ABSTRACT
This research is aimed at providing a cost-effective technique for groundwater exploration in Zaria and its Environ. The study made use of Remote Sensing data to generate thematic maps of a slope, water body proximity and drainage and lineament density. Maps of Geology and Soil were used to generate thematic maps of geology and soil respectively. The pair-wise comparison method was used to weight the thematic layers, while modelling was done by weighted overlay technique in a GIS environment. Results revealed three groundwater potential zones of low potential; medium potential zone; and high potential areas, which was chiefly control by high lineament density and close water body proximity within the study area. In terms of areal extent, the low potential, medium potential and high groundwater potential zones cover 48, 580, and 41 Km², respectively. Validation of the model using dry season groundwater configuration map and flow directions showed reasonable agreement, while field data shows a correlation with other similar works in other parts of Nigeria. It was thus recommended that the techniques should be tested in other parts of the country and adopted in delineating groundwater potential zones because of its effectiveness.

Keywords: Remote Sensing, Thematic Layers, GIS, Groundwater, Potential Zones.

INTRODUCTION
Water occurs as surface water in streams, rivers, lakes seas and oceans and as groundwater when it infiltrates beneath the ground surface. Buchanan (1983) puts the groundwater reserve of the world at about 5.0x10²⁶ liters. This volume is more than 2000 times the volume of water in all the world’s rivers. Being naturally filtered in its passage through the ground, it is usually clear, colourless and has excellent quality, being free from microbial contamination and requires minimum treatment (Babiker et al., 2007). Ever increasing population is in need of water which is a prerequisite for life. However, the reality on the ground indicates that many communities lack pipe borne water thus, warranting the need for individuals and local communities to look for an alternative to the conventional public water supply (Aggarwal et al., 2009; Chawla et al., 2010). Groundwater exploitation via hand-dug well and boreholes is far cheaper when compared to conventional surface water programmes. Nonetheless, a major constraint is the complex and erratic nature of groundwater occurrences in crystalline basement terrains with the attendant high rate of well/borehole failure in the absence of proper and adequate pre-drilling hydrogeological investigations (Fashea et al., 2013). Also, groundwater prospect in an area is controlled by other factors such as geology, geomorphology, drainage, surface gradient, proximity to surface water bodies, canals, and irrigated fields amongst others.

Though geophysical, geological, hydrogeological, and photogeological techniques have been employed to delineate groundwater potential zones (Teeuw, 1995; Sander et al., 1996; Edet and Okereke, 1997; Taylor and Howard, 2000; Srivastava and Bhattacharya, 2006), the integration of various conventional methods with Remote sensing (RS) techniques and Geographical Information Systems technology helps to increase the accuracy of results in delineation of groundwater potential zone and also to reduce the bias on any single method (Rao and Jugran, 2003). The present research is aimed at assessing an integrated technique for delineating groundwater potential areas which are the view of proving a cost effective method for groundwater exploration.

MATERIALS AND METHODS
Six different thematic maps were used in the present study. These thematic layers were extracted from different geologic data ranging from Landsat data, Digital Elevation Model (DEM), geological and soil maps. The layers were selected based on the model used in the present work which is the analytic hierarchy approach (AHP) developed by Saaty (1980; 1992), which is a type of Multi-criteria Decision Analysis technique (MCDA). Factors that affect our goal which in this case is the determination of groundwater potential within the study area were noted to include slope, geology, lineament density, drainage density, water body proximity and soil type. The geological and soil thematic maps were generated from digitization of the existing geological and soil maps of the area. The drainage and slope thematic maps were extracted from the Digital Elevation Model while the lineament map was prepared using the automatic line extraction of principal component analyzed (PCA) from Landsat ETM+ data.
The relative importance of the features of each individual factor to the groundwater potential was determined intuitively. Pair-wise comparison on a scale from 1 to 9 as developed by Saaty (1980; 1992) was used to create a matrix comparing features within each theme based on its importance to groundwater potential following the approach of Rao and Jugran (2003), Machiwal et al. (2011), Mukherjee et al. (2012), Singh et al. (2013), Fashae et al. (2013) and Adeyeye (2015). The weights of features associated with individual themes were calculated by the Saaty’s AHP and the eigenvector technique.

The classification was done on the basis of weights obtained from pair-wise comparisons done with the help of

![Flow Chart of Methodology Adapted in the present Work](image)

**RESULTS**

A total of six thematic maps were generated and were combined (integrated) to produce the groundwater potential map (GWPM). These are geology, soil, drainage density, lineament density, slope, and water body proximity. According to Aponbiede (2015), the study area has five distinctive rock types namely: Schist, Porphyritic Gneiss, Coarse-grained Granite and Migmatite. Normalized weights of respective rocks based on contribution to groundwater potential as obtained by pair-wise comparison are 26, 21, 19, 18 and 16 respectively.

Fluvisols, cambisols, regosols, luminous and lixisols are the soil groups found in the study area (SOW - VU, 1997). Normalized weights of 29, 21, 19, 16 and 15 were assigned to respective soil classes based on their perceived contribution to groundwater potential. The drainage density within the study area ranged from 0 – 1.27 km/km² and was reclassified into four categories as 0 – 0.32 km/km², 0.32 – 0.63 km/km², 0.63 – 0.95 km/km², and 0.95 – 1.27 km/km².

Lineament density within the study area ranged from 0 – 1.27 km/km² (Figure 4.5a) and was classified into five categories as follows 0 - 0.49 km/km², 0.49 – 0.98 km/km², 0.98 – 1.47 km/km², and 1.4 – 1.96 km/km² and 1.96 – 2.45 km/km² covering 610 Km² (79%), 105 Km² (14%), 39 Km² (5%), 11 Km² (1%) and 5 Km² (1%) of the study area accordingly. In the same vein, normalized weights of 9, 12, 18, 25 and 36 were assigned to the successive categories based on their perceived contribution to groundwater potential using pair-wise comparison.

The slope of the ground within the study area ranged from 0 – 9.35% (Figure 4.4a) and was grouped into three classes namely: 0 – 3.11%, 3.11 – 6.24% and greater than 6.24% (Figure 4.3b) with each respective class covering 764 Km² (99%), 5 Km² (0.7%), and 0.3 Km² (0.3%) of the study area respectively. The various categories were correspondingly given normalized weights of 55, 25 and 20 using pair-wise comparison. The classified maps of the various thematic layers used in the present study given in

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**Fig. 1:** Flow Chart of Methodology Adapted in the present Work

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Fig. 2: Classified Geologic Map of the Study Area

Fig. 3: Classified soil map of the study area.

Fig. 4: Classified water body proximity map of the area.

Fig. 5: Classified Drainage Density Map of the study area

Fig. 6: Classified Slope map of the study area

Fig. 7: Classified Lineament Density of the study area.
DISCUSSION
The groundwater potential map of the area was used to delineate areas with Low, moderate and high groundwater potential areas. The results show that areas with low groundwater potential cover 48 Km$^2$ (19%) of the study area and are mainly found in the north-eastern (around Gidan Daduwa, Gidan Nomad, Dutsin Kura and U. Hassan) and the south-western portions of the study area (around Maje, Dan Mahawayi). The extreme northwest is also characterized by low groundwater potential. Moderate groundwater potential areas run trends in the north-west to the south-eastern direction of the study area as well as part of the south and cover about 580 Km$^2$ (73%) of the area.

High groundwater potential areas cover 41 Km$^2$ (5%) of the study area occurring in pockets in the southeastern and northwestern portion of the study area. High groundwater potential areas also occur preferentially close to streams. Borehole data of the study area are scarce. However two data found falls within moderate groundwater potential zone in the southeastern part of the groundwater potential map with yield ranging from 63.9 m$^3$/day (0.74L/sec) to 58.75 m$^3$/day(0.68L/sec) in Tashan Kadel and Ungwar Waziri respectively, this shows that the result obtains in this study are good. In general, the study area can be said to be a moderate groundwater producing area and that the most controlling factors that control groundwater in the area are, proximity to water bodies which serve as a source of recharge, slope which controls the groundwater flow direction and drainage density. It is hoped that the present study can serve as a guide to groundwater exploration within the study area.

CONCLUSION
Results obtained in the present study and validated by some borehole data has shown that the technique used in the present study are effective and can serve cost in the search for groundwater in another part of the country.

Recommendation
It is recommended that this technique should be applied in other parts of the country most especially in sedimentary areas to further test its credibility.

Authors Contributions
Both authors worked hand in hand from the conceptualization of the work to data collection, analysis and interpretation.

REFERENCES


