. The groundwater is a potential source to address water scarcity in the region. However, before it can be widely used, some information about its distribution, amount, and quality is required. The main objective of this paper is to investigate and map groundwater potentiality in Eastern province using GIS and Multi-Criteria Decision-Making Models such as the Analytic Hierarchy Process (AHP). The results of this study could serve as a supporting tool for decision-makers in future planning of water provision and management.

2. Materials and Methods

2.1. Study Area Description

Rwanda's Eastern Province is one of the country's four provinces. Eastern Province is the largest with 9,813 km^2, the most populous with 3,563,145people, and the least densely inhabited with 380 people per km^2 (NISR, 2023). It is, located between the latitudes of 1°45'00" and 3°30'00"

(Figure 1), with elevation between 1300m and 2200m and characterized by annual rainfall ranging from 827mm to 1200mm distributed over two seasons (Bizuhoraho et al., 2019).

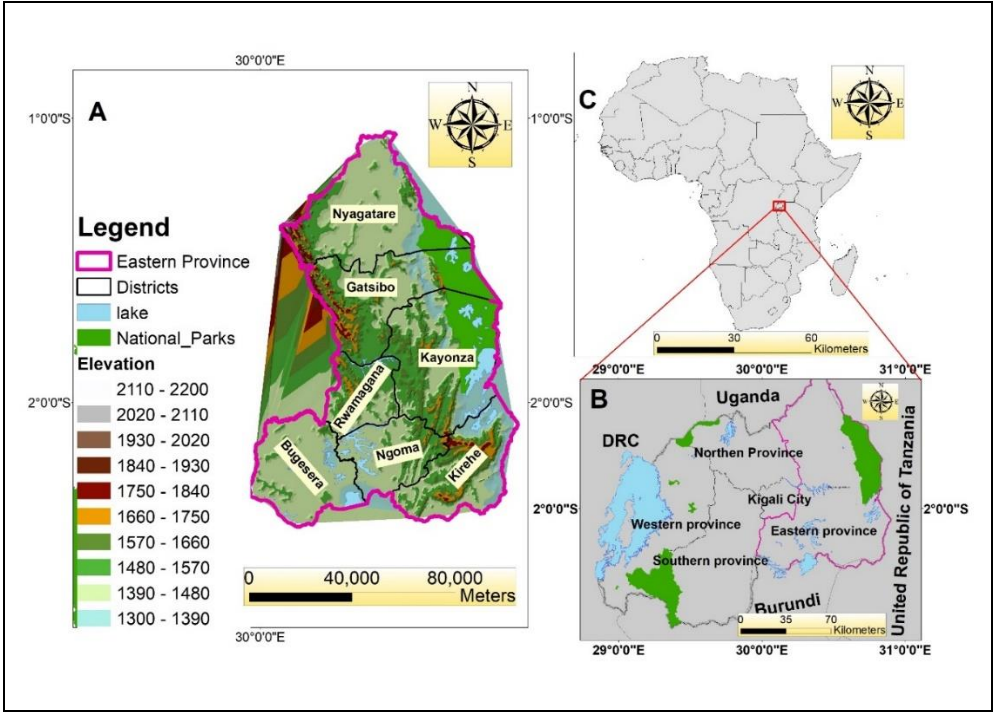

Figure 1: Location of the Study Area in (A), Study Area Location in Rwanda (B) and (C) Rwanda in Africa

2.2. Methods

Using intensive literature review eight important biophysical factors to identify groundwater potential areas were selected.). Biophysical factors (: Lithology, drainage density, rainfall, slope, soil, Land use/land cover, and Normalized Difference Vegetation Index (NDVI). were used to build individual thematic maps for each factor, the ranking was assigned respectively to the individual parameter of every thematic map. Because not all factors have the same level of influence on ground-water potentiality in the area, the weight of each factor had to be decided. The Analytic Hierarchy Process (AHP) a multicriteria approach tool was used to weigh factors, by converting subjective evaluation into quantitative data by assigning scores to numerous factors. This method takes the lead in qualitative method, which is based on expert opinions. The final thematic maps were weighted and overlaid to produce the final groundwater potentiality map. To objectively evaluate and confirm the accuracy of the results borehole yield data were compared to final potentiality classes.

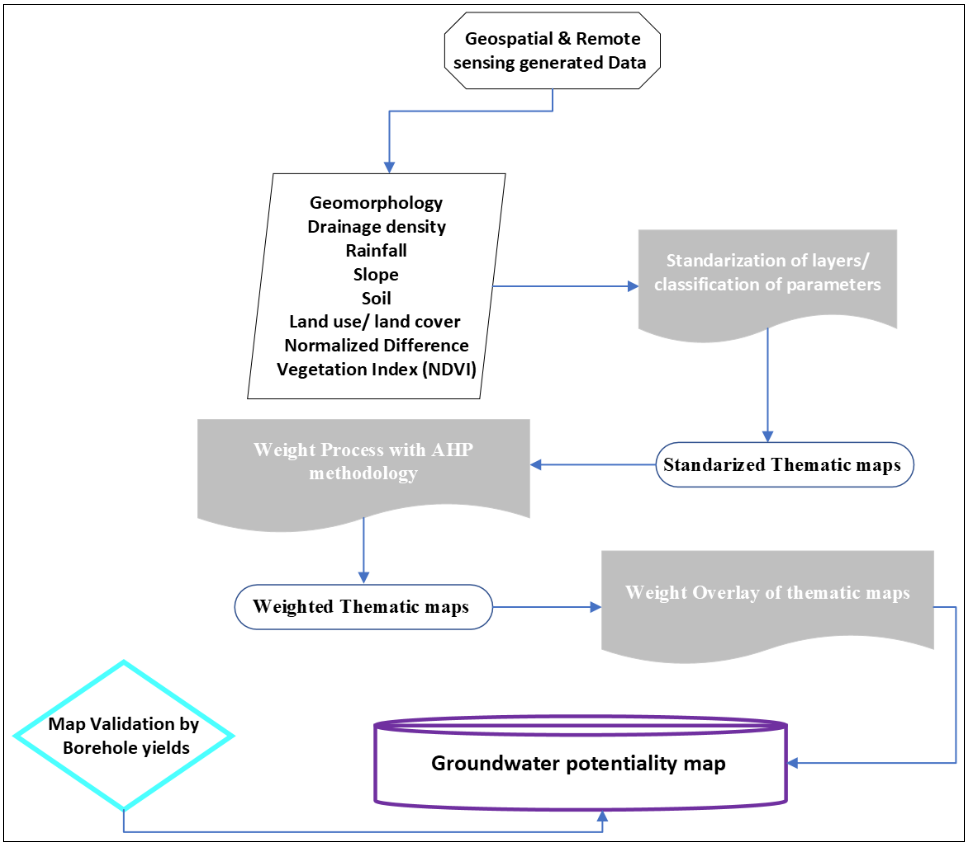

Figure 2: Methodology flowchart

2.2.1. Thematic Map Preparation and Source of Data

Using literature review on groundwater potentiality (Ahirwar et *al*., 2020; Das et *al*., 2019, 2020; Ghosh et *al*., 2016; Shekhar & Pandey, 2015; Singh et *al*., 2021; Vasudevan et *al*., 2015; Yeh et *al*., 2016) Seven factors (Geology, drainage density, rainfall, slope, soil, Land use/ land cover, and Normalized Difference Vegetation Index (NDVI) were selected for making different thematic maps (Figure 3).

2.2.1.1. Rainfall

Rainfall is often the main source of groundwater recharge since it allows the water to permeate soils and fissures beneath the surface. It determines the volume of runoff that can be stored in recharge basins to boost infiltration (Zghibi et *al*., 2020). According to Yeh et *al*. (2016), in both tropics and subtropics, rainfall is the primary source of groundwater recharge. The rainfall of our study ranges between 633-1550 mm per year (Figure 3a). The annual mean precipitation from 1981 to 2016 of 39 meteorological stations of Eastern Province were used. From the Rwanda Meteorology Agency 39 stations data a rainfall distribution map was created using the inverse distance weighted approach (IDW).

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2.2.1.2. Drainage Density

The total length of all rivers in a drainage basin divided by the drainage basin's total area is known as drainage density. A drainage network's structural study assists in determining the characteristics of a groundwater recharge zone (Ahirwar et *al*., 2020). To prepare the drainage density map (Figure 3f), the Digital Elevation Model (DEM) layer obtained from the University of Rwanda's Centre for Geographic Information Systems and Remote Sensing was used. The DEM layer assisted in generating stream orders that were used in calculating drainage density using line density tool in GIS Arc toolbox.

2.2.1.3. Slope

Slope is a crucial factor considered in various predictive models and environmental management (Singh et *al*., 2021). Slope is a good indicator to identify groundwater potentiality, as area of steep slope increases runoff, while low sloped area increases infiltration and groundwater recharge (Vasudevan et *al*., 2015). The slope (Figure 3d) of our study area was calculated in percentage (%) using Digital Elevation Model (DEM) layer obtained from the University of Rwanda's Centre for Geographic Information Systems and Remote Sensing. The DEM was processed in surface tool in GIS Arc toolbox.

2.2.1.4. Soil

The composition of soil has a great influence on groundwater recharge (Adel Zghibi et *al*., 2020). MINAGRI's soil texture data was used to build Rwanda soil map (Figure 3g). In our study area, we have characterized the groundwater potentiality by considering the percentage of clay in soil. According to Ali et *al*. (2019), the quantity of clay content in soil influences the infiltration capacity of an area, the higher the clay content, the lower the infiltration, and lower the clay content in soil, the higher the infiltration, and groundwater recharge.

2.2.1.5. Land Use/Land Cover

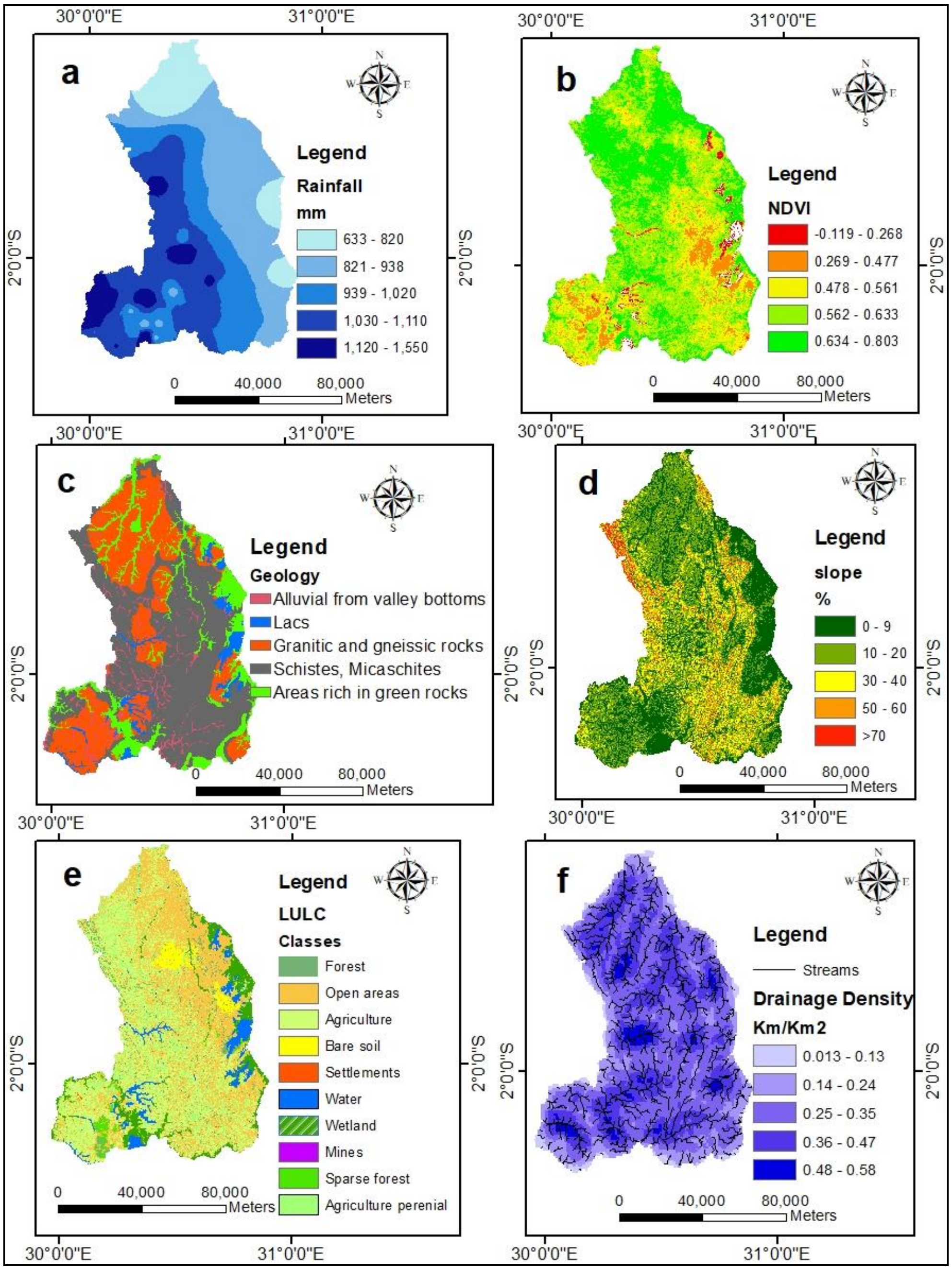
LU/LC is important in assessment of groundwater distribution and development of an area (Das et *al*., 2019; Zghibi et *al*., 2020). Different LULC have distinct effects in terms of run-off and infiltration capacity (Rahmati et *al*., 2016). To make the final thematic map (Figure 3e) we used 2018 data from CROM DSS of Rwanda Water Portal.

2.2.1.6. Normalized Difference Vegetation Index (NDVI)

Normalized Difference Vegetation Index (NDVI) is often employed as an indirect indicator of groundwater accessibility (Singh et *al*., 2021). Greater NDVI values are directly related to the availability of sufficient shallow groundwater. The NDVI thematic layer (Figure 3b) was delivered from CROM DSS data.

2.2.1.7. Geology

Groundwater percolation and penetration are entirely influenced by geology as porosity and permeability in aquifer rocks are components of geology (Ifediegwu, 2022; Patle, 2019). This was also pointed out by Yeh et *al*., (2016), who argued that in the occurrence and spread of groundwater, lithology (Figure 3c) is crucial. Thus, geology is a key factor that was used in this study for evaluating groundwater potential. The lithology of our study area is composed of alluvial from valley bottoms; quartzites dominating the levels; granitic and gneissic rocks; schists, and quartzmicaschites. Some quartzitic levels; minor shales, micaschites, quartzites peat bogs - carbonaceous, acidic soils marshy areas - Dominant clays - Carbonaceous soils; areas rich in green rocks (Dolerites, Gabbros, Amphibolites). The lithology was classified into main dominating types which are alluvial from valley bottoms; granitic and gneissic rocks; schists, quartz micaschites; areas rich in green rocks (Dolerites, Gabbros, Amphibolites).


a
Legend
Rainfall
mm
633 - 820
821 - 938
939 - 1,020
1,030 - 1,110
1,120 - 1,550
b
Legend
NDVI
-0.119 - 0.268
0.269 - 0.477
0.478 - 0.561
0.562 - 0.633
0.634 - 0.803
c
Legend
Geology
Alluvial from valley bottoms
Lacs
Granitic and gneissic rocks
Schistes, Micaschites
Areas rich in green rocks
d
Legend
slope
%
0 - 9
10 - 20
30 - 40
50 - 60
>70
e
Legend
LULC
Classes
Forest
Open areas
Agriculture
Bare soil
Settlements
Water
Wetland
Mines
Sparse forest
Agriculture perenial
f
Legend
Streams
Drainage Density
Km/Km2
0.013 - 0.13
0.14 - 0.24
0.25 - 0.35
0.36 - 0.47
0.48 - 0.58
30°0'0"E
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2°0'0"S
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40,000
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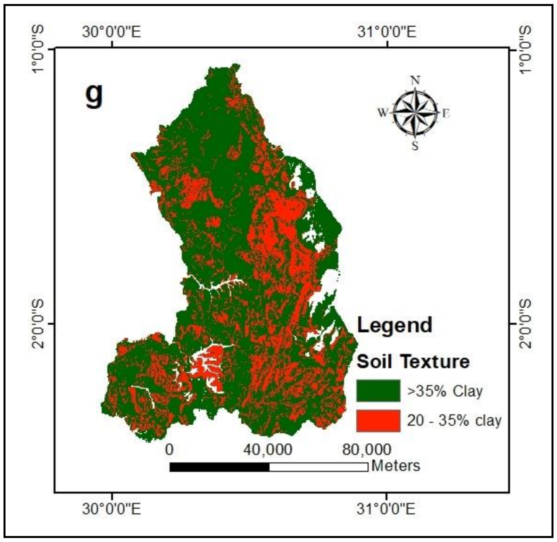

Figure 3: Thematic maps

2.2.2. Standardization and AHP Weighting of Factors

AHP is a well-known model for assigning a normalized weight to each thematic layer of a groundwater prospecting factor (Ahmadi et al., 2021). It is intended to find solutions for challenging decision-making situations. The parameters from selected factors that influence groundwater potentiality were ranked from 1-9 (Table 1) and their weight influence was calculated in Table 1. The level of importance of one factor to another was assessed through saaty's scale based on different experts' opinions.

Table 1: The fundamental scale of Saaty

Importance of factors on Saaty's scale	Scale naming
1	Equal importance
3	Moderate importance of one over another
5	strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between the two adjacent judgments

Source: Adapted from Saaty (1987)

Pairwise comparisons were completed with different expert's using the AHP priority calculator questionnaire online using the AHP Online System (for more detail: https://bpmsg.com/ahp/ahp). Experts to participate in online questionnaire were selected basing on their expertise in water and natural resource management. One expert in charge of forestry and natural resources, another

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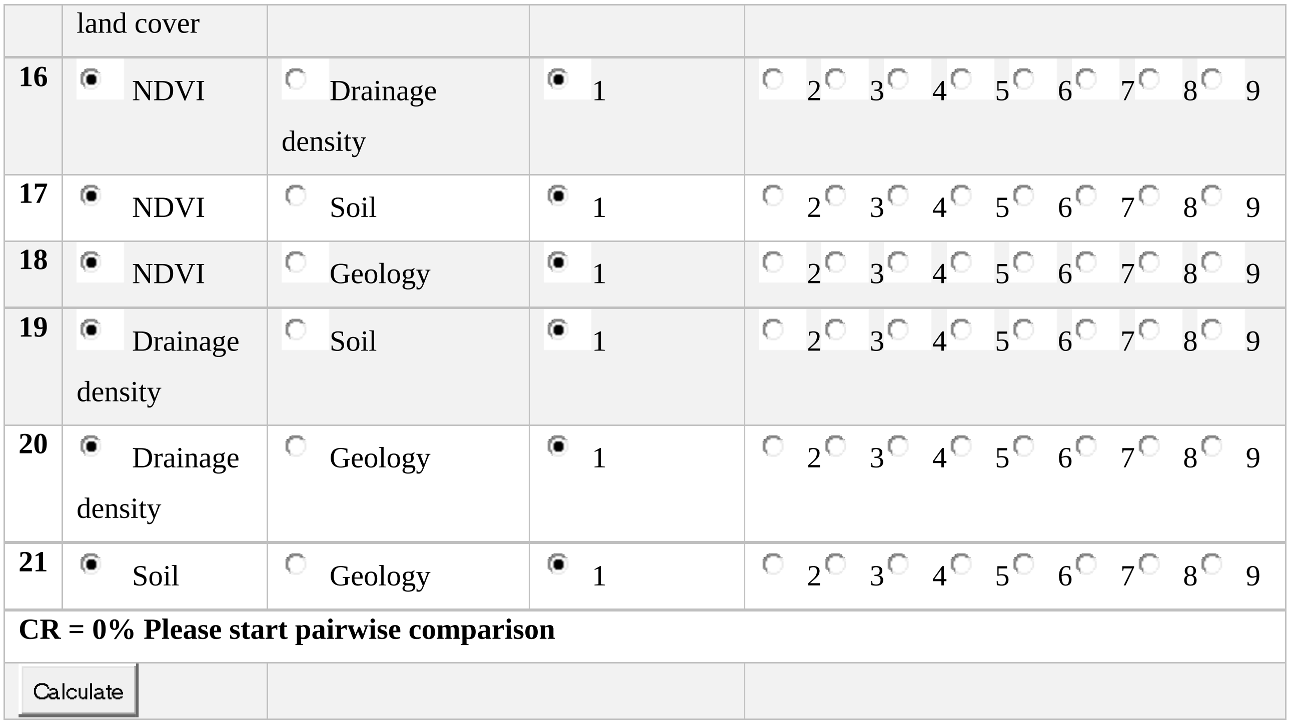
from agriculture and natural resources management from Bugesera, Rwamagana, Nyagatare and Kayonza districts participated in questionnaire completion in Table 2. The following is the questionnaire used in pairewise comparison of various factors with respect to AHP priorities. Factors were compared by considering the importance of one factor to another on a scale from 1 to 9 (Table1).

A - wrt AHP priorities - or B?			**Equal**	**How much more?**
1	● Rainfall	○ Slope	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
2	● Rainfall	○ Land use/ land cover	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
3	● Rainfall	○ NDVI	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
4	● Rainfall	○ Drainage density	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
5	● Rainfall	○ Soil	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
6	● Rainfall	○ Geology	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
7	● Slope	○ Land use/ land cover	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
8	● Slope	○ NDVI	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
9	● Slope	○ Drainage density	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
10	● Slope	○ Soil	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
11	● Slope	○ Geology	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
12	● Land use/ land cover	○ NDVI	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
13	● Land use/ land cover	○ Drainage density	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
14	● Land use/ land cover	○ Soil	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
15	● Land use/	○ Geology	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9



	land cover			
16	● NDVI	○ Drainage density	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
17	● NDVI	○ Soil	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
18	● NDVI	○ Geology	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
19	● Drainage density	○ Soil	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
20	● Drainage density	○ Geology	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
21	● Soil	○ Geology	● 1	○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
CR = 0% Please start pairwise comparison				
Calculate				

Source: Adapted from (Goepel, 2018)

The results from the pairwise comparison are found in below Table 2. These are the resulting weights for the criteria based on pairwise comparisons.

Table 2: Weight considered for Factors Influencing Groundwater Potentiality

Factors (criteria)	**Resulting weights**	**Rank**
Geology	26.0%	1
Drainage density	12.3%	5
Rainfall	17.4%	2
Slope	9.0%	7
Soil	12.4%	4
Land use/ land cover	13.3%	3
Normalized Difference Vegetation Index (NDVI)	9.7%	6
∑100	100%	

As recommended by Adams & Saaty (2003), Saaty's consistency test must be used in the pairwise comparison approach to ensure that the decision-maker is not making random or unreasonable pairwise comparisons. Saaty (1987) suggested a consistency ratio of the matrix less than or equal to 10%. Our matrix was consistent since the calculated consistency ratio of the matrix comparison was 6.7%.

Table 3: Standardization of Criteria

Factor/Criteria	**Unity**	**Sub-criteria**	**Classes Rating and Naming**	**Weight**
Rainfall	Mm	633-816	1: Poor	17.4
		817-999	2: Fair	
		1000-1180	3: Moderate	
		1190-1360	4: Good	
		1370-1550	5: Excellent	
Slope	%	0-9	5: Excellent	9
		10 - 20	4: Good	
		30 - 40	3: Moderate	
		50 - 60	2: Fair	
		>70	1: Poor	
Land Use/Land Cover		Forest	5: Excellent	13.3
		Open areas	4: Good	
		Agriculture	4: Good	
		Bare soil	3: Moderate	
		Settlements	2: Fair	
		Water	5: Excellent	
		Wetland	5: Excellent	
		Mines	3: Moderate	
		Sparse forest	4: Good	
		Agriculture perennial	4: Good	
NDVI		-0.39	1: Poor	9.7
		0.269 - 0.477	2: Fair	
		0.478 - 0.561	3: Moderate	
		0.562 - 0.633	4: Good	
		0.634 - 0.803	5: Excellent	
Drainage density	Km/km^2	0.013 - 0.13	5: Excellent	12.3
		0.14 - 0.24	4: Good	
		0.25 - 0.35	3: Moderate	
		0.36 - 0.47	2: Fair	
		0.48 - 0.58	1: Poor	
Soil	%Clay	>35% Clay	1: poor	12.4
		20 - 35% clay	4: Good	
Geology		Alluvial from valley bottoms	5: Excellent	26
		Quartzites dominating the levels	4: Good	

		Granitic and gneissic rocks	1: Poor	
		Schists, quartz micaschites. Some quartzitic levels	3: Moderate	
		Minor shales, micaschites, quartzites	3: Moderate	
		Peat bogs - Carbonaceous, acidic soils	2: Fair	
		Marshy areas - Dominant clays - Carbonaceous soils	1: Poor	
		Areas rich in green rocks (Dolerites, Gabbros, Amphibolites)	3: Moderate	

3. Results and Discussions

To define the probable groundwater recharge zone, we weighted seven thematic maps which are lithology, NDVI, drainage density, land cover, rainfall, slope, and soil. The lithology of the study area is dominated by the most competent aquifer type which is quartzites embedded among the less competent schists. And more the existence of the alluvium that is composed of clayey soils with limiting transmissivity and low-yielding boreholes. Different lithology types were classified into five main classes (1: poor, 2: fair, moderate, 3: good, 4: excellent) regarding the water infiltration and permeability capacity of retaining water (Table 3).

The slope of the study area is ranging from 9% to >70% with poor to excellent potentiality for groundwater respectively. The slope classification was done based on the fact steep slopes have the low potentiality for groundwater replenishment, while the low slope zones have a good potential for groundwater storage (Hasan et *al*., 2022; Ifediegwu, 2022; Patle, 2019). The amount of rainfall as the most key component in determining a region's potential recharge zones varies from 633mm to 1550mm. As discussed by Singh et *al*. (2021), higher rainfall distribution may enhance infiltration potential, which would increase aquifer recharge. Thus, the intensity of rainfall ranging between 633 to 816 mm was classified as poor for groundwater potentiality whereas 1370m -1550m was an excellent zone for groundwater potentiality.

Drainage density and groundwater recharge are connected. The location with low drainage density shows a higher infiltration rate, which delivers excellent groundwater potential (Arunbose et *al*., 2021). The study area's drainage density values (Fig. 3f) range from 0.013 to 0.58 km/km^2 with poor to excellent ground water potentiality respectively. The region's soil types have quite a big influence on the ability of the land to hold water and recharge the groundwater (Melese & Belay, 2022). The percentage of clay content in soil was used to classify the soil, where the higher the clay percentage in soil, the lower the infiltration of groundwater

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(Wondim, 2016). The clay content in the soil of the study area ranged from 20% to over 35% of clay in soil.

The NDVI of the study area varies from -0.39 to + 0.803 as shown in Figure 3b and Table 3. Increased NDVI (Normalized Difference Vegetation Index) levels are directly associated with the occurrence of adequate groundwater sources (Singh et al., 2021). Hence, the highest area with NDVI values (0.634 - 0.803) was considered excellent in groundwater potentiality. The total thematic maps are classified, converted into raster format, and added to one another using the AHP overlay operation in ArcGIS software to delineate the groundwater potential zone in the current study area. This is done after computing the final AHP weights of all the thematic layers and rating of their individual characteristics. With regard to groundwater potential, seven categories are determined: excellent (12 km^2), Good (1732 km^2), Moderate (5976 km^2), Fair (1002 km^2), and poor (173 km^2) groundwater potential zones. The extent and distribution of these zones are depicted in Figure 4. The findings of the current study showed that the eastern portion of the study region has good prospective zones. It was also found that the region has moderate groundwater potential in the Middle West.

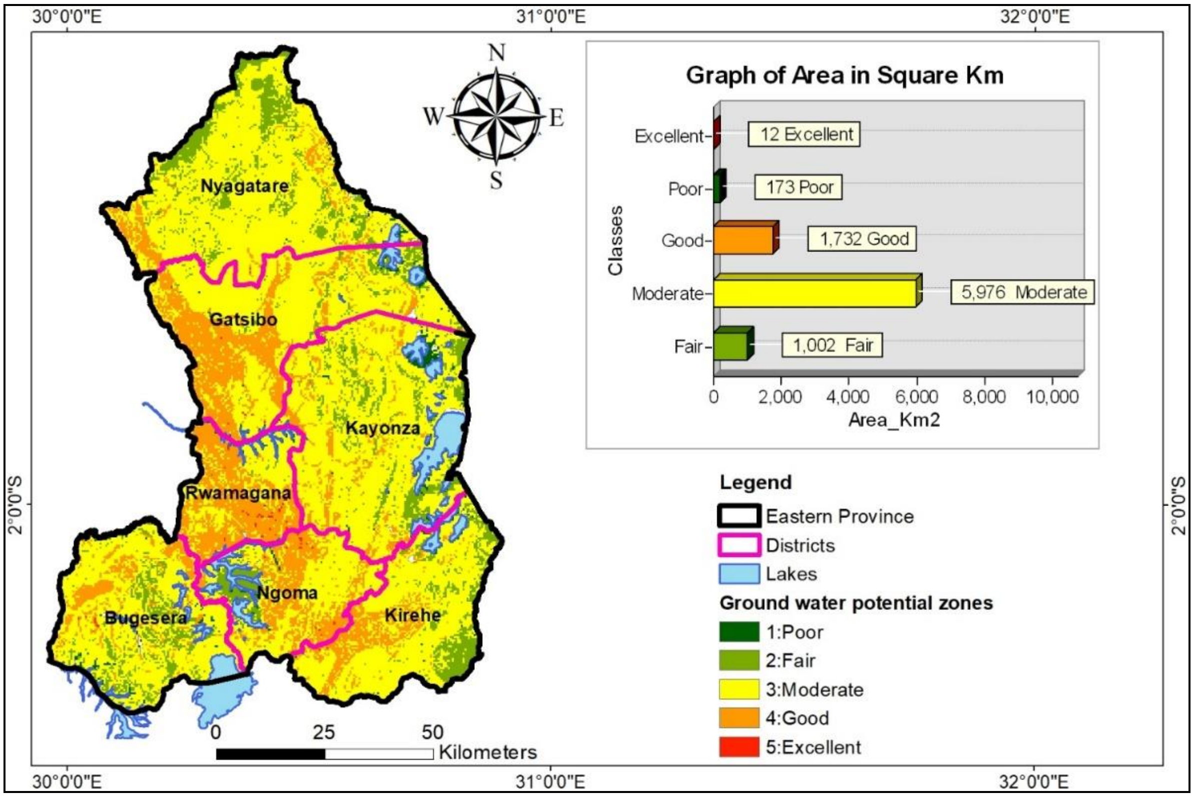

Figure 4: Groundwater Potential Map

The resulting of groundwater potential map (Figure 4 & Table 4) revealed that Rwamagana district has the biggest cover of good and excellent ground potential zone with 59% and 1% of good and excellent ground water potential zone respectively. The potentiality of Rwamagana

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District is due to the presence of high intensity rainfall compared to other districts of the eastern province. Rwamagana district is also covered with some alluvial of valley bottom which are shallower than sedimentary and fissured rock and facilitate the ground water infiltration. In additional, the dominating schists, micaschists and quatzites from metamorphosed sedimentary rocks origin facilitate the water infiltration and underground storage. Nyagatare district is the worst in ground water potential zone with only 6% of the total area classified as having good groundwater potential. A considerable area of Nyagatare district has low rainfall intensity comparing to other districts, this affects the ground water potentiality of that region.

Table 4: Groundwater Potential Zones by District

Rwamagana			Nyagatare		Ngoma		Kirehe		Kayonza		Gatsibo		Bugesera	
Gridcode	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%
1: Poor	17	3	8	0	26	3	13	1	55	3	23	2	31	3
2: Fair	5	1	317	17	67	8	164	15	212	12	76	5	162	14
3: Moderate	236	37	1401	76	438	55	764	68	1342	79	955	63	830	70
4: Good	375	59	117	6	268	34	185	16	155	9	473	31	159	13
5: Excellent	5	1	0	0	3	0	0	0	0	0	1	0	2	0

4. Results Validation

To validate the results of the study, the potential groundwater map (Figure 4) was overlaid with borehole yield data extracted from water portal eastern province borehole yield map of Rwanda Water and Forestry Authority (RWFA). The numbers of wells were evaluated for various groundwater potential zones with distinct yield ranges. In Table 4 & Figure 5 below, 4 out of 6 (67%) of the point are in good groundwater potential area with yields ranging from >5-10 m3/h and >10-15 m3/h of yield, while 2 out of 6 (33%) are moderate groundwater potential area with yield ranging in >1-3 m^3/h.

Table 5: Groundwater Control Yield/Classes

ID	Borehole yield (m^3/h)	Groundwater potentiality Classes
1	>5-10 m^3/h	Good
2	>1-3 m^3/h	Moderate
3	>5-10 m^3/h	Good
4	>10-15 m^3/h	Good
5	>5-10 m^3/h	Good
6	>1-3 m^3/h	Moderate

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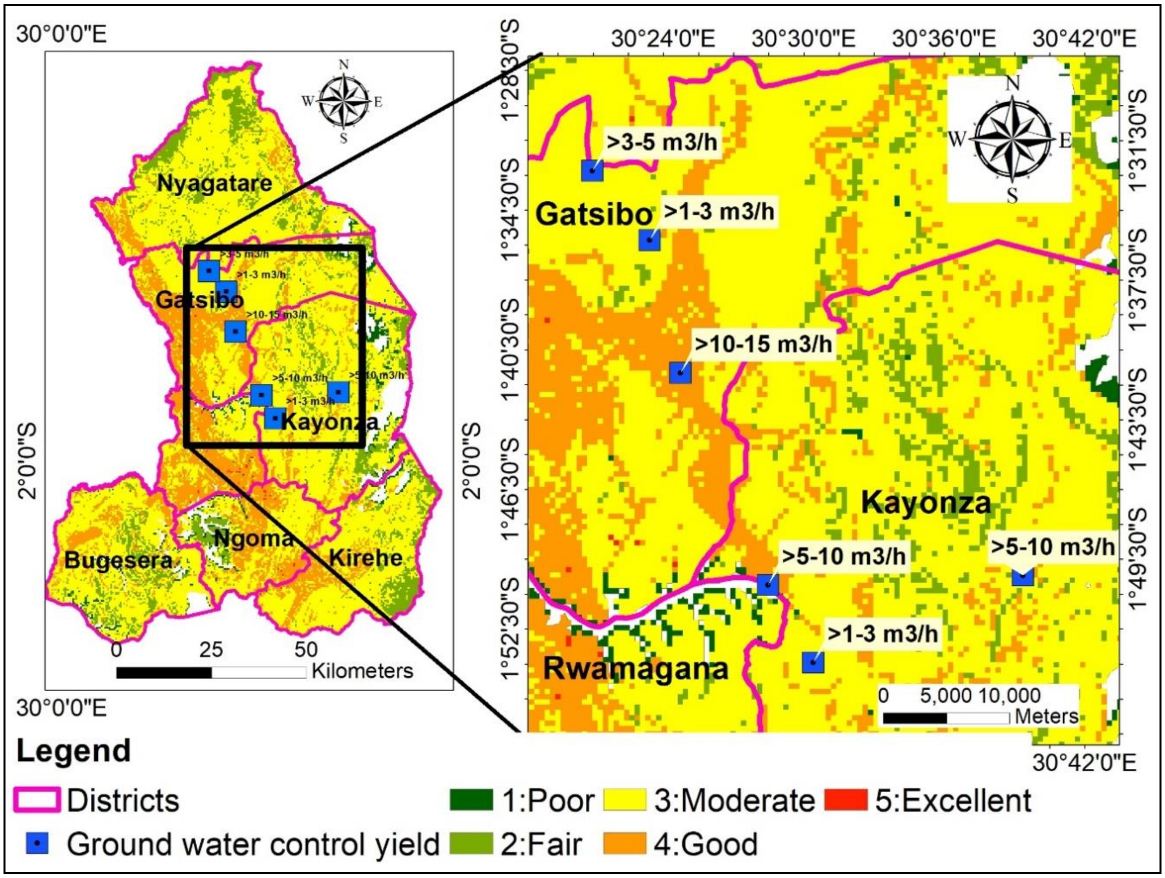

Figure 5: Ground water potentiality validation

5. Policy Implications and Future Research Needs

A clear understanding of ground water potential zones was given by the assessment of biophysical factors mainly rainfall and geology (lithology) of the region. Basing on the ground water potential mapping, water managers and policymakers can create targets that can significantly increase ground water resource management in eastern province of Rwanda by evaluating ground water potentialities of districts. The cornerstone to effective ground water resource management is the expansion of ground water-specific modern observation techniques such geospatial and remote sensing technologies. In places with limited resources, time and data geospatial tools and remote sensing data have been used to offer information that is used in planning and monitoring of water resources management. Government and water policy decision-makers can use the maps produced by this technology (geospatial and remote sensing) as a preliminary guide when choosing potential sites for groundwater resources when drilling new boreholes(Yeh et al., 2016). Consequently, as geospatial and remote sensing techniques would offer timely and cost-effective methods for identifying and limiting the target areas for groundwater exploration, these tools and data sources would be advised for groundwater resource allocation, exploration and governance.

6. Conclusion

Using a GIS-based AHP technique approach, a methodology for demarcating the groundwater potential recharge zonation map has been provided in this study. There were created several GIS layers. Depending on how well each layer could retain groundwater; different categories were assigned to each layer. The weights of different themes are determined using AHP. This tool seems to offer a flexible technique for making and supporting decisions. The groundwater potential map was overlaid with the borehole yield data, and the number of wells with various yield ranges for various groundwater potential zones were assessed. The final results indicated that the recharge of ground water is influenced by various factors such as lithology, NDVI, drainage density, land cover, rainfall, slope and soil. The final map from factors thematic maps showed that the groundwater potential recharge zones as poor, fair, moderate, good, and excellent, which, respectively, cover 173 km^2 (1.9 %), 1002 km^2 (11.3%), 5976 km^2 (67.2%), 1732 km^2 (19.5%) and 12 km^2 (0.1%) of the research region. Geology (lithology) and rainfall were two the significant factors that had the most impact on the distribution pattern of the ground water potential areas. The findings show that most of the eastern portion was good for groundwater recharge due to the abundant rainfall and a good lithology for ground water infiltration and storage. Rwamagana district had the largest coverage with 59 percent and 1% of good and excellent ground water potential zones respectively.

The findings revealed a unique way how combining geospatial technologies like GIS and satellite remote sensing data with the AHP technique is effective in identifying groundwater potential areas. The efficient and reliable results from the final groundwater potential map may help determine key areas for the implementation of water conservation in public and private projects and programs as well as for the sustainable development of groundwater. The study's findings can be also adopted in the planning and governance of watershed development programs to ensure proper management of watersheds.

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