LANDSAT REMOTE SENSING DATA AS AN ALTERNATIVE APPROACH FOR GEOLOGICAL MAPPING IN TANZANIA: A CASE STUDY IN THE RUNGWE VOLCANIC PROVINCE, SOUTH-WESTERN TANZANIA

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ABSTRACT

Rungwe Volcanic Province (RVP) is mostly covered by extrusive rocks that overlain the Precambrian basement. The use of Landsat data in this area has revealed the need of effective use of these data in geological mapping programs in Tanzania. Landsat band ratios 5/1, 3/7, 5/7 and 5/4 as well as R: G: B composite images 7:4:1, 7:5:4, 1/3:5/7:3/5 and 4/5:6/7:4/6 played an important role in identifying different rock types in the study area. Ratio images managed clearly to distinguish between mafic and felsic rocks whereby two lithological blocks were identified, Block 1 covers a combination of intrusive and metamorphic rocks while Block 2 is dominated by extrusive rocks. Composite images went further to the discrimination of individual lithological units in which different rock types were identified, example phonolitic trachytes, basalts, tephrites and granitoids. Vegetation overlap problem was cleared up by results from classification in which the thick vegetated areas were discriminated. Hence, results from Landsat data analyses showed clear lithological correlation between Landsat images and the available geological map in the study area. Apart from these data to show that they are effective in geological mapping, the performance showed by Landsat data suggests they can substitute geophysical data which are relatively very expensive.

INTRODUCTION

In the past days geological mapping was performed through fieldwork i.e. traversing, but nowadays things have gone far whereby other sophisticated methods which are efficient in terms of time and money have been introduced to work together with traditional geological mapping. Acquisition of data by remote sensing is among the technological advancement that has been realized, and in geological aspect, the technique is normally used in acquiring Earth's surface geological data for instance structural features, lithologies, lithological sequences, relative age of rock strata, types of drainage, soil type, vegetation cover etc (Drury 1993). This technique when used together with field mapping, professionally ground truthing, it makes geological mapping more effective and efficient in all aspects of cost.

Moore *et al.* (2007) used remote sensing data (Landsat-5) to quantify basaltic rock outcrops during the Clark Area Soil Survey. Moreover, remote sensing is nowadays intensively used in mineral explorations. Example Landsat Thematic Mapper (TM) and Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) images are some of the remote sensing data that are frequently used in geological exploration and mapping of hydrothermal alteration zones (Buckingham and Sommer 1983, Kaufmann 1988, Drury and Hunt 1989, Carranza and Hale 1999, Crosta and Filho 2003, Assiri *et al*. 2008, Warner and Farmer 2008).

The application of remote sensing faces setbacks when it comes to interpretation of geological and structural data because different surface conditions such as vegetation, agricultural activities and weathering crust may act as hindrance to geological and structural signals (Drury, 1993). By considering these facts, it is therefore essential to assess the applicability of individual remote sensing tools as well as other factors to remove errors and noises before any interpretation of remote sensing data. Removal of noise and cloud cover effects can well be performed through special techniques such as filtering found in remote sensing software. For the case of geological analysis band rationing is a prominent method in reducing haze and vegetation cover effects (Carranza 2002).

Near infrared (NIR), mid-infrared (MIR) and shortwave infrared (SWIR) electromagnetic windows in remote sensing are very useful in geological analysis. Example, for the Landsat thematic mapper (TM) data, band-5 and band-7 have been proved to be more successful in discriminating different rock types and effective in identifying zones of hydrothermal alteration (Crosta and Moore 1989, Drury 1993, Carranza and Hale 1999, Ferrier *et al.* 2002, Crosta and Filho 2003, Moore *et al.* 2007).

About 15% by area of Tanzania has not been geologically mapped up to recent. According to the Geological Survey of Tanzania (GST) most of the geological data including all related information which were used during geological mapping of the already mapped areas, were obtained from geophysical and geochemical surveys based on field geological mapping. Along with this fact, there is no indication whether remote sensing data which is among the recent successful modern mapping technique has been intensively used in the geological mapping programs in Tanzania. Remote sensing data has only been applied to study vegetation covers and volcanism of the Oldoinyo Lengai Mountain (Ngusaru *et al.* 2002, Kervyn *et al.* 2008). Rungwe Volcanic Province (RVP) is one of the areas that have geologically mapped using classical methods by Harkin and Harpum, (1958). This study therefore uses RVP the already mapped area by using classical techniques to prove the robustness of the remote sensing data.

Geology of the study area

Rungwe Volcanic Province (RVP) is located in the southern highland province of Tanzania, northwest of Lake Nyasa approximatelly1000 km from the business city of Dar es Salaam (Fig. 1). Rungwe volcanic pile is raised on the Precambrian basement (i.e. Ubendian Belt, Ukinga and Buanji Groups) and in the Karroo and Cretaceous sediments. Unconformity separates volcanic rocks from basement rocks in this area (Harpum, 1955 and Teale, 1936). Volcanic rocks are described as a group of trachytic, basaltic, phonolitic lavas and tuffs (Harkin 1954). These rock groups are related to a number of volcanic centers from which the general sequence was established (Fig. 2). Moreover, the frequent occurrence of olivine basalts throughout the sequence which is significant, suggests that the trachytes and phonolites were derived from a parent basaltic magma. According to Harkin and Harpum (1958), the RVP is divided into two fold divisions which are older and younger extrusives. Older extrusive includes North Porotos, Mbeya Block, Elton Plateau and Kiwira as major extrusive centers (Fig.1, Fig.2). In the North Poroto, basaltic lavas are the oldest relative to trachyandesites, trachytes, phonolitic trachytes, phonolites and tuff. Mbeya Block comprises phonolites which are younger than basaltic lava and the undifferentiated layer. In the Elton plateau, agglomerates are younger than tuffs and phonolite lava breccia present in the area, and at Kiwira the dominant rocks are mostly basaltic lavas. Younger extrusive includes the major central volcanoes of Rungwe, Kiejo and Tukuyu. Rungwe is covered by phonolitic-trachyte lava and tuffs, olivine-basalt, phonolitic trachyte lava, pumice and ash from a nest of cone-lets within the Rungwe caldera. The oldest dated Rungwe lavas have an age of 0.25 ± 0.01 Ma (Ebinger *et al.* 1989). Kyejo is occupied by younger volcanic rocks with a sequence of basaltic lavas and phonolitic trachytes which form mini-cones and finally eruption of basaltic lavas. Based on oral accounts passed down by past generations, this eruption occurred at approximately 1800 AD (Harkin 1960).Tukuyu is covered by low basaltic domes and some phonolites.

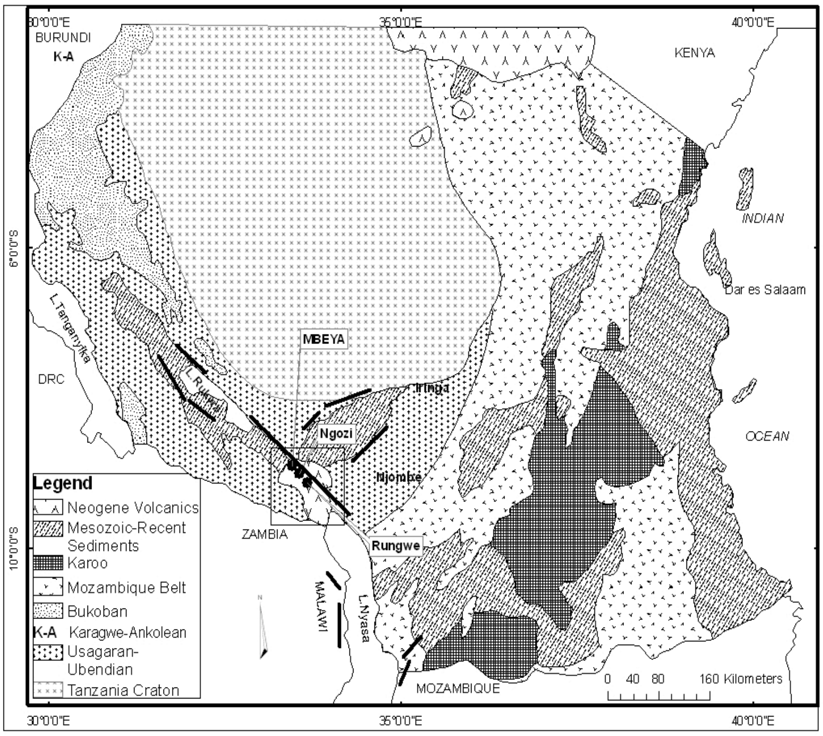

Figure 1: Geological map of Tanzania showing the major tectono-stratigraphic Subdivisions and regions (modified from Pinna et al., 2004). Rungwe Volcanic Province (area in squared box) is located in Rungwe, SW Tanzania in Mbeya region and the thick solid lines indicate Nyasa Rift System.

The RVP is occupied by most of the rift faulting which is reflected as the dominant control in the alignment of volcanological features, these major faults make up the Nyasa Rift System and the dominant direction of these faults is NNW-SSE (Fig. 1). Also there are a number of subsidiary faults parallel to the main Nyasa Rift, some of these faults give rise to "step" faulting on the Nyasa Rift Scarp (Harkin and Harpum 1958). According to the study done by Fontijn *et al.* (2010) in this area, volcano in RVP will erupt in future of which they have suggested a detailed investigation on eruption history to this area.

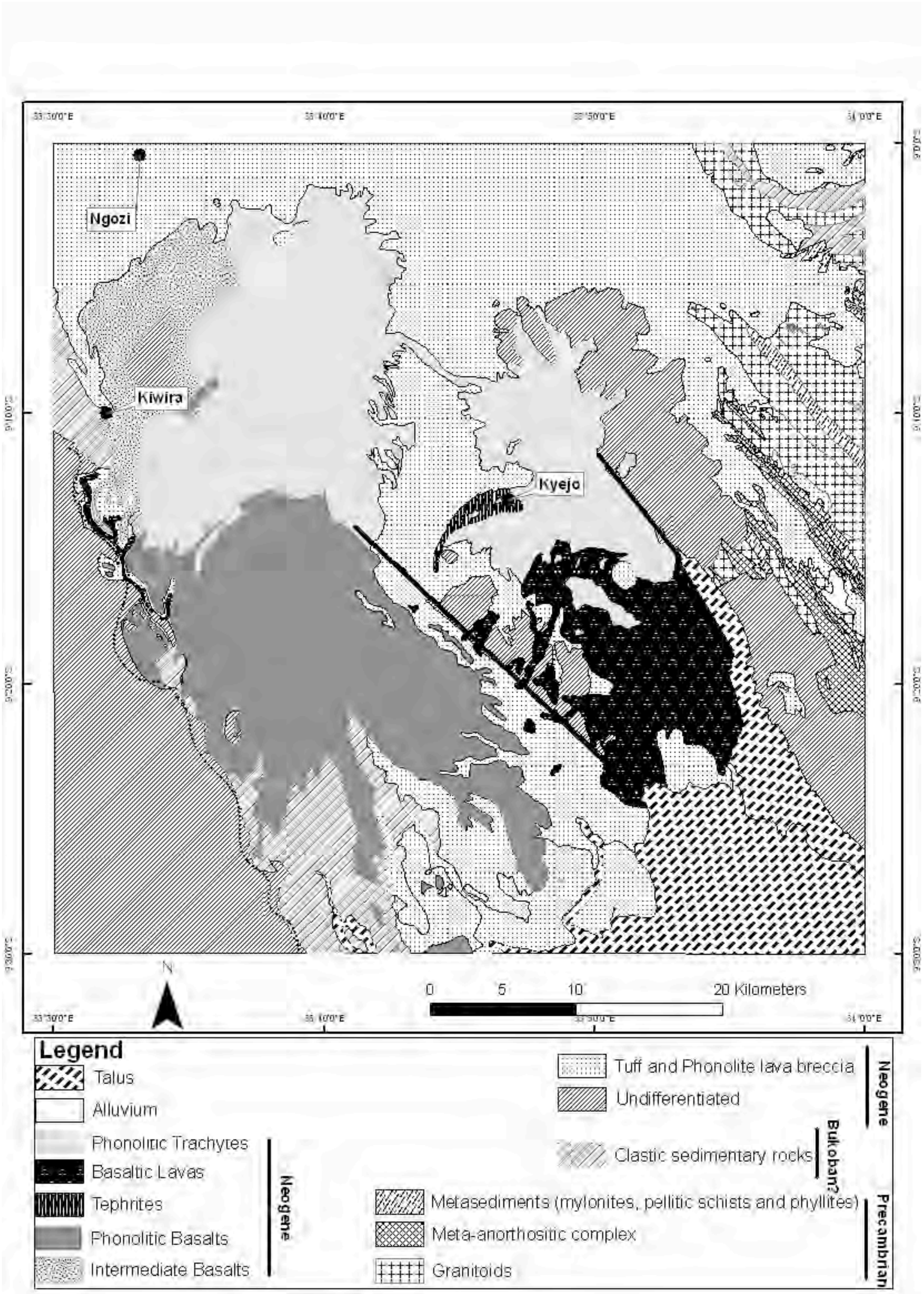

Figure 2: Geological map of the Rungwe Volcanic Province (RVP) modified from Harkin and Harpum (1958). Thick solid lines are the major faults in the rift system.

MATERIALS AND METHODS

Analysed images for this study are sub-scene of Path 169 Row 066 Landsat TM imagery acquired on 06 May 2003. The sub-scene represents the RVP within 9˚00_15.84″ - 9˚27_52.44″S latitudes and 33˚29_54.07″ - 33˚59_51.00″E longitudes. The software used in the analysis is PCI Geomatica V9.1.0 developed by the PCI Geomatics Company (2003). RVP sub-scene was georeferenced by using four control points which are stream junctions and the resulted root mean square error was 0.827.

Extraction of geological information from satellite data depends on the recognition of different patterns on an image resulted from the spectral arrangement of different tones and textures, but before analysis, remote sensing images need to be processed to remove the unwanted noises. In general, all these processes were performed to create enhancement which then resulted to contrast between objects within a satellite image.

Band ratios are effective in reducing effects of illumination direct from the sun, slope and shadows to the marked degree; they are prepared simply by dividing digital numbers of each pixel in one band by another pixel of the other band which acts as denominator, those pixels in the two divided bands should be of the same location. Moreover, as reported by Drury (1993) and Darning (1998), ratios like 3/1, 3/5, 3/7, 5/1, 5/4, 3/7 and 5/7 have shown great influence on the discrimination of lithologies and with this fact in this study some of these ratios were used to differentiate and identify RVP rock types.

Depending on the rock reflectance properties, individual images were used and played important role in rock identifications; the idea that oxide minerals show high reflectance in TM-3 and TM-5, and absorption anomaly in TM-1 was used to differentiate them from other rock minerals. Iron-rich rocks were identified using ratio of Landsat TM band 5/4 and rocks associated with clays/hydroxyl minerals which have high reflectance in band 5 and absorption of radiations in band 7 were discriminated from other rocks by simply rationing band 5 against band 7. Therefore, clay-rich rocks as it has also been reported by Darning (1998) are clearly identified using these bands as they appear as light pixels in gray scale colours.

In the mineral spectrum normally there is an overlap between the oxide and hydroxyl reflectance and reflectance from vegetations, the two groups both have high reflectance in band 4, band 5 and band 7. This interference is a barrier and normally makes the whole process of Landsat data analysis quite difficult. However, in this study the unsupervised classification played a vital role in overcoming this overlap and this made easy to differentiate the vegetation covered areas from those with bare soils and rocks.

Bands 1,3,4,5 and band 7 were chosen for the unsupervised classification since each band has its own significance in the lithological discriminations. Band 4 normally is dominated by reflections from vegetations while the remained bands are better in reflections and absorptions from rock forming minerals like oxides and hydroxyls (Carranza 2002).

Additionally, due to the rock discrimination power of the colour composite images like those used by Rowen *et al.* (1974), Raines *et al.* (1978) and Riley *et al.* (2006), example 7:5:4, 7:4:1, 3/1:5/7:3/5 and 4/5:6/7:4/6 represented in R: G: B has also applied in this study.

RESULTS AND DISCUSSION

Ratios of Landsat TM bands played an important role in Landsat image interpretation and identification of different lithologies. Two lithological blocks (block 1 and block 2) in the RVP were identified in 5/1, 3/7, 5/7 and 5/4 ratios (Fig.3). Block 1 is coverd by intrusive and metamorphic rocks whereas Block 2 is dominated by extrusive rocks. Example, in band ratio 3/7, the dark coloured intrusive, metamorphic and sedimentary rocks to the NE part of the area are discriminated from the entire light coloured extrusive rocks (Block 2), which cover more than 70% of the study area.

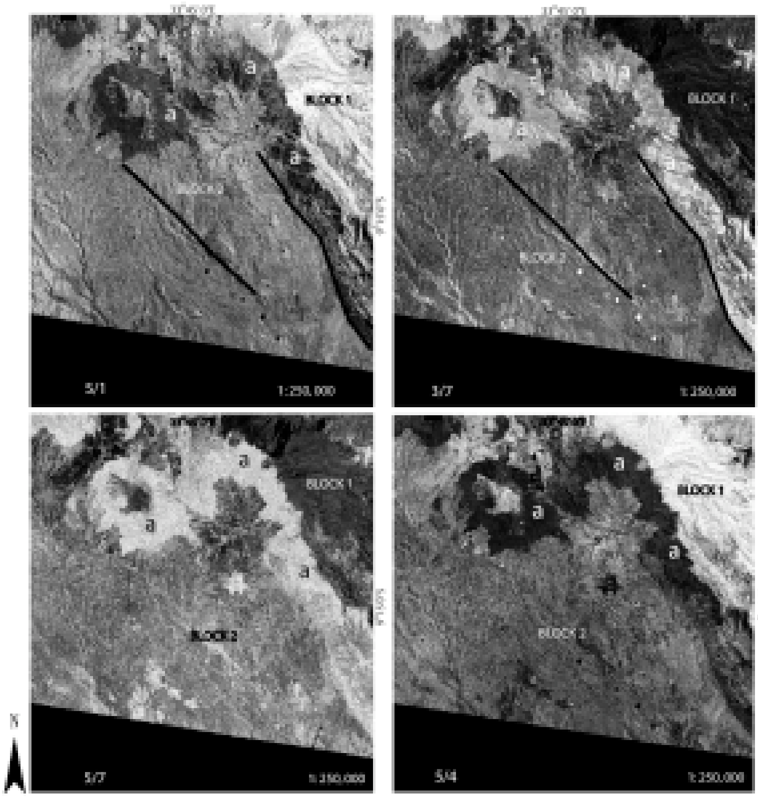

Figure 3: Landsat TM band ratios of the Rungwe Volcanic Province (RVP), locations indicated by letter a = thick vegetated areas.

Similar results revealed in other ratios show different signature from the two Blocks because of very thick vegetation (Fig. 4). In Fig. 3, a 5/4 ratio image, an area marked ‘a’ is covereds by thick vegetation; this area appears darker than areas under the two blocks with bare soils and rocks. These results means that the ratios have managed to some extent to evade the interference between vegetations and lithologies which have been reported from different studies example in Crosta and Moore (1989).

Colour composite images went further to the individual lithological unit discrimination, images 7:4:1, 7:5:4, 1/3:5/7:3/5 and 4/5:6/7:4/6 (Fig.5) were able to differentiate individual intrusions (e.g. granites, migmatites, gabbros and dolerites), extrusions (intermediate basalts, basalts, phonolites, tuffs, phonolitic trachytes, tephraytes and the undifferentiated rocks) and Buanji sediments same as those seen in the geological map of Harkin and Harpum (1958)

Figure 4: Picture showing thick vegetated areas around mount Rungwe in Rungwe Volcanic Province.

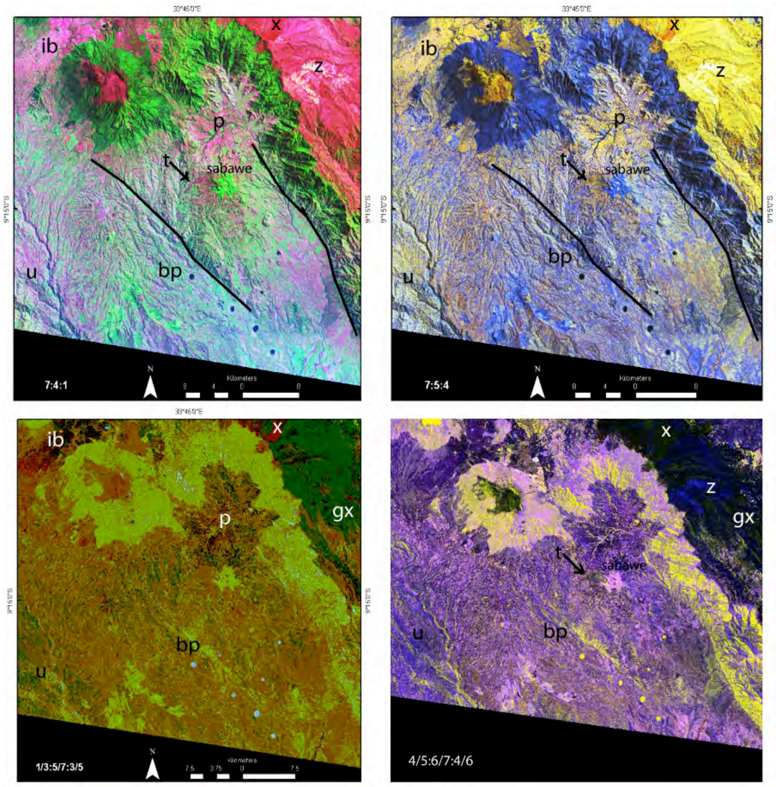

Figure 5: R: G: B composite images of the Landsat data in RVP. Letter ib = intermediate basalts, p=volcanic tuffs, u= undifferentiated rocks in the geological map, bp= phonolites and basaltic lavas, x and z = new unidentified features, gx = granitoids, t = sabawe tephrites.

Volcanic tuffs of phonolitic trachytes marked by a letter 'p' are well identified in the R: G: B composite images whereby in composite 1/3:5/7:3/5, 7:4:1 and 7:5:4 images show a clear difference between phonolitic trachytes and other lithological units (Fig. 5). Further, in 1/3:5/7:3/5 image phonolitic trachytes are more distinctive and represented in red to dark-red colours. Similar phenomenon happened on intermediate basalt 'ib' (Fig.5) and in 1/3:5/7:3/5 image the rocks appear dark red. The Sabawe tephrite indicated by an arrow and a letter 't' (Fig. 5), despite of their small area coverage, they are clearly identified in 4/5:6/7:4/6, 7:5:4 and 7:4:1 composite images. In all three images, the shape of the trachyte unit as observed on the geological map of Harkin and Harpum (1958) was reproduced. The undifferentiated rocks (marked 'u' in Fig. 5) indicated in the geological map of Harkin and Harpum (1958) show similar signature as the one reflected from the intrusive rocks to the NE of the study area. The similarity is emphasized by their colour in the composite images 1/3:5/7:3/5 and 4/5:6/7:4/6 although not intense as the NE intrusive rocks. Their faint colour could probably suggest metamorphic rock unit. Then fieldwork i.e. ground truthing is needed to confirm. There is no clear distinction between phonolites and basaltic lavas, they both have same signature as shown by having same colour in all four composite images ('bp' Fig. 5). Landsat satellite images also showed a powerful discrimination between individual granitoids ('gx' Fig.5). The 1/3:5/7:3/5 and 4/5:6/7:4/6 composite R: G: B images revealed obvious differentiation of granitoids whereby in 4/5:6/7:4/6 image, the granitoids themselves appear in blue and green colours with clear boundaries due to their difference in mineralogical content.

There are two new features seen in Landsat images ('x' and 'z' Fig.5) and are not shown in the geological map of Harkin and Harpum (1958). Interesting features like these support the need of ground truthing purposely for clearing doubts emerged in the analysis.

The unsupervised classification by using all seven bands has attested positive in identifying the major rock types present in the study area, intermediate to mafic extrusive rocks (red coloured), felsic extrusive and intrusive rocks (pink coloured) (Fig.6). Results from classification perfectly discriminated the thick vegetated areas (green colour), and from these results the overlap between band 5 and 4 from vegetation signatures was avoided.

Additionally, this classification helped to disclose the hindrance of the vegetation cover in RVP whereby it has revealed that area previously named undifferentiated rocks found to be underlain by intermediate to mafic extrusive rocks. This is proved through open patches in the thick vegetated areas whereby reflections from these patches fall in the red coloured class (Fig. 6) which represents the intermediate to mafic extrusive rocks in the geological map of Harkin and Harpum (1958).

Landsat data also revealed to be capable of depicting lineaments during geological mapping, two NNW-SSE trending major faults (indicated in dark solid lines) were clearly identified in ratio images 5/1 and 3/7 (Fig. 3) as well as in composite images of bands 7:4:1 and 7:5:4 (Fig. 5). The direction of these faults reported to coincide with the tectonic grain of the pre-Karoo rocks in the eastern half of the area (Harkin and Harpum, 1958). Furthermore, from the observations of the ratio and composite images, it shows that band 7 is the most useful band in depicting lineaments on the earth's surface.

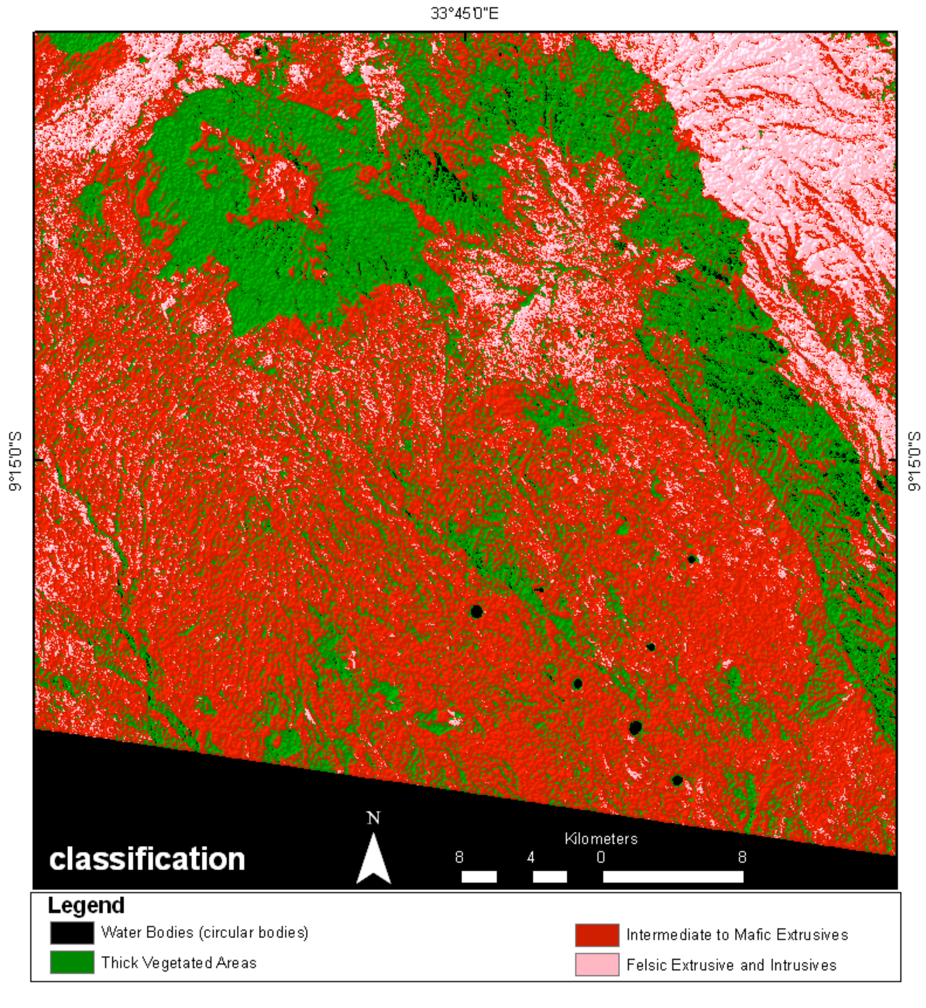

Figure 6: RVP classification image created from all 7 Landsat bands.

CONCLUSION

Band ratios and composite images have played a great role in discriminating and identifying different rock types. Results from this study suggest that large part of geological mapping can be done through the use of Landsat data as an alternative approach and additionally they are cheap compared to the geophysical data, sometimes these data are free of charge. Moreover, to the third world countries example Tanzania, the approach is a solution to the unavailability of fund which has been an ordinary song from our national governments.

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