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Original Paper

Application of Remote Sensing in Identifying and Mapping of Exposed Rock Massifs, Potential Quarry Sites in Yaounde-Cameroon

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Abstract

Since 2010, Cameroon opted for an aggressive mineral exploration in order to attain the status of an emerging country by 2035. Thus, any surface and sub-surface resources found important has to be valorised. This study therefore seeks to contribute towards the drive to an emerging nation initiative through the identification and mapping of exposed rock massifs in the city of Yaounde using Remote sensing techniques. The fieldwork constituted of locating the geographic coordinates of some rock outcrops with the GPS, projecting the samples on the a geo-referenced satellite image using GIS software (ArcGIS) and simulating the spectral behaviour of those spots to those of similar reflectance in order to conclude as the targets. This was then treated in GIS software for proper mapping to be done. The study revealed that Yaounde is actually endowed with enormous exposed rock massifs which can actually be valorised for construction works. Some of the exposed rocks are surrounded by vegetation especially at the outskirts of the city, others are actually engulfed within built-up areas with difficult accessibility while others could only be exposed on excavated areas for construction. Some are already under exploitation while others are not. Some of the rock outcrops were spotted of shallow extensions while others are small in surface areas but project deep down the soil. These results are of importance for use by quarry companies and the government of Cameroon through its Ministry of mines for onward allocation of exploitation permits.

Keywords

exposed rocks, quarry, remote sensing, spectral discrimination, Yaounde

1. Introduction

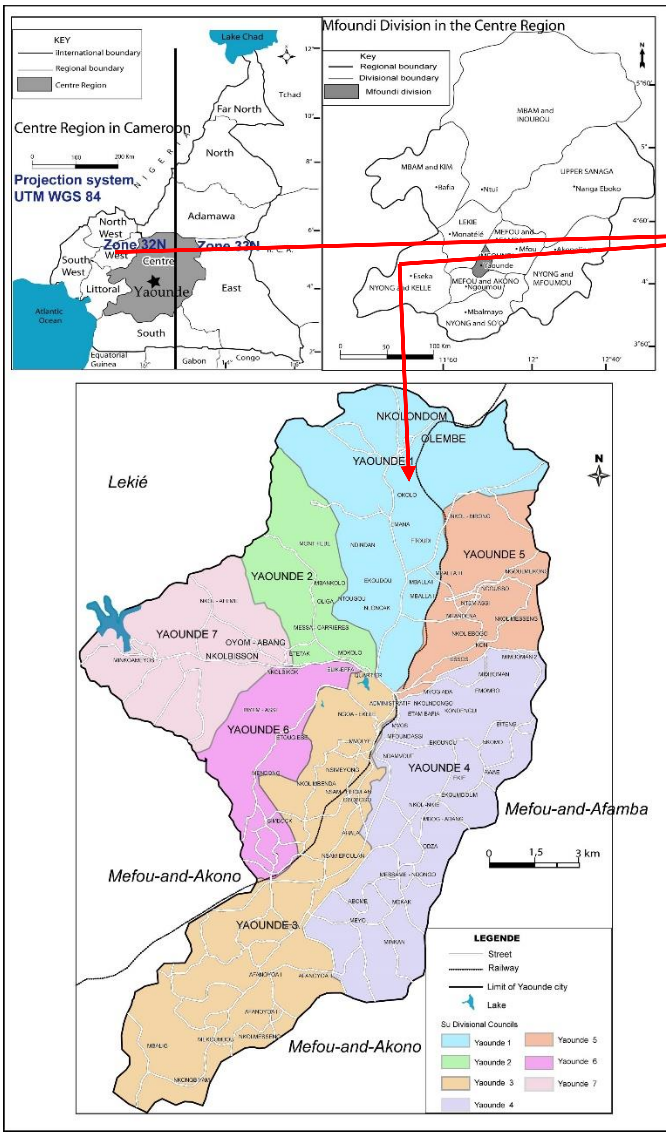
Aggregates resulting from the crushing of rocks constitute main construction materials throughout the world. These rocks sometimes remain intrusive or become extrusive by projecting to the surface that facilitate their identification for exploitation. Some countries are endowed with these resources while others are not. To this effect accords are signed for the exchange of certain resources between countries. This is the case between Cameroon and some south East Asian countries for exportation of fresh water sand. Such accords also exist between Niger and some European countries for export of uranium. For the case of uranium, they are mostly exposed to the extent that there is no need for techniques to be deployed for their identification. Their main use is to generate electricity rather than for construction.

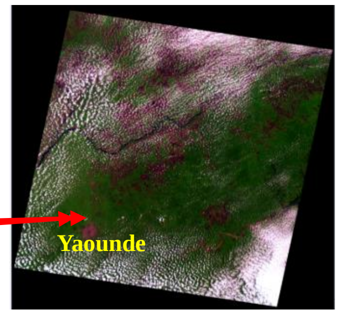
The rock outcrops that constitute the base of this study include gneiss, schist, amphibole, granite, quartzite and syenite. In parts of the Adamawa, West and North West Regions of Cameroon, the outcrops of these rocks cover extensive surfaces without any exploitation. This is simply because of the cost of transportation to the construction sites. According to the mining Code of Cameroon, any quarry company has to pay taxes to the local council area where the exploitation site is located. In the forested parts of the country, their limited surfaces of exposure is an indication of an extensive basement substratum and due to their proximity to major construction sites, most of them are under exploitation. This is the case of the massif around Limbe and Tombel both in the South West Region exploited by DANGOTE, a cement manufacturing enterprise based in Douala, the economic capital of the country. Those in Centre, Littoral and South Regions are mostly exploited by private quarry companies supplying to the major cities of Yaounde, Douala, Ebolowa, etc.

Rock massifs within the city of Yaounde, which constitute the target in the use of Remote Sensing in this study, can be considered as bare surfaces. Their spectral responses in the visible range from above 200 in Red, between 80 to 100 in Green and below 50 in the Blue. Some of the surfaces are dark but their exposure and resistance to weathering provides them with a coat, and depending on its inclination it develops a clear grey colour over the years that have high reflection properties thereby facilitating their identification using Remote Sensing techniques.

Since 2014, the Confederation of African Football (CAF) attributed the hosting rights of the African Football competition to Cameroon. Yaounde alone was programmed to host two pools thus the construction of a new stadium went underway. Apart from the stadium, new hotels were programmed for construction, old ones were to be renovated and expanded, new streets to be tarred, etc. thus justifying the high demand for quarry products. Furthermore, Yaounde is one of the fastest growing cities in Cameroon. From the last census, its population was about 1,800,000 inhabitants, this population today is estimated at about 2,700,000 inhabitants. Its spatial extension is presently estimated at 185km^2. In recent years, i.e., from 2012, two additional cement industries have gone operational in the country to supplement the lone one that exists since independence. It then became plausible to use remote sensing techniques to identify and map out all the rock massifs, potential sites for quarrying in order to satisfy the increasing demand this time around.

The city of Yaounde located within the Cameroon southern plateau stretches on longitudes 11°24’51’’ to 11°34’ 29’’ East of the Prime Meridian and on Latitudes 3°51’23’’ to 4°1’28’’ North of the Equator. Its average altitude is 760 metres above sea level constituting generally of elevated land that is surrounded by relatively lower altitudes. It is referred to as a city of 7 hills that have long passed to 11 hills due to its rapid expansion. Figure 1 locates the city within the administrative setup of Cameroon and on a Landsat image.





Yaounde as seen on Landsat satellite image scene

Figure 1. Location of Yaounde in Cameroon and on Landast Image

2. Methods and Techniques

2.1 Data Collection

This study which aims at identifying with various techniques and mapping of the rock massifs in Yaounde depended on the following data obtained through respective tools. The data was then treated in order to obtain the expected results.

- Landsat 8 satellite image downloaded from the Internet on which digital prospection of the rock outcrops was effectuated;
- Geo-referenced IKONOS image of Yaounde of 1 m resolution from where all the streets were drawn;
- GPS eTrex 10 with a precision level of 3 m with which some samples of rock outcrops were located to be projected on the geo-referenced Landsat image;
- A computer whose characteristics could enable the handling of Remote Sensing and GIS processing of data. Thus this mostly concerned the RAM which is 4 GB, capacity of 500 GB of the hard disc;
- Topographic map of Yaounde at scale of 1/200 000 obtained from the National Institute of Cartography which served in orientating the movement for the registration of rock outcrop samples using the GPS;
- Remote Sensing software (ENVI) where the processing of the Landsat image was carried out;
- Official Vector files for Cameroon obtained from the National Institute of Cartography which served in the location and delimitation of the study area;
- GIS software (ArcGIS), where geo-referenced shapefiles for Cameroon were treated and the samples projected.

The choice of the Landsat satellite image is simply because it is of multi-band and multi-date. It has a low resolution of 30 m whose scene covers a surface of 185x185 km. It is well adapted in assessing large surface phenomena and since Yaounde is so vast horizontally, about 183.5 km^2, it is for this reason it constituted the choice of this study.

2.2 Data Treatment

To pre-treat the image, and given the fact that Landsat image has 7 bands, a band combination was determined at 5, 4, 3 bands that provided a coloured image. Geometrically, the scene was resized to extract the zone of interest at the size of 700x1130 pixels as shown on Figure 3. The image was then opened in ArcGIS software and following the projection system that Cameroon conforms to (UTM WGS 84, zone 32 North), the sample rock massifs located with GPS during fieldwork were projected in order to determine their spectral behaviour of the targeted zones (Figure 4). This then acted as guide to do image interpretation and determine the rest of the rock massifs in Yaounde. Figure 2 shows a flow chart on how data was collected from the field.

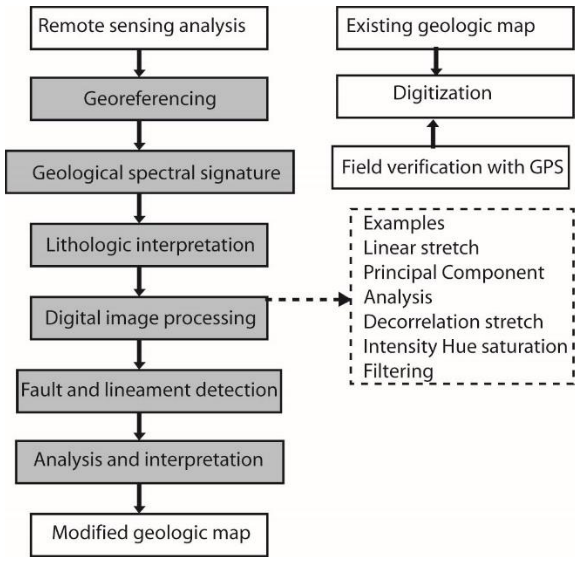


Figure 2. Flow Chart of Data Collection and Treatment

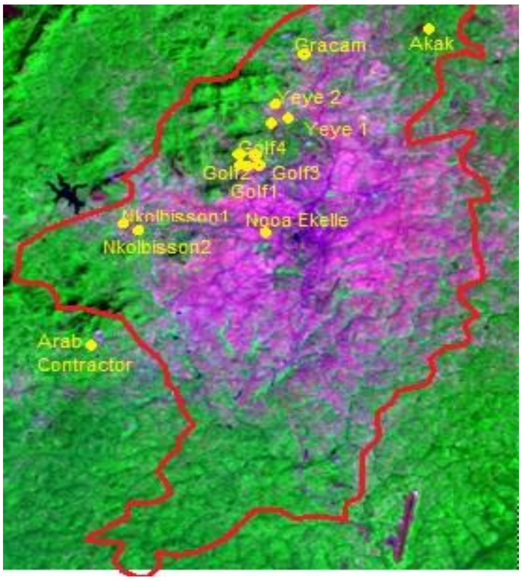


Figure 3. Resized Image from Scene p185r057 of Landsat with Projected Vector Layer of Yaounde and Sampled Rocks

Computer Assisted image interpretation was carried out using iteration techniques comprising of direct and indirect clues such as general geologic setting, alteration zones, associated rocks, structure, lineaments, oxidation products, morphology, drainage and vegetation anomaly, since only rarely is it possible to directly pinpoint the occurrence and mineralogy of a deposit based solely on remote sensing data. Locating exposed rocks relies primarily on knowledge of the general geological makeup of the area. Therefore, a little basic landform geomorphology about the assumptions of rock exposures is relevant.

To evaluate the different aspects of the application of remote sensing in identifying and mapping of rock massifs in Yaounde, the approach focused on the lithological, structural and alteration mapping. Emphasis was on multispectral analysis as such data can help identify and thematically map out areas of specific themes as is our case of rock massif exposures. To effectively carry this out, we relied on multi-thematic approach thus combing GIS to Remote sensing as they helped in analysing large number of spatial data with different attributes and formats in sub-setting the areas of interest where rocks outcrop.

After effectuating unsupervised classification to determine the number classes that make up the image, sampling was done. This sampling did not take into consideration all the classes as revealed by the unsupervised classification. Taking the rock massifs as the target, the rest of the classes were ignored. The supervised classification using band 5 was that of maximum likelihood. Drone images were complimented in order to validate the samples collected during fieldwork as shown on figure 4.

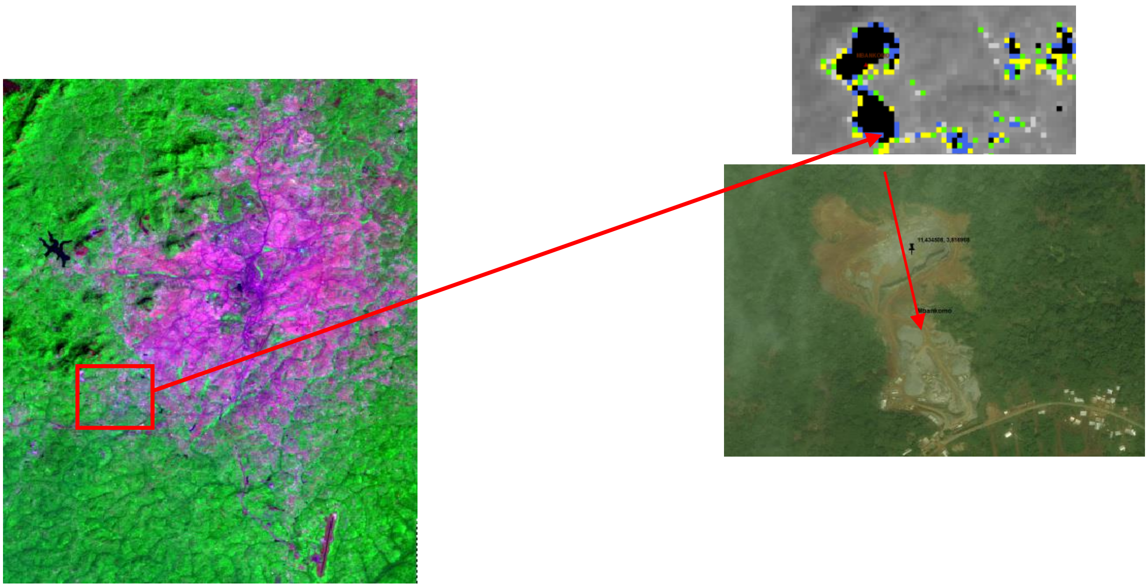


Figure 4. Procedure in Sampling and Validating Rock Massif Samples with Drone Image

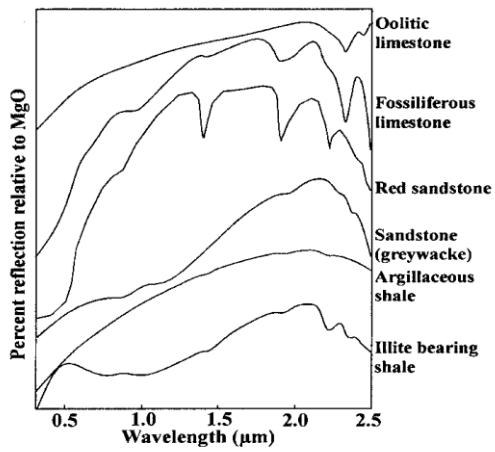
3. Results

3.1 Spectral Signatures of Rocks

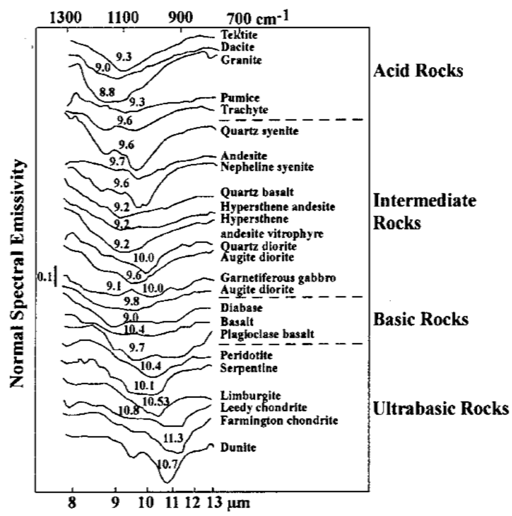
Many studies have been conducted in the identification and mapping of rocks from satellite image analysis. This has mostly been in the visible short-wave infrared, mid-infrared and thermal infrared intervals. This establishes the scientific background for the interpretation of remotely sensed data. It should be noted that exposed rock surfaces give an insight into the relationship between original rock and superficial alteration products, allowing the development of reconnaissance criteria that may also be applied in other areas with similar environmental conditions.

It has long been known that rocks can be distinguished from each other under ideal conditions by their spectral signatures in the thermal emission region of the spectrum (Lahren et al., 1998; Sabine et al., 1994). In general, the dominating features in sedimentary rocks are due to the additional presence of carbonate which produce absorption bands between 1.9 and 2.3 m (Figures 5 a, b and c). All sedimentary rocks generally have water absorption bands at 1.4 and 1.9 m while clay shales have an additional absorption feature at 2.1-2.3m. The similarity of the spectra for a class of rocks, such as granite allows a composite signature to be generated which can be used as a representative for all granites. The broad absorption due to ferrous ion is prominent in rocks such as schists. Water and hydroxyl bands are found in schists, marble and quartz (Hunt & Salisbury, 1976). Basing on laboratory experiments, Figure 10 confirms that rocks possesses the potential to be classified from airborne to satellite sensor data if sufficient spectral detail is generated. Photo 1 illustrates the exposed rocks in some parts of Yaounde.

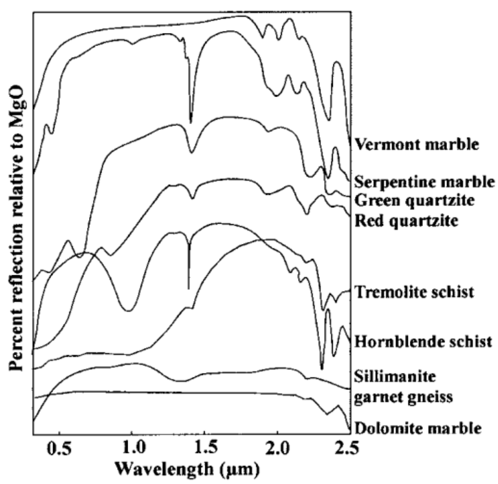
Photo 1. Exposed Rock at Mbankolo Hill (11°31’27”/3°47’23”)



a) Reflectance of Sedimentary Rocks



b) Thermal Infrared Transmission of Igneous Rocks



c) Reflectance of Metamorphic Rocks

Figure 5. Spectral Behaviour of Rocks at Different Wavelengths of the Spectrum

3.2 Sampled Rocks Projected

Basing on this scientific context, the classification of the Landsat image enabled us to discriminate between zones of high concentration of exposed rocks and those of low concentration. Furthermore, this discrimination also took into consideration bare ground, rock surfaces, roof tops of various colours and quarry sites. In the sampling process, three types of pixels could be identified in the classes of 32, 33 and 34 which all correspond to areas of bare ground with very little vegetation. These could either be built areas or areas susceptible to be exposed rock massifs. From this step, the radiometric amelioration through interactive stretching enabled us to discriminate between exposed rock massifs from the rest of similar spectral behaviour. Table 1 shows the samples of the exposed rocks collected from the field while Figure 6 shows the projection of these points on a geo-referenced high resolution IKONOS satellite image covering Yaounde.

Table 1. Samples of Exposed Rocks Registered with the GPS within Yaounde

No.	Place	X (in UTM metres)	Y (in UTM metres)
1	Ngoa Ekelle	777905,34	426436,28
2	Gracam	778510,35	438564,41
3	Yeye 1	777296	435663,82
4	Yeye 2	777308,14	436359,57
5	Golf 1	777083,81	430905,08
6	Golf 2	777132,4	430972,38
7	Golf 3	777070,38	431012,91
8	Golf 4	777110,79	431101,66
9	Nkolbisson1	771780,51	426646,62
10	Nkolbisson2	770953,54	426634,73
11	Arab Constructors	770384,1	422271,84
12	Akak	784648,78	441305,78

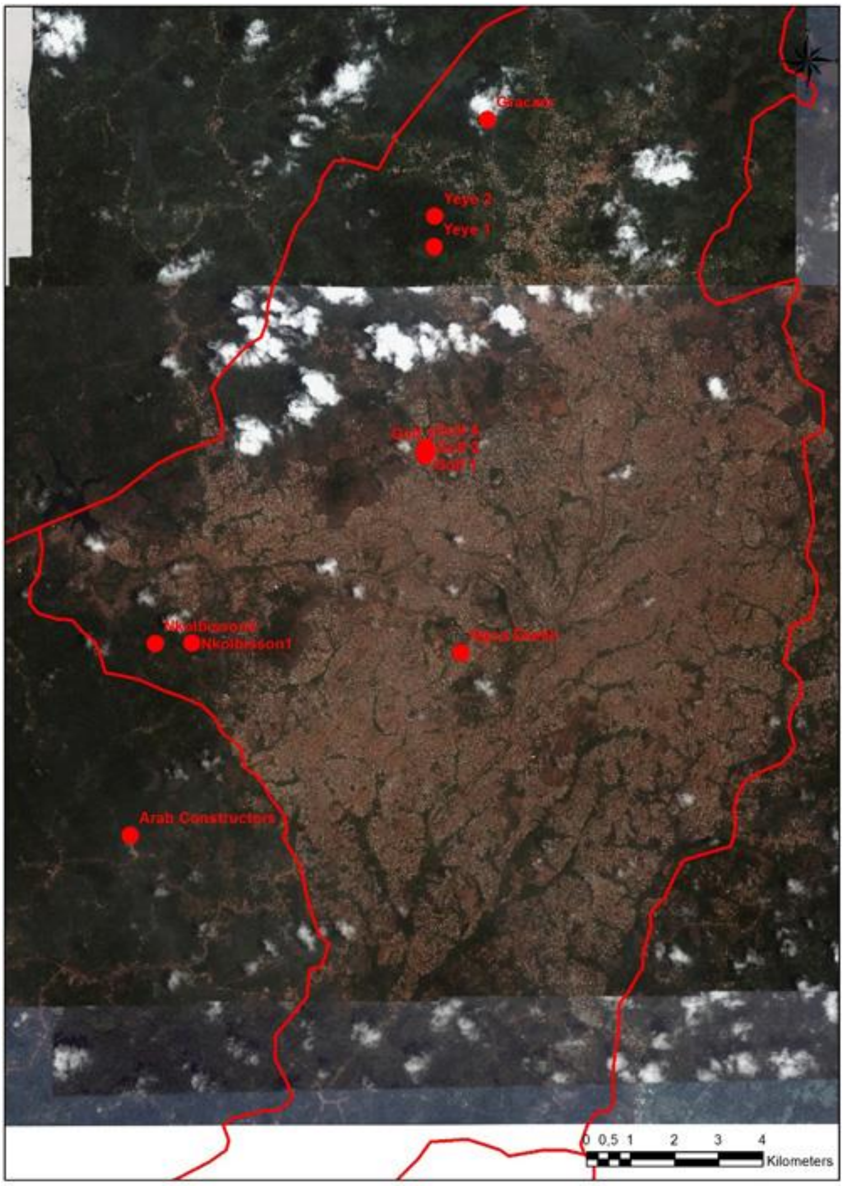


Figure 6. Projected Verification Points on a Geo-Referenced Satellite Image

Using band 5 of Landsat TM that ranges from 0,845-0,885μm wavelength of the spectrum, the colours of green, blue and yellow on the image represent the pixels retained to indicate the exposure of rock massif which are either quarries under exploitation or not. It is noticed that these colours surround black spots on the image; these black spots were determined to be either bare ground, exposed rock, roof of houses, burnt areas or other esplanades without vegetation. Discrimination had to be effectuated to isolate exposed rocks from the rest of similar spectral behaviour through filtering and interactive stretching (Figure 7).

On Figure 8, the surrounding grey colour indicates vegetation and for the case of Yaounde and its environs, this is forest vegetation. The green colour indicates cleared surfaces especially around dwellings, in some cases showing some coloured roof tops. The blue colour shows water or wet surfaces. At the particular moment when the image was acquired, i.e., during the dry season, this indicates dry wet surfaces. The yellow colour mostly indicates houses or plots under construction. Finally the black colour indicates rock outcrops as revealed by field investigations.

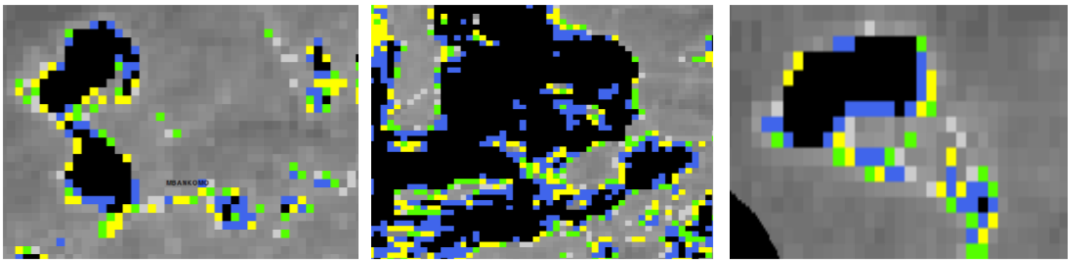


Figure 7. Presentation of Pixels Potential Representation of Exposed Rocks

Photo 1. Exposed Unexploited Rock in Built Up Area

Photo 2. Arab Contractors Quarry Site

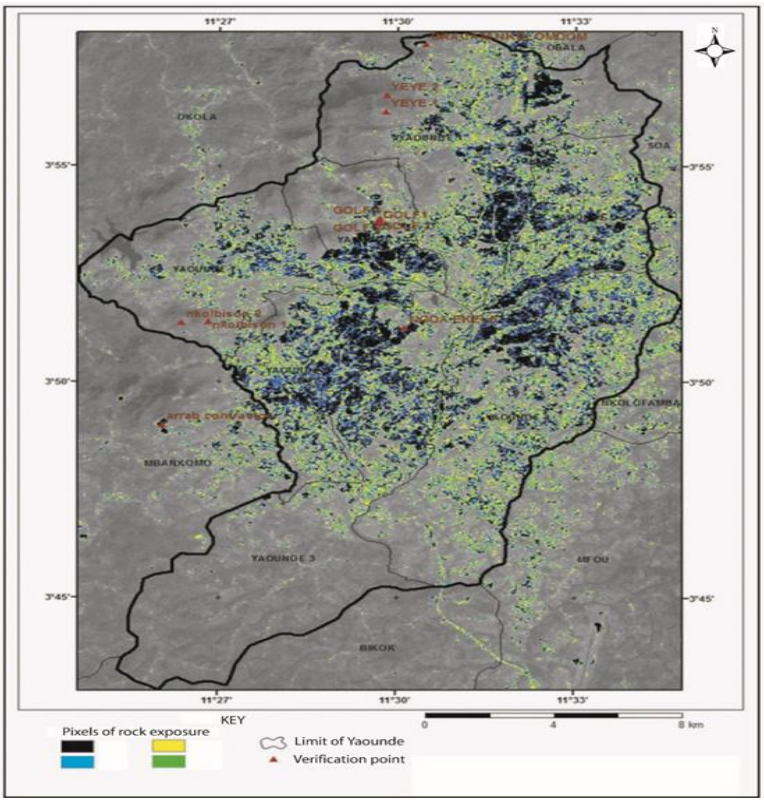


Figure 8. Classified Image of Yaounde with the Use of Band 5 Landsat TM

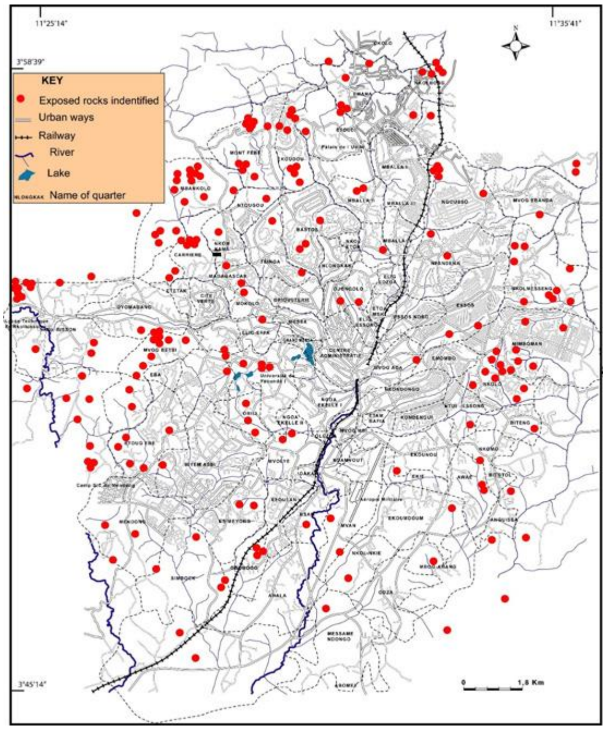


Figure 9. Exposed Rock Massifs in Yaounde

4. Analysis

4.1 Clues to Lithological Mapping

Satellite images provide a broad based clue through which lithological information can be deduced. This lithological information includes general geologic setting, weathering/landform, drainage, structural features, soil, vegetation and spectral characteristics. In the case of sedimentary rocks for example, especially those exposed at hillsides or sloppy areas, or by folding and faulting as is the case of Mount Mbankolo in the NW of Yaounde, bedding is one of the strongest clues to lithological composition in images. These linear features are long and even spaced, fewer in number (in comparison to those produced by foliation in metamorphic rocks) and constitute rather continuous ridges and valleys.

Another clue that led to the identification of exposed rock massifs in Yaounde are the drainage density, drainage pattern and vegetation, even when the rocks are not exposed. Yaounde being in a humid tropical forest with humid climate, the main clue to the presence of sandstone is the wide spacing of drainage and the roundness of topography. It should be noted that intrusive igneous rocks are generally massive, isotropic and homogenous which can easily be observed on satellite images. Their shapes (batholiths, laccoliths, dykes, sills, etc.), dimension, distinct image tones and topography expression also contribute to their identification.

In the case where our focus was on extrusive rocks especially those of igneous type (potential quarry sites), they could easily be delineated by distinctive landforms, differences in image tone, drainage pattern and vegetation distribution. In closely integrating them with surrounding sedimentary strata, intrusive igneous rocks were more subtly expressed than extrusive rocks. Landsat images thus provided a suitable platform in the identification and mapping of these exposed rock massifs.

4.2 Clues to Structural Mapping

Linear features can easily be identified on aerial photographs since they are often at larger scale. But these linear features are poorly seen on Landsat image. We are not saying that exposed rocks are considered as linear features here but that linear features act as clues to the presence of exposed rock massifs. Linear features indicate the form and position of folds, joints, faults, lithological contacts and other geologic features that may lead to the presence of exposed rocks. In general they indicate only immediate surface and near-surface conditions and are poor guides to concealed deposits. In Yaounde one cannot find linear features that exceed 5 km, though most are short, less concentrated and spaced, they indicate the geometry of faults and other structures thereby providing a local structural pattern. They are useful in defining the target areas, local settings on which they may indicate exposed rocks but this has to be complimented by detailed field studies. Some linear patterns provide the most favourable conditions for the presence of exposed rocks. These are the abandoned excavated escarpment quarry at Ngoa Ekelle neighbourhood, the exposed rock surfaces at the slopes of Mount Mbankolo (Golf area), the isolated rock domes in Bastos quarter, the rock surface of Gracam and Nkolbisson just to name but a few.

Before the image analysis, topographic map of Yaounde at scale 1/200 000 provided the basis of reconnaissance for structural mapping. This optimized planning for fieldwork. But some difficulties were faced in integrating lineament map with exposed rock model as some of the features mapped as lineaments could not indicate the presence of exposed rocks. Basing on studies conducted by Akhavi et al. (2001), they integrated lineament structures derived from Landsat images with a dataset of known occurrences in GIS in order to better comprehend the exposed features. Takir et al. (1999) correlated lineament intersection density to alteration and observed that lineament intersection density is nearly twice as dense as altered zones. It is only through this multi-technique approach that gained validity in the determination of exposed rocks in Yaounde.

4.3 Clues to Alteration Mapping

Remote sensing techniques have proven the feasibility to detect particular surface phenomena no matter the image used. But such techniques have differences in areas of application. For example it becomes more complex in built-up areas unlike in un-built areas. It should be noted that properties of some exposed rocks present diagnostic spectral features that enable their remote identification. It is certain weathering processes expose some surfaces such as hydrothermal alteration processes and mask the spectral response of underlying rocks with coatings. Hence, it becomes imperative that field verification was performed in order to validate the existence of such rocks in certain areas of the city.

The colour of the rocks played a key role in their identification. Following the analysis of Buckingham and Sober (1983), when iron oxides are present in a rock, the rock colour can be red, brown, orange or yellow. On the other hand, if there are clay minerals, we have pale colours of yellow, violet, green, and beige.

Landsat TM stood as the base data for treatment because of the availability of mid-infrared bands in which the characteristic spectral features of most hydrothermal minerals are present. After the traditional band combination was effectuated, index analysis was performed which include bands 5 and 7 (clay mineral index), bands 3 and 1 (iron oxide index), and bands 5 and 4 (ferrous index). This index analysis discriminated between weathered and un-weathered rocks.

Given the fact that the detection of the exposed rocks was in a built-up area which posed as a handicap to Landsat treatment, radiometric enhancement was applied as earlier proposed by Fraser and Green (1987). In this application, there were difficulties due to the similarities in the reflectance spectra of the rocks. Thus, the effect of roof tops, other bare surfaces and esplanades could be discriminated.

5. Discussion

Identification and mapping methods adopted by geo-engineers mostly focus on identifying anomalies that are associated with the target areas. Such methods are complex and they need both analysis and integration of multi-thematic information which aid for decision taking over time and at different stages. This justifies why GIS had to be integrated into this study. Its usefulness is based on the fact that it was possible to analyse the large number of geo-referenced spatial data with different attributes and formats. Target sites could be located following their geographic coordinates, distances from reference spots in the city to target sites easily determined thus establishing their accessibility and possibility to evaluate the surfaces covered by some of the exposed rocks. All these activities were possible thanks to the use of the GIS, which did not only provide a geo-referenced surface but also registered exposed rock surfaces with the GPS were project for sampling to be done. An interactive database could be developed which greatly facilitated access to information from each exposed rock in the city of Yaounde.

Apart from the above, the developed database for this study can be projected over a time interval in order to assess the level of exposed rock exploitation certainly noticed if some of the surfaces are occupied by other phenomena. This data can equally be generated on other remote sensing data, geophysical data, geochemical data, geological data (structural, lithological), topographic data (DEM) and perhaps mineral occurrence data for other analysis. This has the possibility of combining relational database and spatial data analysis though it was not the focus of this study.

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