IJIRR

International Journal of Information Research and Review
Vol. 04, Issue, 12, pp.4938-4945, December, 2017

REVIEW ARTICLE

GROUNDWATER PROSPECTS IN KIRUNDO DISTRICT, NORTHERN BURUNDI: MODELING BY REMOTE SENSING AND GIS

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ARTICLE INFO

Article History:

Received 12th September, 2017
Received in revised form
27th October, 2017
Accepted 07th November, 2017
Published online 30th December, 2017

Keywords:

Groundwater prospects zones,
Integration,
Remote sensing and GIS.

ABSTRACT

The importance of groundwater is growing due to the rising demand in the Kirundo District northern part of Burundi and Remote Sensing (RS) and Geographic Information System (GIS) have come as a set of modern tools in the investigation/identification of the Groundwater potential zones - an important bounty of Groundwater. The input data for this study included Geology, lineaments, drainage density, land use/land cover, soil cover, and nature of landscape and distribution of land-surface slope. RS data products used are Landsat TM image, viz., TM 5–4-3 as well as ASTER G DEM of 30 m resolution. A groundwater prospect map is produced by integrating thematic maps, viz., geology, lineament density, drainage density, land use/land cover, soil and slope maps. The groundwater prospect zones of Kirundo district was found to be very good (7.82 km^2), good (80.45 km^2), moderate (107.17 km^2), low (421.58 km^2), poor (360.07 km^2), respectively 1, 8, 11, 43 and 37% of the study area. Based on this investigation, it has been possible to identify villages that are important from the point of view of groundwater prospects in the Kirundo District, Burundi.

INTRODUCTION

The water stored underground in the cracks and spaces in soil, sand and rock throughout the Great Lakes basin, constitutes an immense unseen water resource estimated to be equal in volume of water in Lake Michigan (i.e., 4,920 km^3 or 1,180 mi3). (Report to the International Joint Commission from the IJC Great Lakes Science Advisory Board, February 2010.) GW, a major natural resource in the Great Lakes Basin, supplies drinking water in the basin, and many manufacturing outfits and other industrial and agricultural use are met by GW. In addition to human uses, other important functions of GW are in maintaining base-flow flow in streams, lakes and wetlands by slowly and consistently discharging water during periods of little or no rainfall. Discharge to streams during periods of no surface runoff is essential to support aquatic organisms, especially during periods of drought. Issues generally involve the amount of groundwater availability, the quality and/or the connection to an ecosystem (Grannemann, Hunt, Nicholas, Reilly and Winter, 2000).

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The amount of GW available depends on many climatic and hydrogeological factors. However the International Joint Commission from the IJC Great Lakes Science Advisory Board better characterize and understand groundwater, control known contamination sources, and restore and protect groundwater quality and quantity in the Great Lakes Basin. The importance of groundwater in the Great Lakes Basin is now more fully understood than in 2000 when the Council of Great Lakes Research Managers and the International Joint Commission decided to evaluate the status of groundwater resources in the basin. The Commission and the Council have emphasized the need for research related to groundwater. Many researchers have used the mix of RS and GIS techniques in delineating GW prospect (Jha *et al*. 2007; Chowdhury *et al*. 2010; Eastman 1999). A blend of these two techniques amply proved its efficiency in GW zonation reported from various parts of theworld (Jhariya *et al*. 2016). Integration of the two technologies has proven to be an efficient tool in groundwater studies (Krishnamurthy et. al 1996, Sander 1996, Kamaraju et. al 1996, Saraf and Choudhury 1998).Water is insufficient supply resource in Kirundo district. Most of all water used for domestic purposes comes from groundwater sources. In this study, a Geographical Information System (GIS) integration tool is proposed to demarcate the groundwater potential zone in a soft rock area using six hydrogeologic themes: geology, drainage density, lineament density, land use/ land cover, slope variability and soils.

Regional settings

Kirundo district is one of the numerous depressions known in the inter-lacustrine zone of East Africa. It covers an important part of northeastern Burundi and southeastern Rwanda. It is surrounded, to the North, East and South, by dissected plateaus whose quartzitic crests overhang the depression. To the West, the depression of Bugesera is bounded by the North-South trending valley of the Kanyaru River both in Burundi and Rwanda (Moeyersons, 1977). In Burundi, Bugesera region is one of the 11 natural regions and covers the northern extremity of the provinces of Muyinga and Kirundo. The study area covers 1,102.16 sq km Fig.1.

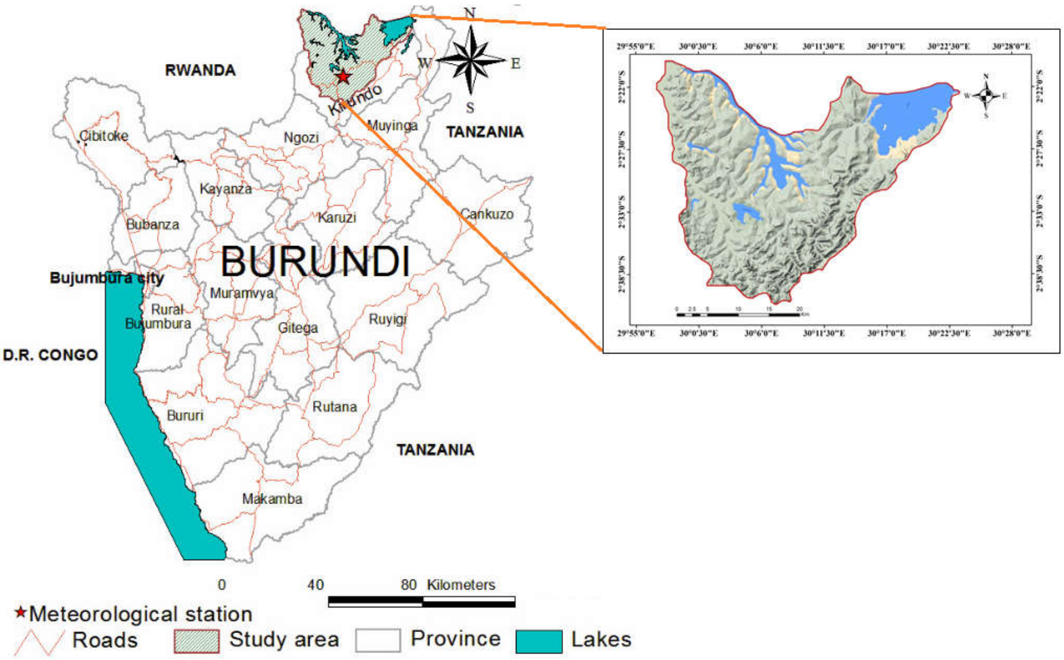

Fig. 1. Location and study area

Topography

According to the Africover project (FAO, 2003), four landform classes can distinguished within the study area: depression (53%), hills and mountain foot ridges (27%), alluvial plain (3%) and plateau (1%). Thus, geomorphologically, the study area mainly consists of a depression located around the so-called "*Lacs du Nord*" (northern lakes) which is characterized by a slightly undulating topography with elevations ranging between 1320 and 1500 m above mean sea level (a.m.s.l). However, some isolated peaks within the depression can reach an elevation exceeding 1600 m. This depression is surrounded, to the South and East, by a more rugged landscape, i.e. hills and mountain foot ridges, wherein crests peak up to 1800 m while the valley bottoms lie at about 1320 m a.m.s.l. This landform is dissected by numerous V-shaped valleys in which flow small perennial streams. It is important to note that most of water springs are located within this landform. The depression is dissected by an important network of large valleys where lie Holocene sediments, swamps and a number of shallow lakes.

In some areas, this complex of swampy valleys and lakes is flanked by narrow alluvial plains where sediments from highlands are deposited. Underlined by the quartzitic formation of Ruganza, the small plateau is perched over the Mutumba Mountain, South-West of the study area. Overall, the elevation ranges between 1321 m and 1873 m above the mean sea level with a mean elevation of 1427 m. The highest elevations are observed to the South and East of the study area where a more rugged topography marks the transition from the Bugesera depression towards the highlands of Bweru.

Climatologic and meteorologic conditions

The climatic regime for the area, as for the whole of Burundi, is characterized by distinct wet and dry seasons controlled by south-easterly and north-easterly monsoons. The longer south-easterly monsoon brings rain between about February and May while the shorter north-easterly monsoon is responsible for the rainfall occurring between September and November Fig.3.

There are equally two dry seasons namely the long and short dry seasons. The long dry season generally covers the months of June through August while the short dry season occurs between December and January. Average monthly rainfall for the period 1970 through 2016 shows that the long rainy season accounts for 45.3 % of the total yearly rainfall and the highest rainfall occurs in April.

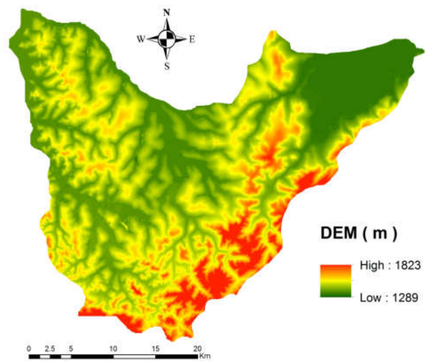

Fig. 2 Study area, DEM

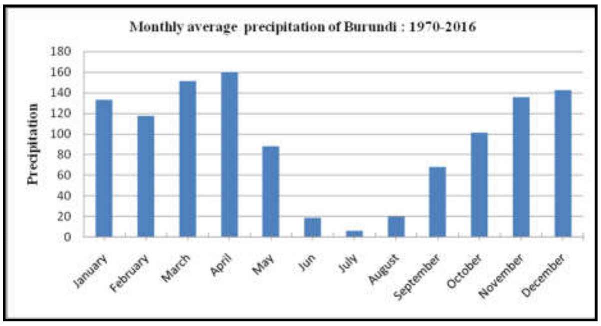

Fig. 3. Monthly average precipitation of Burundi: 1970-2016

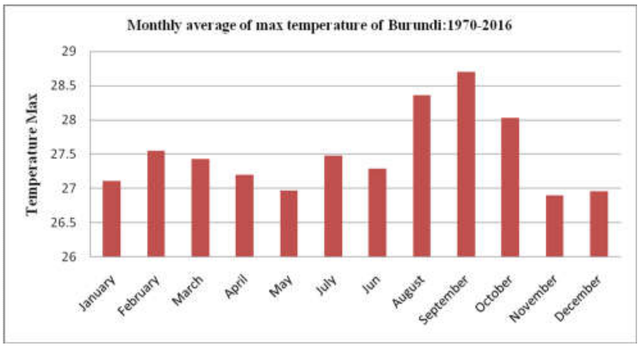

Fig. 4. Monthly average of max temperature of Burundi: 1970-2016

Table 1. Statistical analysis- precipitation and temperature

	Précipitation, mm	T, max. °C	T, min.°C
Minimum:	5.47	26.9	14.4
Maximum:	159.6	28.7	17.1
Mean:	94.9	27.4	16.3
Variance:	3061.2	0.33	0.67
Standard Deviation:	55.32	0.57	0.819

The short rainy season accounts for 26.7% of the total annual precipitations with the highest precipitation occurring in November. Thus, a hydrologic year in Burundi starts in September with the beginning of the short rainy season and ends in August, at the end of the long dry season. For the period 1970 through 2016, the monthly precipitation varies between a minimum of 5 mm and a maximum of 159 mm, respectively recorded in July and April. The average monthly precipitation for the whole period of records amounts to 95 mm.

MATERIALS AND METHODS

The methodology employed is summarized in the Work flowin Fig.5. Multiple parameters such as, slope, Geology, lineament density, drainage density and soil texture were analyzed by an approach using normalized weights to explore the prospects of GW. The input data, i.e., thematic maps of the parameters analyzed, were aggregated from secondary sources and Toposheets (1:50,000 scale).Slope map, lineament density map, drainage density map, are created out of ASTER G DEM 20m resolution and Landsat is the basis for deriving land use/land cover map.The secondary data is the basis of deriving Geology map and soil map.Software platforms Arcmap 10.2 was used for the GIS modeling, Erdas Imagine was used in digital image processing for the remote sensing to create landuselandcover and rockwork , Geomatica 2017 were used for creating lineament map.

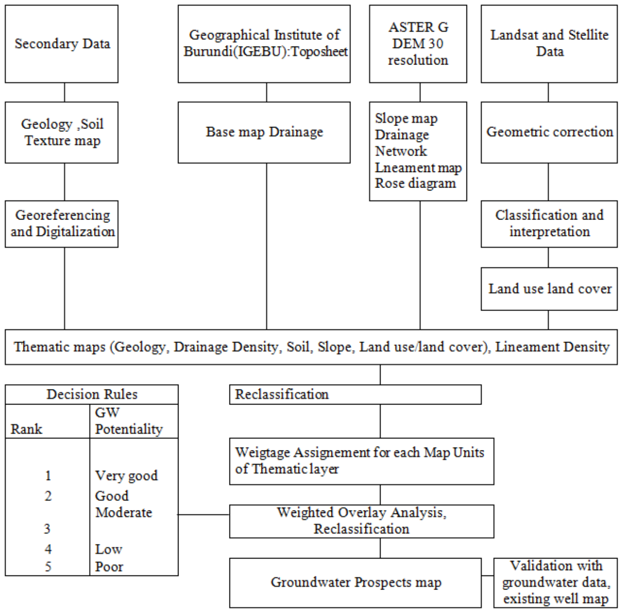

Fig. 5. Work flow showing data and methods employed for the study

The workflow illustrating the methodology for demarcating the GW prospects in Kirundo District, Northern Burundi.

GIS modelling and criteria vis-à-vis GW prospects

All the thematic maps, slope, Geology, lineament density, drainage density and soil texture were evaluated according to its relative importance in the prediction of GW potential. Appropriate weights are assigned to each of these attributes; water is drained or retained differently according to the factor. A factor with a higher weight has a larger capacity of drainage of water and a factor with a lower weight has a lower capacity of drainage water, the water retained is high. Integration of these attributes with their respective weights is computed through weighted overlay analysis in a GIS platform.In this study, the following equation is used to estimate Groundwater Potential Index (GWPI).

$$GWPI=(SL_wSL_{wi}+DD_wDD_{wi}+LD_wLD_{wi}+LU_wLUwi+SO_wSO_{wi}+GG_wGG_{wi})$$

Where GWPI Groundwater Potential Index, SL = slope, DD = drainage density, LD = lineament density, LU = land use and land cover,SO = soil, GG = Geology, 'w' = normalized weight of atheme, 'wi' = normalized weight of the individual features of a theme.

RESULTS AND DISCUSSION

Multi-influencers of groundwater prospects

Land use/land cover

Land use/land cover (LULC) classes of Kirundo district, obtained from Landsat L8 OLI/TIRS. LULC information is an important component influencing in groundwater modeling in regard to hydrology and water quality.

Table 2.Ranks and weight assigned for different groundwater control parameters

		Rank		Rank		Rank		
Soil	Porosity	3	Specificyield	2	Specificretention	1	Total	Weight
Clay	4	12	3	6	5	5	23	27%
Loamysand	5	15	4	8	4	4	27	32%
Sandy loam	3	9	5	10	3	3	22	26%
Organicsoil	2	6	2	4	2	2	12	14%
Geology		3		2		1		
Geology1	4	12	3	6	4	4	22	15%
geology2	3	9	4	8	3	3	20	14%
Geology3	1	3	1	2	1	1	6	4%
Geology4	6	18	5	10	2	2	30	21%
Geology5	5	15	4	8	4	4	27	19%
Geology6	2	6	3	6	5	5	17	12%
Geology7	1	3	6	12	6	6	21	15%
Slope		3		2		1		
0-10	4	12	4	8	4	4	24	40%
10-20	3	9	3	6	3	3	18	30%
20-40	2	6	2	4	2	2	12	20%
>40	1	3	1	2	1	1	6	10%
DD		3		2		1		
0-0.15	5	15	5	10	5	5	30	40%
0.15-0.4	3	9	3	3	3	3	15	20%
0.4-0.65	2	6	2	4	2	2	12	16%
0.65-0.94	2	6	2	4	2	2	12	16%
0.94-1.6	1	3	1	2	1	1	6	8%
LD		3		2		1		
0-0.3	4	12	4	8	4	4	24	47%
0.3-0.6	2	6	3	6	2	2	14	27%
0.6-1	1	3	1	2	2	2	7	14%
1-1.6	1	3	1	2	1	1	6	12%
LU		1		2		3		
Water body	2	2	2	4	1	3	9	16%
Vegetation	3	3	3	6	5	15	24	42%
Open forest	4	4	4	8	2	6	18	32%
Builtup	1	1	1	2	1	3	6	11%
Layers		3		2		1		
Soil	3	3	1	2	1	3	8	6%
Geology	4	4	3	6	4	12	22	17%
Slope	3	3	3	6	4	12	21	16%
DD	5	5	5	10	5	15	30	23%
LU	4	4	2	4	2	6	14	11%
LD	6	6	6	12	6	18	36	27%

Geology1*:Holocene (alluvium)
Geology2**: Granite intrusion
Geology3***: Ngozi (phyllite, schist, mica schist, quartzo-phillite)
Geology4****:Undiffentiated complex (granite, pegmatite &metasediments)
Geology5*****: Migendo or Murehe (mica schist, quartzop-hyllite)
Geology6******: Nyagisozi or Nyabihanga (psammite, psmmoschist, quartzite, conglomerate)
Geology7*******: Ruganza (quartzite)

Table 3. Relative weights of various thematic layers and their corresponding classes

No	Layer	Weight	Sub-domain/mapunits	Weight
1	Geology	17%	Geology1	15.4%
			geology2	14.0%
			Geology3	4.2%
			Geology4	21.0%
			Geology5	18.9%
			Geology6	11.9%
			Geology7	14.7%
2	Slope	16%	0-10	40.0%
			10-20	30.0%
			20-40	20.0%
			>40	10.0%
3	Drainage Density	23%	0-0.15	40%
			0.15-0.4	20%
			0.4-0.65	16%
			0.65-0.94	16%
			0.94-1.6	8%
4	LineamentDensity	27%	0-0.3	47%
			0.3-0.6	27%
			0.6-1	14%
			1-1.6	12%
5	Land use/Land cover	11%	Weter body	15.8%
			Vegetation	42.1%
			Open vegetation	31.6%
			Built	10.5%
6	Soil	6%	Clay	27.4%
			Loamysand	32.1%
			Sandy loam	26.2%
			Organicsoil	14.3%

The land use in our study area is largely dominated by agricultural land with sparse forest plantations and some relicts of natural vegetation comprising shrubs, savanna and marshy vegetation. Vegetation represents 31 %, which underlines the continuing expansion of agricultural land to the detrimental of forest and natural vegetation. Vegetation is given high rank due to its high potential for groundwater storage. Water bodies and the surrounding marshland represent 42 % of the study area. Human settlement is characterized by a dispersed pattern which is typical of most of the developing countries (0.22 %). The only urban settlement is the small city of Kirundo

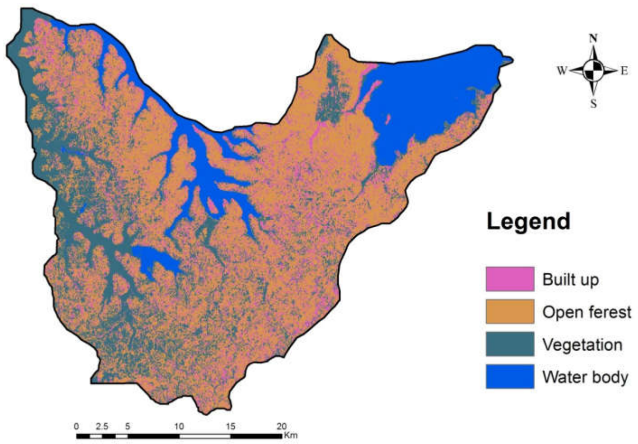

Fig. 6 Land use/land cover of Kirundo district

Table 4. Areal Distribution of LU/LC

Land use/cover	Area, km^2	Area,%
Built up	0.7023	0.22%
Vegetation	96.9639	31%
Open forest	83.4359	27%
Water body	131.8392	42%

Slope

There's one more important factor in groundwater movement, and that's gravity. Gravity doesn't just pull objects down to the surface of Earth; it also pulls some things down through the ground. All water flows downhill because gravity causes it to do so, so both surface and groundwater flow from high to low. Slope class of low value i.e, 0-11.9 degrees is assigned with high rank. The DEM was used to produce slope maps.

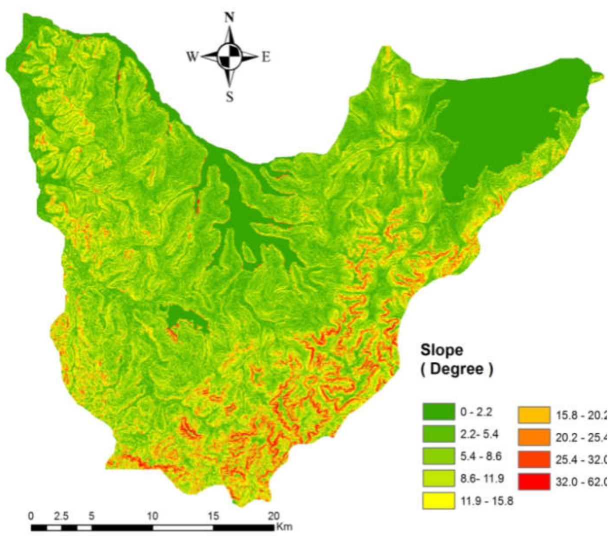

Fig. 7 Slope map of Kirundo district

Geology

Geologically, Bugesera region (the major part of Burundi) belongs to the Kibaran belt, a mezoproterozoicorogenic belt in Central-Eastern Africa, stretching from Katanga (Democratic Republic of Congo) to southwestern Uganda through Burundi, northwest Tanzania and Rwanda (Fernandez-Alonso *et al*., 2006) It is a continuous pelitic-arenaceous belt, more than 1500 km long, but which occupies a restricted fault bounded zone

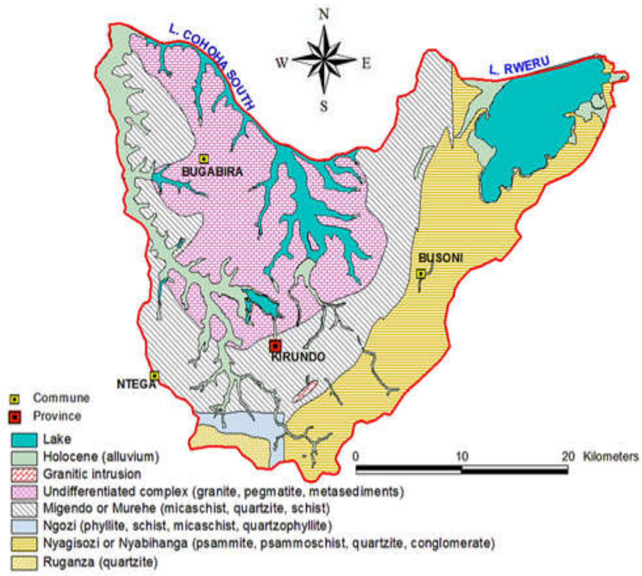

Fig. 8. Geological setting of the study area (source: Cartesgéologiques 1/100 000 publiées: feuillesNgozi (1983), Muyinga (1986) and Busoni (1989)

ranging from 100 to 500 km in width. Locally, the Kibaranbelt is known as Burundi Supergroup. Rocks belonging to the Burundi Supergroup are dominated by pelitic rocks with quartzitic intercalations, which are mature and well sorted in lower levels, but progressively more immature and poorly sorted in upper levels. The Supergroup of Burundi is intruded by abundant peraluminous two micas granites and along a 350 km narrow zone by mafic and ultramafic intrusions including peridotites, norites and anorthosites (Buchwaldt *et al*., 2007).

Soil

Clay and sand are both very porous materials for this reason. On the other hand, sediment like limestone is less porous because the particles fit together like puzzle pieces, closing up those pores. Porosity tells us how much water the soil can take in, but not how fast it does so. We call the rate of water infiltration into the ground permeability. To better understand this, think of a sponge and a rock. A sponge is very permeable because it absorbs water very quickly. A rock on the other hand, is not very permeable because it really doesn't absorb water very well at all.Soil is the same way - some sediment easily absorbs water, while others do not. Sand, on the other hand, is both porous and permeable. It can hold a lot of water and is happy to take it in. Limestone is a tricky one though, because it is very permeable, but not very porous. So it will absorb water very well, but its capacity is not as large as something like clay or sand, until it starts absorbing water! Water dissolves limestone easily, so as it is absorbed it creates new holes inside, making it more porous as time goes on. In fact, most of the world's aquifers are made of limestone for this very reason. (Source:http://www.geologyin.com/ 2015/03/ factors-that-influence-groundwater.html).

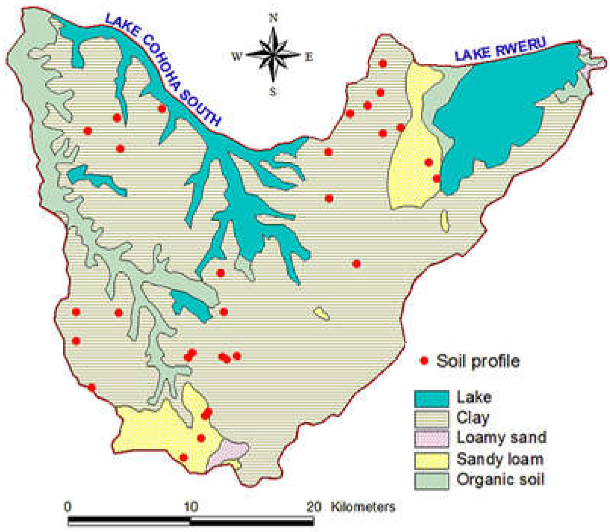

Fig. 9. Soil map of the study area (source: Soil map of Burundi at 1/250000 by Sottiaux *et al.*, 1988)

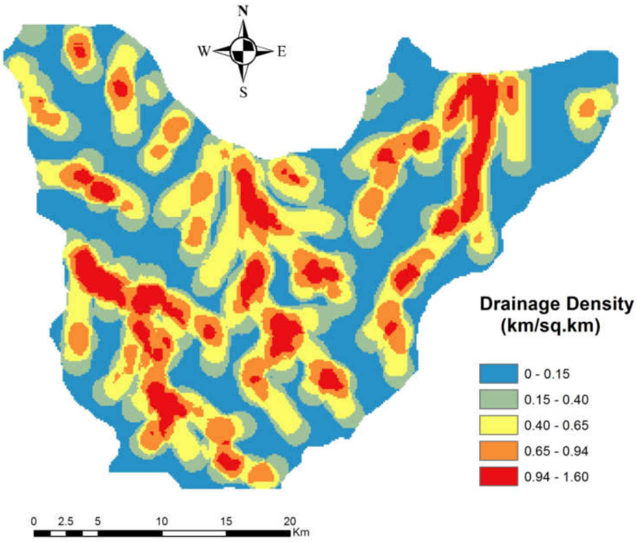

Fig. 10. Drainage density of Kirundo district

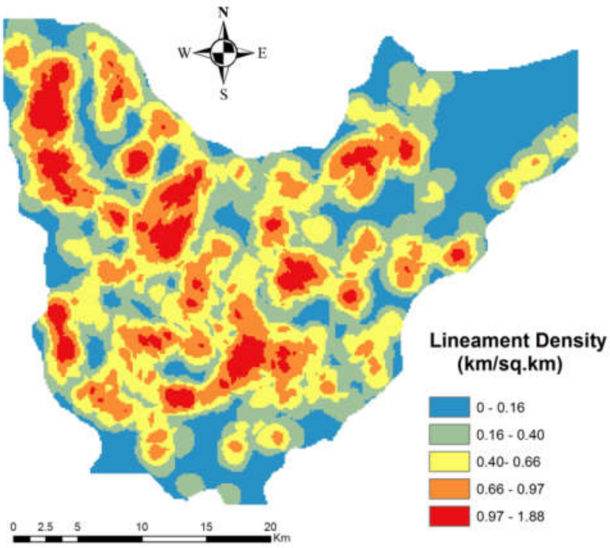

Fig. 11. Lineament density of Kirundo district

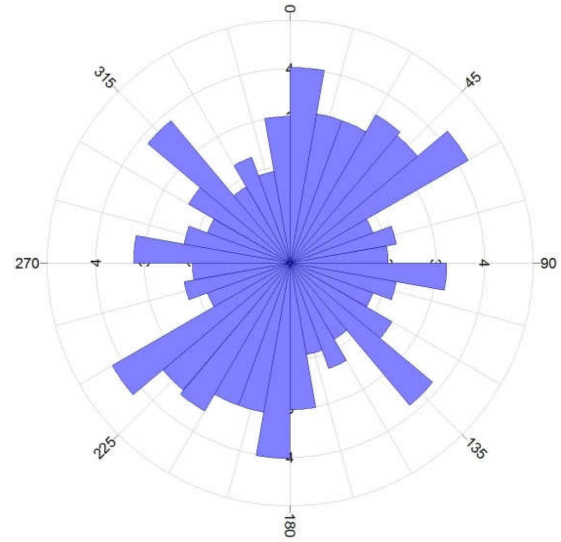

Fig. 12. Rose diagram of Kirundo district

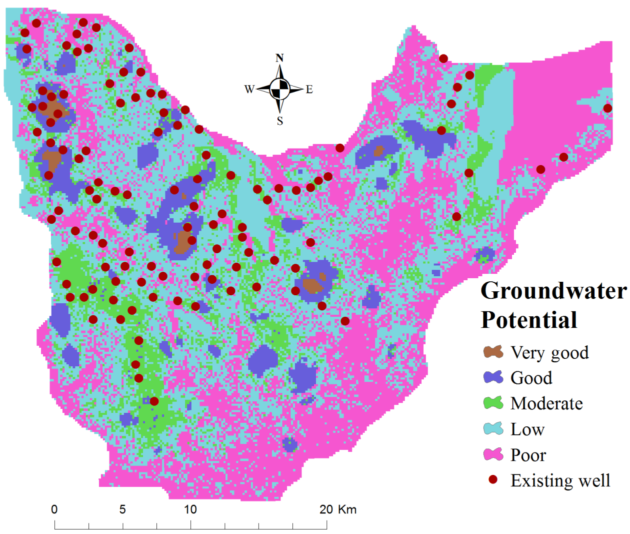

Fig. 13. Groundwater prospect map of Kirundo district

Clay represents 80% organicsoil: 11%, undifferentiated complexe (granite, pegmatite, and metasediment): 28.3% Holocene (alluvium): 12.2% Granitic intrusion: 0.1% Data on ground water indicates relationship with porosity and permeability of soil and rock.

Drainage density and lineament density

Drainage density, Dd and lineament density**,** a fundamental concept in hydrologic analysis, is defined as the length of drainage per unit area. The term was first introduced by Horton (1932) and is determined by dividing the total length of streams within a drainage basin by the drainage area. A high drainage density reflects a highly dissected drainage basin with a relatively rapid hydrologic response to rainfall events, while a low drainage density means a poorly drained basin with a slow hydrologic response (Melton, 1957). The potentiality for groundwater is influenced by the presence of lineaments density and drainage density. A less drainage density is assigned high rate and areas having high density are not suitable for groundwater. The drainage density is reclassified into five categories, viz 0-0.15, very low; 0.15-0.4, low; 0.4-0.65, medium; 0.65-0.94, high and 0.94-1.6 very high.

Table 5. Geology-Lithologic types and extent

Lithology	Area, km^2	Area, %
• Granitic intrusion	1.25	0.1%
• Holocene (alluvium)	108.35	12.2%
• Migendo or Muehe (micaschit,quarzophyllite)	274.55	30.9%
• Ngozi (phyllite, schist, micaschist, quartzophllite)	14.66	1.7%
• Nyagisozi or Nyabihanga	225.14	25.3%
• Ruganza (quartzite)	13.14	1.5%
• Undifferentiated complex (Granite, Pegmatite &Metasediment)	251.42	28.3%

Areas of high lineament density go with good aquifers (Haridas *et al*. 1994, 1998). The data on ground water configuration with reference to the lineament pattern and drainage density indicate a good relationship with the density of lineament and drainage density. The rose diagram shows the dominant direction of lineaments or breaks in rocks of the study area.

Table 6. Soil class and extent

Class	Area, km2	Area, %
Clay	695.45	80.0%
Loamysand	6.86	0.8%
Sandy loam	71.31	8.2%
Organicsoil	95.89	11.0%

Table 7. GW Potential Zones

Zone	GW potential	Area, km^2	Area ,%
1	Very good	7.8209	1%
2	Good	80.4591	8%
3	Moderate	107.1743	11%
4	Low	421.5833	43%
5	Poor	360.0761	37%

Demarcation of Groundwater prospect zones

All thematic maps were integrated into a raster based GIS. The modeling involves delineation of groundwater zones based on six thematic maps: geology, lineament density, drainage density, land use/land cover, soil and slope maps The delineation of groundwater potential zones was made by grouping the raster composite layer, into different potential zones; Very Good, Good, Moderate, Low, and Poor Fig.13. The values assigned to different classes for all thematic layers are given in Table 7.

Validation

Groundwater investigations are not credible without field verification. Confidence estimates can be derived from a combination of suitable field observations together with supporting 'evidence' from other data sources (e.g. Sander *et al*. 1996 and 1997, Mabee *et al*. 1994).

The validity of the model developed was tested against the borehole data, which reflects the actual groundwater potential. Groundwater prospect zones were correlated with existing well sites data and Groundwater potential zones demarcated through the model are in agreement with bore well data. Integration of the two technologies has proven to be an efficient tool in groundwater studies (Krishnamurthy et. al 1996, Sander 1996, Kamaraju et. al 1996, Saraf andChoudhury 1998).

Conclusion

In this study ASTER-GDEM and Landsat data along with other data sets have been utilized to extract information on the hydrogeomorphic features of a hard rock terrain in the Kirundo District, Burundi. Data sources of this study are chiefly IRS-LISS-II, supported by DEM, drainage net work, lineaments, soils, climate etc. and the analysis is in ArcGIS 10.2. The specific intent of the present study is isolation/identification of suitable sites of GW potential, which is dependent on occurrence and distribution of suitable aquifer sediments and rocks as well as suitably placed recharge zones. Criteria for GIS analysis have been defined on the basis of appropriate weights assigned to different themes represented as specific map layers and according to their relative contributions. Such integration helps in developing a suitable groundwater discovery and management plan for a hard rock terrain.In the present project, various groundwater potential zones in Kirundo district have been delineated using remote sensing and GIS techniques. Map layers of Geology, slope, land-use, lineament, drainage and soil, were transformed to raster data using feature to raster converter tool in ArcGIS. The raster maps of these factors are assigned an appropriate rank and weight computed from multi influencing factor (MIF) technique. The groundwater potential zones thus obtained were divided into four categories, very good, moderately good and poor zones. The result depicts the groundwater potential zones in the study area that are found to be helpful in better planning and management of groundwater resources.The study suggests reservoir induced artificial groundwater recharge downstream of surface water reservoirs. The results demonstrate that the integration of remote sensing, GIS combine with traditional fieldwork and models provide a powerful tool in the assessment and management of water resources and development of groundwater exploration plans.

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