UNIVERSITY OF RWANDA

COLLEGE OF SCIENCE AND TECHNOLOGY (CST)

SCHOOL OF ENGINEERING

Application of Geographical Information System and Analytical Hierarchy Process for groundwater Potential Zone Mapping.

Case Study: Eastern Province, Rwanda

A Master's Degree Thesis Submitted to

THE COLLEGE OF SCIENCE AND TECHNOLOGY (CST)

SCHOOL OF ENGINEERING

Master's Program in Water Resources and Environmental Management

Submitted by: **NIYIGABA Anastase**

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****2022****

Declaration and Approval

This is to declare that this master's research entitled "Geographical Information System based Analytical Hierarchy Process for groundwater Potential Zone Mapping. Case study: Eastern Province, Rwanda," is submitted in respect of all requirements of University of Rwanda, College of Science and Technology (CST), the School of Engineering.

The thesis is submitted in full originality and high quality for obtaining a Master's of science in Water Resources and Environmental Management.

This dissertation contains the author's own work except where specifically acknowledged.

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TABLE OF CONTENTS

TABLES

FIGURES

ACRONYMS

AHP: Analytical Hierarchy Process

DEM: Digital Elevation Model

GIS: Geographical Information System

GWPZ: Groundwater Potential Zone

GWR: Groundwater Resource

LU/LC: Land-use/Land-cover

MCDM: Multi Criteria Decision Making

RS: Remote Sens

ABSTRACT

Groundwater is considered as earth's the best and largest fresh water resource, and it is the main water source for human's daily water consumption like bathing, drinking, cleaning, washing, etc. Identification of groundwater potential areas is very important for future planning for different water use opportunities that can need abstraction mainly in dray areas with low annual rainfall. The groundwater recharge is influenced by different mainly the rainfall, lithology, land use land cover, lineament density, drainage density and slope.

During our study for groundwater potential zone mapping as a case study in Eastern Province of Rwanda, Geographical information System (GIS) and Analytical Hierarchy Process (AHP) were used. GIS Was used for analyzing and organizing special and attribute data and finally it was used for weighted overlay analysis of thematic layers (rainfall, lithology, land use land cover, lineament density, drainage density and slope). AHP was used during the pairwise comparison of thematic layers and determines influence and scale of each layer to Groundwater recharge. The weighted percentage for each layer was determined and then used in GIS for overlay analysis. In order to make sure that the pairwise comparison is consistent, the consistent ratio for our matrix of 6x6 was 4.6% which is lower than 10% as a recommended as high limit for large matrix.

The main goal of our research was to assess the groundwater potential zones using GIS and AHP model and the Eastern Province of Rwanda was taken as case study. The eastern province was chosen because of its water scarcity due low precipitation and long dry period. The groundwater should be looked after as an alternative source of water that can complement the existing surface water sources. The groundwater should be used for small scale irrigation, domestic use and cattle watering which are dominant in Eastern province.

The generated final map of groundwater recharge zone is showing that Bugesera and Rwamagana District are well recharged, Kayonza and Kirehe have a low groundwater stock. In general, the East part of Eastern province including the Akagera National Park has a very low groundwater storage comparing to the remaining parts of this Province.

Key Words: Groundwater, Geographic Information System, Analytical Hierarchy Process, Eastern Province, Pairwise Comparison.

CHAPTER 1. GENERAL INTRODUCTION

Groundwater is an underneath surface water that saturates all soil pores under the water table (Roger, 2013). The groundwater keeps meandering in the aquifer layers until it discharges in surface water body like lakes, rivers, spring or oceans. Water has an economic value because it's different use like domestic activities, livestock watering, construction, recreation as well as different activities in industries like washing, cooling and is the main ingredient for different manufactured products. The water should be taken as the backbone for the development of any country in the world.

Groundwater occupy up to 60% of the world's freshwater supply, which is about 0.6% of the entire world's water (Foster, 2003). The occurrence of groundwater depends on many factors and most influencing parameters on groundwater recharge are: rainfall, geology or geomorphology, slope, drainage density, land-use/ Land-cover as well as land forms (Roger, 2013).

Currently, Geographic information system (GIS) and Remote Sensing (RS) are playing a major role as new technics for groundwater study and exploration where they can be used to delineate hydro geomorphological units (Solomon, 2003). Integrations of different influencing parameters to groundwater occurrence should help us to get more information on this hidden resources which is normally difficult to assess. Among those parameters, we can highlight the rainfall in the region, soil type, geomorphology, the landforms, the slope, drainage density as well as any other parameter that can influence the groundwater (Hammouri, 2012).

Exploitation of groundwater is normally very expensive as it involves drilling and other civil work activities. Any mistake related to false information could pose many problems and losses in case the drilled aquifer is not well studied and doesn't have enough groundwater reserve. Reliable information on groundwater potential area is very key because it is a basis for site selection (Jousma, 2008).

Nowadays the technology has evolved and geo information system is becoming a leading tool for storing, managing, and displaying special data often encountered in water resources management (Tsihrintzis, 1996). In groundwater, GIS is used for analysis of spatial parameters and their attributes that have direct influence on groundwater recharge. The combination of all influencing parameters is done through weighted overlay analysis. Evaluation of influence of each parameter should be analyzed by using different existing methods but for our research, Analytical Hierarchy

Process; the method for complex decision making was preferred. It is based on pairwise comparison matrix where the consistency ration is also checked (Bernasconi, 2010).

During our Research for groundwater potential areas mapping in Eastern Province, thematic layers having the influence on groundwater recharge (rainfall, drainage density, lithology, slope, lineament density and land use/land cover maps) haven been prepared. All thematic layers were georeferenced in the same coordinate system with the same spatial resolution of 90m. The attributes were reclassified in five categories each reflecting the categorization of the final map showing the five categories of areas in terms of groundwater potential. These categories are: very low, low, moderate, high and very high potential zone.

1.1. The Problem statement

Rwanda with its green hills and valleys, and relatively with high average rainfall, it could be taken as a water rich country. However, rainfall is not equitably distributed over the entire country. In addition, the climate change contributes to frequently short and intense rain seasons, which causes floods and droughts in different areas. The Rwanda water availability per capita is averaging around 670m^3/per/annum which remains low and our country is on the list of ranked among the world's water scarce countries.

Rwanda has a high population density with a population growth of 2.3% which is expected to keep increasing in coming years. The increase of the population will put a high pressure on existing water resources because the production from different sectors like agriculture, livestock, and industries will be increased to satisfy the demand.

To do so, groundwater which is still under-utilized water resource in Rwanda will need to be looked after in order to supplement the surface water resources which is normally utilized in different sectors.

The argument to make more use of groundwater in agriculture is that:

- in some areas there is no enough surface water available such as large areas of the Eastern part of Rwanda, although some researches assume that there is groundwater table available at low depth that can easily be accessed provided the technology is easily available;
- groundwater usage for irrigation is easy to start at small scale and requires no large infrastructure;
- According to Kovacs (2014), Groundwater allows precision farming with much higher returns. With respect to the latter for instance complementary irrigation of rain-dependent crops allows

one to compensate for dry spells in critical stages of the rainy period or in general to reduce the exposure to more erratic rainfall patterns that are expected with climate change. In the Eastern Province for instance rainy seasons in recent years have been delayed.

Groundwater development can also help close the gap in domestic water provision and increase the coverage in rural and urban water supply (FAO, 2016). Population growth is also a major factor here, making the drinking water mission a ‘race against time’.

The Eastern province is characterized by recurrent water scarcity due to the lack of springs and other surface water sources in the region. The other source of water that can be used is the groundwater. However, before its extensive use it is needed to have some information on its distribution, quantity and quality. It is in this line that our research will help to get required information as mentioned above.

1.2. Objectives

The main objective of this research project is to evaluate the spatial distribution potential of groundwater in Eastern province of Rwanda, by using Geographic information System (GIS) and Analytical hierarchy process model (AHP).

Specific Objectives

- To collect and process attribute data and shape files of influencing parameters (rainfall, Lithology, drainage density, slope, land use/land cover and lineament density) for groundwater occurrence.
- To analyze through AHP model the level of influence of each parameter for groundwater recharge.
- Delineate and analyze the generated groundwater potential zone map at Province and district level.

1.3. Research Questions

- Are the selected parameters (Rainfall, lithology, slope, drainage density, lineament density and land use land cover) really have influence on groundwater recharge?
- Are these parameters have the same influence for delineating the groundwater potential areas?
- What are the areas having high potential and low potential of ground water in Eastern Province?

1.4. Relevance of the research

The practical development of groundwater resource has a significant effect on the improvement of the community livelihood. The Rwanda's groundwater is still under-utilized due to different factors and the main cause is the lack of reliable information on distribution of this hidden resource. In fact, generating groundwater potential map has a big effect to enhance sustainable management of groundwater resource in Eastern Province even in Rwanda.

Thus, our research has been carried out to identify potential areas of groundwater resource for its better management and utilization. Accordingly, this research contributes by providing delineated groundwater potential zones through implementing Geographic information System (GIS) and Analytical Hierarch Process (AHP) model to have proper administration, management, and sustainable use of groundwater resources in Eastern Province.

1.5. Limitation of the research

During this study, mapping of groundwater potential zones was limited to the analysis and overlay of thematic layers and no drilling activities were carried out.

1.6. Research organization

The thesis entitled Geographical Information System based Analytical Hierarchy Process for groundwater Potential Zone Mapping, case study: Eastern province of Rwanda, is composed by five chapters. The first chapter contains the preliminary and background, research problems, relevance of the research, limitation of the research and research organization. The second chapter contains the review of similar other researches done on groundwater potential mapping. The third chapter describes the materials and methodology used as well as understanding the study area. The fourth chapter focuses on results presentation and interpretation of generated groundwater potential zone map. The fifth and the last chapter contains the conclusion and recommendation.

CHAPTER 2. THE RELATED LITERATURE REVIEW

2.1. Literature review

2.1.1. Overview on groundwater resource

The world groundwater refers to the water found in underground in the clacks and soil voids, sand and rocks.it is stored in and moves slowly through geologic formations of soil, sand and rocks called aquifers. The groundwater recharge is described as the movement of water from the unsaturated zone to saturated zone (Matthews, 2014). The groundwater recharge is occurring only when the infiltration takes place and water moves under the soil surface and reaches the saturated zone (Central Ground Water Board. India 200). Many factors may affect the occurrence and movement of groundwater, such as rainfall, lithology, soil structure, drainage, slope, land use/land cover, landform and climate (Lindsey, 200). Consequently, for better understanding of groundwater recharge in a given area, it is very crucial to consider those parameters.

2.1.2. Current situation of groundwater inn Eastern Province

According to Rwanda National Water Resources Master Plan (2015), The Eastern province of Rwanda is identified as an area with repetitive water scarcity due to low average rainfall and lack of springs due its topography. The alternative source of water that can be used in this region is groundwater. However, before its exploitation and use, there is a need to have sufficient information on its special distribution, its quality and quantity.

The Eastern Province is relatively a flat land comparing to other regions in Rwanda and it is laying in Eastern Plains region where the altitude is ranging between 1,000 m and 1,500 m. the average rainfall in Eastern Province is the lowest in Rwanda and it is between 800mm to 1000mm per year. This Province, is known to have the highest evapotranspiration rate in Rwanda due to the high temperature which is ranging between 13oC to 28oC. Within the Eastern province can be found some wetlands. Along the southern and eastern border, the Akagera River is present with its many lakes and wetlands

The following hydrogeological units can be found in Eastern province (Muchez, 2014):

- Quartzites: interbedded throughout the less competent schists, it is the most competent aquifer type identified in East.
- Schists: considerably less competent than granites and easy to fracture and erode. The fractures easily fill up with weathered materials.

- Granites (Mainly Bugesera and Nyagatare): overall competent and relies on fractures for recharge and transmissivity.
- Alluvium: overlaying most aquifer types. The alluvium mostly consists of clayey soils which, even though recharge will be high, will not provide high yielding boreholes because of the constricting transmissivity. In some cases, coarse sediments are deposited, and high potential can be identified. Coarse sediments are more common close to meandering fast flowing rivers.
- Spring potential: the topography of Eastern province doesn't allow formation of springs except in western part of Gatsibo (higher altitudes). For other areas relatively flat, the groundwater is exploited through the use of boreholes for domestic use.

2.1.3. Role of GIS and RS for groundwater potential investigation

According to Arulbalaji (2019) geographic information System (GIS) and remote sensing are very useful and very cheap for groundwater assessment. An important step toward robust management of groundwater exploitation is mapping groundwater potential zones (GWPZs). For this purpose, different methods based on indirect analysis are used such as geophysical survey, hydrological investigations, and test drilling. These old technics are still the most widely used in Rwanda for studies related to groundwater assessment, and are considered costlier, time consuming and limited to easy access areas (Tsihrintzis, 1996).

Therefore, for better understanding of groundwater distribution, integration of spatial analysis tools, such as geographic Information System(GIS) and Remote Sensing is vital and could help the decision makers understand the spatial distribution of groundwater (Tsihrintzis, 1996).

Allafta (2021) said that remote sensing(RS) and Geographical information system(GIS) is the best and advanced technology to monitor earth disasters like earthquake, landslide volcanoes and management of mineral and groundwater.

Shimpi (2019), has conducted the comparison of existing groundwater monitoring methods like numerical modeling, geophysical modeling with the application of geographical Information System (GIS) and remote sensing (RS). He concluded that GIS and RS is the cheapest method for groundwater assessment comparing to other methods which are laborious, expensive and time consuming. In line with the above methods (Vanum, 2016) said that groundwater is a hidden resource beneath ground surface which cannot be observed directly by our eyes. Stevens (1963), in his research said that too many technics exist which give information on groundwater potential zones such us hydrological investigation, geophysical seismic refraction, geo electrical investigation, but they are very expensive and time consuming. Suliman (2021), highlighted that geographic information System (GIS) and Remote sensing (RS) are the recent and best technology cheap and not time consuming for groundwater assessment and exploration.

A good number of research have been done analyzing the contribution of GIS and RS on ground water recharge and potential zones identification. Ahmed (2006) in his publication, he has analyzed the groundwater potential in his research titled: integrated RS and GIS based for assessing groundwater potential, case study in the middle Awash River, Ethiopia. Vanum (2016) has conducted a research on groundwater potential and recharge zone based on GIS and remote sensing. And in this publication, key parameters having influence on groundwater recharge have been identified like lineament map, drainage density, soil map, slop map and land use/ land cove.

Lastly, Ndatuwong (2017) has done an evaluation of groundwater potential zones using integrated method of RS, geophysics and GIS in the Vindhyan basin, India. This proves a broad idea about the groundwater in the region and the groundwater potential zones map generated was verified by using the yield of drilled boreholes and the results were good with high accuracy.

CHAPTER 3. MATERIALS AND METHODS

3.1. Materials

3.1.1. Description of the study area

The Eastern Province is the largest and least densely populated of Rwanda. It was created in early January 2006 during the government decentralization program that re-organized the country's local government structure. It has seven Districts: Bugesera, Gatsibo, Kayonza, Ngoma, Kirehe, Nyagatare and Rwamagana

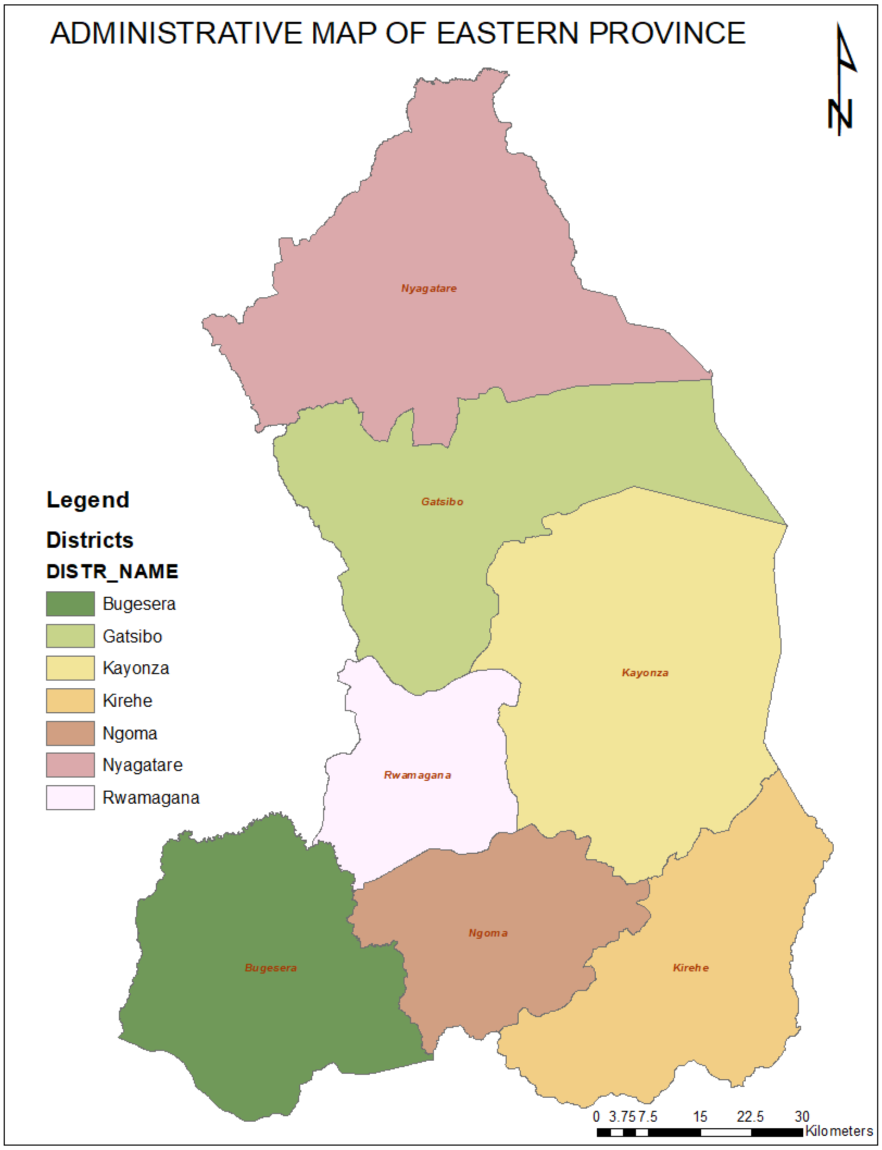


Figure 1: map of Eastern Province with District

It has seven Districts: Bugesera, Gatsibo, Kayonza, Ngoma, Kirehe, Nyagatare and Rwamagana. The Eastern Province having an area of 9,813km^2 comprises the former Kibungo, Umutara, most of Kigali Rural and part of Byumba (Source: Eastern Province Website).

3.1.2. Economic activities in Eastern Province

Most of the land, except for protected areas, is deforested with almost all indigenous tree cover has been removed. The land is predominantly used for agricultural processes. Even though most natural forest cover is severely reduced, trees are adopted into agriculture through agroforestry practices; these are mostly exotic species, like Eucalyptus. They are common practices for soil and water conservation measures, and erosion is therefore minimized. These practices include, terracing, contour bunds, mulching, and contour ploughing, grass strips, tree strips, slope protection with trees, and wetland protection.

3.1.3. Rainfall

(Joseph, 2020), described that the annual rainfall in Eastern Province is between 800 – 1000 mm. this rainfall is relatively low in Nyagatare and Bugesera Districts, while Ngoma and the eastern parts of Gatsibo and Kayonza are relatively high. The rainy season has two peaks from February to April and October to November. The dry season is generally from June to August with almost no rainfall. This rainfall trend is almost similar throughout the entire province.

3.1.4. Drainage

According to the drainage map of Rwanda, the Eastern province has a poor drainage network. This province is characterized by repetitive water scarcity due to lack of springs and other surface water. Due to the topography of the Eastern province which is generally flat, the spring potential is low because its flat land doesn’t allow springs formation except in western part of Gatsibo (higher altitudes)

The eastern province is known to have many lakes and wetlands along the southern and eastern border. Those lakes are manly floods lakes of Akagera River and some of them are Rweru in South, Mugesera, Sake, Nasho, Mpanga, Cyambwe and Ihema.

The water scarcity is common in Eastern Province due to poor drainage network and it should be supplemented by exploitation of groundwater. But, any use of this hidden water resource needs deep assessment on its quantity and quality as well as its spatial distribution.

3.1.5. Hydrogeology of Eastern Province

SHER ingenieurs co s.a (2019), identified different hydrogeological units or aquifers types located in Eastern Province as follow:

- Alluvium: overlaying most aquifer types. Overall, the alluvium mostly consists of clayey soils which, even though recharge will be high, will not provide high yielding boreholes because of the constricting transmissivity. In some cases, coarse sediments are deposited, and high potential can be identified. Coarse sediments are more common close to meandering fast flowing rivers.

- Schists: considerably less competent than granites and easy to fracture and erode. The fractures easily fill up with weathered materials.
- Quartzite: interbedded throughout the less competent schists, it is the most competent aquifer type identified. Where not fractured or faulted, transmissivity and recharge is nonexistent. Very high potential and transmissivity in the rare places where the beds of quartzite are crossed by perpendicular valleys, breaking through.
- Granites mainly found in Nyagatare and Bugesera: overall competent and relies on fractures for transmissivity and recharge.

3.2. Methods

Geographic information system (GIS) and Analytical Hierarchy Process tools were used to delineate groundwater potential zones in Eastern Province of Rwanda. To do so, the following steps have been followed:

1. Identification of influencing parameters for groundwater recharge;
2. Identification of source of data and their collection;
3. pre-processing;
4. input dataset;
5. reclassification of layers;
6. AHP pairwise comparison of parameters and determine weightage or influence of each parameter,
7. Overlay analysis of reclassified parameters in ArcGIS,
8. Analysis and ranking the generated GWPZs map.

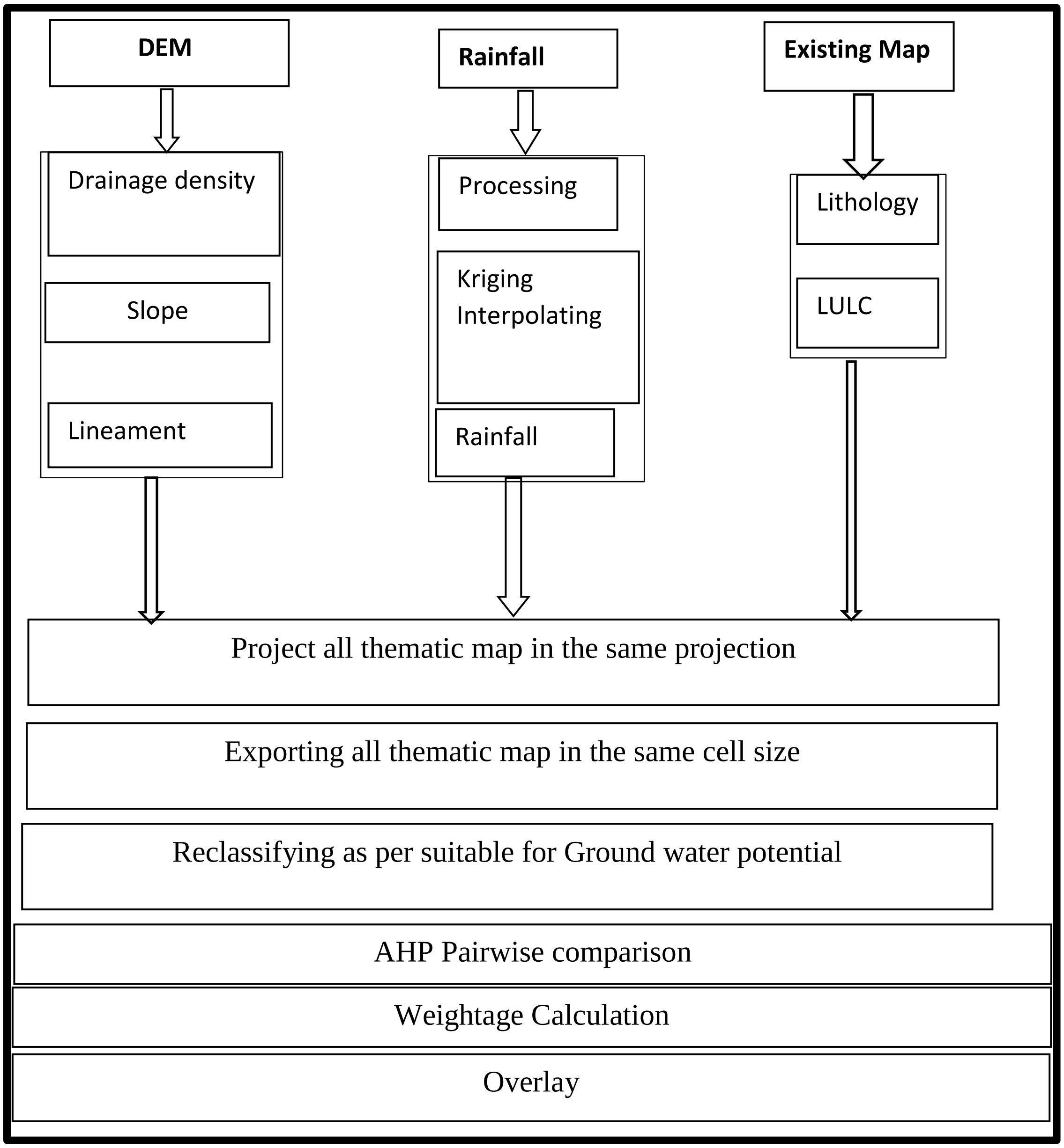


Figure 2: Methodology flow chart

CHAPTER 4. THE DATA DESCRIPTION AND ANALYSIS

4.1. Data Description

4.1.1. Source of Data

The source of law data and thematic layers used in in this research are summarized in the following table.

Table 1: Source of data

Data Type	Data Source	Generated layer	Special resolution
DEM of Rwanda	http://igskmncngs506,cr.usgs.gov/gmtd	Drainage density, slope and lineament density	90m
Rainfall	Rwanda Meteo	Rainfall map	90m
Geological map	Geological survey of Rwanda	Lithology map	90
Existing data	RWB	Land use/land cover map	90m

4.2. Data preparation

Different thematic map have been prepared from different sources as shown in the table above. The Slope and drainage density map were generated from DEM and the lineament was manually digitized from the hill shade map of Eastern Province. Land-use land-cover and Lithology map were prepared form existing layers obtained from Rwanda Water Resources Board.

The special distribution of rainfall was interpolated in ArcGIS by using kriging method. The long-term time series of rainfall of thirty years; from 1981 t0 2017 have been used. The data used for rainfall interpolation were collected from fourteen stations located in Eastern Province including: Gashora, Juru, Ruhuha, Nyamata, Kibungo, Nyamugali/Kirehe, Kirehe, Rwinkwavu, Kawangire, Nyagatare, Mwurire, Musha, Rwamagana and Gishari. In order to easy the overlay process, all maps have been exported and put in the same coordinate system, the same spatial resolution and the same number classification of their attributes. The maps were then reclassified and converted into raster format which is used in overlay analysis.

In order to now the weight of each parameter to be used in overlay process, AHP pairwise comparison was done and a respective weightage for each parameter was calculated depending on its influence on groundwater recharge.

4.3. Description of parameters for groundwater potential zone mapping

4.3.1. Lithology

Soil type plays a vital role in controlling the infiltration rate of precipitated water and water holding capacity of the area. Consequently, it can be considered as one of the parameters for the delineation of groundwater potential zones (Kumar, 2016). The behavior of each lithological unit for groundwater recharge and their aquifer characteristics are describes in the table below.

Table 2: Lithology Classification

Parameter	Units	Characteristics
Lithology	Sedimentary rocks(sandstone, limestone and shale)	Very high
	Igneous rocks(granite, Basalt,)	Moderate
	Metamorphic rocks(gneiss, slate, marbre, schist and quartzite	Low

Ammar, A. I., & Kamal, K. A. (2019)

4.3.2. Lineament density

The lineament density is an important parameter for evaluating groundwater recharge (Tiren, 2010). The geological lineaments are the manifestation at the earth's surface or deeper geological structures faults and fractures that have obvious displacement, ruptures that have no significant fracture displacement (Liu, 2021). In our research, lineament length density was used and it represent the total length of lineaments in unit area:

$Ld = (\sum L)/A$ in Km/Km^2. The higher is lineament density the higher is groundwater recharge

Table 3: Lineament Classification

Parameter	Criteria Value km/km^2	Classification
Lineament density	0-0.25	Poor
	0.25-0.50	Very low
	0.50-0.75	Low
	0.75-1	Moderate
	1-1.25	High
	1.25-1.50	Very high

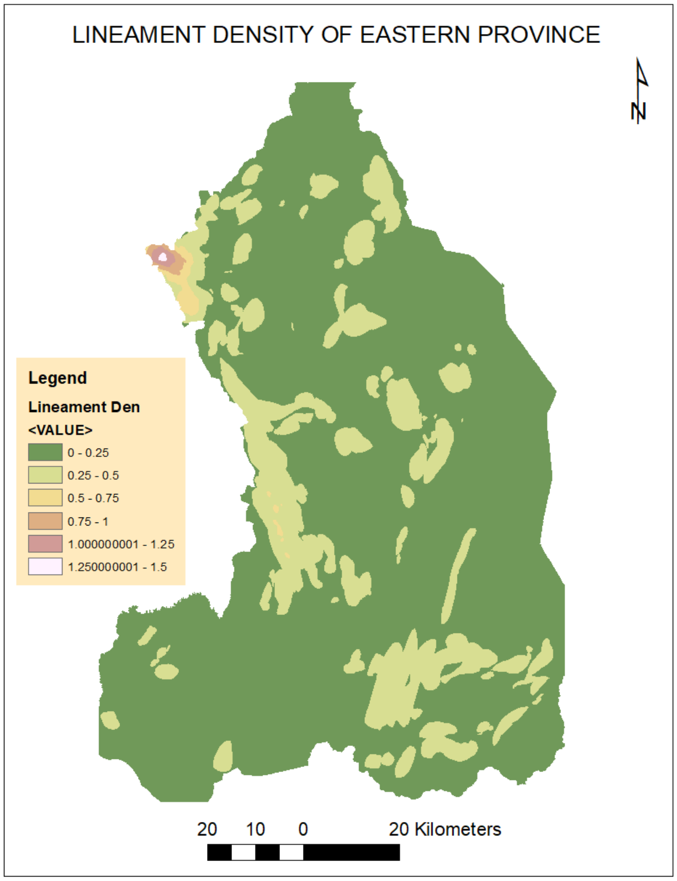


Figure 3: Lineament density of Eastern province

4.3.3. Slope

The slope gradient directly influences the infiltration of rainfall and could be considered as one of parameters of groundwater recharge (Werner, 2007). It can also give a general indication of groundwater flow direction (Prasad, 2018). The slope percentage map of the study area was generated from DEM of 90m resolution using a spatial analysis tool in arcGIS. The slope percentage of the study area varies between 0 to 48%. Six classes were formed and the flat slope is likely to have high infiltration rate and steep slope areas have a low infiltration due to high runoff.

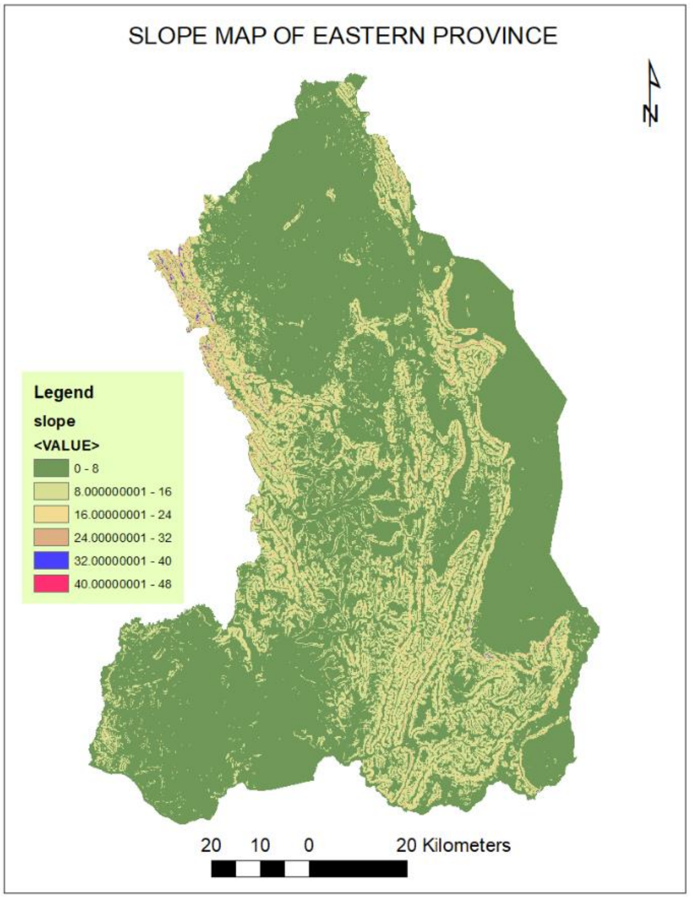


Figure 4: Slope map of Eastern Province

Table 4: Contribution of slope on groundwater recharge

Factor	**Value in degree**	**Classification**
Slope	0-8	Very high infiltration
	8-16	High infiltration
	16-24	Moderate infiltration
	24-32	Low infiltration
	32-40	Very low infiltration
	40-48	Extremely low infiltration

4.3.4. Drainage density

Drainage density is one of important parameters influencing groundwater recharge (Magesh, 2012). The drainage density is linked with water percolation properties of underlying lithology, consequently having a close relation with groundwater mapping.

The drainage density is an inverse function of permeability. An area with low permeable surface will have high drainage density and water coming from precipitation will have a high runoff and vice versa. As a result, high drainage density implies low groundwater potential (Solomon, 2003).

Table 5: Drainage density for groundwater potential zones in Eastern provinces

Factor	**Value in km/km2**	**Description**	**Contribution to groundwater recharge**
Drainage density	0-0.18	Poor	Good
	0.18-0.36	Very low density	Good
	0.36-0.54	Low density	Good
	0.54-0.72	Moderate density	Moderate
	0.72-0.90	High density	Moderate
	0.90-1.08	Very high density	poor

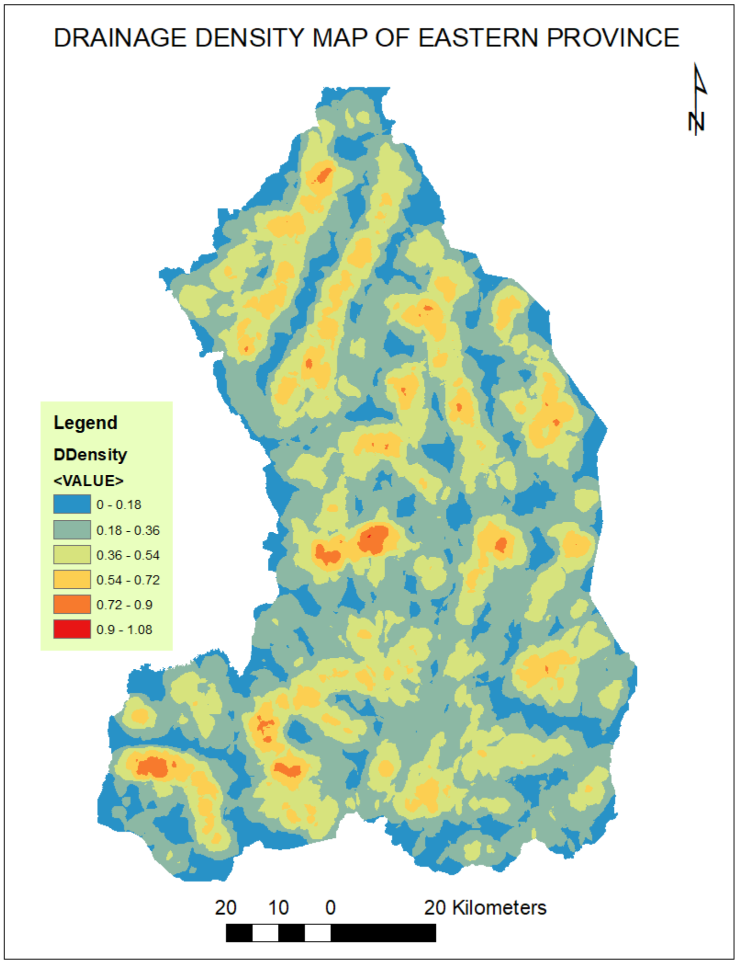


Figure 5: Drainage Density for groundwater potential and recharge

4.3.5. Rainfall

Rainfall is one of important factors to delineate groundwater potential zones. In fact it is the main source of natural groundwater recharge. Rainfall map was generated from historical rainfall data of thirty years from meteorological stations located within the eastern Province.

As it is shown in figure below, the mean annual rainfall in Eastern Province is varying from 704mm to 1297mm. the rainfall intensity plays a significant role on infiltration, reason why the weigh was given to the rainfall classes in the table below.

Table 6: Rainfall classification

Parameter	Value in mm	Rank
Rainfall	704-801	Very low
	801-887	low
	887-976	moderate
	976-1,078	high
	1,078-1297	Very high

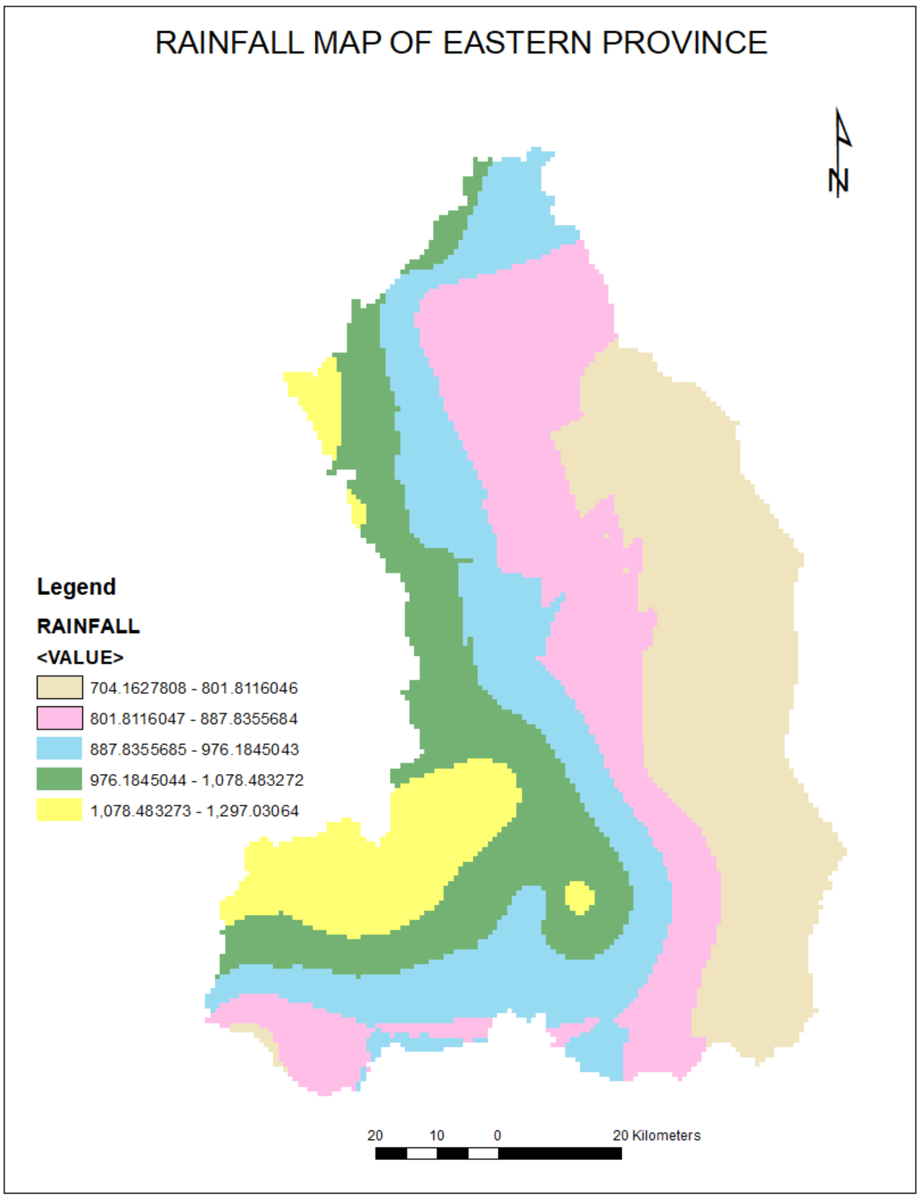


Figure 6: Rainfall Map of Eastern Province

4.3.6. Land-use/Land-cover

Land use/land cover includes the type of soil deposits, the distribution of urban areas, water bodies and vegetation covers in a given area. It is an important factor affecting groundwater recharge as it has a direct effect on the hydrological process of surface runoff (Tolche, 2021). Water bodies, agriculture area and waterlogged zones are excellent for groundwater recharge, while built up area, bare lands and exposed lock surface area will not all groundwater recharge (Naha, 2020).

The classification of LULC types found in Eastern Province and their contribution to groundwater recharge are summarized in the table below.

Table 7: Land use/Land Cover classification

Factor	Classification	Raking
Land use/ Land cover	Buildup area	Very poor
	Open agriculture	Poor
	Open land	Poor
	Closed agriculture	Moderate
	Forest plantation	High
	Irrigation	Very high
	Natural Forest	Very high

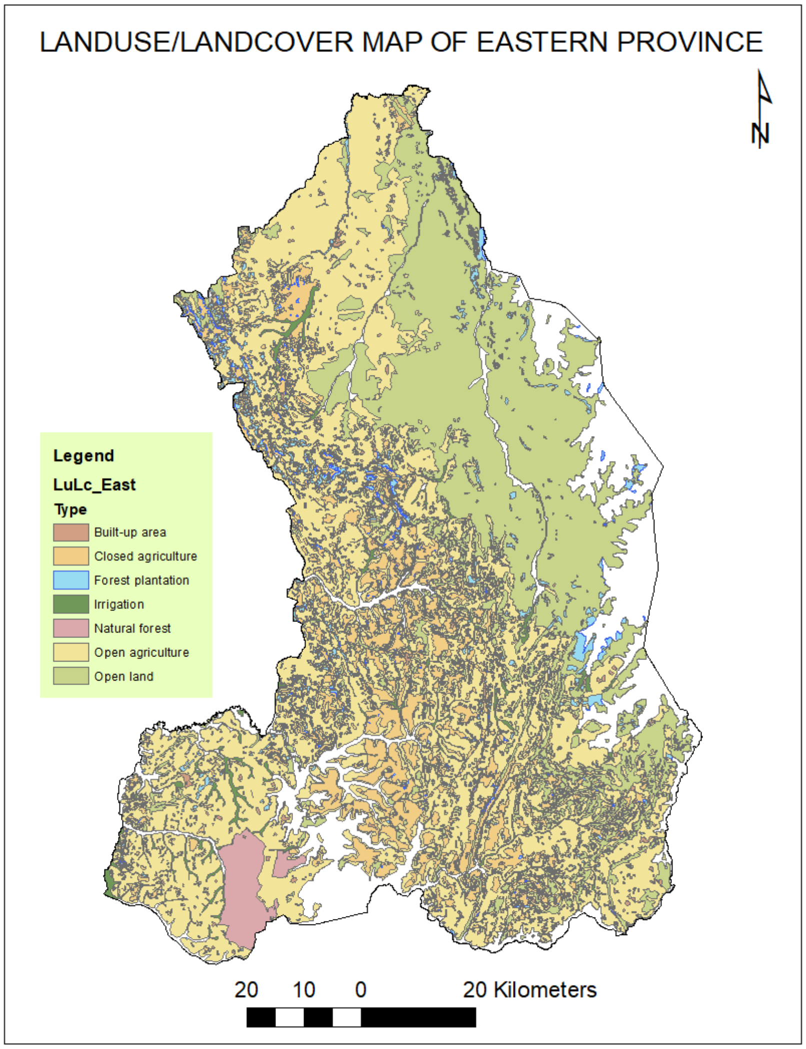


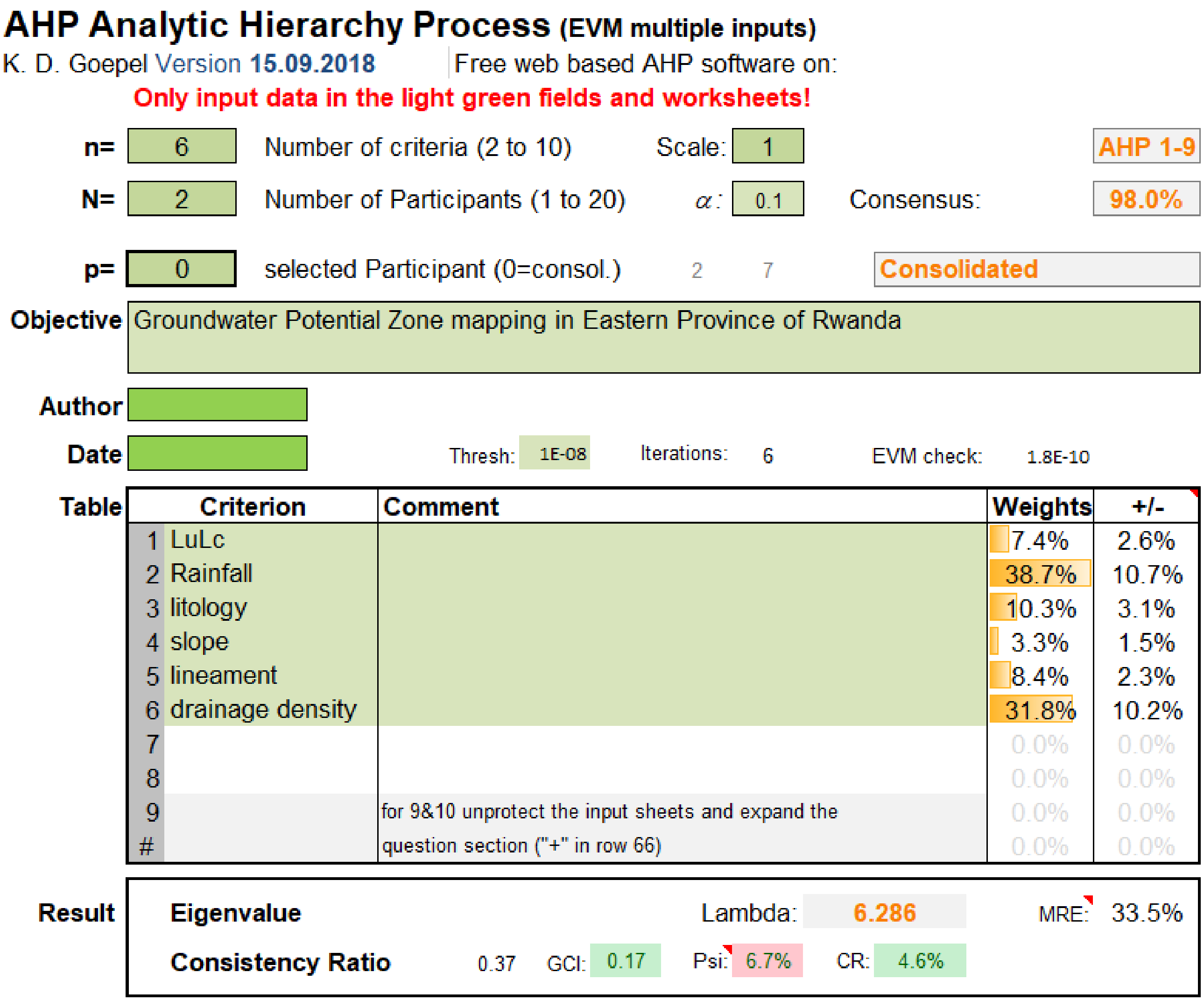
Figure 7: Land use/Land cover map of eastern Province

4.3.7. Weight assignment to parameters

In this research, six parameters (lithology, slope, LULC, Rainfall, Drainage density, lineament density) were used to delineate the ground water potential zone in Eastern Province of Rwanda. The influence of these parameters for groundwater potential zonation is not the same (Magesh, 2012). The weight of each parameter was assigned basing on its influence on the movement and storage of groundwater and referring to literatures (Zhang, 2021).

The pairwise comparison matrix was carried out by using AHP techniques. Thereafter, pairwise comparison matrix assigned weights to each thematic layer and the consistency ratio (CR) was automatically generated by AHP model.

During the pairwise analysis using AHP model, an area having a high lineament density was given high weight. An area having high drainage density was assigned very low weight, an area with low slope was given high weight and vice versa. Since rainfall affects directly the groundwater recharge, the high weight was assigned to areas with high mean annual rainfall. For lithology, high weigh was given to coarse texture.



AHP Analytic Hierarchy Process (EVM multiple inputs)

K. D. Goepel Version 15.09.2018 | Free web based AHP software on:

Only input data in the light green fields and worksheets!

n= 6 Number of criteria (2 to 10) Scale: 1 AHP 1-9

N= 2 Number of Participants (1 to 20) α: 0.1 Consensus: 98.0%

p= 0 selected Participant (0=consol.) 2 7 Consolidated

Objective: Groundwater Potential Zone mapping in Eastern Province of Rwanda

Author

Date Thresh: 1E-08 Iterations: 6 EVM check: 1.8E-10

Table	Criterion	Comment	Weights	+/-
1	LuLc		7.4%	2.6%
2	Rainfall		38.7%	10.7%
3	litology		10.3%	3.1%
4	slope		3.3%	1.5%
5	lineament		8.4%	2.3%
6	drainage density		31.8%	10.2%
7			0.0%	0.0%
8			0.0%	0.0%
9		for 9&10 unprotect the input sheets and expand the	0.0%	0.0%
#		question section ("+" in row 66)	0.0%	0.0%

Result

Eigenvalue Lambda: 6.286 MRE: 33.5%

Consistency Ratio 0.37 GCI: 0.17 Psi: 6.7% CR: 4.6%

Figure 8: AHP Analytic Hierarchy Process Results

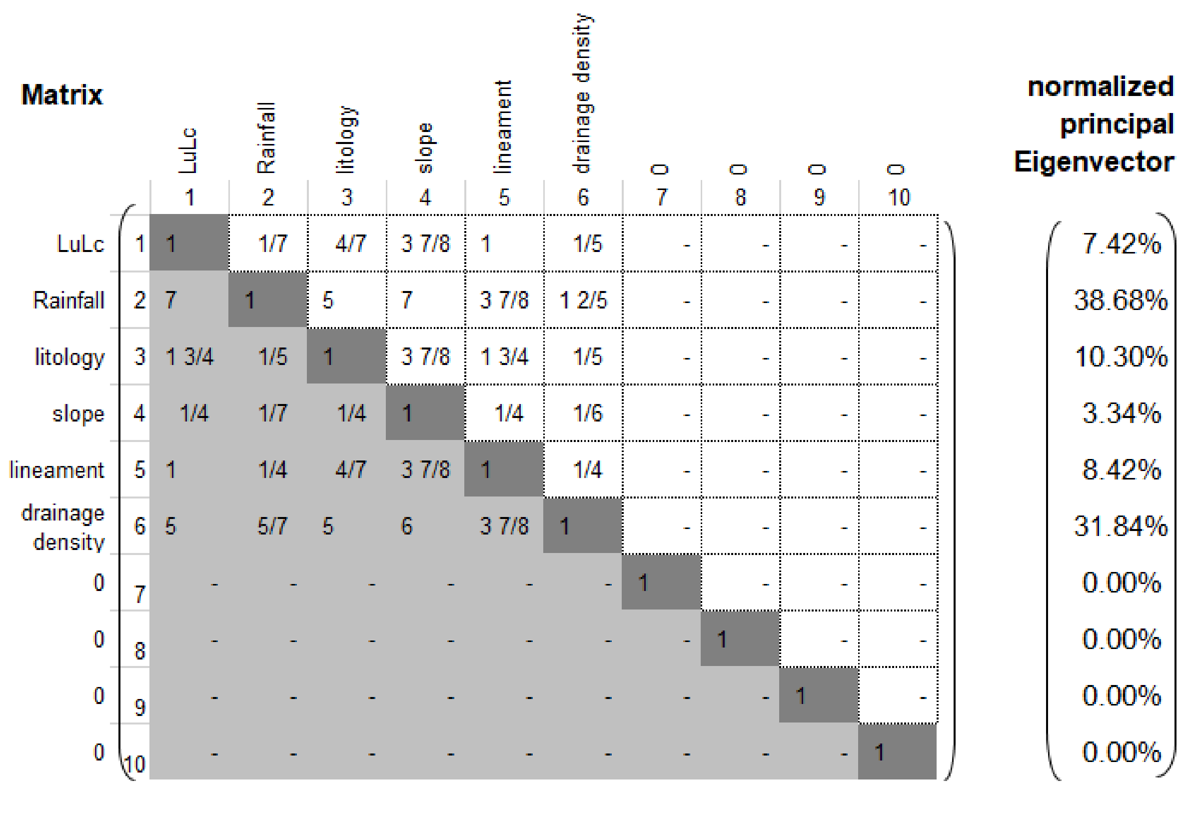
According to the results in the figure above, AHP has attributed the weightage percentage to analyzed criteria as follow:

Table 8: Weightage percentage to analysed criteria

Criteria	Weightage attributed
Land use/ Land cover	7.4%
Rainfall	38.7%
Lithology	10.3%
Slope	3.3%
Lineament	8.4%
Drainage Density	31.8%

4.3.8. Weight Normalization

The weights were normalized by averaging the values in each row to get corresponding ranking, which gives the results of normalized weights of each parameter as presented in figure below. From the results, the rainfall has the highest value rather than other parameters



Matrix		LuLc 1	Rainfall 2	litology 3	slope 4	lineament 5	drainage density 6	0 7	0 8	0 9	0 10	normalized principal Eigenvector
LuLc	1	1	1/7	4/7	3 7/8	1	1/5	-	-	-	-	7.42%
Rainfall	2	7	1	5	7	3 7/8	1 2/5	-	-	-	-	38.68%
litology	3	1 3/4	1/5	1	3 7/8	1 3/4	1/5	-	-	-	-	10.30%
slope	4	1/4	1/7	1/4	1	1/4	1/6	-	-	-	-	3.34%
lineament	5	1	1/4	4/7	3 7/8	1	1/4	-	-	-	-	8.42%
drainage density	6	5	5/7	5	6	3 7/8	1	-	-	-	-	31.84%
0	7	-	-	-	-	-	-	1	-	-	-	0.00%
0	8	-	-	-	-	-	-	-	1	-	-	0.00%
0	9	-	-	-	-	-	-	-	-	1	-	0.00%
0	10	-	-	-	-	-	-	-	-	-	1	0.00%

Figure 9: Pairwise Comparison Matrix and Normalized Weight

4.3.9. Constancy Ration

In order to ensure that the weight assigned to each parameter is reflecting the reality, the consistency ratio (CR) must be less than 0.05 for 3x3 matrix, 0.09 for 4x4 matrix and 0.1 for larger matrix, the pairwise comparison is said to be consistent (Kumar, 2009). For our case, the matrix is 6x6 and the calculated CR=4.6% which is less than 0.1 for large matrix. Then our comparison is valid.

4.4. Results and Discussion

4.4.1. Groundwater potential zones generation through overlay analysis

Overlay analysis is an operation in GIS for superimposing the multiple layers of datasets that representing different themes together for analyzing or identifying relationship of each layer. Overlay analysis represent the composite map by the combination of different attributes and geometry of datasets. During the overlay analysis, the six parameters (Rainfall, slope, lineament, LULC, drainage density and lithology) were used in order to generate the composite map of groundwater potential zones in Eastern Province

The following formula can summarize the process of overlay analysis

GWPZM= 38.7*RRf +3.3* RSl + 8.4*RLd + 31.8*RDd + 7.4*RLuLc + 10.3*RLith

Where, **RRf:** Reclassified rainfall map, **RSl:** Reclassified slope map, **RLd:** reclassified lineament density map, **RDd:** Reclassified drainage density map, **RLuLc:** Reclassified land use/ Land cover map and **RLith:** reclassified lithology map.

The map of groundwater potential zones in Eastern province is showing five categories named as very high, high, moderate, low and very low potential zones.

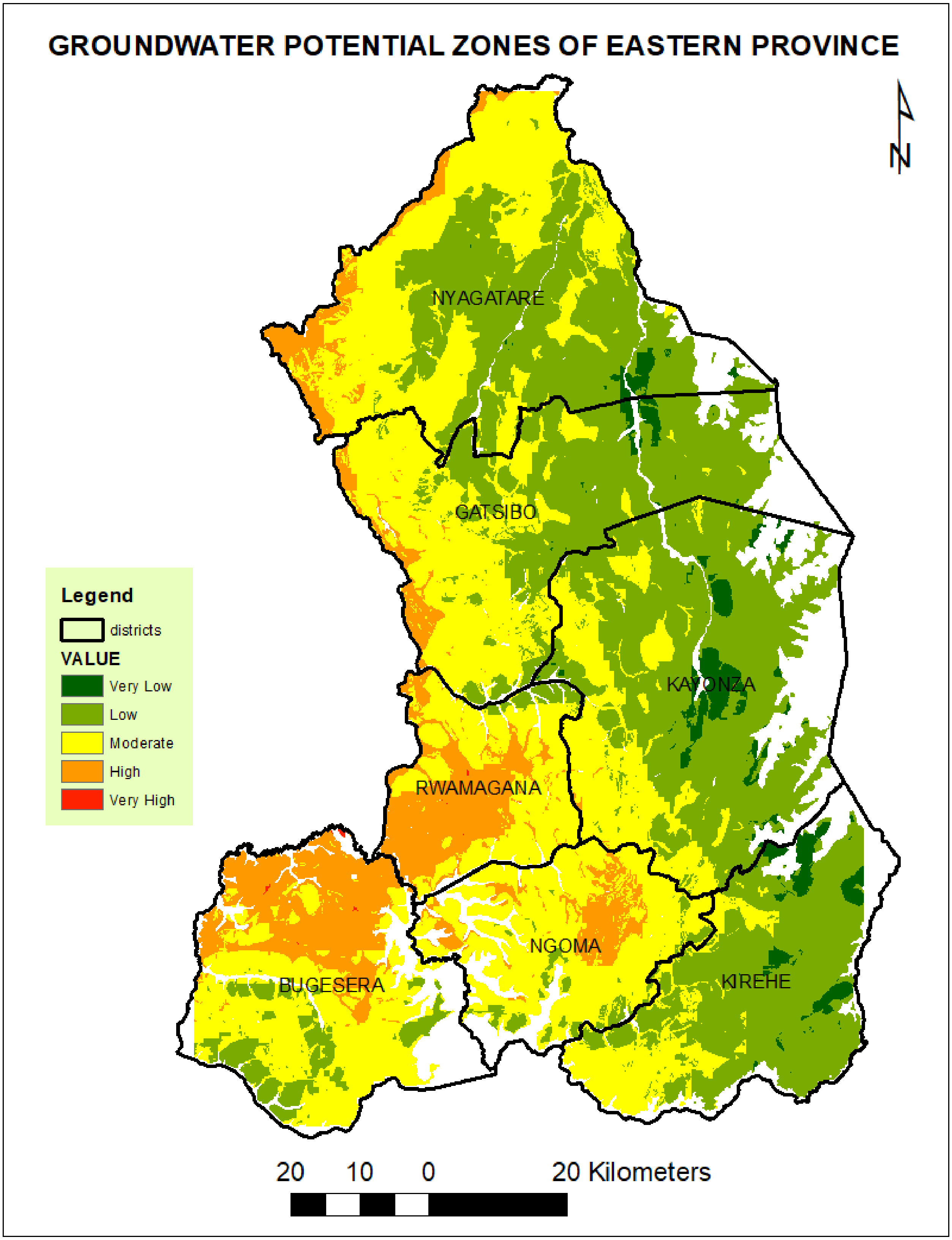


Figure 10: Groundwater potential zones map of Eastern Province

The generated map of groundwater potential zones is showing five categories namely: very high, high, moderate, low and very low groundwater potentiality. Very low groundwater potential cover

217.8km2 of the entire province, low groundwater potential covers 3,560.6km2 and it mainly laying along the eastern part of the study area. Moderate groundwater potential cover 3496.9km^2 and it is it is found in western part of the study area. The moderate groundwater potential areas have groundwater resource that can be exploited and utilized for different water uses.

High to very high groundwater potentials are covering 966.4 km^2 and 2 km^2, respectively and they are manly found in Bugesera and Rwamagana Districts in the lowland of Akagera River. According to this study, the Eastern Province has a good Ground water resources covering the three categories; Very high, high and Moderate that can be utilized for different water use like irrigation, cattle, domestic use, etc.

Table 9: Summary of groundwater potential zones of Eastern Province

No	**Groundwater classes**	**Area in km**	**Area in %**
1	Very high	2	0.024
2	High	966.4	11.723
3	Moderate	3496.9	42.419
4	Low	3560. 6	43.192
5	Very low	217.8	2. 642

4.4.2. Relationship of produced GWPZ and existing groundwater data

Groundwater information data collected from Rwanda water Resources Board related to borehole yield have been overplayed on the generated GWMZ map. The boreholes have been classified into categories regarding their production capacity during the pumping test. They have been grouped as follow: 0 to 1.2m3/hour, 1.2 to 201m3/hour and 2.1 to 3 m3/hour. Besides some exceptions, it was found that the dried boreholes and those having low water production capacity are falling in in low and very low GWPZ.

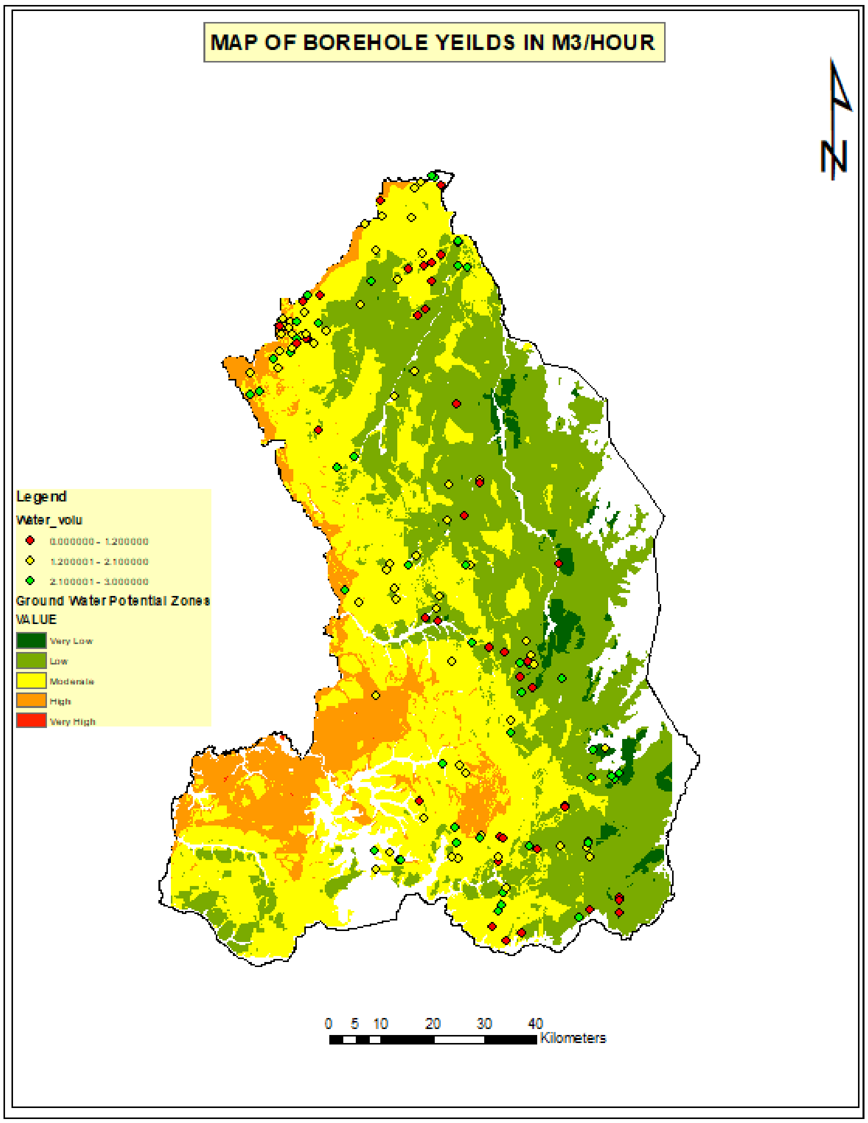


Figure 11: Map of boreholes and their yields

4.4.3. Groundwater Potential Zones by District

4.4.3.1. GWPZ in Nyagatare District

According to the map generated, Nyagatare District has a good GWPZ in Kiyombe, Karama, Tabagwe, Rwempasha Musheri, Matimba, Mukama, Gatunda, Mimuli, Gatsibo and a part of Katabagemu Sectors.

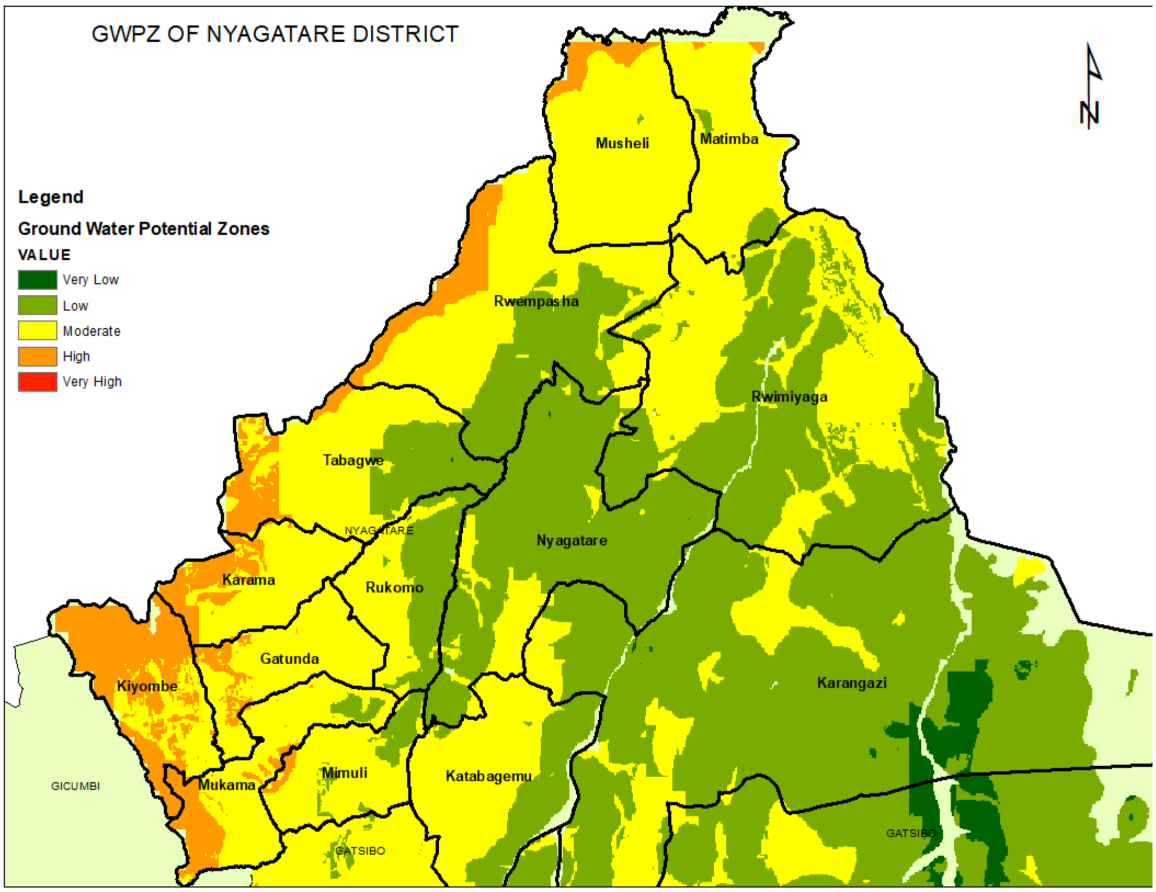


Figure 12: GWPZ in Nyagatare District

The areas with low to very low GWPZ were mainly found in Karangazi, Nyagatare and Rwimiyaga Sectors. According to the results, Nyagatare District has potential areas where groundwater should be exploited and utilized for different purposes.

4.4.3.2. GWPZ in Ngoma District

The Results for GWPZ show that the District of Ngoma in general has a good rate of groundwater in all Sectors. The sectors of Rukumberi, Mugesera, Rurenge, Remera, Kibungo, kazo can be ranked as the best area for Groundwater Resource (GR).

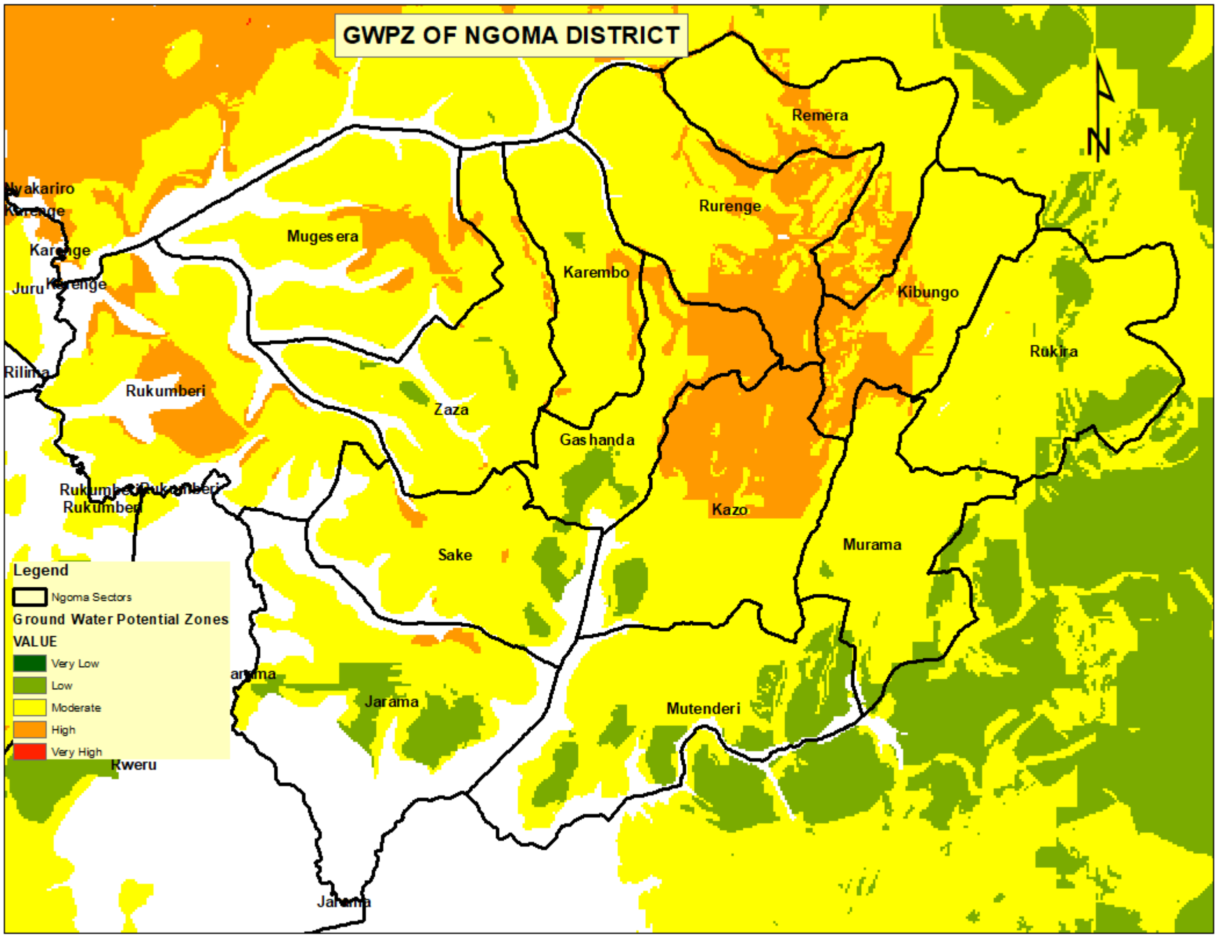


Figure 13: GWPZ in Ngoma District

According to the results found, Ngoma District has a high potential to develop Different projects for Groundwater resource utilization.

4.4.3.3. GWPZ in Kirehe District

The Results for GWPZ analysis show that Kirehe District is dominated by low groundwater recharge, except some sectors like Gahara, Gatore and Musaza that have a moderate rank.

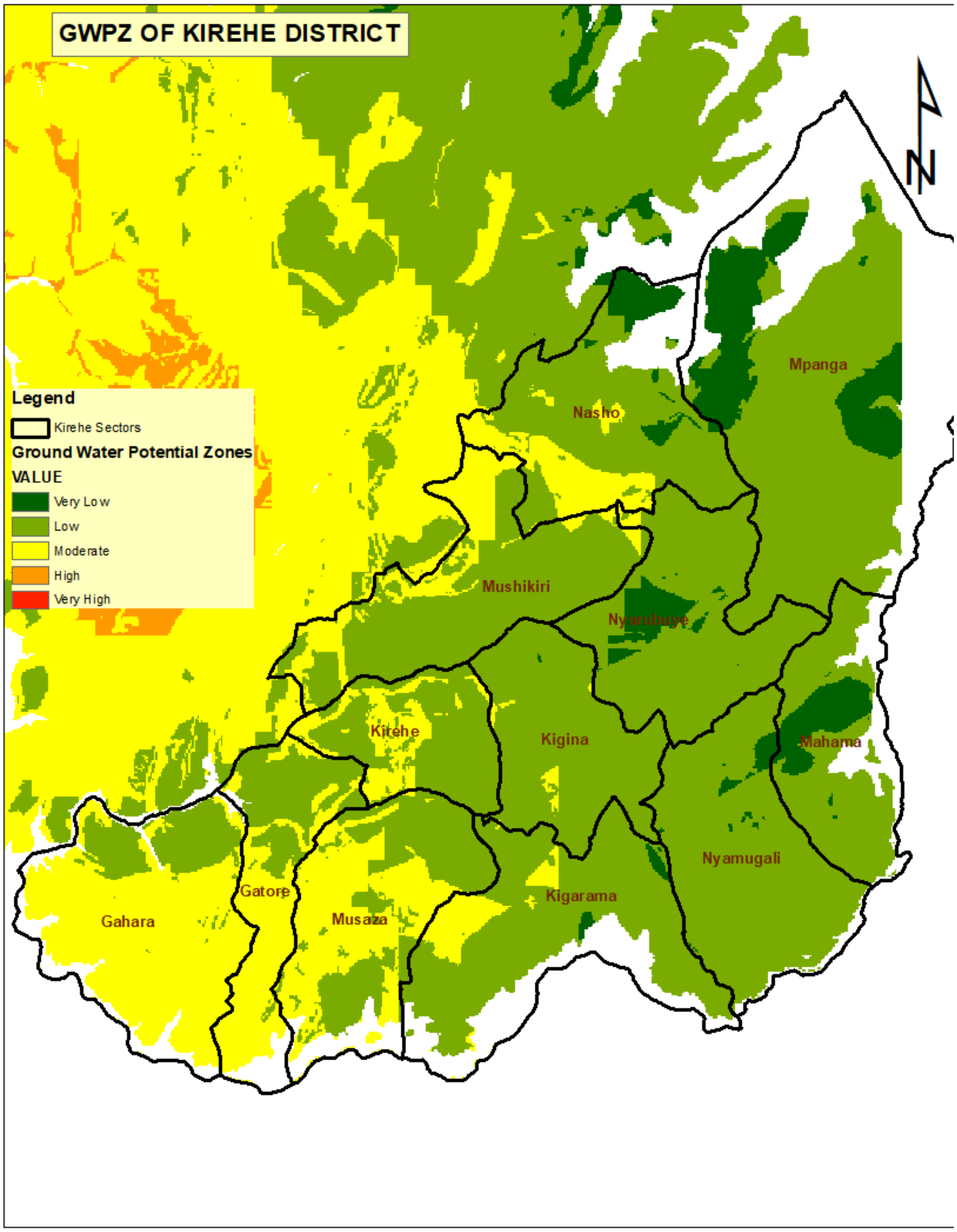


Figure 14: GWPZ in Kirehe District

According to the results, it is not advisable to develop big projects related to groundwater exploitation in Kirehe District. Only small scale water utilization like boreholes should be done where the areas are ranked as moderate. Fortunately, Kirehe District is rich in surface water; lakes of Nasho complex and Akagera Rivers that can supplement the scarcity of groundwater reserve in this area.

4.4.3.4. GWPZ in Kayonza District

The Map of GWPZ for Kayonza District shows that this District is dominated by low to very ranks for groundwater resources mainly in Ndego, Rwinkwavu, Mwiri and Murundi Sectors.

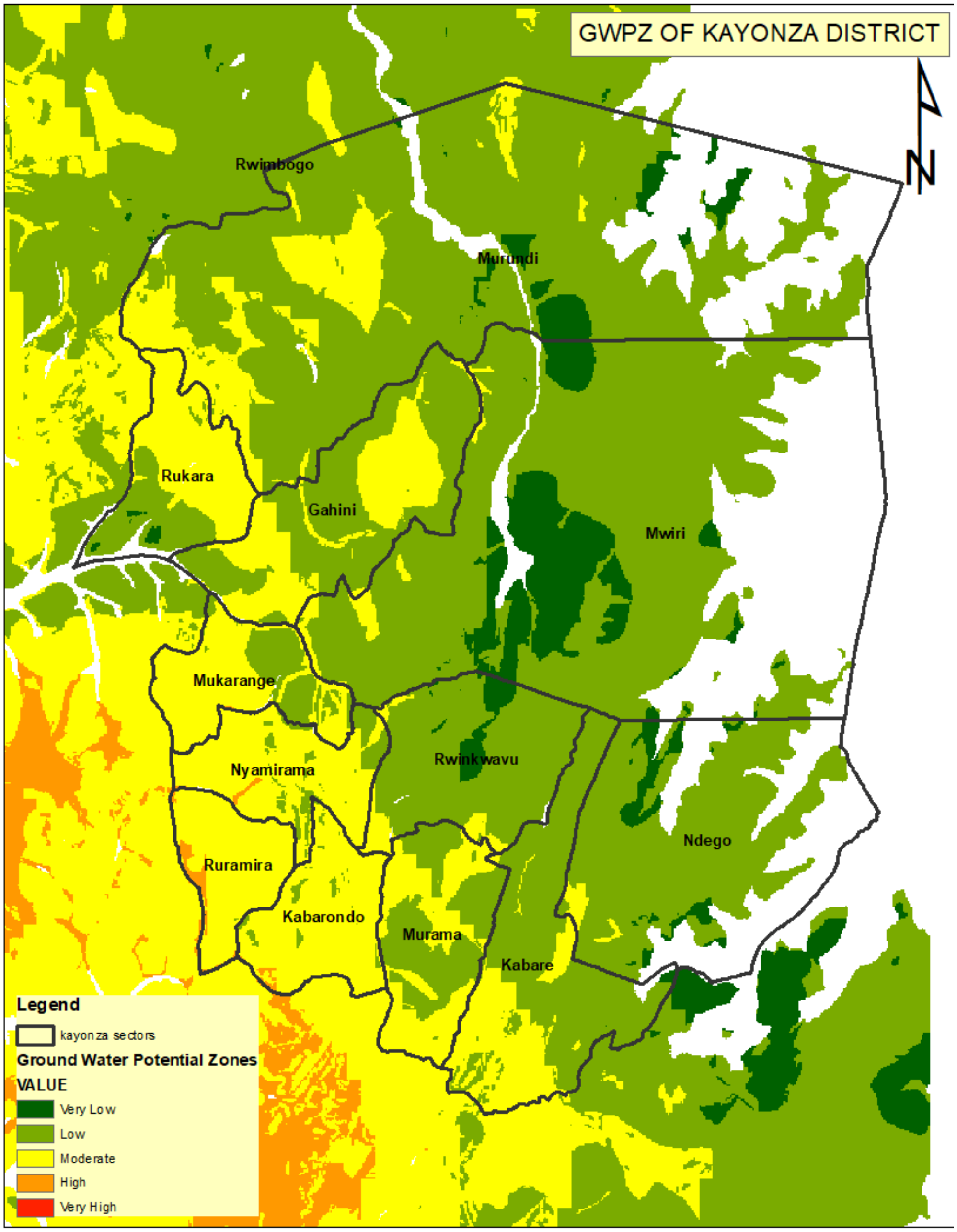


Figure 15: GWPZ in Kayonza District

The Sectors of Kabarondo, Ruramira, and Mukarange have high and moderate ranks for groundwater resource which can be exploited for small scale projects like boreholes for domestic use and cattle as well as small irrigations. The District of Kayonza has alternative way to develop big projects by using existing water resource from many lakes located in this District.

4.4.3.5. GWPZ in Gatsibo District

The map of GWPZ of Gatsibo District shows that the district has a high potential of groundwater resource. The Sectors like Gasange, Muhura, Kageyo and Nyagihanga are ranked the best areas for GWPZ and the Rwimbogo Sector comes as the area with poor groundwater resource.

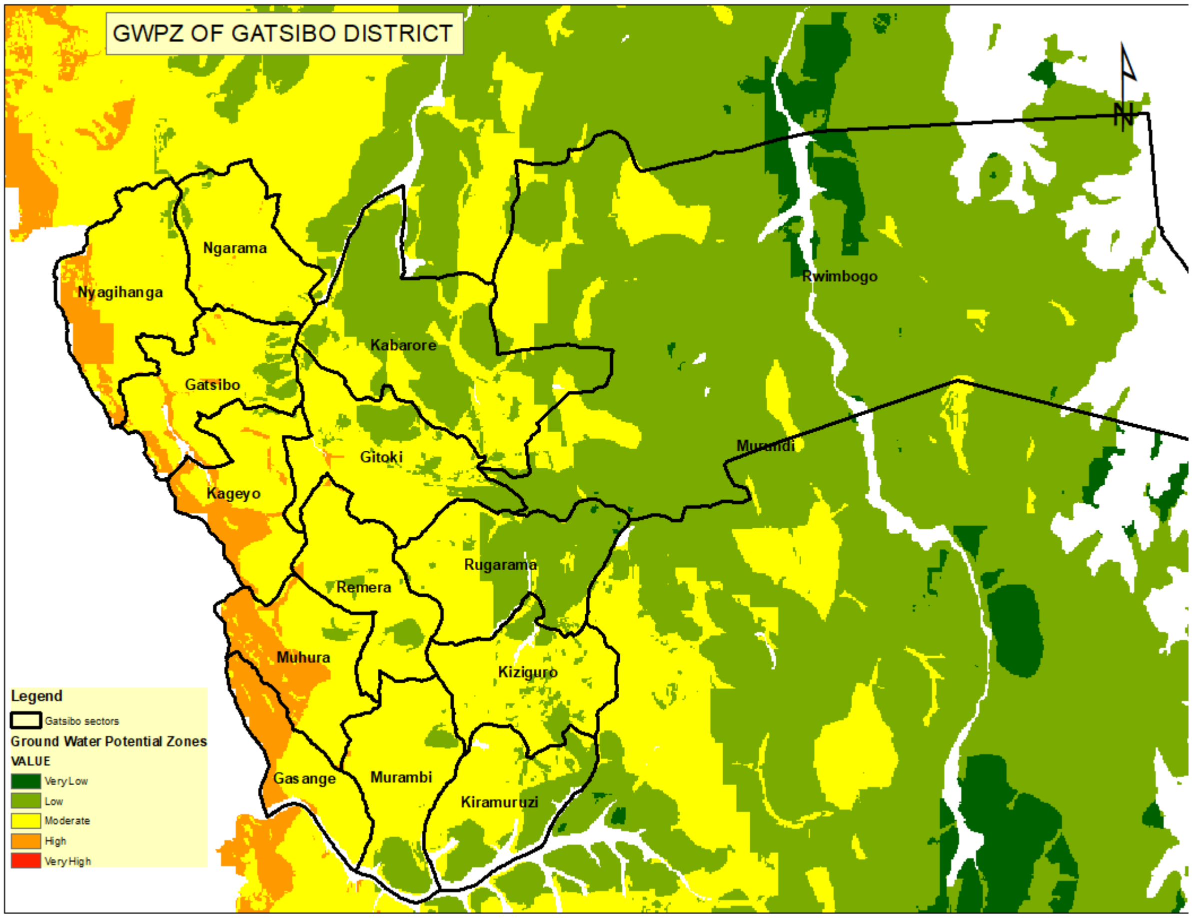


Figure 16: GWPZ in Gatsibo District

In General, some projects related to GWR (groundwater Resource) should be developed at small to large scale in Gatsibo District in areas showing a good potential for groundwater reserve.

4.4.3.6. GWPZ in Bugesera District

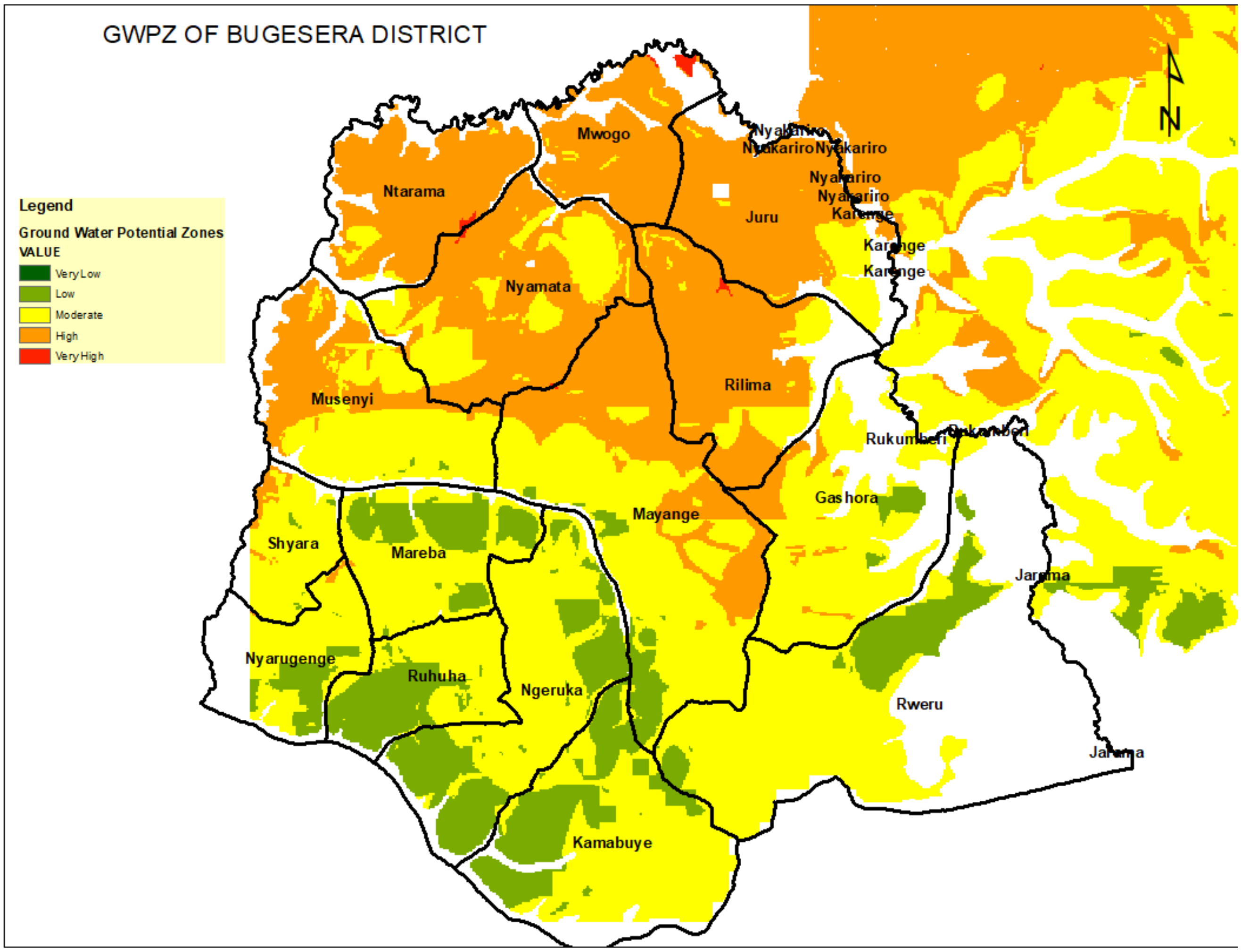


Figure 17: GWPZ in Bugesera District

The map of GWPZ of Bugesera District shows a high potential of groundwater recharge mainly the area covering the sectors of Mwogo, Ntarama, Nyamata, Juru, Rilima, Musenyi and Mayange shows a high potential for GWR and big projects related to groundwater utiliziation are possible in this area. According to our findings, Bugesera District should be ranked as the best area in Eastern Province that has enough groundwater reserve.

4.4.3.7. GWPZ in Rwamagana District

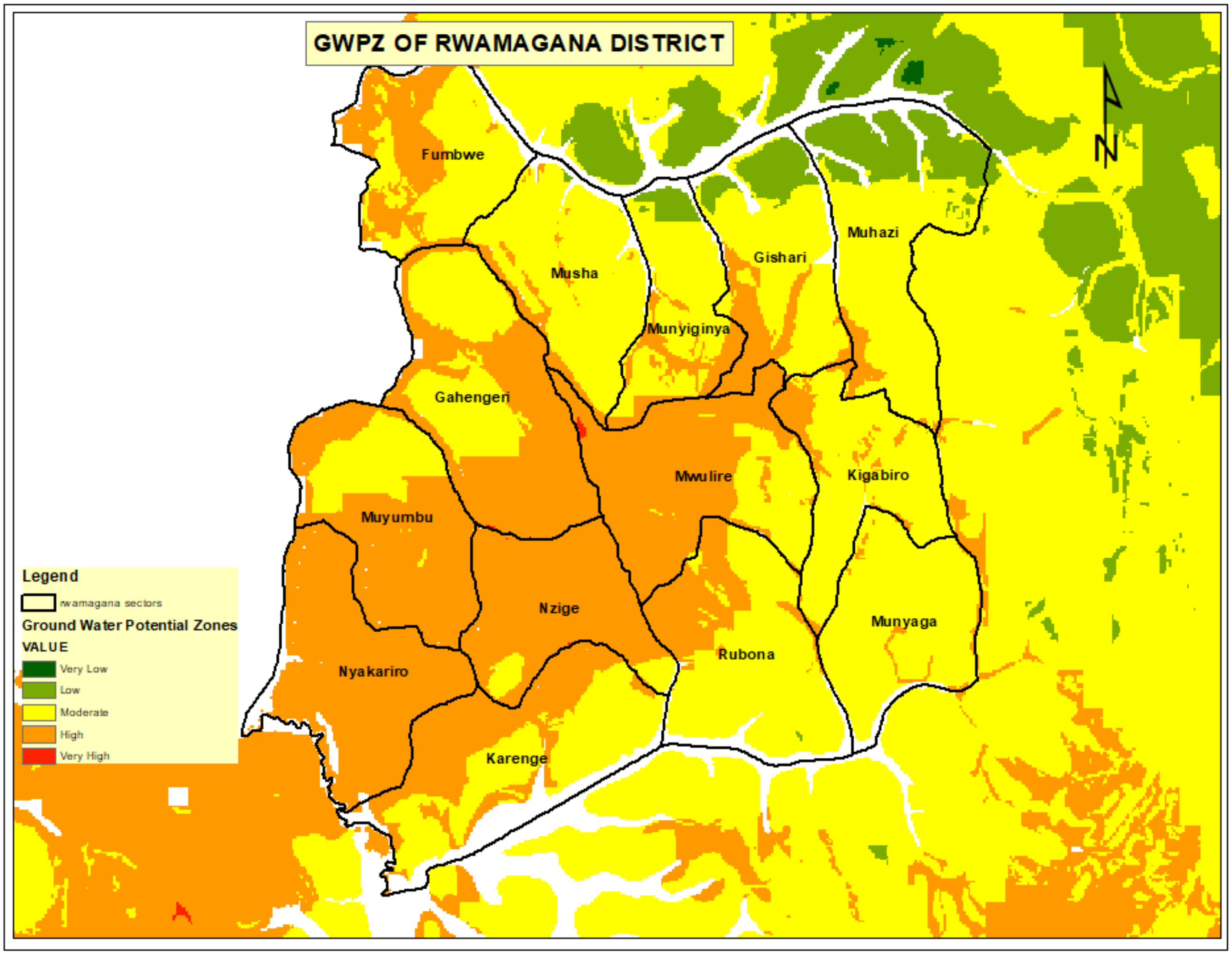


Figure 18: GWPZ in Rwamagana District

The map of Rwamagana District for GWMPZ is showing that almost all Sectors are in good range for having enough GWR. The area covering the Sector of Nyakariro, Nzige, Gahengeri, Mwurire and Fumbwe are ranked with high possibility for having the GWR. Only areas surrounding Lake Muhazi including Munyiginya, Gishari and Muhazi Sectors have a low possibility of Groundwater recharge. In general, Rwamagana District has a high potential for having enough groundwater which can be utilized for small to big scale projects development mainly in the area showing a good groundwater recharge.

CHAPTER 5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Our study titled "Geographical information System based Analytical Hierarchy Process for groundwater Potential Zone Mapping. Case Study: Eastern Province, Rwanda" was well conducted and GWPZs have been delineated based on the influential factors for groundwater occurrence. During our research, six parameters which have more effect on the occurrence of groundwater recharge prior to overlay analysis. By assigning quantitative weights to selected parameters, it was possible to identify the influence for criteria and prioritize them.

The pairwise comparison was consistent as the consistent ratio calculated is equal to 0.04. If the result of consistency ratio is greater than 0.1, the value is unacceptable and the pairwise comparison must be re-evaluated. For our case, the consistency ratio was less than 0.1 and the value was accepted for further analysis.

The generated groundwater potential zone of Eastern Province has five categories namely, very high, high, moderate, low and very low potential zones. The results are showing that the eastern Province has high groundwater potential areas mainly in Bugesera, Rwamagana and Ngoma District and there is an opportunity to develop small to big scale development projects relaying on groundwater resource extraction in this province.

In this research, we appreciated the role of GIS and AHP model for groundwater potential zones delineation, as they are time and cost effective tools to conduct a kind research on groundwater which is normally very expensive.

5.2. Recommendations

During this research, a map of groundwater potential zone was generated and the following recommendations have been made in order to understand very well the change and occurrence of groundwater resources in Eastern Province:

- ✓ For field verification, drilling and pumping test should be done in each delineated category
- ✓ Reinforce the groundwater monitoring plan by installing new monitoring stations within a good network that can cover the entire Eastern Province

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Appendix

Table 10: List of Boreholes and their production capacity

ID	DISTRICT	LAT	LON	ALTITUDE	DRILLED DEPTH （m)	DIAMETER OF CASING PIPE	Water volume （m3/h）
1	NYAGATARE	-1.44	30.12041667	1611	81	140	2.5
2	NYAGATARE	-1.435222222	30.13572222	1556	81	140	3
3	NYAGATARE	-1.402861111	30.11944444	1655	81	140	1.5
4	NYAGATARE	-1.311361111	30.18986111	1476	95	140	2
5	NYAGATARE	-1.266	30.22047222	1478	81	140	2.2
6	NYAGATARE	-1.242416667	30.33013889	1346	81	140	3
7	NYAGATARE	-1.072944444	30.45108333	1301	87	140	1.2
8	NYAGATARE	-1.170861111	30.48119444	1308	72	140	1.8
9	NYAGATARE	-1.455638889	30.47841667	1339	72	140	1
10	NYAGATARE	-1.399305556	30.40602778	1352	72	140	2.5
11	NYAGATARE	-1.068055556	30.41730556	1310	81	140	2
12	NYAGATARE	-1.1427	30.32071389	1338	42	140	1.5
13	NYAGATARE	-1.129280556	30.35020278	1319	81	140	0.55
14	NYAGATARE	-1.311888889	30.20094444	1459	60	167	2
15	NYAGATARE	-1.367713889	30.18988611	1413	46	140	2.5
16	NYAGATARE	-1.376941667	30.15975278	1486	50	140	3
17	NYAGATARE	-1.188147222	30.337675	1335	72	140	2
18	NYAGATARE	-1.341533333	30.21915833	1401	54	140	2
19	NYAGATARE	-1.365261111	30.17094444	1451	48	140	2
20	NYAGATARE	-1.283508333	30.310375	1352	54	140	1.6
21	NYAGATARE	-1.311019444	30.17318889	1546	42	140	2.2
22	NYAGATARE	-1.334636111	30.19187222	1449	45	140	1.5
23	NYAGATARE	-1.323205556	30.17673889	1498	39	140	2.5
24	NYAGATARE	-1.238661111	30.37565278	1349	56	140	2.1

25	NYAGATARE	-1.318905556	30.17906111	1498	54	140	1
26	NYAGATARE	-1.329561111	30.25257222	1360	50	140	2.1
27	NYAGATARE	-1.078111111	30.40464167	1306	51	140	1.9
28	NYAGATARE	-1.060616667	30.43949444	1292	82	140	2.2
29	NYAGATARE	-1.3944	30.16862778	1460	72	140	2
30	NYAGATARE	-1.195061111	30.45221111	1320	80	140	0.9
31	NYAGATARE	-1.129505556	30.40014444	1365	58	140	1.9
32	NYAGATARE	-1.057819444	30.43561111	1292	50	140	2.4
33	NYAGATARE	-1.443094444	30.36943611	1356	50	140	1.9
34	NYAGATARE	-1.193477778	30.42042222	1367	84	140	1.5
35	NYAGATARE	-1.265555556	30.24138889	1474	61	140	1
36	NYAGATARE	-1.307777778	30.17555556	1544	76	167	2
37	NYAGATARE	-1.342222222	30.2175	1387	91	140	1.1
38	NYAGATARE	-1.328888889	30.18444444	1488	49	140	0.7
39	NYAGATARE	-1.336944444	30.20944444	1403	61	140	1.8
40	NYAGATARE	-1.315555556	30.2375	1420	75	167	2.4
41	NYAGATARE	-1.313611111	30.18027778	1518	49	140	0.6
42	NYAGATARE	-1.276666667	30.21083333	1520	53	140	1
43	NYAGATARE	-1.321111111	30.17944444	1508	72	140	1.8
44	NYAGATARE	-1.341944444	30.20194444	1367	44	140	2.5
45	NYAGATARE	-1.358333333	30.19361111	1428	50	140	2
46	NYAGATARE	-1.334722222	30.17472222	1534	51	140	2
47	NYAGATARE	-1.319444444	30.17222222	1527	68	140	0.8
48	NYAGATARE	-1.326666667	30.1675	1547	54	140	0.6
49	NYAGATARE	-1.296111111	30.21305556	1457	62	140	1.5
50	NYAGATARE	-1.349444444	30.23027778	1382	53	140	2.1
51	NYAGATARE	-1.241491667	30.24476389	1428	66	140	0.6
52	NYAGATARE	-1.349827778	30.20036944	1456	53	140	0.8
53	NYAGATARE	-1.173022222	30.48071389	1290	63	167	2.5
54	NYAGATARE	-1.213769444	30.48112222	1296	49	140	2.5
55	NYAGATARE	-1.291072222	30.42383056	1360	52	140	0.6
56	NYAGATARE	-1.301019444	30.41022222	1362	65	140	1.2

57	NYAGATARE	-1.2414	30.43671944	1429	45	140	0.6
58	NYAGATARE	-1.099694444	30.34757222	1324	59	140	1.2
59	NYAGATARE	-1.335180556	30.21621389	1415	49	140	2
60	NYAGATARE	-1.214833333	30.42288611	1342	63	140	0.6
61	NYAGATARE	-1.209361111	30.43546389	1322	59	140	0.9
62	NYAGATARE	-1.218166667	30.49627778	1346	69	140	2.5
63	NYAGATARE	-1.218958333	30.39524722	1353	51	140	1.2
64	NYAGATARE	-1.224783333	30.25467778	1415	63	140	0.7
65	NYAGATARE	-1.242425	30.330075	1346	79	140	2.5
66	NYAGATARE	-1.170775	30.48118889	1308	72	140	2.4
67	NYAGATARE	-1.399241667	30.40583333	1352	74	140	2
68	NYAGATARE	-1.311836111	30.20101944	1459	61	140	2.2
69	NYAGATARE	-1.377002778	30.15988611	1486	50	140	2.3
70	NYAGATARE	-1.129333333	30.35036111	1319	79	140	1.5
71	NYAGATARE	-1.324119444	30.187125	1463	49	140	1.8
73	KAYONZA	-1.814511111	30.44374722	1447	45	140	1.5
74	KAYONZA	-1.936591667	30.66156389	1408	51	140	3
75	KAYONZA	-1.907002778	30.47100833	1431	49.5	140	2
76	KAYONZA	-1.737277778	30.50295	1359	63	140	1.8
77	KAYONZA	-1.961641667	30.59082778	1356	54	167	2.5
78	KAYONZA	-1.932805556	30.58845833	1402	49	140	0.7
79	KAYONZA	-1.883136111	30.53603611	1454	65	140	0.7
80	KAYONZA	-1.883252778	30.53608611	1454			
81	KAYONZA	-1.739088889	30.49414167	1369	60	140	3
82	KAYONZA	-1.873566667	30.50671667	1449	53	167	2.3
83	KAYONZA	-1.891355556	30.56134167	1486	44	140	0.6
84	KAYONZA	-2.01	30.57361111	1407	52	140	1.5
85	KAYONZA	-2.030277778	30.57333333	1408	48	140	2.5
86	KAYONZA	-1.951944444	30.61111111	1357	54	167	2.5
87	KAYONZA	-1.952111111	30.61130556	1357			
88	KAYONZA	-1.910833333	30.60583333	1318	51	140	2.5
89	KAYONZA	-1.906111111	30.6025	1328	58	140	1.2

90	KAYONZA	-1.910255556	30.58801667	1368	50	140	2
91	KAYONZA	-1.912911111	30.61457778	1328	58	140	2
92	KAYONZA	-1.896230556	30.60911389	1350	62	167	1.8
93	KAYONZA	-1.835166667	30.446275	1449	40	140	1
94	KAYONZA	-1.870325	30.59977222	1360	37	140	2
95	KAYONZA	-1.910438889	30.58817222	1372	54	167	2.5
96	KAYONZA	-1.735527778	30.65736389	1300	76.5	140	1.2
98	NGOMA	-2.209377778	30.52121944	1443	75	140	2
99	NGOMA	-2.254002778	30.37809722	1330	68	140	1.5
100	NGOMA	-2.254027778	30.37804167	1330			
101	NGOMA	-2.239405556	30.36250833	1331	54	140	1.4
102	NGOMA	-2.271263889	30.33748611	1331	63	140	1.8
103	NGOMA	-2.150422222	30.41518333	1337	42	140	0.7
104	NGOMA	-2.251527778	30.48168611	1348	63	140	1.5
105	NGOMA	-2.213175	30.55416111	1389	61	140	1.5
106	NGOMA	-2.213111111	30.55420556	1389			
107	NGOMA	-2.256836111	30.55053056	1365	72	140	0.7
108	NGOMA	-2.217333333	30.55856667	1367	76.5	140	0.8
109	NGOMA	-2.248397222	30.55286111	1367	71	140	1.7
110	NGOMA	-2.215838889	30.52006667	1444	58.5	140	2.2
111	NGOMA	-2.180305556	30.42257222	1339	48	140	1.9
112	NGOMA	-2.088880556	30.48490278	1347	71	140	1.8
113	NGOMA	-2.085269444	30.45486111	1337	58	140	2.5
114	NGOMA	-2.248961111	30.46935278	1376	82	140	2
115	NGOMA	-2.223602778	30.47939167	1338	52	140	2.5
116	NGOMA	-2.195955556	30.47688889	1288	72	140	2.5
117	NGOMA	-2.238363889	30.33633333	1328	45	140	2.5
118	NGOMA	-2.254130556	30.38248611	1329	56	140	2.5
119	NGOMA	-2.102886111	30.49451944	1354	72	140	1.9
121	GATSIBO	-1.777958333	30.37003056	1477	63	140	2
122	GATSIBO	-1.798661111	30.37423333	1449	44	140	2
123	GATSIBO	-1.598238889	30.46507778	1354	50	140	2

124	GATSIBO	-1.803683333	30.30999722	1491	63	140	2
125	GATSIBO	-1.568166667	30.27065833	1430	40	140	2
126	GATSIBO	-1.548875	30.30120556	1390	48	140	2.5
127	GATSIBO	-1.794038889	30.44785556	1456	66	140	1.5
128	GATSIBO	-1.782652778	30.28542222	1534	71	140	3
129	GATSIBO	-1.745822222	30.35754722	1486	59	140	1.9
130	GATSIBO	-1.503558333	30.23870833	1381	56	140	1
131	GATSIBO	-1.831094444	30.42525	1456	74	140	1
132	GATSIBO	-1.722088889	30.40952778	1395	80	140	1.5
133	GATSIBO	-1.650675	30.49173889	1320	56	140	1.2
134	GATSIBO	-1.660275	30.46136111	1337	48	140	2
135	GATSIBO	-1.737186111	30.39572778	1413	43	140	2.5
136	GATSIBO	-1.736797222	30.36318889	1496	74	140	2
137	GATSIBO	-1.590194444	30.51868611	1336	65	140	2
138	GATSIBO	-1.594175	30.5188	1336			
139	GATSIBO	-1.568136111	30.27063611	1430	40	140	2.5
141	RWAMAGANA	-1.965591667	30.3372	1444	67	140	1.8
143	KIREHE	-2.247972222	30.7095	1462	68	140	2
144	KIREHE	-2.062111111	30.71552778	1312	49	140	2.2
145	KIREHE	-2.310777778	30.56058333	1353	50	140	2.4
146	KIREHE	-2.111666667	30.75305556	1303	54	140	2.3
147	KIREHE	-2.235833333	30.61972222	1402	71	140	0.8
148	KIREHE	-2.058055556	30.7375	1289	54	140	2.1
149	KIREHE	-2.228333333	30.66027778	1376	56	140	1.5
150	KIREHE	-2.394722222	30.56583333	1405	49	140	1
151	KIREHE	-2.160277778	30.66805556	1682	49	140	1.2
152	KIREHE	-2.303611111	30.56583333	1357	65	140	2.1
153	KIREHE	-2.318333333	30.76138889	1339	51	140	1.2
154	KIREHE	-2.339722222	30.71166667	1357	53	140	0.6
155	KIREHE	-2.324444444	30.7625	1400	56	140	0.5
156	KIREHE	-2.231138889	30.704875	1382	90	140	2
157	KIREHE	-2.221961111	30.70676111	1439	72	140	2.5

158	KIREHE	-2.223147222	30.70852778	1420	81	140	2.5
159	KIREHE	-2.221961111	30.70676111	1439	72	2.5	37.8
160	KIREHE	-2.344336111	30.55129722	1379	63	140	2.5
161	KIREHE	-2.102036111	30.76113056	1280	45	140	2.4
162	KIREHE	-2.381722222	30.59179722	1361	81	140	1
163	KIREHE	-2.230002778	30.60663889	1375	72	140	2.5
164	KIREHE	-2.108627778	30.74974444	1307	72	140	2.3
165	KIREHE	-2.369861111	30.54074444	1354	81	140	0.7
166	KIREHE	-2.369844444	30.54087778	1354			
167	KIREHE	-2.333611111	30.55696111	1379	74	140	2.5
168	KIREHE	-2.346488889	30.76255556	1418	65	140	0.8
169	KIREHE	-2.354566667	30.69165556	1422	60	167	2.5
170	KIREHE	-2.110127778	30.71281389	1310	50	167	2.5
171	KIREHE	-2.160588889	30.66806111	1682	49	140	0.6