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Integrated Geospatial Technique for Potential Groundwater Zone (PGZ) Identification

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Abstract—*A groundwater development program requires a large volume of data from various sources. An integrated remote sensing, MCDA and GIS study can provide the appropriate platform for convergent analysis of large volumes of multidisciplinary data and decision making for groundwater studies. Geospatial technologies have become an important tool in water studies due to their capability in developing spatio-temporal information and effectiveness in spatial data analysis and prediction. The sustainable development and management of groundwater resource needs quantitative assessment, based on scientific principle and recent techniques.*

The analysis of PGZs can use the parameters such as drainage density, elevation, geology, geomorphology, land use and land cover, lineaments-dykes, rainfall, slope and soil pattern etc. and can assign weightage by using Analytical Hierarchical Process etc.; then weighted overlay analysis in ArcGIS will accurately find the zone for groundwater distribution.

The overall assessment as presented in this study highlight that mapping of groundwater potential using integrated RS/GIS/MCDA/AHP/WLC approach could be an effective means of characterization of groundwater potential zones as well as serving as a useful tool and guide in groundwater exploration and development could serve as a base line study for future water management projects in the area. This Integrated geospatial techniques could serve as a base line study for future water management projects in order to ensure sustainable ground water utilization.

Keyword*: Ground water, GIS, Remote sensing, groundwater modeling.*

1. INTRODUCTION

Water, one of the *panchaboothas* is vital for sustaining lives and one of the most important natural resource for the sustenance of life, the availability of water supply in terms of quantity and quality is essential to human existence. Due to fast urbanization and phenomenal growth in human population, the demand for water supply increases rapidly (Choudhary *et al.*, 1996). Groundwater accounts for about 30% of earth's freshwater, is one of the most important natural resources and the largest accessible source of fresh water (Sharma and Kujur, 2012; Neelakantan and Yuvaraj, 2012). The demand for this natural resource is increasing due to rapid industrialization and population growth, leading to its scarcity in some regions and it plays an important role in global climate change and satisfying human needs. During the last couple of decades, there has been a rapid development in various fields, particularly agriculture, industry and energy. This has led to growing demand for irrigation, domestic and industrial need (Singh *et al.*, 2011). Groundwater is said to be a more dynamic renewable natural resource and plays important role in drinking, agricultural and industrial needs as a timely assured source compared with surface water; however, availability with good quality and quantity inappropriate time and space is also important (Rao 2006; Chowdhury *et al.*, 2009). Therefore, locating groundwater potential zones, monitoring and conserving this vital resources has become highly crucial (Rokade *et al.*, 2004; Kumar and Kumar, 2011). Earlier water was abundant and was used judiciously. But as time progressed the increased population and its associated agricultural and industrial expansion impose demand on limited resources (Siebert *et al.*, 2010). Rapid population growth combined with increasing demand of water from multiple sectors such as municipal, agricultural, industries, and tourism becomes a major issue in the country. Due to scarcity and pollution of surface water resource, people moved on to exploit the ground water resource (Bharti and Katyal, 2011). Groundwater prospect in an area is controlled by many factors such as geology, geomorphology, drainage, slope, depth of weathering, presence of fractures, surface water bodies, canals and irrigated fields amongst others (Jain, 1998; Nag and Ghosh, 2012). The increased usage leads to overexploitation of various sources of water and thereby creates a condition of water scarcity.

Geospatial technologies have become an important tool in water studies due to their capability in developing spatio-temporal information and effectiveness in spatial data analysis and prediction (Ghayoumian *et al.*, 2007; Nagarajan and Singh, 2009; Subagunasekar and Sashikkumar, 2012). Based on groundwater quality and geospatial analysis, measures were suggested to protect groundwater resources. Variation in groundwater chemistry with time provides information on the impact of land use land cover changes on the water quality (Bridget and Reedy, 2005). Several conventional methods, such as geological, hydrogeological, geophysical, and photogeological techniques were employed to delineate groundwater potential zones. However, recently, with the advent of powerful and high-speed computers, digital technique is used to integrate various conventional methods with satellite image/remote sensing (RS) techniques and geographical information system (GIS) technology. It is the effective tools for delineating the groundwater potential zones. The traditional methods of ground water exploration are not only tedious but also consume lot of time and money and require skilled manpower (Sander *et al.*, 1996). Remote sensing and GIS tools can be used to detect areas with high potential for groundwater exploration (Wahyuni *et al.*, 2008; Deepika *et al.*, 2013).

Remote sensing and GIS Application of these tools helps to increase the accuracy of results in delineation of groundwater potential zone and also to reduce the bias on any single theme (Redowan *et al.*, 2014; Salari *et al.*, 2014). The AHP has been successfully applied in several studies of water resource management by integrating MCDA (Saaty 1980, 1986, 1992) with RS and GIS techniques. However, in the recent years, with the advent of powerful and high-speed computers, digital technique is used to integrate various conventional methods with satellite image/remote sensing(RS) techniques and GIS technology (Talabi and Tijani 2011).

In the present study, groundwater potential zone is suggested to determine using remote sensing (RS), GIS, Multi-Criteria Decision Analysis (MCDA) techniques and the Analytic Hierarchy Approach (AHP) is used to determine the weights (WLC) of various themes for identifying the groundwater potential zone based on weights assignment and normalization with respect to the relative contribution of the different themes to groundwater occurrence.

2. TECHNIQUES FOR GROUND WATER EXPLORATION

In recent years, numerous studies reported that multi-criteria decision making (MCDM) offers an effective tool for water resource management by adding structure, auditability, transparency, and accuracy to decisions (Adiat *et al.*, 2012; Mallick *et al.*, 2014).

Digital Elevation Model (DEM), ArcGIS and ERDAS Imaging processing software were used to perform the hydrogeomorphological, lineament density and lineament intersection density maps (Fig.1) for different groundwater potential zones with the lineament intersection density map also identified cluster zones in the range (Table.1) of 0-0.05, 0.05-0.16, 0.16-0.29, 0.29-0.43 and 0.43-0.77 km/sq km in Ekiti State, Southwestern Nigeria (Gabriel *et al.*, 2014).

Table 1: Groundwater Prospect of Ekiti State based on Lineament Intersection Density

Lineament Intersections Density Colour Code	Lineament Intersections Density Range (Km/Sq Km)	Groundwater Prospect
Deep Blue	0.43 – 0.77	Very High
Light Blue	0.29 – 0.43	High
Green	0.16 – 0.29	Moderate
Orange	0.05 – 0.16	Low
Brown	0 – 0.05	Very Low

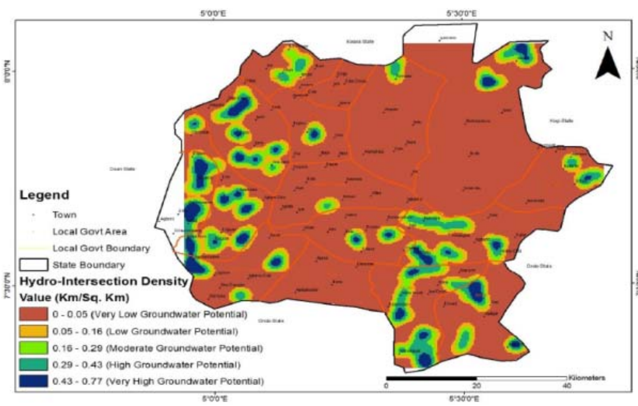

Figure 1: The Lineament Intersection Density, Map of Ekiti State, Southwestern Nigeria. Source: Gabriel *et al., 2014*

Gustafss (1993) used GIS for the analysis of lineament data derived from SPOT imagery for groundwater potential mapping in a semi-arid area in southeastern Botswana. Also, Jain (1998)demonstrated the use of hydrogeomorphological map by using Indian Remote Sensing Satellite Linear Imaging Self-Scanning II geocoded data on 1 : 50 000scale along with the topographic maps to indicate the groundwater potential zones in qualitative terms (i.e., good to very good, moderate to good and poor). Lalbiakmawia (2015) using RS (LISS III) and GIS environment ARCINFO (10.1 version) five thematic layers viz., land use / land cover, slope morphometry, geomorphology, lithology, geological structures like faults and lineaments were generated groundwater potentiality map (Fig.2) with the very good potential zone is 8.17% where the ‘poor’ potential zone is high 37.24 % in the northern part of Mizoram, India.

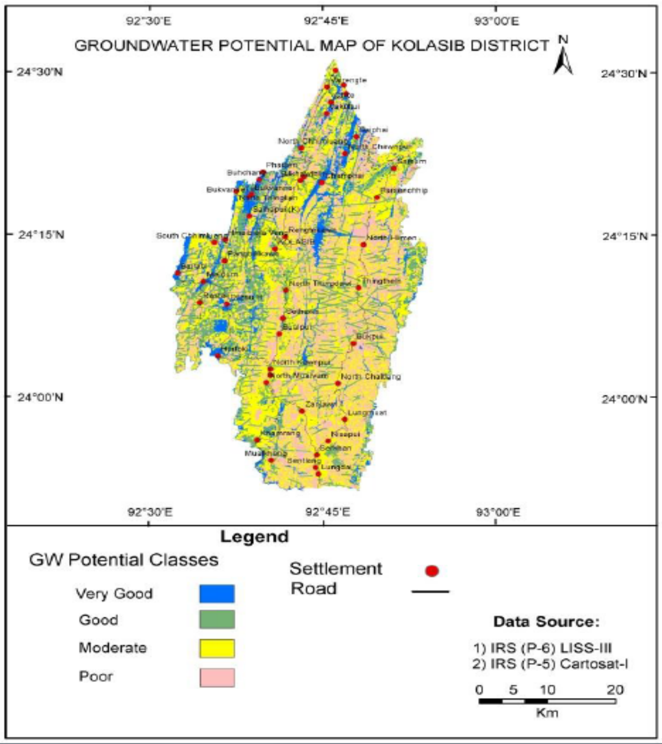

Figure 2: Groundwater potential map of Kolasib district, Mizoram, India, (Lalbiakmawia, , 2015).

GIS plays a key role in maintaining data and analyzing optimal locations. GIS is a tool that reduces time andcost of the site selection and provides a digital data bank for future monitoring program of the selected sites.Multi Criteria Decision Analysis (MCDA) in GIS environmental is used to combine layers of spatial datarepresenting the criteria and to specify how the layers are combined. The Analytical Hierarchy Process (AHP) isa method of MCDA that is implemented within GIS, which defines weights for criteria selected.

Analytic hierarchy process is a structured method used for analyzing and organizing complex decisions using the principle of psychology and mathematics. This information is further synthesized to derive the relative ranking of alternatives. AHP is suitable for taking complex decisions which involve the comparison of parameters that are difficult to quantify (Table 2).

Table 2: Couple Comparing Matrix and Prioritized Factor Rating Value in the Kangsabati Irrigation Command Area (KICA).

Factors	1	2	3	4	5	6	7	8	Rating
1) NDVI	1	1/2	1/3	1/4	1/5	1/6	1/7	1/9	0.024
2) Relief	2	1	1/2	1/3	1/4	1/5	1/6	1/8	0.031
3) Soil	3	2	1	1/2	1/3	1/4	1/5	1/7	0.048
4) Slope	4	3	2	1	1/2	1/3	1/4	1/6	0.069
5) Drainage	5	4	3	2	1	1/2	1/3	1/5	0.103
6) Geology	6	5	4	3	2	1	1/2	1/4	0.146
7) Geomorphology	7	6	5	4	3	2	1	1/3	0.205
8) Land use	9	8	7	6	5	4	3	1	0.378

Source: Consistency Ratio (CR)-0.037 (Mondal 2012).

The analysis of PGZs totally nine parameters have been considered for the study such as, drainage density, elevation, geology, geomorphology, land use and land cover, lineaments-dykes, rainfall, slope and soil pattern and its classes have been assigned using Analytical Hierarchical Process, then weighted overlay analysis in ArcGIS used to find out the result of 95 per cent accuracy in Mysore (Ramu *et al.*, 2014*;* Fig. 3).

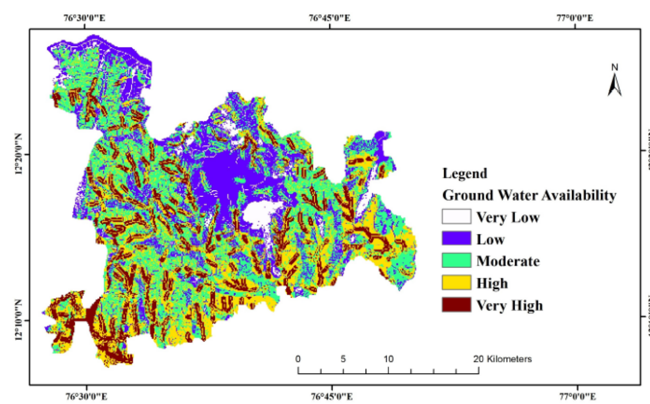

Figure 3: Groundwater Potential zones of Mysore (Ramu, *et al.*, *2014)*

3. WLC TECHNIQUE

The use of the WLC method for the selection of potential sites for water harvesting has been widely used over the last years. Many of the studies use a WLC method in a GIS environment for the selection of potential sites for water harvesting such as (Baban, and Wan-Yusof, 2003) Boolean technique, based on the variables, are either true or false. The use of Boolean method for identifying the optimum sites for water harvesting projects have been addressed in many studies (Madrucci, *et al.*, 2008).

Burrough (1986) defined a GIS‘‘ as a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purpose’’. GIS thus enables a wide range of map analysis operations to be undertaken in support of groundwater potential zonation of an area. Delineating the potential groundwater zones using remote sensing and GIS is an effective tool. In recent years, extensive use of satellite data along with conventional maps and rectified ground truth data, has made it easier to establish the base line information for groundwater potential zones (Harinarayana *et al.,* 2000; Muralidhar *et al.,* 2000; Chowdhury *et al.,* 2010). Rapid and advances in the development of the Geographical Information System (GIS) which provides spatial data integrationand tools for natural resource management have enabled integrating the data in an environment which has been proved to be an efficient and successful tool for groundwater studies (Jaiswal *et al.,* 2003). GIS techniques was employed (Tekena *et al.,* 2016)to delineate the groundwater recharge potential of the northern part of Edo state using remote sensing data and integration of multi influencing factors (MIF) with weighted index overlay analysis (WIOA) using multi-criteria approach of lithology, lineament density, slope, soil cover, drainage density and land use land cover (Fig. 4).

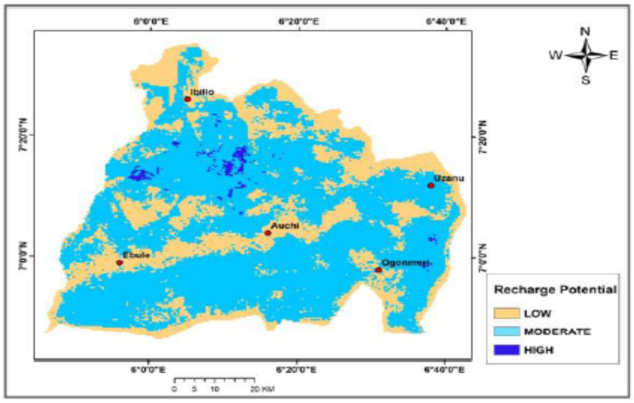

Figure 4: Potential groundwater recharge map of Edo state Nigeria Tekena *et al.*, (2016).

4. INDIAN APPLICATION

Bera and Bandyopadhyay (2015)Integrated use of remote Sensing and GIS can provide the appropriate platform for convergence of multidisciplinary data from various sources for appropriate planning developed and tested for the evaluation of the groundwater resources of Dulung watershed, Paschim Medinipur District, West Bengal and a small part of the adjoining Jharkhand state. The groundwater protential zone using weightage index is prepared.

The groundwater potential zone map prepared by GIS , Indian remotesensing (IRS-P6) images and integration of hydrologic parameters (geomorphology, geology, soil and slope) of the Gangolli basin was divided intofour zones based on the score range viz., very good, good, moderate and poor. Result of morphometric analyses with the hydrologic parameters indicates that 99 % area of SB-III and SB-X are under very good to moderate groundwater potential zone. This study clearly demonstrates that hydrological parameters in relation with morphometric analyses are useful to demarcate the prospect zones of groundwater (Deepika *et al.,* 2013; Table 3).

Table 3: Sub-basin-wise score range obtained by the integration of hydrologic parameters, total area (km^2) of groundwater potential zones and their areal coverage (%) in Gangolli.

Groundwater potential zones	Score range	Area (km^2)	Sub-basin-wise areal coverage (%)									
			I	II	III	IV	V	VI	VII	VIII	IX	X
Very good	42–53	217.58	–	0.43	39.48	12.17	11.30	25.85	1.43	5.34	10.25	31.01
Good	32–42	486.34	0.15	21.32	18.67	11.16	29.63	37.87	54.62	49.91	41.63	39.41
Moderate	22–32	353.04	4.82	24.21	41.38	7.70	50.82	12.49	14.87	15.23	34.89	29.17
Poor	12–22	443.84	95.03	54.04	0.47	68.97	8.26	23.79	29.07	29.52	13.23	0.41

Source: Deepika *et al.,* 2013

Jaiswal *et al.,* (2003) studied groundwater potential mapping by using remote-sensing andGIS in the areas of Gorna and Maldhya Paradesh in India by the layers of lithology , geologystructures, find use, drainage channel, soil characteristics and slope were integrated in GIS environment, and the map of ground water potential was prepared for considered area. The results of this study areused to detect suitable areas to extract drinkable water for rural population. The delineation of groundwater potential zones studied in New Delhi (Mallick, *et al.,* 2014), Udaipur, India (Machiwal, 2011) Bankura distict, west Bengal (Nag and Lahiri 2011) Karnataka, India (Manjunatha *et al.,* 2016) Varahanadhiwatershed, Tamil Nadu, India (Ramamoorthy and Rammohan 2015) Guntur district, Andhra Pradesh (Rao 2006). Karmakar and Natarajan, (2015) identifying the ground water potential zones(figure) in Ambarwatershed, Sehore , Madhya Pradesh using geospatial techniques which includes remotesensing, GIS , CSI and MIF techniques is found efficient to minimize time and money and most of the area of this watershed is moderate to very poor zone (Table 4).

Table 4: Zonation basis suitable for water percolation and potential area in, Sehore , Madhya Pradesh

Zone	Suitability area (%)	Potential area (%)
Very poor	30.9	0.07
Poor	10.9	28.90
Moderate	11.4	38.97
Good	12.2	31.97
Excellent	34.6	0.09

Source: Karmakar and Natarajan, (2015).

A GIS integration tool is proposed to demarcate the groundwater potential zone in a soft rock area using seven hydrogeologic themes: lithology, geomorphology, soil, net recharge, drainage density, slope and surface water bodies from remote sensing data (IRS-1B LISS-II) in Midnapur District, West Bengal, India. The evolved GIS-based model of the study area was found to be in strongagreement with available borehole and pumping test data Shahid *et al.,* (2000). Pinto *et al.,* (2017) employed AHP-coupled MCDA, GIS and RS techniques to integrate hydrogeological, geomorphologic as well as climatic data to evaluate groundwater resources of the Comoro watershed in Timore Leste (Fig.6). The major purpose is to delineate the groundwater potential zones of the study area and to develop a prospective guide map for groundwater exploration/exploitation so as to ensure optimum and sustainable development and management of this vital resource. The analysis reveals that out of 250 km^2 area, around 13.5 km^2 is identified as a very high potential zone (Table. 5) for groundwater occurrences at the downstream of the Comoro River in the western part of the city.

Table 5: Classification of groundwater potential zone and the degree of area coverage with the respective yield category

Potential zone	Area (%)	Area (km^2)	Yield classification (l/s)
Very high	5.40	13.50	32.06
High	4.80	12.00	19.57
Moderate	2.00	5.00	12.50
Poor to very poor	87.80	219.50	na

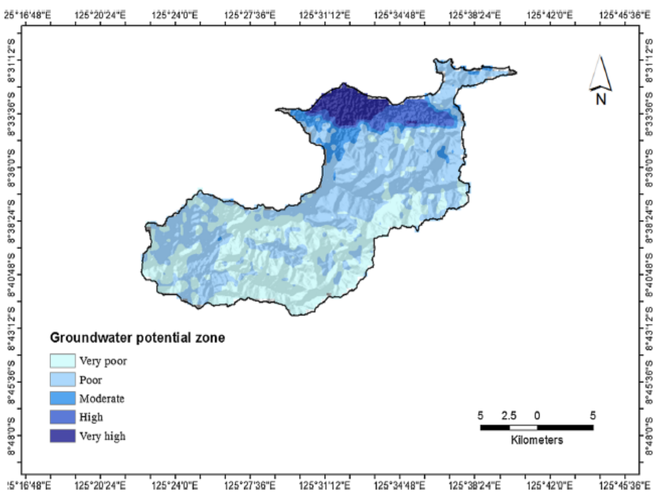

Figure 6: Groundwater potential zone map in the Comoro Watershed, TimorLeste (Pinto, *et al.*, 2017)

Shahid *et al.*, (2000) performed modeling of ground water sources in soft rocks of Midmapur withthe width of 163km located in west Bengal state of India by using remote-sensing and GIS layers of lithology, geomorphology, soil, feeding, stream density, slope and surface atermasses were prepared to predict groundwater potential zone. Theresults of this model have higher accommodation with real data (Cowell, *et al.*, 1983). Siva, *et al.*, (2017)delineate the possible ground water potential zone with RS, Geographical Information System (GIS), Mult iCriteria Decision Making (MCDM) technique and AHP in the sengipatti region, Tamil Nadu by the rate of infiltration and storagepotential of groundwater is governed by multiple parameters like lithology, geomorphology, slope, drainage density and so on. Result indicate that 32.28% of the area is high ground water potential zone and 34.1% area was moderate ground water potential zone and 33.63% area is low ground water potential zone.Nag and Kundu (2016)used to prepare various thematic layers, e.g., hydrogeomorphology, slope and lineament density by remote sensing and GIS techniques. The maps(Fig.7) were then transformed to raster data using feature to raster converter tool of software like MicroImages TNT mips pro 2012 .Excellent groundwater potential zonesconstitute 1.5% of the total block area, good groundwater potential zones occupy majority of the block, coveringapproximately 53%, and the moderate potential zones occupy about 45% of the total block, poor potential zonesoccupy very small portion 0.5% in in Kashipur Block of Purilia District, West Bengal.

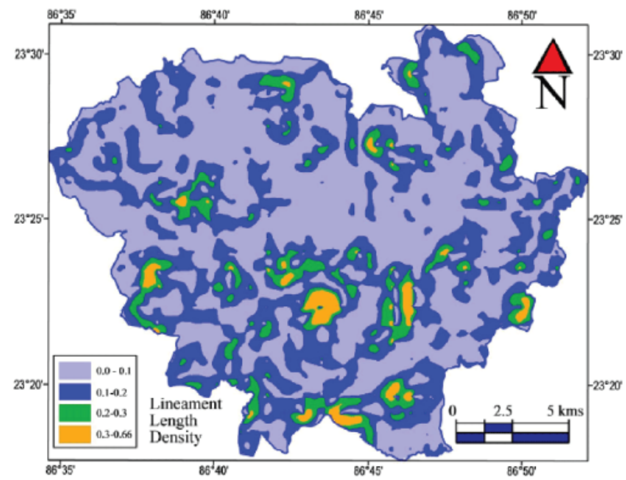

Figure 7: Groundwater potential zone map of Kashipur Block of Purilia District, West Bengal Nag and Kundu (2016).

Krishnamurthy *et al.*, (1996) used GIS and remote-sensing technology to determinesuitable areas for ground water source in south of India with the layers are geology, topography, faults and fractures, surface waters, drainage, stream density and slop.Mentioned mapped on the basis of groundwater importance to super, extremely good, good, medium and poor classes. At last, a weight was assigned to each factor on the basis of theirimportance by Satty's pairewise comparision matrix. The results showed that suitable areas are quartz range (weathered fault) and slopes lower than 5 %. Bera and Ahmad, (2016) delineated using remote sensing and GIS technique. Thematic map such as Geology, hydro geomorphology, Land Use / Land Cover, Drainage density, Slope and Water table maps are prepared in Arc GIS 10.1 based on weighted overlay analysis and result of the study can serve as guideline for future artificial recharge projects in order to ensure sustainable ground water utilization.

5. INTERNATIONAL APPLICATION

Satellite imageries (Landsat 8 ETM+), Digital Elevation Model (DEM), and geological map are used to prepare various thematic layers such as rainfall, geology, slope, lineament and drainage, using ArcGIS 10.2.2, Envi 5.2, ERDAS 2014, and PCI Geomatica 2013 software to to delineate groundwater potential zones (GWPZ, Fig. 8). The GWPZ map reflects about 14 % (587 km^2) of the total area (4258 km^2) has highest recharge potential and 6 % (268 km^2) of the area was the minimum recharge for groundwater, besides the lowest precipitation in Qena-Safaga-Bir Queh, The central Eastern Desert (Golden project) Kashouty (2017).

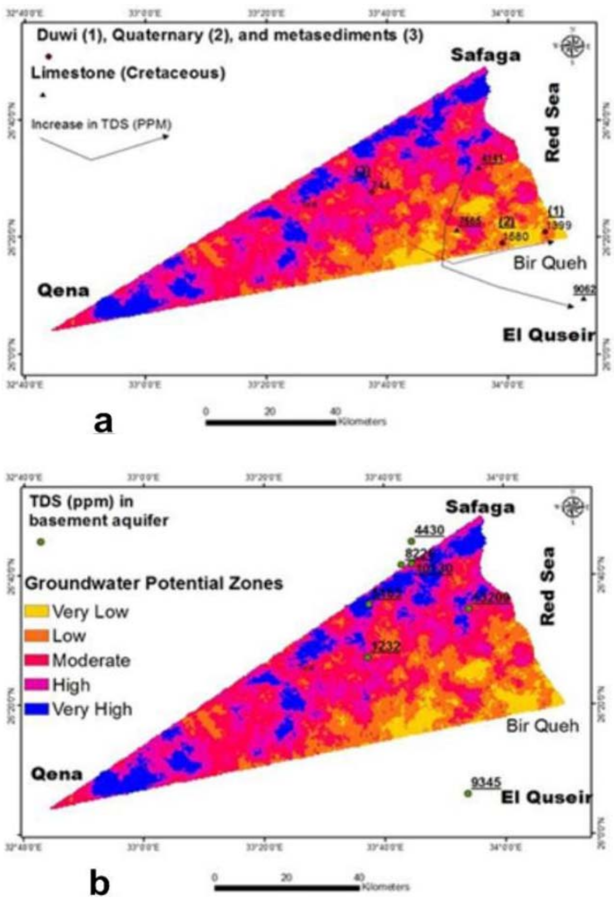

Figure 8: Validation of the groundater potentiality map in Qena-Safaga-Bir Queh area Kashouty (2017).

RS and GIS were utilized to generate five thematic layers, lithology, lineament density, topology, slope, and river density considered as factors influencing the groundwater potential. The multicriteria decision model (MCDM) was integrated with C5.0 and CART to to the classification result, the four grades of groundwater potential zones, "very good, " "good, " "moderate, " and "poor, " occupy 4.61%, 8.58%, 26.59%, and 60.23%, respectively, with C5.0 algorithm, while occupying the percentages of 4.68%, 10.09%, 26.10%, and 59.13%, respectively, with CART algorithm so that, the C5.0 algorithm is more appropriate than CART for the groundwater potential zone prediction in the southwestern part of Ritu county Duan *et al.*, (2016, Fig. 9).CART algorithm Lin, *et al.*, (2006) showed more application than other decision tree algorithms. C5.0 algorithm (Klein *et al., 2012;* Quinlan, 1996; Kotsiantis, 2007) the decision tree techniques, serves as an enhancement ofC4.5 and shows relatively better classification result, for it can simultaneously handle continuous and categorical variables, with the unbiased processing.

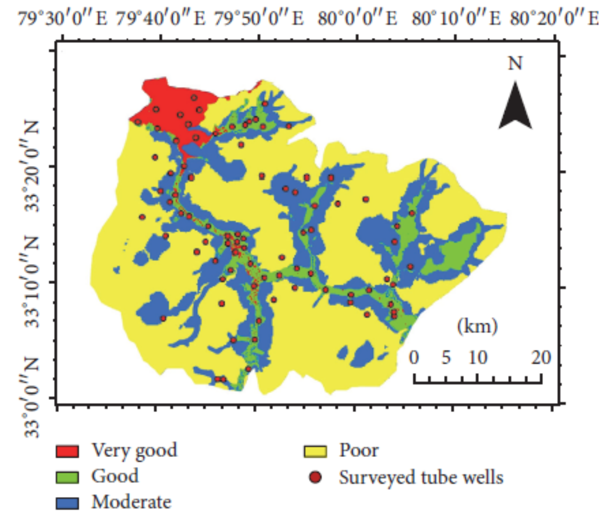

Figure 9: Groundwater potential map of the study area based on C5.0. and CART in the southwestern part of Ritu county, Duan *et al.*, (2016).

Al-shabeeb, (2016) aimed to select the optimum sites for water harvesting in the Azraq basin of Jordan through the use of GIS techniques, A water harvesting suitability map(Fig.10)was then generated following the weighted linear combination (WLC) method with the criteria were the Rainfall, Slope, Soil Clay contents, Drainage Density, Lineament Density and Geology. In addition, seven socio-economic factors that conflict with existing human activities, and thus, affecting the water harvesting were identified based on experts recommendations and literature review.

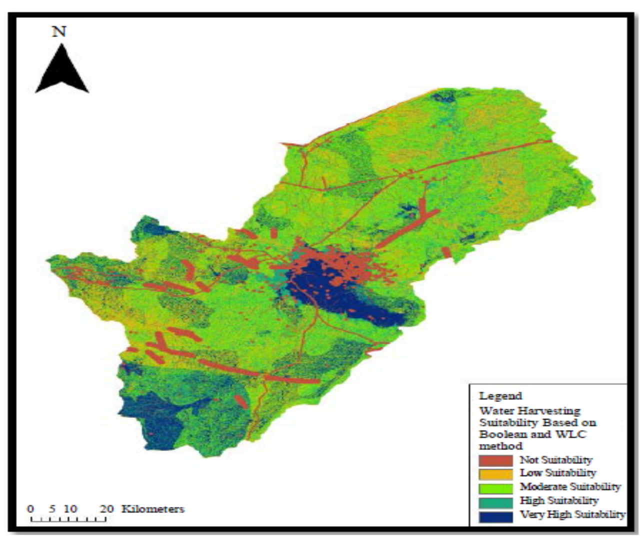

Figure 10: Final suitability map for water harvesting in the Azraq basin of JordanAl-shabeeb (2016).

6. CONCLUSION

A groundwater development program requires a large volume of data from various sources. An integrated remote sensing, MCDA and GIS study can provide the appropriate platform for convergent analysis of large volumes of multidisciplinary data and decision making for groundwater studies. Geospatial technology is a rapid and cost-effective tool in producing valuable data on geology, geomorphology, lineaments and slope, etc. that plays a significant role in deciphering groundwater potential zone. The sustainable development and management of groundwater resource needs quantitative assessment, based on scientific principle and recent techniques. The overall assessment as presented in this study highlight that mapping of groundwater potential using integrated RS/GIS/MCDA/AHP/WLC approach could be an effective means of characterization of groundwater potential zones as well as serving as a useful tool and guide in groundwater exploration and development could serve as a base line study for future water management projects in the area. This Integrated geospatial techniques could serve as a base line study for future water management projects in order to ensure sustainable ground water utilization.

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