INTEGRATED REMOTE SENSING AND GIS TECHNIQUES FOR GROUNDWATER EXPLORATION IN SEMI-ARID REGION: A Case of Karamoja Region – Uganda

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Abstract

Groundwater is a precious resource that covers wide geographical extent. Proper evaluation is required in order to ensure prudent use of groundwater resources. The current groundwater assessment in Karamoja region, as in many parts of the world, uses Apparent Resistivity and Vertical Electrical Sounding, which has limited coverage to some localized usually predetermined areas. Comprehensive groundwater development program needs a wide area coverage and large volume of multidisciplinary data.

In the present study, an integrated remote sensing and GIS based methodology is developed and tested for the evaluation of groundwater resources of Karamoja Sub Region, Northeastern Uganda. The components of the study are delineation of the groundwater potential zones in the area and evaluation of the relationship between delineated groundwater potential zones and aquifer characteristics.

The groundwater potential zones are determined by the relevant layers, which include hydro-geomorphology, lineament density, slope, drainage density, overburden thickness and aquifer depth, rainfall, geology, land use, and soil were integrated in Arc/Info grid environment.

Weighted index overlay method developed by Multi Criteria Analysis (Analytical Hierarchy Process) was used to assign weights to the different map layers. All the information layers were been integrated through GIS analysis, employing the use of Natural Break (Jenks) method for classification. Alexandru groundwater potential zoning using the Transmissivity values was used for the final classification of the potential zones and correlation with ground-truth data. Over 70% correlation was achieved showing the significance of GIS in groundwater mapping.

Key words: *Groundwater exploration, interpretation Methods Remote sensing & GIS.*

Introduction

Dependency of groundwater in Uganda is more in the semi-arid region of Karamoja where prolonged droughts leave most of surface waters dry. Karamoja Data Centre (KDC) estimated that about 80% of the urban population and 60% of the rural population in the region depends on groundwater.

Karamoja Region of North eastern Uganda is chronically drought-prone and faces acute water scarcity for both irrigation and drinking purposes. While the surface water resources in the area are non-existent or inadequate to meet the local need, the groundwater resources are not explored sufficiently *(Karamoja Data Centre, 2003).*

The search for promising groundwater areas involving satellite remote sensing, GIS, traditional hydrological data and field investigations integrations is becoming a common method for groundwater assessment.

Remote sensing and GIS are playing a rapidly increasing role in the field of hydrology and water resources development with "numerous successes". The use of GIS in hydrogeology is only at its beginning, but there have been successful applications that started to develop

(Das D., 1997). These claims and many more are spreading far and wide and thus, will be tested in the present study. The study focused on mapping potential groundwater availability zones for sustainable development and management of the resource in the North Eastern Uganda - Karamoja region. The question is therefore; to what significant level does Integrated Remote Sensing and GIS methodology relates to the ground truth data

The geology of the region is complex and predominantly underlain by complex basement of banded acid gneisses and undifferentiated banded acid biotite magmatic gneisses. These rocks are highly metamorphosed from north-south trending forming low-lying wide ridges. Metamorphic rocks are known hydrogeologically to have poor potential for groundwater. This is because their mechanism of formation involves high pressure and temperature, making them to flow as the mineralization changes. This makes them fail to rapture (cause fractures essential for water holding) hence poor groundwater potential. The trend of the ridges indicates the axial trend of folding, which control most of the drainage system, and tends to be straight because it is controlled by the jointing.

Most groundwater in the region occurs in the weathered or fractured rocks found generally deep, ranging from 41m to 125m with average depth of 72m. However, in areas bordering the western ends of the region, especially the southern part, has high potential of shallow aquifers due to occurrence of weathered regolith overlying the competent bedrock. The regolith thickness is highly variable depending on the topography of a particular area but ranges from 4m to 46m, consists mainly of sandy-clay, and highly weathered granite.

In this study an integrated remote sensing and GIS based methodology for the evaluation of groundwater potential zoning is developed and tested for Karamoja Sub Region, Northeastern Uganda as a strategy of the exploration of groundwater.

Description of the Study Area

The region of Karamoja extends over an area of 27,900 square kilometres. Karamoja sub region lies in North-eastern part of Uganda in the coordinates $4^{\circ}16'15''$ north, $34^{\circ}58'05''$ east, $1^{\circ}31'09''$ South and $33^{\circ}31'47''$ west. It is bordered in the north by Sudan, in the east by Kenya, in the west by the Districts of Kitgum, Pader, Katakwi and Kumi, form the south by Sironko and Budaka Districts.

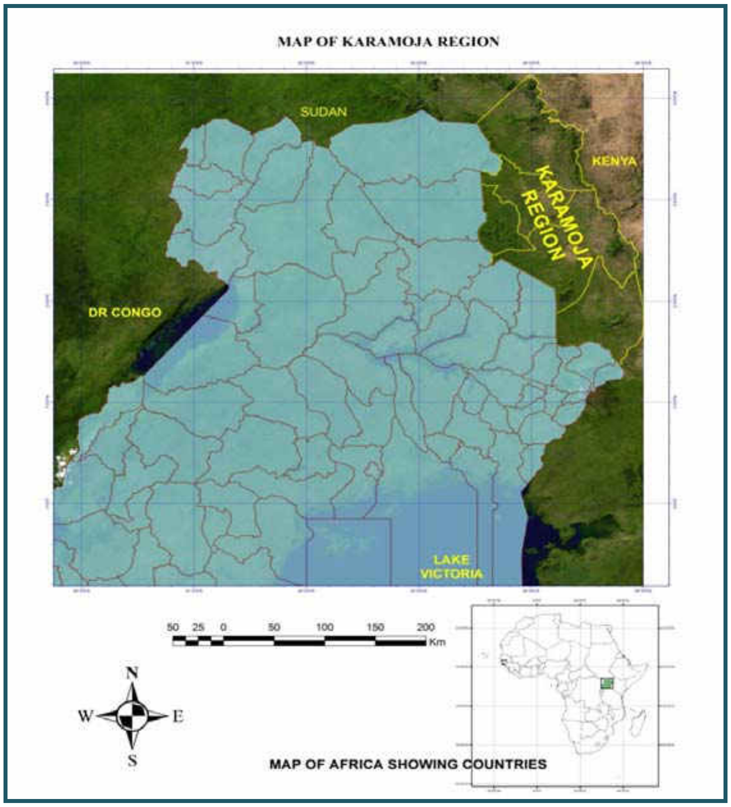

Figure 0.1 Map of Uganda showing Karamoja Region

The area is generally flat with intermittent outcrops of volcanic rocks and hills with semi-desert type of vegetation covered with seasonal grasses, thorned plants, and occasional small trees. From topographical maps, the average elevation of the plain of Karamoja lies at around 1400 meters above sea level. The large mountains, Mt. Kadam, Mt. Napak, and Mt. Moroto lying at the periphery of Karamoja have peaks reaching around 3000 meters and higher.

The rainfall regime is short and unreliable; the hydrological map indicates that rainfall ranges from 699 – 1251 mm annually from one part of the region to another. The temperature is well over 30^0C for most part of the year.

METHODOLOGY

The methodology for this research revolves around the techniques of integration of thematic layers and modelling using GIS and Remote sensing to delineate groundwater potential zones. The details of each step are explained in the following subsections

Weighting using Multi Criteria Analysis Method

Individual class weights and map scores was assessed based on Saaty's Analytic Hierarchy Process. Analytic Hierarchy Process (AHP) is one of Multi Criteria decision-making method that was originally developed by Saaty, (1980). In this method, a pair wise comparison matrix was prepared for each map using Saaty's nine-point importance scale and this matrix was solved using Eigen Vector method.

Layers Classification

The classification method adopted for study was ArcGIS Natural Breaks (Jenks) classifier method. This was chosen because classes are based on natural groupings inherent to the data. The objective of the Jenks-Caspall algorithm is to place similar data values in the same class by minimizing the sum of the absolute deviations about class means. In other words, grouping is done by picking the class breaks that best group similar values and maximizes on the differences between classes i.e. classes are set where there are relatively big jumps of the data values.

Generation of Thematic Layers

The different themes of maps were generated and the classes of the themes were coded for easy reference.

Slope

The slope layer was derived from the 90x90m DEM which was downloaded from *www.seamless.usgs.gov* and processed using ArcGIS/Info 9.2 software. The result of the slope aspect scores are as shown in Table 0.1.

Table 0.1: Slope Aspect Scores

Slope	Description	Code	Score
0-7%	Almost Flat	FL	43
8-20%	Undulating to Flat	UD	29
21-55%	Hilly Disserted	HD	15
56-140%	Steep Dissected	SD	08
>140%	Very Steep Mountainous	VS	05
TOTAL			100

Saaty's Consistency Ratio, CR = 0.0153

Drainage Density

A surface drainage map has been prepared from 90x90m DEM. The drainage layer was processed using ArcHydro 2.0 extension, and the drainage of order five was processed in ArcGIS and the layer labelled. The drainage density was calculated using Kernel's method. The drainage density in km/sq.km was categorized in five classes. The scores were calculated and tabled as in the Table 0.2 below,

Table 0.2: Drainage Density Scores

Drainage density Km/Km^2	Theme Category	CODE	Score
< 0.6	Very Low	VL	41
0.6 – 1.5	Low	LW	27
1.5 – 3.0	Moderate	MD	16
3.0 – 4.5	High	HG	10
4.5 <	Very High	VH	07
TOTAL			100

Saaty's Consistency Ratio, CR = 0.0228

Geomorphology

A geomorphologic map of scale 1:250,000 were, on the basis of specific relief and characteristic nature, the geomorphologic features present in study area were classified into (i) Swamp (ii) Floodplains (iii) Lower alluvial fan (iv) Upper alluvial fans (v) Lower fan terrace (vi) upper fan terrace (vii) Denudated/Dissected slope (viii) Hills. These were assigned scores as in Table 0.3 below

Table 0.3: Geomorphologic Scores

Geomorphology type	CODE	scores
Permanent Swamp	PSW	31
Floodplains	FLP	23
Lower alluvial fan	LAF	16
Upper alluvial fans	UAF	11
Lower fan terrace	LFT	8
Upper fan terrace	UFT	5
Denudated/Dissected slope	DDS	4
Hills.	HLL	3
TOTAL		100

Saaty's Consistency Ratio, CR =0.0340

Soil

The soil layer was classified to the normal soil nomenclature based on the parent Rock from which the soils came from, FAO soil description and Ugandan soil series. Assignment of the scores was related to basic infiltration rate for commonly occurring soils adopted from a study made by Brouwer (1990). It has been interpolated to suit the analysis criteria and the scored calculated as in the Table 0.4.

Table 0.3: Soil Scores

Soil Type	Basic Infiltration Rate (mm/hr)	CODE	Score
Sand	>30	SD	36
Sandy Loam	20-30	SM	25
Loam	15-20	LM	16
Sandy clay Loam	10-15	SCL	11
Clay Loam	5-10	CM	6
Sandy Clay	2-5	SC	4
Clay	<2	CL	3
TOTAL			100

Saaty's Consistency Ratio, CR = 0.0238

Land-use

The land cover was obtained by processing the landsat image. Landuse Classification using remotely sensed imagery requires suitable imagery. Optimum Index Factor (OIF), which is a statistic value, was used to select the optimum combination of three bands of the satellite image, which was BRG 147 combination and was used for this study. The classification and the fusion were done and the confusion matrix gave average accuracy of 69.8%, average Reliability of 88.0% thus the overall accuracy of 78.9%

The classed land cover was then analyzed using AHP and the weights were assigned as Table 0.5; below.

Table 0.4: Land Layer Scores

Land-use	CODE	Score
Subsistence Farmland	SF	31
Grassland	GL	24
Bush land	BL	20
Woodland	WL	12
Bare land	BR	8
Built-up Area	BA	5
TOTAL		100

Saaty's Consistency Ratio, CR=0.0077

Lineaments

Lineament density analysis for ground water exploration was started by digitizing lineaments from geological map of the study area and processed in ArcGIS. The density in (km/km^2) was calculated as in Table 0.6 below;

Table 0.5: Table Classification of lineament

Classes density in (Km/Km^2)	Description	CODE	Scores
< 0.5	Very Low	VL	4
0.5 – 1.8	Low	LW	7
1.8 – 3.4	Medium	MD	13
3.4 – 5.4	High	HG	27
5.4 <	Very High	VH	49
TOTAL			100

Saaty's Consistency Ratio, CR=0.0190

Geology

The geology map obtained was already classified and no modification was made. The rocks were classified based on their water bearing potential and AHP applied, the results as shown in the Table 0.7 below

Table 0.6: Geology Layer

Rock Category	CODE	scores
Highly quartzied rocks	HQ	30
Volcanic Rocks	VR	22
Acid Gneisses	AG	15
Sediment Alluvium	SA	11
Carbonatite	CB	8
Cataclasites	CT	5
Banded Gneisses	BG	4
Granulites Facies rocks	GF	3
Undifferentiated gneisses	UG	2
TOTAL		100

Saaty's Consistency Ratio, CR=0.0292

Rainfall

Orographic information was collected from rainfall data sets for 18 stations around the region for a period of eighteen years. The range of the mean annual rainfall of the region obtained 699mm to 1251mm/year. This was interpolated and classified into six classes. AHP applied and the results displayed in Table 0.8.

Table 0.7: Rainfall Layer Scores

Range of Rainfall (mm)	Description	CODE	Score
Less than 750	Very Low	VL	4
750-890	Low	LW	7
890-975	Moderate	MD	12
975-1056	Moderately High	MH	20
1056-1139	High	HG	24
Greater than 1139	Very high	VH	33
TOTAL			100

Saaty's Consistency ratio, CR=0.0027

Integration of Thematic Layers and Modelling through GIS

After understanding their behaviour with respect to groundwater control, the different classes were assigned suitable weights, according to their importance with respect to other classes in the overlay process. AHP applied and the results as in Table 0.9 below.

Table 0.8: Inter-Map Weighting Scores

Map Category	Score	CODE
Geomorphology	25	Mge
Geology	22	Mgl
Rainfall	20	Mrf
Soil	13	Msl
Slope	07	Msp
Lineament	06	Mln
Landover	04	Mlu
Drainage Density	03	Mdr
TOTAL	100	

Saaty's Consistency ratio, CR=0.0340

Map Production – Groundwater Potential Zone (GWPZ)

All individual class weights were multiplied with map scores and kept in linear summation equation to result in a unified weighted map. This was done using ArcGIS model builder Fig 0.2 and the result classified into five potential zones from High Potential zone to negligible potential zones according to Alexandru, (1972). The model was executed and the results were as displayed in the map Figure 0.3

$$GWPZ = (Mgp \times Gp) + (Mge \times Ge) + (Mso \times So) + (Mrf \times Rf) + (Mlu \times Lu) + (Mdd \times Dd) + (Msl \times Sl) + (MLd \times Ld) \quad . (0.1)$$

Where:

Gp – geomorphology
Ge – geology Thematic Map
So – Soil Thematic Map
Rf - Mean annual rainfall
Lu – Land use Thematic Map
Dd – Drainage density Thematic Map
Sl – Slope Thematic Map
Ld – Lineament Thematic Map
ArcGIS model builder window

Mgp – geomorphology map coefficient
Mge – geology Map coefficient
Mso – soil Thematic Map coefficient
Mrf – rainfall map coefficient
Mlu – land use map coefficient
Mdd – Drainage map coefficient
Msl – Slope map coefficient
Mld – Lineament map coefficient

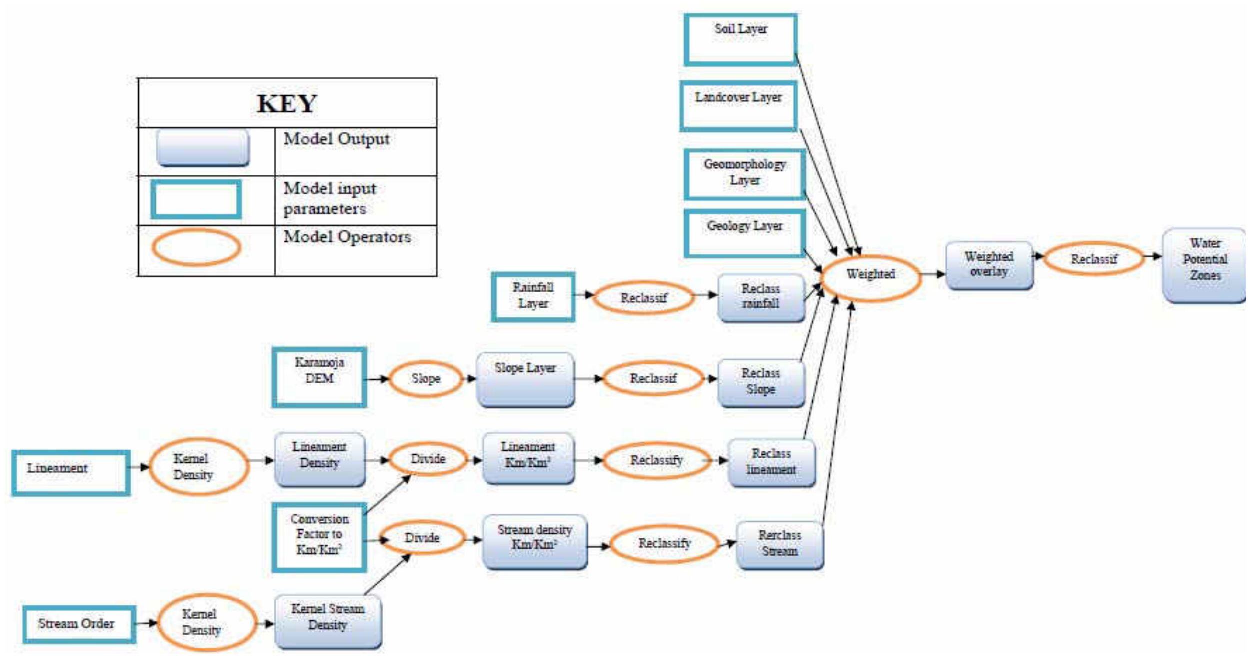

Figure 0.2: ArcGIS Model Builder flow chart

Relationship between potential zones and aquifer characteristics

In evaluating the relationship between potential zones and aquifer characteristics, borehole drilling logs and pumping test data were collected as point data for forty-four sites and aquifer parameters were analyzed. The AquiferTest software was used to analyze the pump test data. Aquifer thickness, screened interval, pumping rate, static water level before pumping, and dynamic water level are the inputs for the software. The aquifer parameter used in this study was the Transmissivity, T in m^2/day.

RESULTS AND DISCUSSIONS

Integration of thematic layers and modelling through GIS yielded the groundwater potential mapping, which was classified as High potential, moderate potential, low potential, very low potential, and negligible potential according to Alexandru (1972), as having Transmissivity of >500, 50-500, 5-50, 0.5-5, and <0.5 m^2/day respectively.

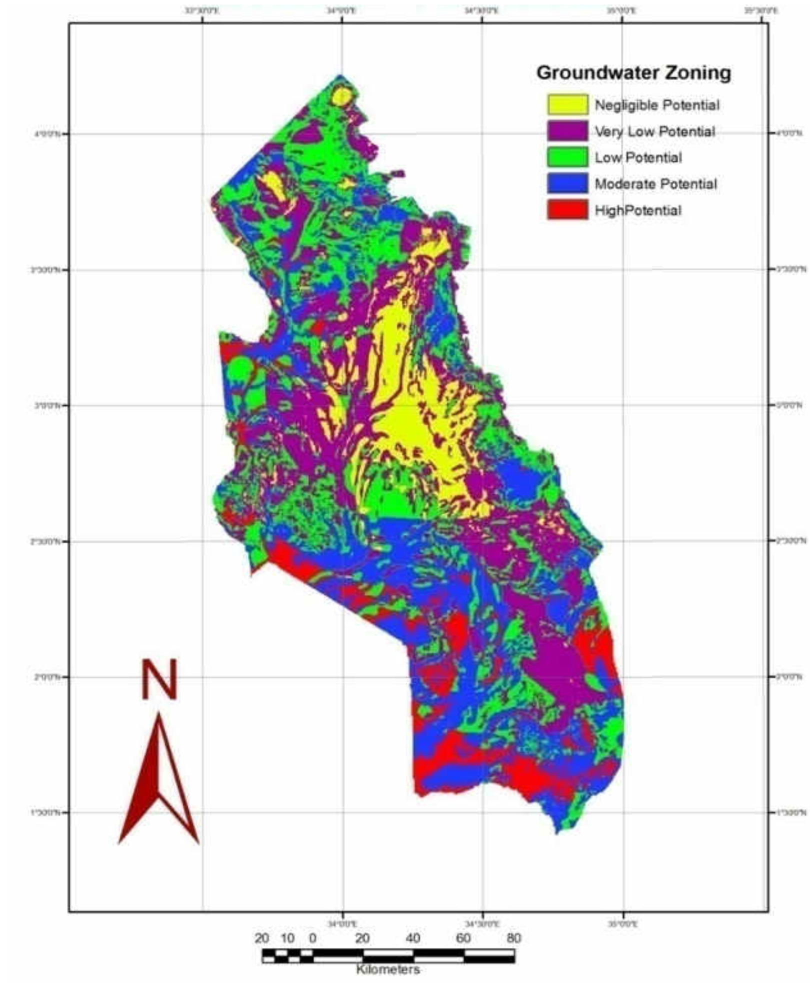

Figure 0.3: **Groundwater Potential Zones**

GROUNDWATER POTENTIAL ZONING

The GIS classification above was analyzed by proportion of different layers available in these zones and the results are summarized in Table 0.1. It has been observed that groundwater potential zone has been influenced as described below.

High Potential Zone

This is characterized by very high rainfall and subsistence farming land use. Soil layer is clay type and the geomorphology is of alluvial fans in the lower deposits where the slope is described as flat. The lineament and drainage densities are moderate and the geology of the area is sediment alluvial. It should be noted here that this descriptions tends to concur with numerous literature especially *(Mukherjeel, A.D.,1996)* who stated “the geomorphic features like alluvial fans, buried pediments, old stream channel and deep seated interconnected fractures are indicators of subsurface water accumulation”.

Table 1.0: Biophysical Characteristics of Groundwater Potential Zones

Classification of Groundwater potential - Alezandru (1972) using Transmissivity Values	High Potential	Moderate Potential		Low Potential			Very Low Potential			Negligible Potential
	500< m^2/day	50-500 m^2/day		5-50 m^2/day			0.5-5 m^2/day			<0.5m^2/day
Rainfall (mm)	VH	VH	VH	VH	MD	MD	VL	MH	VL	VL
Landuse	SF	SF	BL	SF,GL	SF	GL	GL	SF	WL	GL
Soil Type	CL	SC	CL	CM	SC	SC	CM	CM	SM	CM
Geomorphology	LAF	LFT	LAF	LAF	LAF	LAF	UAF	LAF	HLL	UFT
Lineament (km/km2)	MD	VL	LW	MD	VL	LW	MD	VL	VL	VL
Slope (%)	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL
Drainage density (Km/Km^2)	MD	LW	VL	MD	HG	MD	MD	LW	HG	VH
Geology	SA	GF	BG	GF,AG	SA,AG	BG	BG	SA,GF	BG	AG

Note: the coding used in the table above is as presented in the weighting tables in the thematic layer tables

Moderate Potential

This region is characterized by very high rainfall and subsistence farming with bush land cover. The region fall in the alluvial fan and lower fan terraces, these regions are known for their high infiltration rates. They are in the flat terrain with very low lineament and drainage densities.

Low Potential

The low potential is found in the moderate rainfall region with greater proportion of land use being grassland with subsistence farming blended in several places. The soil is predominantly sandy clay with alluvial fan geomorphology in a flat terrain. The drainage density is moderate and the geology of the area is predominantly Acid gneiss. Lineament density ranges between moderate to high.

Very Low Potential

The rainfall in this region fall in the very low category, the land use is predominantly woodland with some grassland here and there. The soil type is clay loam with alluvial fan in the upper terrace and hilly geomorphology. The topography can be described as flat with drainage densities ranging from high to moderately high.

The geology of the area is banded gneiss and granulites facies rocks. These rocks are highly metamorphosed and metamorphosed rocks are known hydrogeological to have very poor potential for groundwater. This explains the poor groundwater potential of the region as whole.

Negligible Potential Zones

The rainfall in these areas is in the class of very low. The areas are characterized with high drainage density and acid gneiss geological formations, which are known to have high water bearing potential. This thus, tries to explain the high effect of drainage density on groundwater occurrences.

Aquifer characteristics and delineated groundwater zones evaluation

The evaluation of the relationship between the delineated groundwater potential zones and aquifer characteristics can be seen as a validation of the GIS groundwater potential exploration method.

Groundwater Classification by Borehole Data

This classification was derived from categorizing the borehole Transmissivity in to the five potential zones according to Alexandru and the proportion of each class expressed in percentage Table 1.1. According to this classification, as seen below, the groundwater potential of the Region can be said to be low to very low potential.

Table 1.1: Groundwater Classification by Borehole Data

Transmissivity, m^2/day	Number of boreholes	Percentage
Negligible potential, < 0.5	3	6.8%
Very low potential, 0.5-5	24	54.5%
Low potential, 5-50	16	36.4%
Moderate Potential, 50-500	1	2.3%
High potential >500	0	0%
TOTAL	44	100%

This confirms what was seen in the literature that the region has low groundwater potential that was attributed to the geological formations of the region.

Groundwater classification by comparing borehole data with GIS data

The proportion of boreholes correctly classified were analyzed and summarized in Table below, for example, in Low potential zones according to GIS, 63% of the boreholes falling in that zones were actually low potential boreholes, 25% very low potential and 12% negligible potential. That means the last two were actually wrongly classified by GIS. This also applies for the rest of the zones. The overall efficiency of the model is 70.5%

Table 1.2: Characteristic groundwater potential zones

	High Potential	Moderate Potential		Low Potential			Very Low Potential			Negligible Potential
Parameter - Alexandru (1972)	**500 < m^2/day**	**50-500 m^2/day**		**5-50 m^2/day**			**0.5-5 m^2/day**			**< 0.5 m^2/day**
Groundwater Potential Zones GIS	**5**	**4**		**3**			**2**			**1**
Groundwater Potential Borehole Zoning	2	4	3	3	2	1	3	2	1	2
Propotion of allocation	0%	50%	50%	63%	25%	12%	17%	79%	4%	0%

CONCLUSION

The findings noted and discussed previously were used in principle, to assess the performance of integrated Remote Sensing and GIS application in groundwater exploration.

Classification of the final zones was related to Alexandru (1972) classification, which categorises groundwater potential according to the aquifer characteristics, thus the potential zones.

Analysis of the borehole data indicated that the region has low groundwater potential especially in the central region. The borehole data analysed for aquifer Transmissivity was used to evaluate the groundwater potential zoning using GIS. This indicated 70.5% correlation showing the effectiveness of GIS application in the field of groundwater exploration.

In applying GIS analysis in groundwater zoning, the weighting became crucial, as assigning wrong weights would provide wrong output. In this sense, multi criteria analysis with Analytical Hierarchy Process (AHP) suggested by Saaty (1988) proved very effective as decisions were checked for consistence before being applied. Besides, the weights normalization provided common platform of comparison and analysis of the GIS data. The use of Natural Break (Jenks) in the classification proved to be ideal, as classes are based on natural groupings inherent to the data.
In conclusion, the present study demonstrated that integrated Remote sensing and GIS based methodology has been developed and tested for evaluation and exploration of groundwater resources in semi arid and mountainous terrain.

It should be mentioned here that the amount of time and cost invested in this research compared to the size of the region (27,900km^2) also points out how effective and efficient is the GIS method. The methodology developed may be applied to similar terrain conditions, with some local considerations and modifications. Further incorporation of geophysical data can enrich the interpretation water management

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