ABSTRACT
The study area is located in the northern Limpopo Province of South Africa. The aim of the study was to identify groundwater targets that could assist in improving the quality of life of rural communities. Airborne magnetic data was interpreted in order to identify dykes, lineaments and magnetic sources that could control on groundwater occurrences. The length, parallelism of magnetic lineaments in some parts of the area suggests emplacement under tensional stress field along pre-existing zones of weakness. Lineaments extracted from the airborne magnetic data and satellite imagery data were superimposed on drainage lines in order to investigate the relative importance of structural features controlling the distribution of surface water and groundwater. In addition, normalized difference vegetation index was used in identify areas of vegetation banding which enable inference of fracture zones and high moisture content in the soil. The study shows that the northern and central eastern parts of the study area are more prospective for groundwater occurrence, while the southern and southwestern parts of the project area are dry with no surface manifestation of the of groundwater. Integration of lineaments derived from aeromagnetic data and Landsat imagery as well with the normalized difference vegetation index was able to identify areas with a potential for groundwater occurrence at a regional scale.

KEY WORDS
Borehole yield, normalized difference vegetation index, digital elevation model, magnetic

1. Introduction
The quality of lives of rural communities is depends on the source of water especially groundwater for domestic purposes. Hence identification of regional potential targets of groundwater which forms the basis of this research will go a long way to improving the quality of lives of local communities. The study area falls under the central part of Capricorn District Municipality in the northern Limpopo Province of South Africa (Figure 1).

The study area lies on highly deformed crystalline basement terrain which is complex and finding sustainable source of water is often a challenge. However, as described by Chilton and Foster (1995), the availability of groundwater occurrence in crystalline basement rocks such as the present study area largely depends on the availability of interconnected structures and weathered horizons. Aeromagnetic data interpretation combined with Landsat imagery and normalized difference vegetation index was used to identify these structures. The detailed analysis of the research findings will be published in the Water SA Journal.

Figure 1: Location map of the study area showing the drainage pattern

2. Hydrogeology
The study area comprises of the high-grade (Southern Marginal Zone of the Limpopo Belt) to the north, and the low grade Archaean granitoid greenstone terrain of the Kaapvaal craton to the south. The northward dipping Hout River Shear zone forms the boundary between the
two large geologic terrains as shown on Figure 2. The Goudplaats-Hout River Group consisting of tonalitic and trondhjemitic gneisses (Barton, 1983) dominate the entire study area. The northern part of the area is largely dominated by the Sand River gneiss of the Limpopo Belt which consists of strongly banded and complexly folded rocks, showing extreme deformation (Kramer et al., 2006). Along the boundary between the Kaapvaal craton and the Southern Marginal Zone, E-W and N-S striking structures cross-cut various types of rocks (Kramer et al., 2006). The dominant rock types in the Southern Marginal Zone are high grade meta-sediments with apparently interlayered gneiss and mafic rocks. These rocks were subjected to structural deformation spanning from mid-Archaean through to the present day (Kramer et al., 2006).

The availability of groundwater in this region has been noted by the previous studies (e.g., Holland and Witt, 2011) but in varying quantities depending on the hydrogeological characteristics of the underlying aquifers. The borehole yields in the crystalline aquifers are relatively low (often less than 1 l/s), but in the deeply weathered and highly fractured regions boreholes can yield in excess of 5 l/s. In this respect, two types of aquifers can be expected to occur in the study area, weathered rock aquifers and fractured aquifers. Both types of aquifers are expected to associate with fracture networks and occur near the surface. The use of airborne magnetic data combined with satellite imagery is therefore important to map lineaments and fracture zones that allow groundwater flow and storage.

3. Methodology

Integration of airborne magnetic data, geological, drainage patterns and satellite imagery (Digital elevation model, Normalized Difference Vegetation Index) were used to delineate areas with high groundwater potential.

3.1 Airborne Magnetic Method

The airborne magnetic survey was flown in 2009 along 200 m separated, N-S lines, using an Cessna 210 at a speed of 60 km/hour and mean clearance of 80 m. Magnetic data was recorded using a Geometrics model G803 magnetometer with an accuracy of 1.0 nT (Ledwaba et al., 2010). Total field magnetic data was recorded using a Geometrics G822A caesium vapour magnetometer with a resolution of 0.01nT and a measuring frequency of 10 Hz. A Geometrics G856AG proton precession magnetometer was used as a ground base station for monitoring diurnal variations.

The airborne magnetic data was interpreted in order to identify dykes, lineaments and magnetic source bodies that have some form of control over the groundwater occurrence.

3.2 Digital Elevation model

The digital elevation data used in the present study area is a product of ASTER Global DEM with a spatial resolution of 30 m by 30m.
3.3 Normalized Difference Vegetation Index (NDVI)

Green vegetation reflects most of the Sun light in the near-infrared (NIR) band but very low reflection from red-visible (RED) band. The simplest normalized difference vegetation index can be expressed as:

\[ \text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} \]  

The range of NDVI varies from -1 to 1 and pixels with high NDVI appear as white tone on a grey-scale image and correspond to vegetation cover, while low NDVI values representing dry areas appear as dark tone. The above equation suggests that in areas where there is dense vegetation the difference gives large values (~1) much more so than would be expected for other land covers with low (~ -1) NDVI values. Since the NIR is invisible to the human eye, the high reflectance in the green band causes us to see vegetation as green. The low reflectance and transmittance in the visible range is caused by the strong absorption of chlorophyll pigments, while absorption effects are less strong in the NIR, but reflectance and transmittance are much higher.

The main advantages of NDVI for groundwater investigation are:

- In dry areas such as the present study area, NDVI indicates the absence or presence of groundwater in fractures, assuming vegetation response to the presence of water.
- Areas with dense vegetation may indicate higher rainfall and presence of groundwater, which may go unnoticed due to perhaps poor density of rain gauges.

In case groundwater fluctuation causes problems, it may be desirable to study the vegetation response through a NDVI and sequential images.

4. Interpretation of Results

4.1 Lineaments

The aeromagnetic interpretation map (Figure 3) shows various linear features which are interpreted as dykes with the exception of NE-SW orientated strike-slip faults that are located in the central part of the area. It also shows several NE-SW striking lineaments that represent the trace of the Hout River shear zone which separates the Kaapvaal craton in the south from the Southern Marginal Zone in the north. Many of the lineaments are characterized by contrasting magnetization and can be conveniently traced from the magnetic map. They extend over hundreds of kilometers which suggest that they were emplaced under tensional stress field along pre-existing zones of weakness. Furthermore, dyke swarms represent the fractures that result from stress field operative during the time dyke emplacement as noted by Stettler et al. 1989. The fracture zones have important implication from groundwater exploration point of view, as productive aquifers correspond to fracture networks that occur below the weathering horizon (regolith).

Known dykes and magnetic lineaments interception points were used to different the dykes in terms of which one is older or younger (D1 to D5 on Figure 3).

![Aeromagnetic interpretation map](image)

**Figure 3: Aeromagnetic interpretation map**

4.2 Digital Elevation model

The southern part of the study area is characterized by elevated topography attaining a maximum altitude of 1700 m above mean sea level. The massive granitic intrusions of the Kaapvaal craton form prominent topographic highs in the south, while the northern part of the study area is characterized by flat morphology. The superimposed drainage lines show increased line density to the south, while becomes sparse towards the north which is consistent with the distribution of rock types.
The southern part of the area is dominated by crystalline basement which are resistant to river incision, while the northern part of the area comprised of meta-sedimentary and meta-volcanic rocks as shown on Figure 4. The sparse drainage lines in the north suggests that the rocks are highly fractured or affected by weathering process which apparently allow seepage of surface water.

Figure 4: Digital elevation model derived from ASTER global DEM

4.3 Relationship between lineaments and borehole yield

As described above, many of the lineaments observed on the aeromagnetic map are interpreted as dykes. An attempt was made to discriminate the lineaments into dykes and faults based on water level and water chemistry sampled from drilled boreholes that are located on the opposite side of the mapped lineaments. However, due to limitation of boreholes in the study area and water chemistry as well as water level, this approach was not successful. As shown on Figure 5, there are only 7 boreholes that fall within the entire study area and the borehole data is inadequate to quantify the relationship between lineaments and borehole yield. In addition, the uncertainty in borehole yield (e.g. ≥6.9 l/s) is too high to interpret borehole productivity in terms of fracture length density. However, lineament density increases in the northern and central eastern parts of the study area which may suggest groundwater potential zones for further detailed investigation. The use of water level, water chemistry and borehole yield may be recommended in this region to ascertain the present interpretation of aeromagnetic data.

Figure 5: Map of lineaments derived from airborne data and satellite imagery

4.4 Normalized Difference Vegetation Index (NDVI)

In the present study, the normalized difference vegetation index (NDVI) was computed using visible and near-infrared bands of Landsat 7 images and shown on Figure 6.

Figure 6: Normalized difference vegetation index map
The NDVI values are relatively high along the Sand River and its tributaries in the northeastern and northern parts of the study area. Areas that are shown by high NDVI represent the availability of dense vegetation and possibly thick regolith or interconnected fractures below the regolith. In contrast, the southern and western parts of the study area are characterized by bare soil with no vegetation cover which is consistent with granite gneiss of the Kaapvaal craton and Peterburs greenstone belt. As shown on Figure 6, the southern part of the greenstone belt mainly comprised of granitic intrusion and Goudplaats -Hout River gneiss that consists of metavolcanic and meta-sedimentary rocks. These rocks are characterized by limited interconnected fractures and weathering horizons suggesting that there is very low porosity and permeability. In general, the low NDVI value in the southern part of the study area is consistent with the lack of interconnected structures and poor permeability thereby low groundwater potential.

6. Conclusion

Integration of lineaments derived from aeromagnetic data and Landsat imagery as well with normalized difference vegetation index was able to identify areas with a potential for groundwater occurrence at a regional scale. The northern and central eastern parts of the study area have groundwater potential while the southern and southwestern parts of the project area are dry. Ground truthing and follow-up geophysical work is recommended to refine the present findings in this paper.

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References


