

ASSESSING LAND COVER CHANGES CAUSED BY GRANITE QUARRYING USING REMOTE SENSING

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ABSTRACT

Dimension stone quarrying in the area between Rustenburg and Brits in the North West Province of South Africa has been in existence for over 70 decades. The unique characteristics of the granite deposits in South Africa resulted in making the country a global producer of the granite rocks. This led to intensified quarrying activities between Rustenburg and Brits town. However, this surface mining method, has a potential to impact the environment in a negative way causing loss in vegetation, depletion of natural resources, loss of scenic beauty and contamination of surface water resources. To assess the land cover changes caused by granite quarrying activities, remotely sensed data in the form of Landsat images between 1998 and 2015 were used. Supervised classification was used to create maps. Accuracy assessment using Google Earth™ as a reference data yielded an overall accuracy of 78%. The post classification change detection method was used to assess land cover changes within the granite quarries. Granite quarries increased by 1174.86 ha while formation of quarry lakes increased to 5.3 ha over the 17-year period. Vegetation cover decreased by 1308 ha in area while 18.3 ha bare land was lost during the same period. This study demonstrated the utility of remote sensing to detect changes in land cover within granite quarries.

1. INTRODUCTION

The extraction of natural resources usually generates environmental impacts on water systems, natural vegetation, agricultural land and other natural resources (Paull *et al.*, 2006). Quantifying the effects that mining activities have on ecosystems is vital for sustainable development and resource management (Latifovic *et al.*, 2005). Since the launch of the first Earth Resources Technology Satellite in 1972 (ERTS-1, later renamed Landsat 1), there has been significant activities related to mapping and monitoring environmental changes caused by anthropogenic pressures and natural processes (Treitz and Rogan, 2004). As a result, remotely sensed data have become a useful tool to complement ground-based environmental monitoring methods that are otherwise confined to point, grid or traverse-based measurements (Lamb, 2000; Lillesand *et al.*, 2014; Rawat and Kumar, 2015).

The main advantages of remote sensing are that it has an ability to cover large areas and reaches inaccessible areas (Cracknell and Hayes, 2007; Koruyan *et al.*, 2012). It provides a relatively low cost means of data acquisition method (Loveland and Dwyer, 2012). Furthermore, remote sensing has spatial resolutions that are suitable for most environmental applications. Another advantage of remote sensing relates to the availability of historical digital data. Such data can be available for decades and thus allow for long-term time-series analysis (Wulder *et al.*, 2008). The mining industry has been an extensive user of remote sensing, but the focus has primarily been on applying the technology to assist with mineral exploration and modelling (Sabins, 1999; Liu *et al.*, 2000; Paull *et al.*, 2006). There is a need to apply the technology for assessing the environmental impacts of mining activities such as quarrying. A number of published research papers have proven remote sensing a useful tool in monitoring and assessing environmental impacts caused by quarrying. Bonifazi *et al.* (2003) conducted a study to determine the capability of remote sensing to monitor abandoned limestone

quarries. The study proved remote sensing to be an effective tool for monitoring such quarries and for surveying their evolution over time. Similarly, Mouflis *et al.* (2008) assessed the visual impacts of marble quarry expansion from 1984-2000 on the landscape of Thasos island, North East Greece. The study estimated various landscape metrics before and after quarrying activities in the study area. Koruyan *et al.* (2012) examined the areal expansion of marble quarries and the change in vegetation around Mugla region from 2001-2009 using remote sensing. More lately, Borana *et al.*, (2014) analysed land use and land cover changes associated with sandstone quarries in the city of Jodhpur in India using Landsat data over a period of 10 years, and showed considerable land cover changes due to mining activities. The above mentioned studies have demonstrated remote sensing to be an efficient and effective tool for mapping and assessing environmental impacts caused by quarrying activities. Even so, not much work has been done on impacts of granite quarries using remote sensing especially in South Africa. The aim of this study was to investigate the effectiveness of remote sensing in detecting land cover changes caused by granite quarries between Rustenburg and Brits area in the North West Province, South Africa.

1.1 History of granite quarrying in South Africa

Quarrying is defined as an open or surface excavation of rock that is primarily used for construction, ornamentation, road building or as an industrial raw material (Hartman and Mutmansky, 2002). The methods employed during quarrying processes depend on the desired size and shape of the stone and its physical characteristics (Ashmole and Motloung, 2008b; Khan *et al.*, 2014; Mendoza *et al.*, 2014). Rocks excavated from quarries are commonly known as dimension stones. A dimension stone can be explained as any rock that may be cut, shaped or selected for use in blocks, as slabs, sheets or construction units of specific size and shape (Maponga and Munyanduri, 2001). The quality of the rock is the

most important aspect of granite marketing. Good quality rock must be free of imperfections such as veins, joints and spots and must have a consistent colour and texture (Maponga and Munyanduri, 2001; Ashmole and Motloung, 2008a). Dimensions stone mining in South Africa, most particularly granite started in the Bon-Accord area, near Pretoria in the late 1930s in the Main Zone of the Bushveld complex. The first quarry in Rustenburg region started in the farm Nooitgedacht 287Q in 1947 (Nex *et al.*, 1998). This was followed by Kudu granite situated in the farm Boschpoort 284Q just 12 km northeast of Rustenburg. Taylor quarry is situated in the farm Tweedepoort 283Q approximately 3km north of Bospoort Dam. The Belfast black granite mining started in Kwaggaskop in 1961 (Ashmole and Motloung, 2008b). Improved mining techniques and increase in quarries has led to an increased production which contributes significantly to the country's economy and job creation (Maponga and Munyanduri, 2001; Ashmole and Motloung, 2008b). According to the Department of Mineral Resources, the South African dimension stone industry has established itself as a major player globally due to unique characteristics of some of the stones found in the North West province such as red granite, black granite and Rustenburg grey (DMR, 2015).



Figure 1: Top: Google Earth™ image showing granite quarry around Brits area (Google Earth™).

2. STUDY AREA

The study area was chosen based on the knowledge of quarrying activity in the area and presented in Figure 2. It is located between Rustenburg and Brits town in the North West Province, South Africa (Figure 3). Granite formations in the North West Province occur in the Main Zone of the Rustenburg Layered Suite in the Bushveld Complex (Nex *et al.*, 1998; Kinnaird, 2005). The mining occurs between Brits and Rustenburg towns. The study area forms part of the Norite Koppies Bushveld vegetation type which extends from Rustenburg in the west to Pretoria in the east and forms part of the Savanna Biome of South Africa. Assessments conducted in the koppies in the study area have indicated that approximately 20 % of the koppies have been transformed mainly due to mining activities and urbanization of surrounding land. The mining activities in these koppies are mostly granite quarries which cause massive damage to vegetation (Lamprecht *et al.*, 2011).

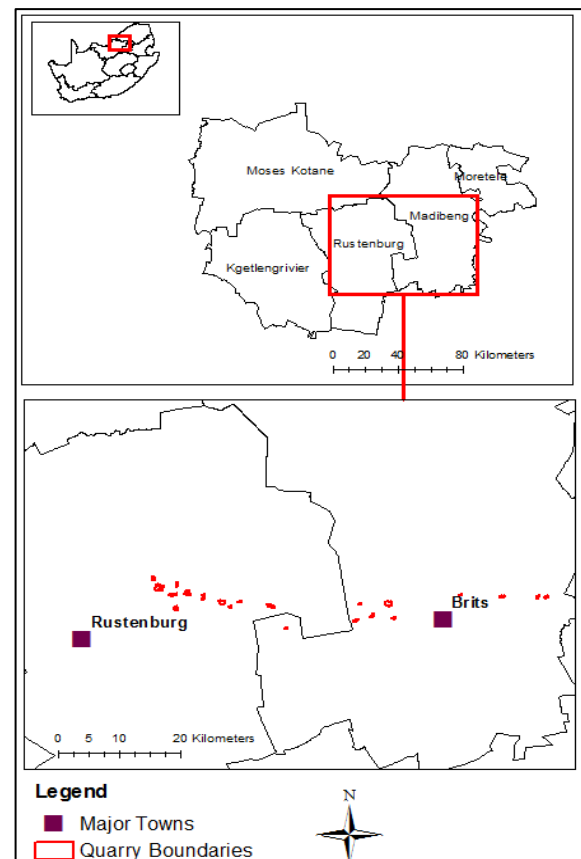


Figure 2: A map showing study area and location of granite quarries.

3. METHODOLOGY

3.1 Sampling and data acquisition

Quarries were sampled based on their spatial coverage and the distance between them. Quarries with spatial coverage of more than 1 hectare were considered for the study. This was to allow for affective comparison with remotely sensed data. A total of twenty quarries were sampled around the study area. A minimum distance of 1 km between quarries was specified when sampling in order to avoid an overlap of samples that may compromise independence of each sample. Granite quarries were located using geographical positioning system (GPS) coordinates acquired from the minerals data base of Council for Geoscience and by using Google Earth™. After acquiring coordinates, Google Earth™ was used to verify the locations as well as to digitize quarry boundaries. Google Earth™ offers Digital Globe images at spatial resolution of 0.5 m and has been used as a source of reference data in remote sensing analysis (Hu *et al.*, 2013; Singh *et al.*, 2015). Landsat images were acquired from the United State Geological Survey (<http://earthexplorer.usgs.gov/>) given in Table 1. Attempts were made to use images acquired during the wettest months between December and March when vegetation is denser; however, the unavailability of suitable images necessitated the use of images outside of this time window. However both March and April are generally known as high vegetation vigour months in the summer rainfall regions of South Africa including the study area.

Location	Sensor	Image dates
Brits-Rustenburg	Landsat 5 Thematic Mapper	16 March 1998
	Landsat 8 Operational Land Imager/Thematic Infrared Sensor	16 April 2015

Table 1: Landsat data used in the study

3.2 Image processing

Images were radiometrically calibrated by converting Digital Numbers (DN) to Top-of-Atmosphere (TOA) reflectance. Following radiometric calibration, multispectral image was created by combining all bands, except panchromatic band for each date. A preliminary comparison between supervised and unsupervised classification showed confusion in differentiating between granite quarries from other mines such as platinum mines as well as build up land using the latter approach; therefore supervised classification was applied in the study. A total of 50 randomly selected points were used to assess accuracy of classes created from the April 2015 image by using Google Earth™ as reference data. Commonly used classification statistics, including overall, producer's and user's accuracy were quantified for the accuracy assessment. Furthermore, kappa statistic was calculated using Equation 1 (Landis and Koch, 1977). Post classification change detection method was performed following accuracy assessment.

$$K = \frac{Po - Pe}{1 - Pe} \quad (1)$$

where Po = observational probability of agreement

Pe = hypothetical expected probability of agreement

4. RESULTS

4.1 Image classification

Seven land cover types were generated from the classification analysis (Figure 3). These include (1) water bodies which describe streams, rivers or dams, (2) vegetation which includes agricultural, natural or forest land surfaces, (3) other mining activities which refers to any other mine in the surrounding areas except for the quarries, (4) granite quarries, (5) exposed geological rock formation, (6) built-up land and (7) barren land.

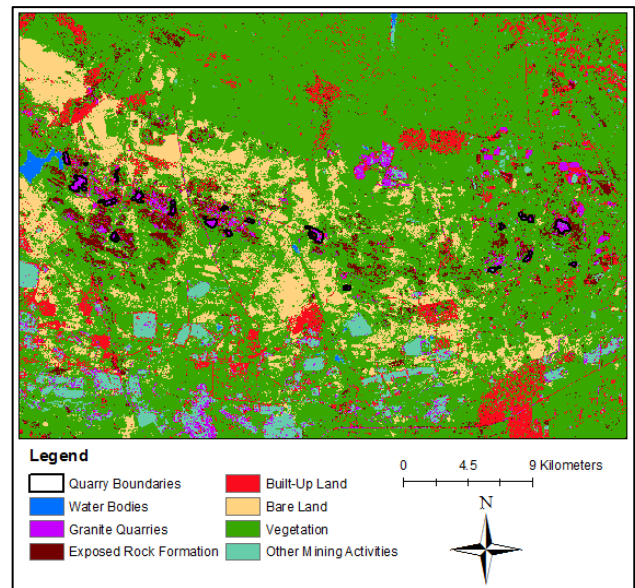


Figure 3: Supervised classified image of 2015

Accuracy assessment was carried out on the 2015 supervised classified image. The results based on 50 random points is presented in Figure 4. The Overall accuracy was 78%, while producer's and user's accuracies varied ~40-100% and ~50-100%, respectively (Figure 4). Kappa coefficient was 0.59, which according to Landis and Koch (1977) is a moderate strength of agreement.

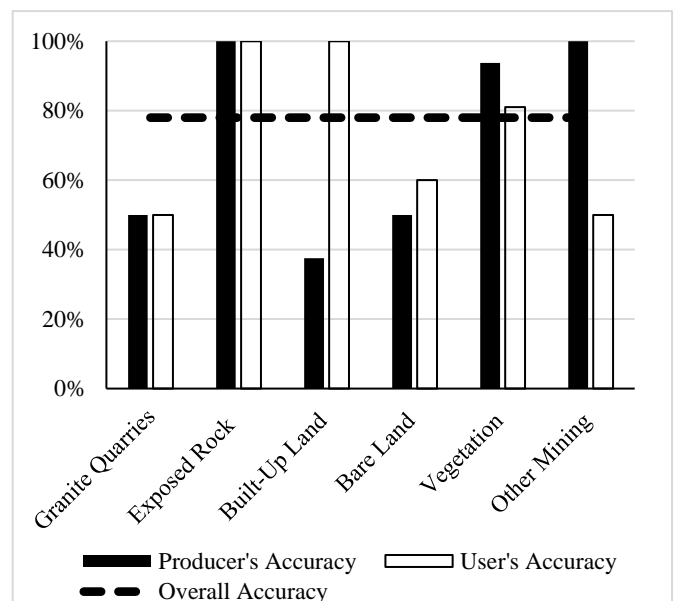


Figure 4: Accuracy assessment results

4.2 Change Detection

Figure 5 shows the difference in land cover in 1998 and 2015. In 1998 the land was covered mostly by vegetation and bare land while in 2015, the same area was covered mostly by granite quarries. Figure 6 shows a comparison between granite expansion from 1998 to 2015. It can clearly be seen from the 2015 image that the area covered by granite quarries has expanded relative to that in 1998.

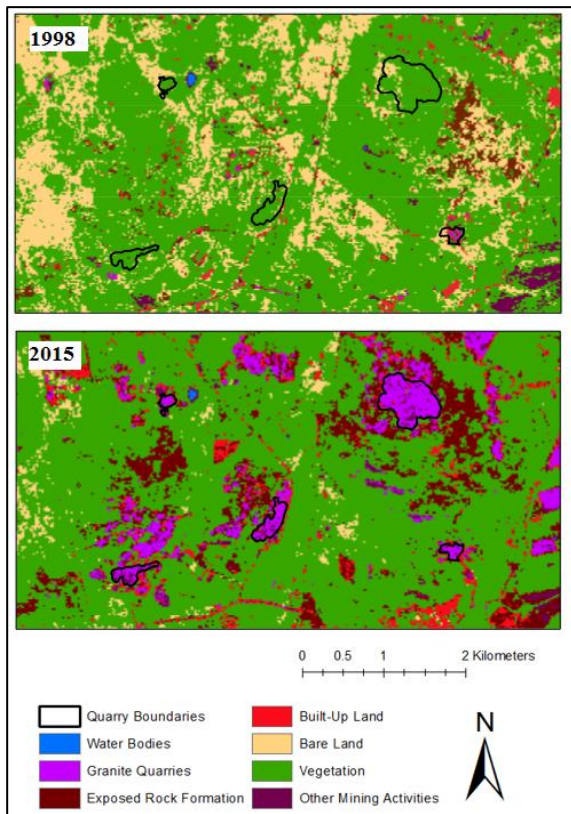


Figure 5: Supervised classified image showing the difference in land cover in 1998 and 2015.

The comparison of land cover status within the granite quarry boundaries in the year 1998 and 2015 is given in Table 2. A significant change from vegetation and bare land to granite quarries was observed. In addition to this, water bodies were also detected within granite quarries. These water bodies are the result of granitic rock excavations that quarry lakes and accumulate water from rainfall and surface flows.

Land cover in 1998	Land cover in 2015
Vegetation	Granite Quarries
Vegetation	Vegetation
Granite Quarries	Granite Quarries
Bare Land	Granite Quarries
Granite Quarries	Vegetation
Bare Land	Vegetation
Vegetation	Water Bodies
Granite Quarries	Water Bodies
Water Bodies	Water Bodies
Water Bodies	Granite Quarries
Bare Land	Bare Land
Granite Quarries	Bare Land
Vegetation	Bare Land

Table 2: Land cover comparison between 1998 and 2015 Images

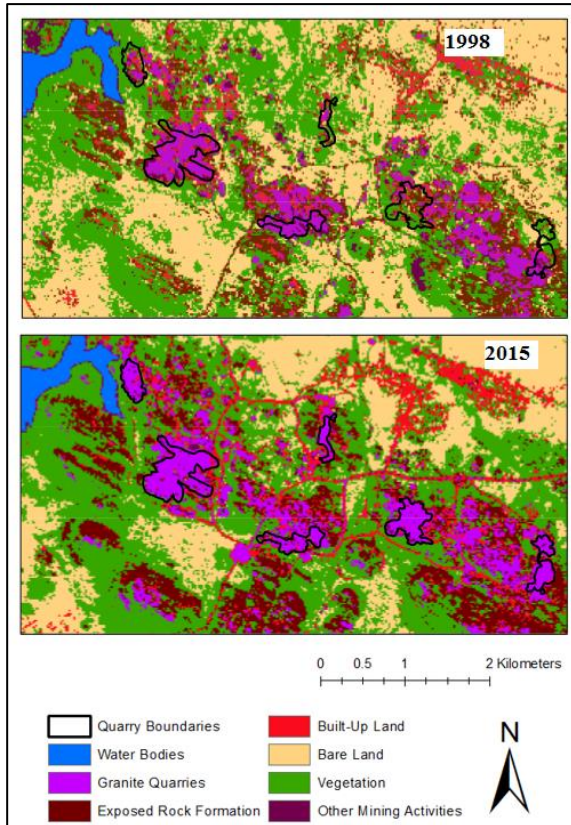


Figure 6: Supervised classified image showing the expansion of granite quarries from 1998 to 2015.

Figure 7 quantifies the difference in land cover change around granite quarries from 1998-2015. An increase of 5.3 ha in water bodies within granite quarries indicates formation of quarry lakes as quarries expand. There has been a considerable increase (approximately 1174.68 ha) in granite quarries from the year 1998-2015. The increase in quarrying activity led to a significant decrease in vegetation with the loss of close to 1308.24 ha in vegetation. Bare land, too, decreased with 18.36 ha around the quarry areas.

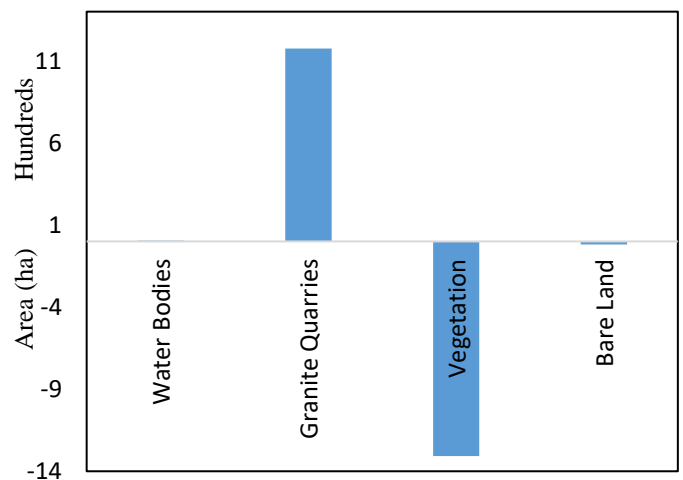


Figure 7: Land cover change (difference) over the period of 17 years around granite quarries

5. DISCUSSION

Assessment of land cover change within granite quarries is very useful in monitoring and quantifying the impacts quarrying has on the environment. Land cover change caused by granite quarries between Rustenburg and Brits towns were effectively mapped using two Landsat images of 1998 and 2015. Landsat was preferred for this study because of its advantages of availability of data at no cost, moderate spatial resolution, higher temporal resolution, large spatial extent and the availability of long historic datasets. Landsat images were classified using supervised classification, this method was favourable because trained classes were able to better differentiate between features with spectral similarities such as quarries, platinum mines and build-up land. Accuracy classification of the 2015 image is 78%. The Kappa statistics was 0.58. The results of accuracy were affected by spectral similarities between granite quarries, other mines in the study area such as platinum mines as well as build-up land. Similar studies of mapping stone quarrying using remote sensing made use of Landsat and ASTER dataset. Even though most of these studies did not report on the accuracy of their classification, Mouflis et al. (2008) obtained overall classification accuracy of 85.7% using object based classification on Landsat imagery for mapping expansion of marble quarries. Most studies however reported, the effectiveness of Landsat imagery to assess land cover change caused by stone quarrying. This observation was confirmed by our findings in this study.

6. CONCLUSION

The results obtained in this study demonstrated that remote sensing is a valuable tool in detecting land cover changes within granite quarries. Supervised classification was found favourable for this study as it could better differentiate features with similar spectral properties like build-up land, quarries and other mining areas when compared to unsupervised classification. There was a significant loss of vegetation and increase in granite quarries between the year 1998 and 2015. It can be concluded that granite quarries like any other mining activity, has the potential to impact the environment negatively.

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