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Full Length Research Paper

Neotectonic belts, remote sensing and groundwater potentials in the Eastern Cape Province, South Africa

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The Eastern Cape Province is surrounded by three major neotectonic belts (south, east and north). Each one of these neotectonic belts has its own particularities. This study aims at characterizing and targeting potentially high yield aquifers in the neotectonic zones in the Eastern Cape Province. The methods used in this study include a comprehensive literature review, examination of digital elevation models and extraction of lineaments through remote sensing. The results indicate the following: 1) the eastern neotectonic belt has a higher density of lineaments oriented NW-SE, which makes it the second important neotectonic belt; these lineaments correlate with the normalized difference vegetation index indicative of a good circulation of groundwater; 2) the surface topography is not uniform, high elevations in the east are related to the uplift that took place in the Quaternary, most vector gradients are oriented E-W; 3) in the south the Eastern Cape great lineament oriented E-W is now considered a neotectonic domain because of many seismic epicenters that occur therein, its geomorphologic shape in a graben type form is a favourable structure for groundwater catchment. This project has given fundemental highlights to characterize the major and potential good yield aquifers in the Eastern Cape Province in south Africa.

Key words: Neotectonics, groundwater, lineament, remote sensing, hot spring, uplift.

INTRODUCTION

Three neotectonic belts almost surround the Eastern Cape Province in South Africa (south, east and north near the country of Lesotho (Figure 1). If the eastern neotectonic belt was qualified as the high level neotectonic domain through remote sensing in terms of abundance of lineaments, a careful examination on the term "neotectonics" would undoubtedly indicate that the true neotectonics occurs in the northern part of the Eastern Cape province near the country of Lesotho. First, this region is located in the Kokstad-Koffiefontein seismic belt that runs in an east-west direction; second, seven hot springs (Figure 2) are present in this remarkable seismic belt of South Africa, near the border with the country of Lesotho.

Another important thing is that in the Kokstad-Koffiefontein seismic belt (Figure 3), in the town of Smithfield near Aliwal North, the local power station might have been built on an active fault, and the Orange River tunnel intersected with much pain a huge aquifer that flooded the place.

In the Eastern Cape northern neotectonic belt, Olivier (1975) found that in the Orange-Fish tunnel flooding occurred after an abnormally well developed fissure-zone was intersected approximately 550 m south of the shaft 2. The inrush of water was associated with the collapse of the tunnel roof, as part of the roof major fissure was exposed by the fateful blast. He noted however that influence of earthquakes on the pattern of semi-diurnal tidal

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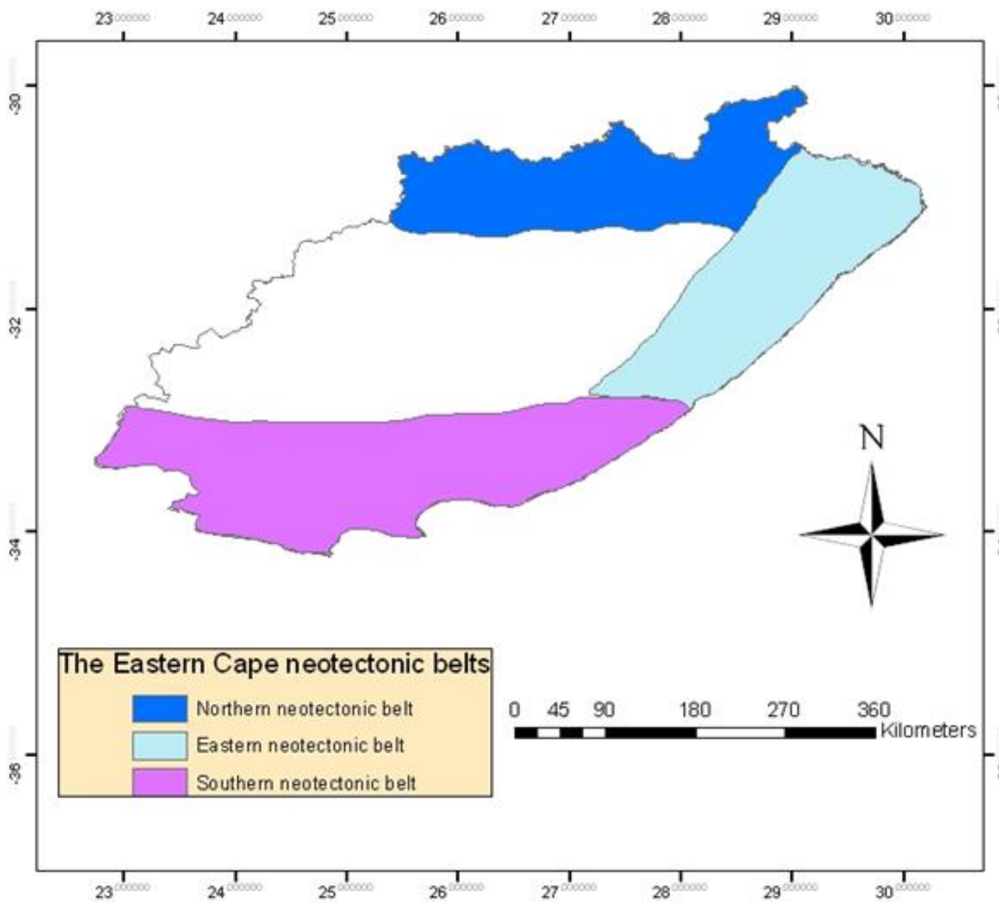

Figure 1. The Eastern Cape neotectonic belts.

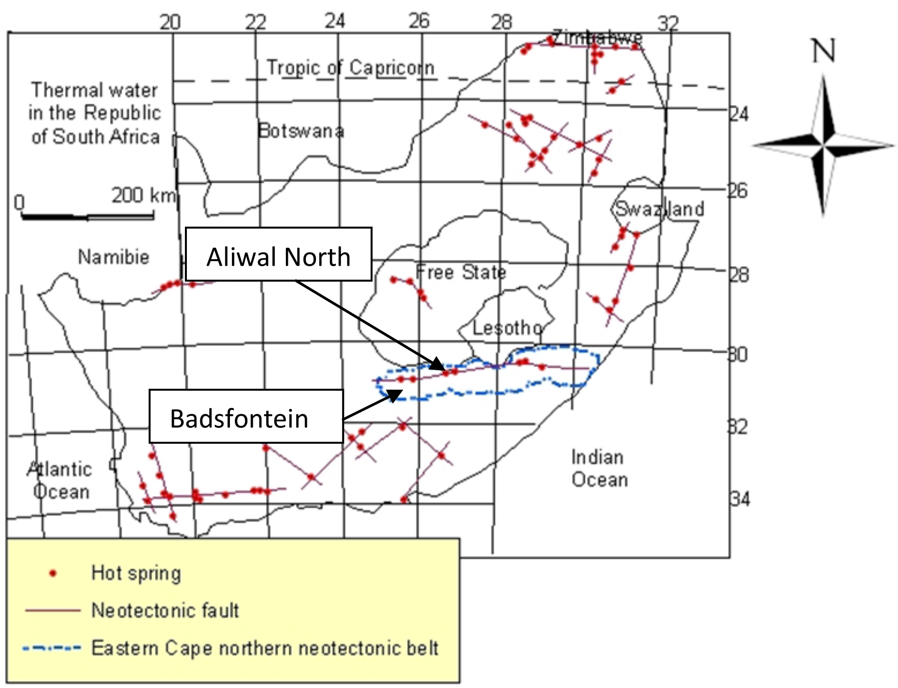

Figure 2. Hot springs in the Republic of South Africa.

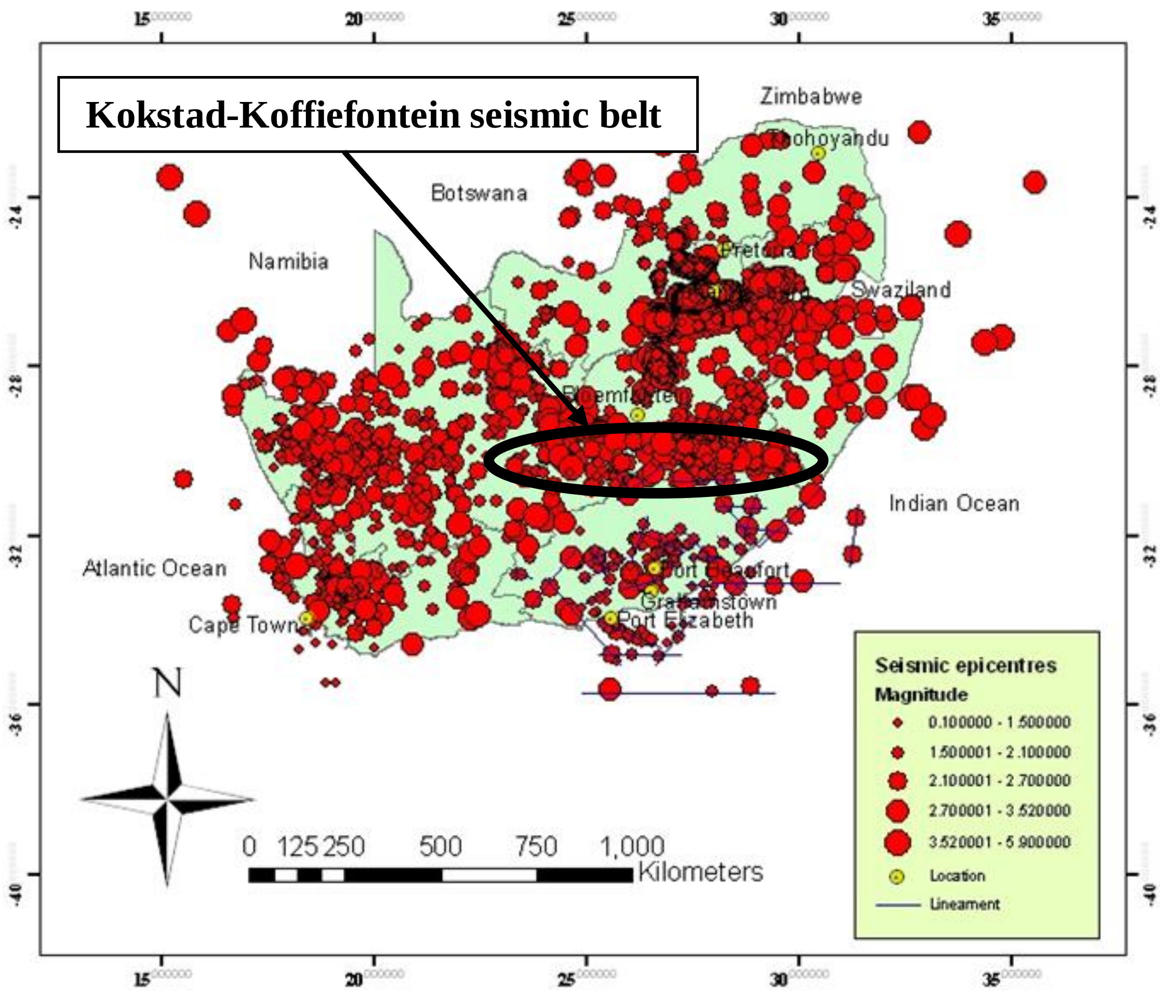

Figure 3. Seismic epicenters of new events in South Africa. Source of data: IRIS Earthquake Browser.

fluctuations is of special interest as regards the flooding problem. The flow of the central thermal spring, on the Badsfontein increased markedly for a period of at least 3 months after a local earthquake was felt during August 1956 (Whittingham of Geological Survey, personal communication, 1970).

During the Ceres-Tulbagh earthquake disaster of 1969 in the Western Province, tremors affected the tunnel area; displacements of 3, 4.6 and 7.6 cm on the graphs in some boreholes after some earthquakes of magnitude 6.5 and 6.2 in 1969 and 1970 were noted. This neotectonic belt is for the above mentioned facts, one of the zones of potentially high yield wells in the Karoo aquifers in the Eastern Cape Province.

In the southern neotectonic belt, the Coega Bavianskloof Fault (CBF) in the Cape Province has reactivated fault scarps that are, in some places, between 2 to 4 m high. The Worcester fault lies south of the CBF, with similar strike and orientation as the CBF, and extends toward the Ceres cluster (Bejaichund et al., 2009); a striking neotectonic activity is the one that occurs in the eastern neotectonic belt, which is mainly characterized by the spectacular uplift from Swaziland to Amatole (Ciskei) in a NNE-SSW trend parallel to the coast line. Artyushkov and Hofmann (1986) mentioned that intensive crustal uplift (Figure 4) began in South Africa in the Oligocene period affecting most of the continental areas after a long period of relative stability. They also indicated that this neotectonic uplift formed most of the positive topographic features on the continent. In southern Africa, the uplift took place in the early Miocene (up to 300 m) and in the late Pliocene and Pleistocene (up to 900 m) with no stretching or shortening of the crust; this is indicative of a plume material in some regions that ascended from below and rapidly spread along the base of the lithosphere and eroded the mantle lithosphere in vast areas beneath the continents. In regions with hot asthenosphere, a strong weakening of the mantle lithosphere which allows its erosion can be associated with the high temperature of

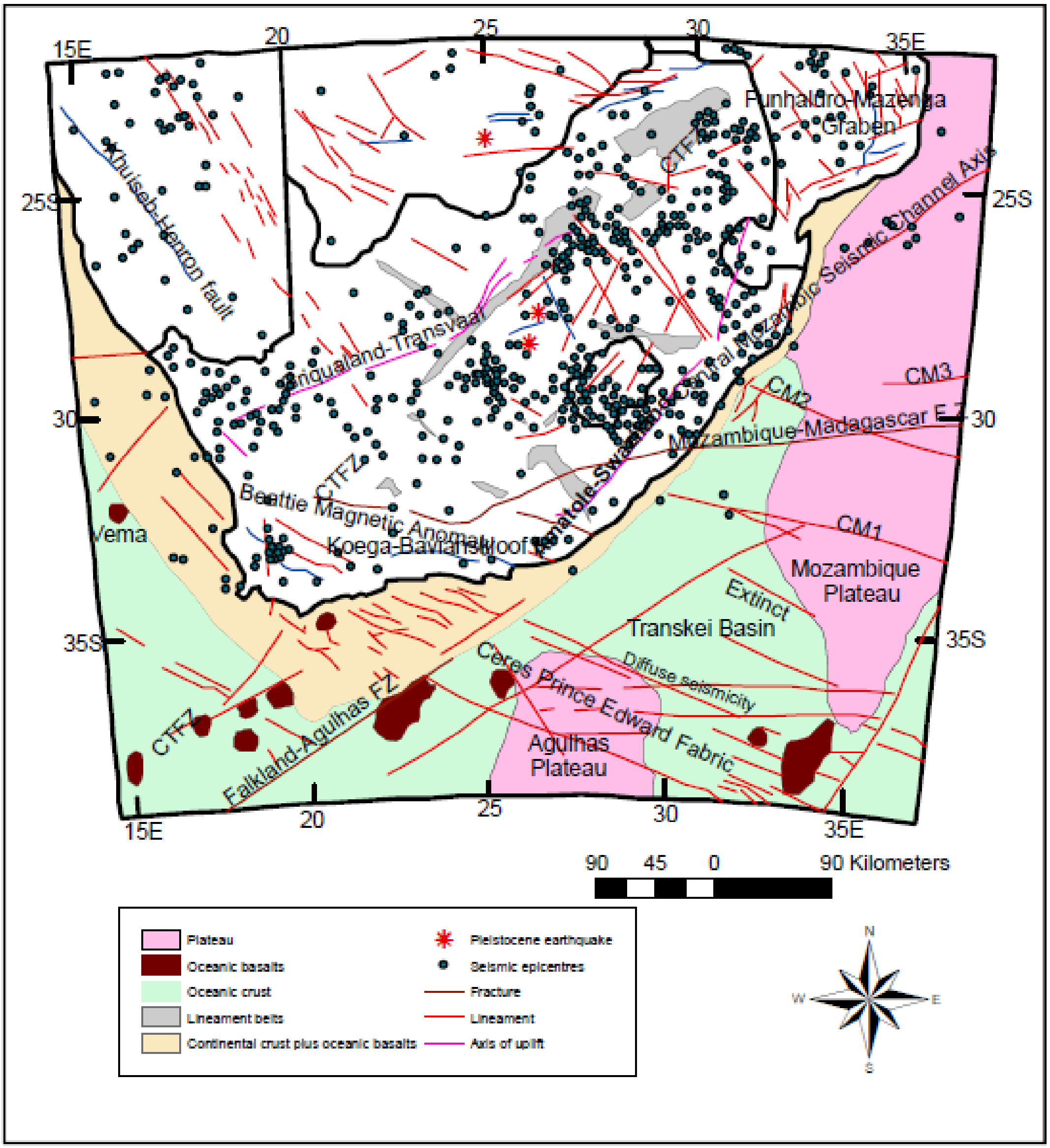

Figure 4. Seismic epicentres in relation to the post-Karoo tectonic framework of South Africa and nearby regions (Andreoli et al., 1996).

the plume material. In regions where the asthenosphere is at moderate temperature, weakening of the mantle lithosphere can result from infiltration of volatiles from the plume material.

Dobson et al. (2010) proposed three competing evolutionary models for the uplift: (1) the major phase of uplift occurred in the late Cretaceous, (2) the major phase of uplift occurred at ~30 Ma, and (3) ~ 900 m of the modern topography being generated rapidly 100 m/Ma in the Plio-Pleistocene (c. 3 Ma). This uplift is controlled by the NNE-SSW trending Miocene-Pliocene Griqualand-Transvaal related to the subsidence of the Kalahari basin (T. Partridge, Personal Communication, 2007) and Amathole-Swaziland (formerly Ciskei-Swaziland) uplift (Figure 4) axes that stretch across almost the whole South Africa – Swaziland region (Partridge and Maude, 2000), and the uplift may be related to horizontal compressive stress. This uplift would have caused most of the rivers to flow toward the Atlantic Ocean, and for Eastern Cape towards the Indian Ocean (Esterhuizen, 2008); it is associated with numerous thermal springs and spas. Maouche et al. (2013) for instance reported that Quaternary and Pliocene travertines, deposited from hot springs, can reveal much about neotectonic and hydrothermal activity from their studies in the Guelma Basin in Algeria.

Remote sensing has been used in many disciplines as a cost effective tool through study of satellite images, especially in groundwater, gas and oil exploration. Geological interpretation derived from remote sensing has been extensively used for the purpose of identification of lineaments and fractured zones along which flow of groundwater may take place.

Mohamed (2010) indicated that the surface lineaments are in parallelism with the subsurface basement fault. Ölgen (2004) stated that Earh scientists have been interested in linear features on the earth's crust since the early period of each observation. Elmahdy and Mohamed (2012) highlighted that lineaments are features that represent pass ways for groundwater accumulation, groundwater discharge and seawater intrusion into coastal and inland aquifers. Burnett (2011) pointed out that lineaments and surface dips are useful for locating trapped groundwater. Contes and Carla (2011) used remote sensing in Puerto Rico, and found that geomorphic data agrees with lineaments as faulting and fracturing in addition to linear bedding control features. Moreover, Ali et al. (2012) mentioned that remote sensing has been used in geology for lithological discrimination of different rock types and delineation of geological and structural features.

Satellite images provide quick and useful baseline information on the parameters controlling the occurrence and movement of groundwater like geology, lithology/ structural, geomorphology, soils, land use, lineaments (for example, Mogaji et al., 2011). Raghou highlighted that the use of satellite remote sensing for groundwater exploration is an established procedures which has a long pedigree, and is a powerful means to target potential groundwater resources. This study was conducted in the Eastern Cape neotectonic belts using satellite imagery, and was aimed at extracting lineaments in order to find zones of high density lineaments that can be used for groundwater exploration. High density lineament zones can also be used while considering environmental issues; nuclear wastes dump sites can be placed in zones not affected by high seismicity and high density lineaments in order to avoid groundwater contamination.

METHODOLOGY

Satellite images (Landsat 4-5 TM) were chosen because they offer good scenes that can be exploited from remote sensing in order to extract linear features. They were downloaded for free from Glovis (Global Visualization View), USGS website by a selection of rows and paths. The scenes were already processed only with systematic correction (Level 1G) due to processing constraints. The systematic correction (Level 1G) provides radiometric and geometric accuracy. Different scenes covering the three neotectonic belts (south, east and north) plus the central inactive zone were used for lineament extraction in ENVI 4.8. Enhancement of images was done in different stages as follows:

1. Linear interactive stretching
2. Smoothing using Median filter 3x3
3. Edge detection using Sobel filter

Images were processed using the Sobel operator with non editable kernels. Georeferenced processed images were then exported to Arc Map for lineament editing. After editing the lineaments, rose diagrams were produced using the Rose Plot 4.0, some scenes were then chosen due to their lineament density for Normalized Difference Vegetation Index (NDVI) in regions where major focus can give directions for groundwater exploration. In order to have a clue on the water flow direction, samples of Digital Elevation Models from each neotectonic belt were selected with associated grids, the southern neotectonic belt with grid 3327, the eastern neotectonic belt with grid 3228, and the northern neotectonic belt with grid 3028. Digital Elevation Models acquired from the National Geo-Spatial Information in the Western Cape (www.cdsm.gov.za) were in excel format (X, Y and Z) with coordinates in WGS84 datum, Hartebeestoek 94 reference system. Samples for each one of these grids were plotted using the Surfer 10 software in order to depict the possible predominant water flow direction and to see the elevation in meters; first the surface topography was plotted, followed by the contour lines and finally the vector gradients. They were then overlayed in order to produce a graphic representation in 3D.

RESULTS

Lineament extraction procedure adopted for this study

Smoothing filter

Smoothing filters are also called low-pass filters because they let low frequency components pass and reduce the high frequency component. The impulse response of a normal low-pass filter implies that all the coefficients of the mask should be positive. One has to bear in mind that low-pass filtering blurs the image and removes speckles of high frequency noise; on the other hand, larger masks will definitely result in noise blurring effect. The parametric low-pass filter is given by a 3x3 kernel where the coefficients are determined by a factor b; when b is equal to 1 the parametric low filter is equal to a mean filter. In Figure 5 smoothing was applied on the image taken from the northern neotectonic belt near the town of Matatiele.

$$\mathrm{c}(b) = \left(\frac{1}{a+b}\right)^2 \begin{bmatrix} 1 & b & 1 \\ b & b^2 & b \\ 1 & b & 1 \end{bmatrix}$$

Stretching

The methods of Gonzalez and Woods (1992) that were adopted for this study indicate that an image pixel distribution can be monitored, a high contrast image contains a wide distribution of pixel count covering the entire amplitude range, whilst image that have a low contrast has pixel amplitudes confining in a relatively narrow range. An example of a stretching that was applied on an image can be seen in Figure 6. The distribution of pixels on the entire amplitude signifies the

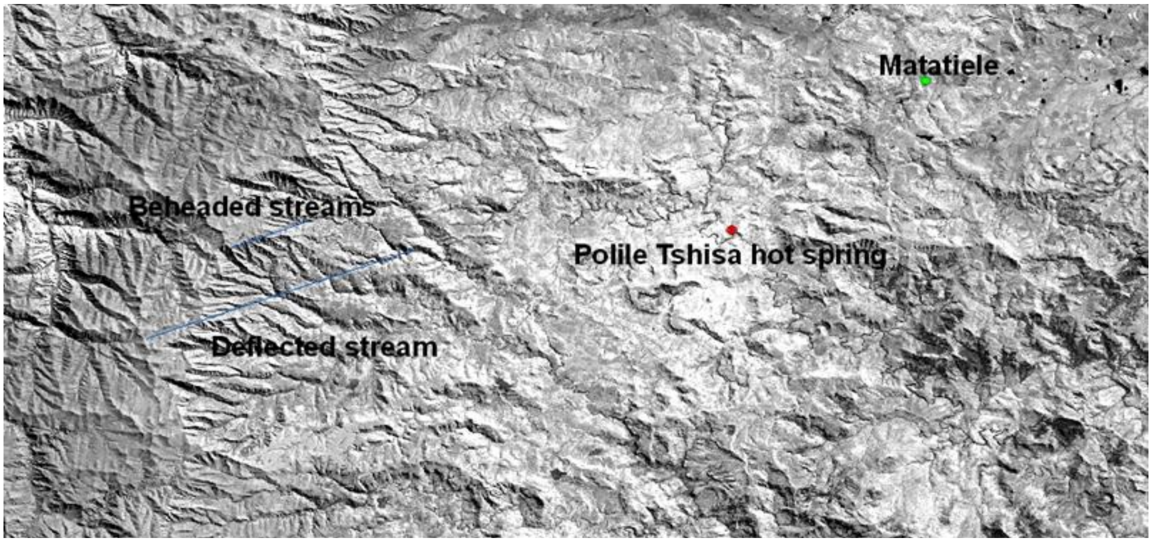

Figure 5. (Smoothed image) Map showing the neotectonic zone around Matatiele, the strike-slip fault in blue and the hot spring.

image was processed with success.

Convolution morphology (Sobel operator)

Before deciding on which filter can be used for automatic extraction of lineaments, satellite images underwent different filters for testing, such as Laplacian, Robert and Sobel. It was found that the Sobel operator was convenient; on the processed image ridges appear white, while valleys appear darkers.

Lineament densities characterization for some scenes

The lineament extraction was done in two stages, after smoothing the image was exported to ArcMap for editing the lineaments that could be easily depicted, then images was convoluted in ENVI 4.8 with the Sobel Operator using a 30% darkening with non editable kernel, and reexported to ArcMap to complete the editing of lineaments. This method was adopted for all the scenes. Scenes were selected according to their path and rows in the neotectonic belts.

The 170/081 scene is characterised by scattered lineaments, though located in the northern neotectonic zone with the presence of the Aliwal North hot spring, no neotectonic fault could be perceived. It takes deep geophysical investigation to highlight the presence of deep structures below.

The scene 169/081, which is also located in the Kokstad-Koffiefontein seismic belt is also characterized by high altitudes that can reach 1600 km at some points. On the satellite image it clearly appears that structures which are seemingly new rivers are deflected by the long fault below; the short fault has beheaded the new rivers; the hot spring might be aligned in a fault system parallel to the strike-slip fault, or it is possibly related to an E-W neotectonic fault that extends to Aliwal North. Many lineaments are found in the western part of the scene, correlating very well with the east part of the previous scene (170/081). These faults are oriented SW-NE and are good indication for groundwater exploration. The satellite image showing the strike-slip faults can be seen in the Figure 5.

The scene Path 168, Row 082 around the town of Port Saint Johns near the East coast is characterized by the presence of three major features: lineaments, faults and dolerite dykes. This area is located near the zone where the Amatole-Swaziland uplift axis took place in the Quaternary. Most lineaments and the few remarkable dolerites are quasi oriented NW-SE, except for the faults that trend in an almost NE-SW at the extreme coast (Figure 7), which is a sample of how lineaments are extracted from all the images.

The scene (Path 169, Row 082) is characterized by increase in lineaments along the east coast, this is almost similar to the area of Port Saint Johns, since this area is also located in the vicinity of the Quaternary Amatole-Swaziland axis of axis; dolerites and lineaments in this neotectonic zone indicate potential high yield wells, the increase in lineament intensity along the coast (Figure 8) might be the consequence of the reactivation along the Agulhas Falkland Fracture Zone in the Indian Ocean combined with the uplift inland. Unlike the previous scenes, the area covered in the scene Path 169, Row 083 this area around the city of East London is characterised by the presence of faults, lineaments, dolerites, which show a general trend in a NE-SW direction,

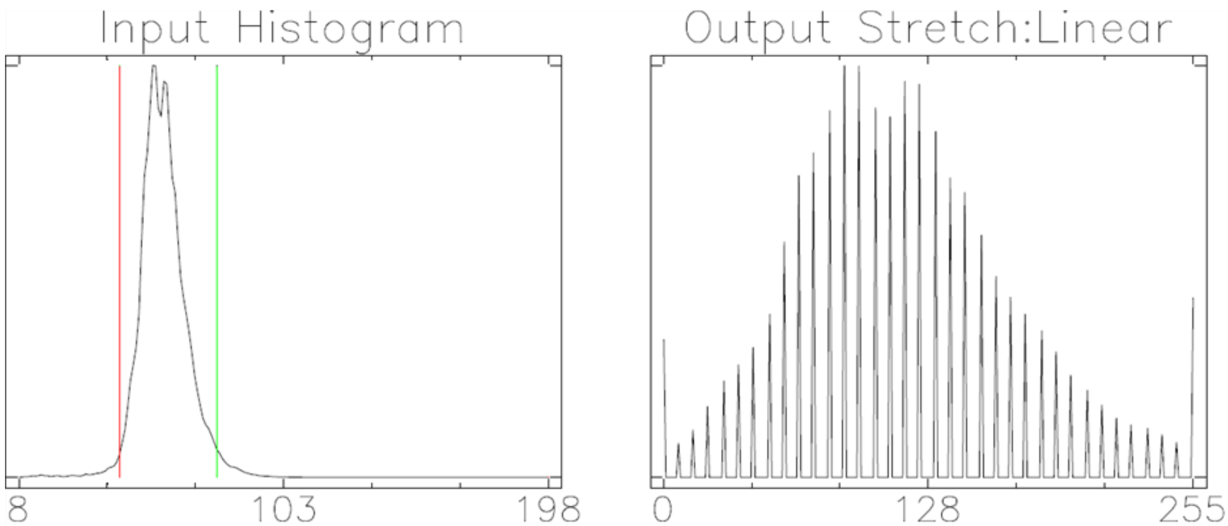

Figure 6. On the left hand side, image before stretching; on the right hand side, an output histogram showing amplitude distribution over the entire range.

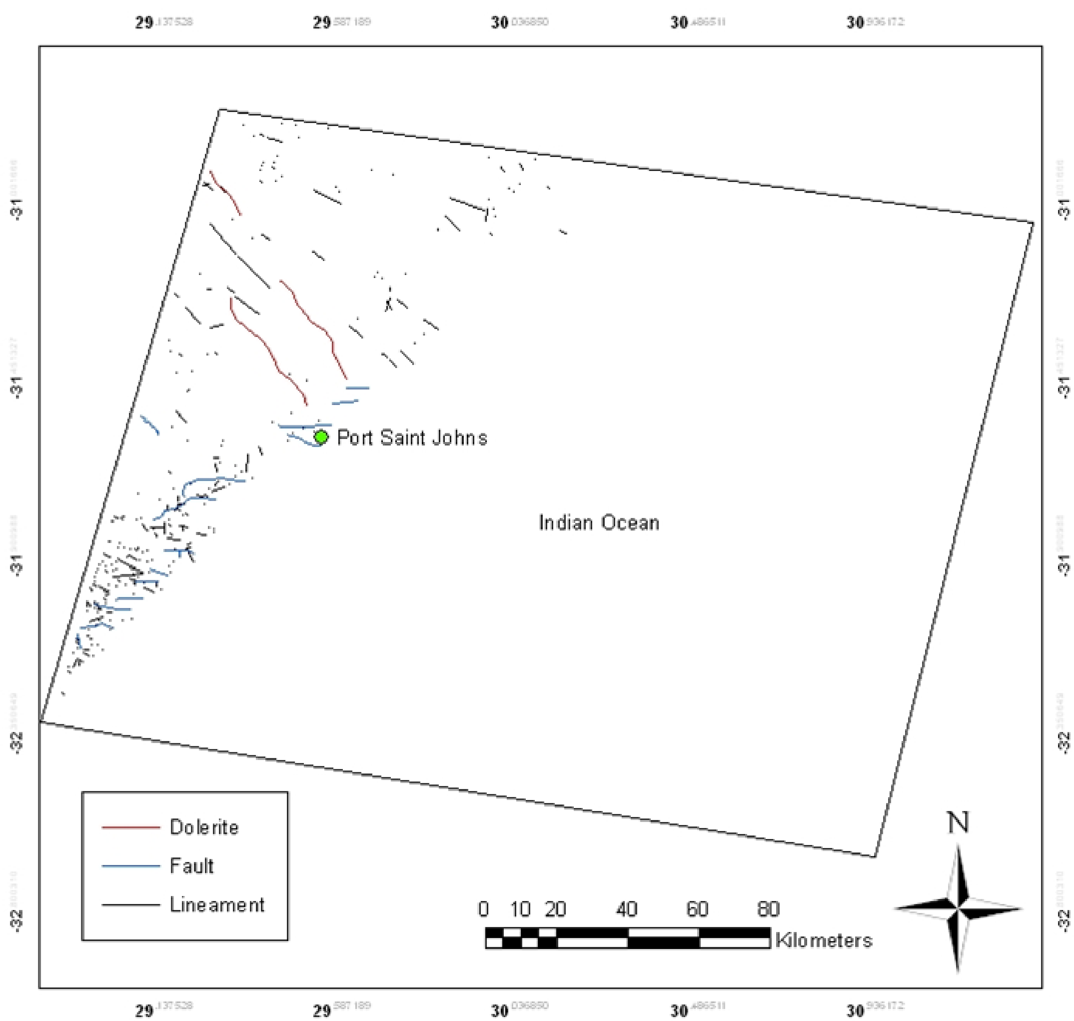

Figure 7. Faults, lineaments and dolerites from scene 168/082.

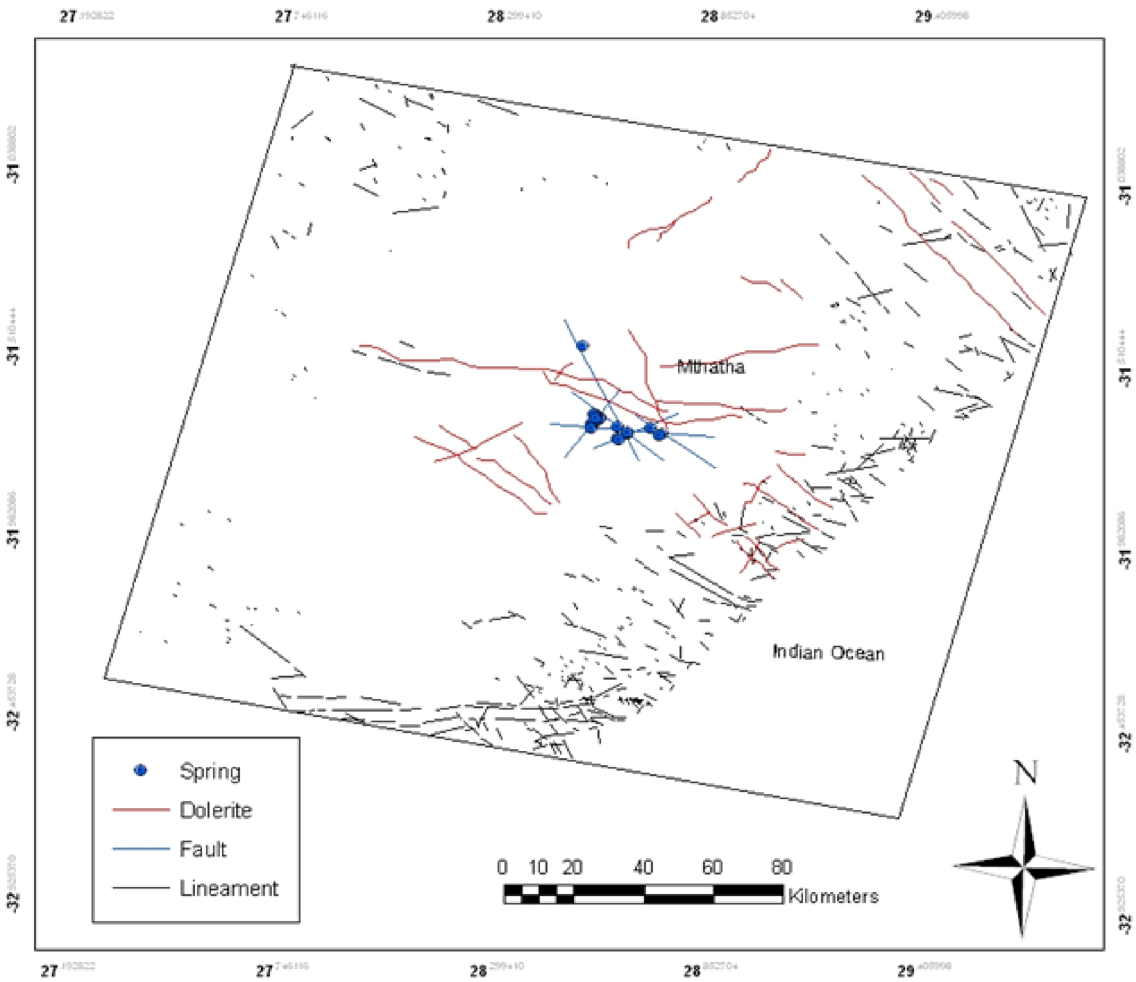

Figure 8. Lineaments extracted from satellite image 169/082.

though few lineaments are oriented SE-NW.What seems to appear to be lineaments as proper surface discontinuity at the geological term sensu stricto, are only negative weathering of dolerites, this can be seen on the satellite image (Figure 9). If there is a negative weathering of dolerite illustrated by a very long linear structure, this negative feature can only be initiated if there is a zone of weakness below the earth surface; dolerite dykes emplacement in the Karoo Basin are unequivocally consequence of the opening of the Gondwana, during this Gondwana opening, extensional fractures were generated and the doleritic magma emplaced itself following these openings to form what are known today as the Karoo dolerite dykes. This is to say that if there is negative weathering of dolerites, this negative weathering is a subsequent event, a negative weathering can only occur where there is already preexisting zone of weakness (fault or fracture below the Earth surface), where water can percolate and weather little by little the dolerite on the surface.

This scene (Path 170, Row 083) located almost in the southern neotectonic belt, is characterised by a big lineament extending from east to west. If more lineaments were observed in the two previous scenes, it clearly appears that the more the examined area is far from the coast, the less the intensity of lineaments (Figure 10). The big lineament intersects both the Fort Beaufort and the Grahamstown fractures, these two intersections are good potentials for groundwater exploration. This big lineament, which can be called the Eastern Cape Province Great Lineament (ECGL) can also be seen on a DEM that was used as an ancillary data, this great lineament has seismic epicenters (Figure 11), and is considered to be a current neotectonic domain.

This great lineament appears as conspicuous linear feature north of the town of Grahamstown; this linear feature crosses the province and stretches from east to west. Field observations indicate that this linear feature is similar to a graben, and is approximately located at the contact Cape-Karoo Supergroups. It was observed NW of the town of Grahamstown at latitude 33.17215 and longitude

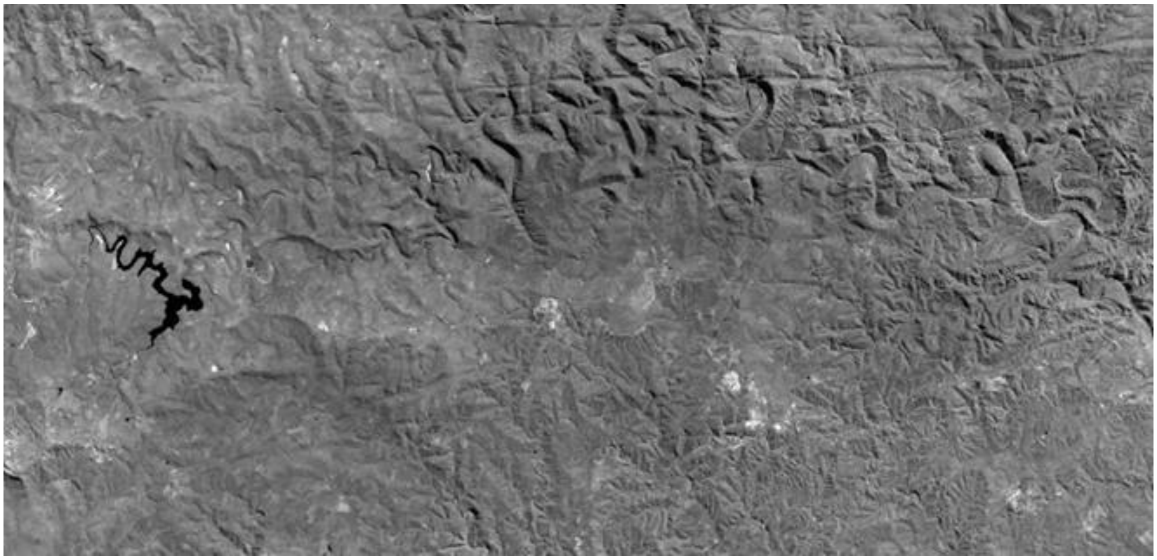

Figure 9. Negative weathering of dolerites depicted as lineaments in a E-W direction.

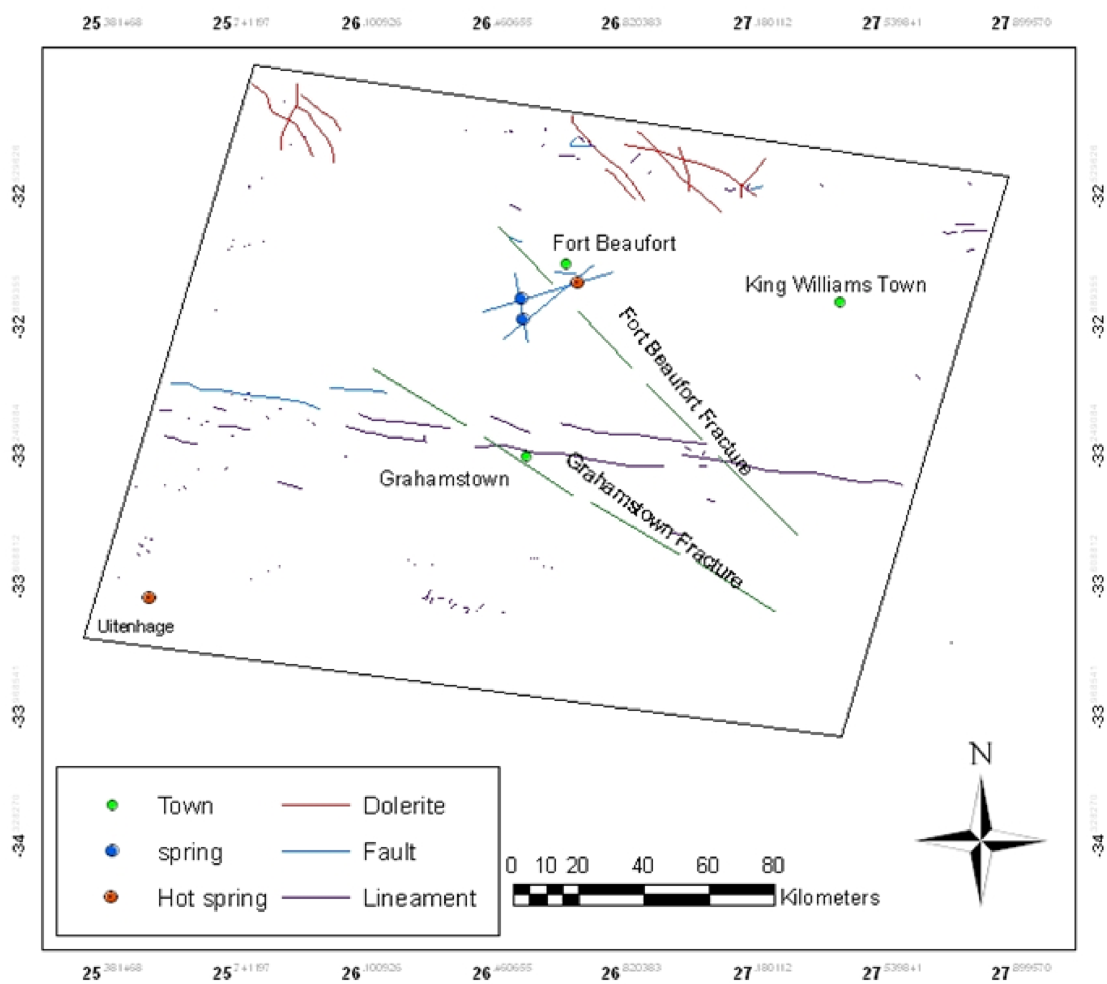

Figure 10. Structures extracted from scene 170/083/.

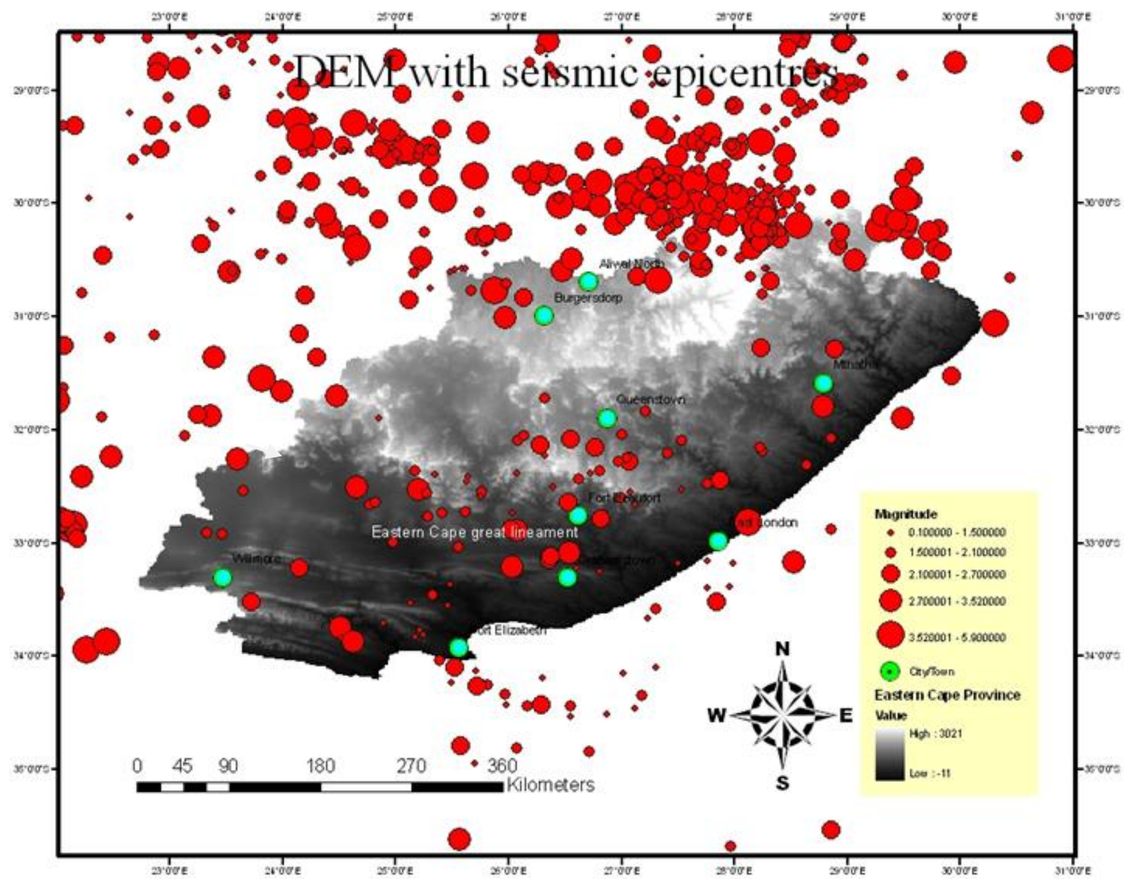

Figure 11. Digital elevation model of the Eastern Cape Province, the great lineament has seismic epicenters within it.

026.32628. Though it generally strikes in an east-west direction, at this point there is a small change, and the recorded strike was N 120°. The space between the two surfaces of the normal faults, which are part of the graben, is almost 200 meters. One surface of the fault has outcrop of quartzites of the Witteberg Group (Figure 12 left), the graben feature can also be seen in Figure 12 (right). This graben forming the major lineament of the Eastern Cape Province has some seismic epicenters; these epicenters can be followed all the way from the border of the Eastern and Western Cape Provinces, they can be seen in Figure 11; this indicate that this lineament is a neotectonic domain, its shape is undoubtedly a good catchment, and these seismic epicenters indicate possible reactivations, which is good for groundwater target. Some extensional fractures were found on a quartzite outcrop, these extensional fractures strike astonishingly the same with the graben itself (N120^{o}), their development is possibly concomitant with extensional movement that is responsible for the graben formation, or there are related to extensional normal faulting that triggers earthquakes in and around Grahamstown, these extensional fractured can be seen in Figure 13 (left), these fractures are in place filled with quartz veins, either in the quartzite or in some quartzo-phyllites.

Normalized difference vegetation index (NDVI)

The NDVI can be in most of the cases associated in the study and exploration of groundwater exploration, it normally indicates the degree of live green vegetation. Live green vegetation can be the surface expression of presence of considerable amount of water below the surface, which can either be related to fractures and faults, and to a certain extent to catchments in which the water accumulates. The NDVI is calculated from the individual measurements as follows:

$$\text{NDVI}=\frac{(NIR-\mathrm{Re}\,d)}{(NIR+\mathrm{Re}\,d)}$$

Red and NIR stand for the spectral reflectance measurements acquired in the red and near infrared

Figure 12. Left: Fault of the graben with quartzite of the Witteberg Group, Cape Supergroup; Right: The graben morphology.

Figure 13. Left: Quartzite affected with extensional fractures, quartz veins in quartzo-phyllite.

regions, respectively. The NDVI varies itself between -1.0 and +1.0. Healthy vegetation absorbs most of the visible light that hits it, and reflects a large portion of the near infrared light. Unhealthy or sparse vegetation reflects more visible light and less near infrared light. Dark areas have low chlorophyll and light areas have more.

In the above paragraph it was indicated that the eastern neotectonic belt is highlighted as the most neotectonic zone because of high lineament densities, this is only when this is referred to the uplift along the Amatole-Swaziland axis; the NDVI is applied only to this zone in the purpose of groundwater exploration. Four scenes (168/081, 168/082, 169/082, 169/083) were chosen, these scenes can be complemented with one scene in the northern neotectonic belt located in the Senqu seismo-tectonic belt. The NDVI was computed on the band 3 and Near Infrared band using ENVI 4.8 software according to the following band math expression:

$$\frac{(float(B4)-(B3))}{(float(B4)+(B3))}$$

In this equation B4 represents the Near Infrared band and B3 the visible band (Red). Images were then interpreted in terms of colour differentiation, lighter areas being representatives of more chlorophyll, and accordingly potential good catchments, and dark areas being representatives of possible poor catchments or areas not affected by fractures and faults, mainly in the neotectonic zones. Scenes chosen for NDVI are those that were depicted as being more affected by high density lineaments as typical examples, mainly Path/Row: 168/082; and 168/083. All the output maps can

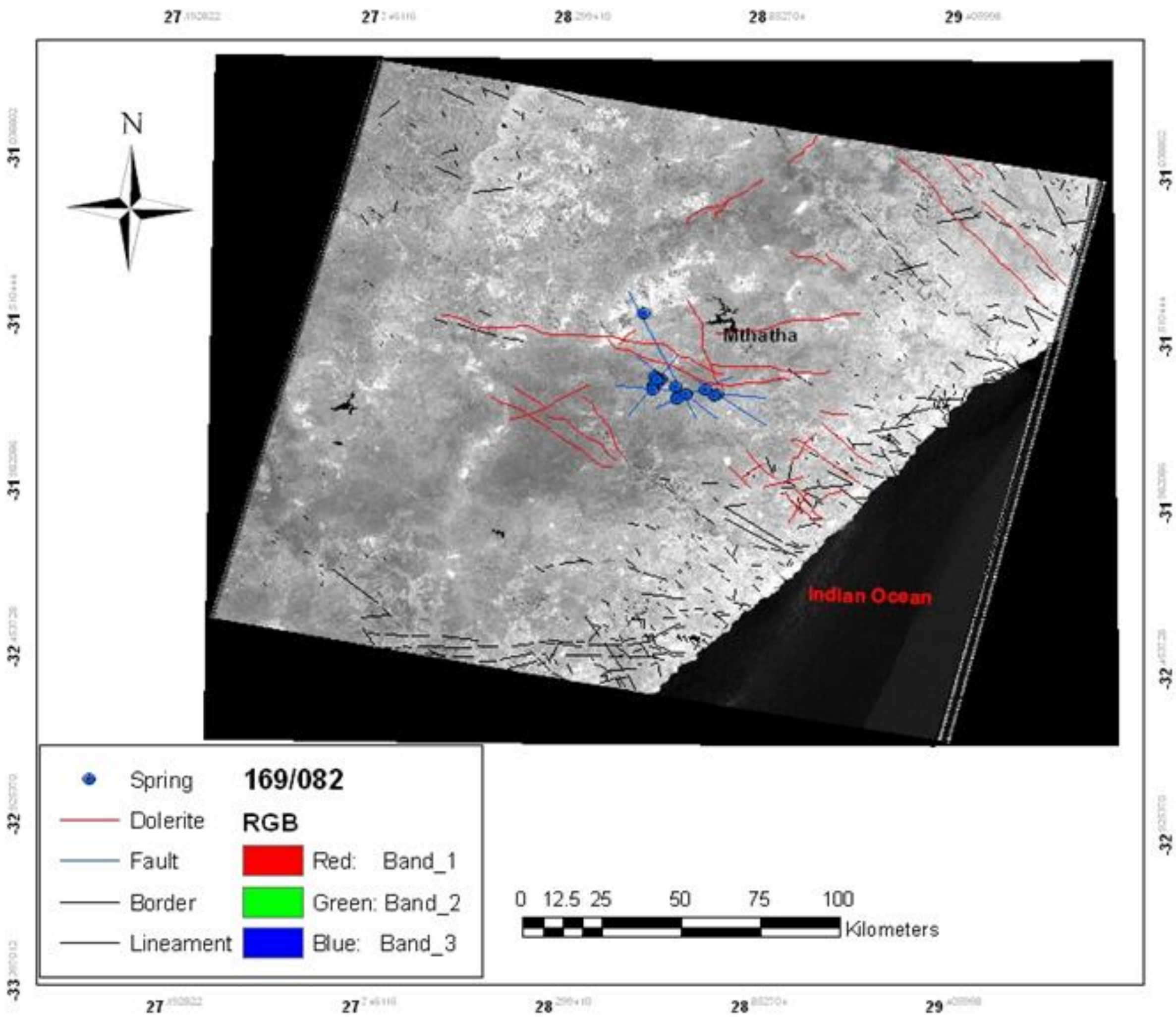

Figure 14. NDVI from the scene 169/082, very potential groundwater resources is highlighted in the east coast.

be seen in Figures 14 and 15.

General trend of lineaments

The lineament trends for all the nine scenes in the three neotectonics belts were deduced in ArcMap using the Rose Plot 4.0 extension. Different notable orientations were categorized using different colours in order to have the major predominant trend that can be considered for future possible groundwater exploration. All rose diagrams for all the three neotectonic belts can be seen in Figure 16.

From the rose plots, it was found that the scenes (169/081, 170/081, 169/083, 170/083, 172/083, 169/082) are characterised by a unifrequency of angle interval between 111 and 140° in the ten examined scenes. Six of the ten scenes show this major trend, which is to be taken into account during groundwater exploration. Histograms in Figure 17 indicate that five scenes, three in the northern neotectonic belt (170/081, 169/081 and 168/081) and two in the eastern neotectonic zone (169/082 and 169/083) have high lineament density. As mentioned above the east coast would be highly considered morphotectonic induced neotectonic zone due to the positive topography related to the uplift that occurred in the Quaternary than the northern neotectonic belt characterised by the Kokstad-Koffienfontein belt and the presence of several hot springs, it can be said that a morphotectonic induced neotectonics would generate more lineaments than a seismically active zone. Kumanan (2001) has found in India that lineament density maxima zones and lineament intersections were buffered out as possible neotectonic zones. In the same order of idea, no considerable high density of lineament was depicted from the Queenstown area (scene 170/082).

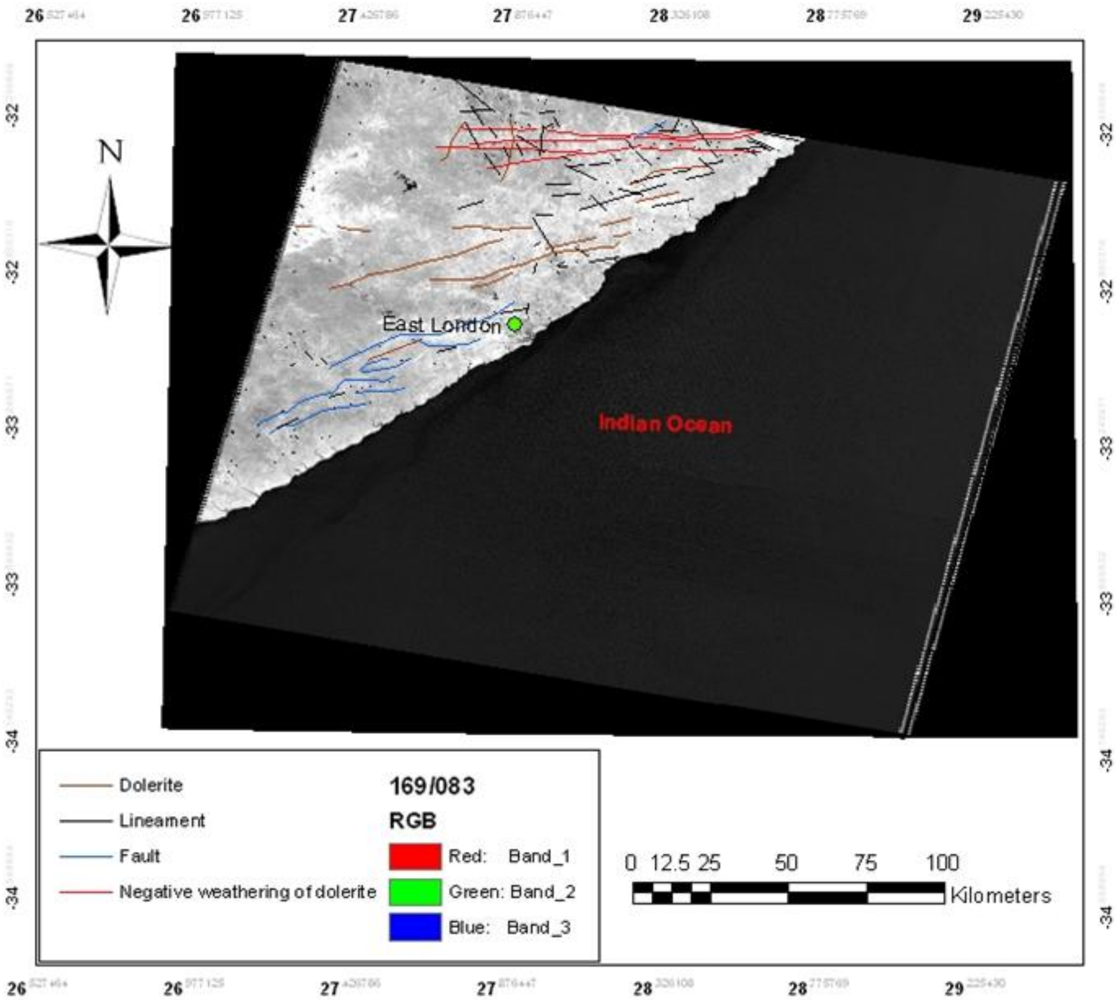

Figure 15. NDVI from the scene 169/083, good potential for groundwater is highlighted.

Geormphologic landform from digital elevation models

Digital Elevation Models can be used as support for hydrological application. With data acquired from the South African National Geo-Spatial Information in relation with the three neotectonic belt were processed using Surfer 10, a small comparative study between these three neotectonic has been done only on the basis of surface topography and vector gradients, the vectors gradients give and indication on the surface water flow. In each neotectonic zone, a grid was picked up randomly, each grid being subdivided in four parts (A, B, C, and D).

In the southern neotectonic belt, many faults such as the Kango Bavianskoof were reactivated in the Quaternary; from DEMs as was mentioned above there is another remarkable lineament, this linear feature is located in the area between south of East London and north of Grahamstown, it is also clearly appearing on the DEMs in the grid 3327d (Figure 18); this remarkable and striking feature is now known as the Eastern Cape Great Lineament (ECGL). It appears from the image in the grid 3327d that altitude does not exceed 125 m, on the hydrological point of view, if the gradient vectors are considered, the flow direction from the surface topography is mostly oriented east-west (Arrows, Figure 18).

In the eastern neotectonic zone, four images of DEMs from the grid 3228 were also considered in order to see what the surface topography and what should the drainage pattern look like. Only one sample was chosen among the four for illustration (Figure 19). It appears from all these figures that the elevation increases reaching 1020 m above sea level with varied geomorphic surface, this might be a consequence of the uplift that the took place in Cenozoic, or this can be a result of dolerite dykes that have resisted the erosional processes to form these outstanding and conspicuous morphologies at such

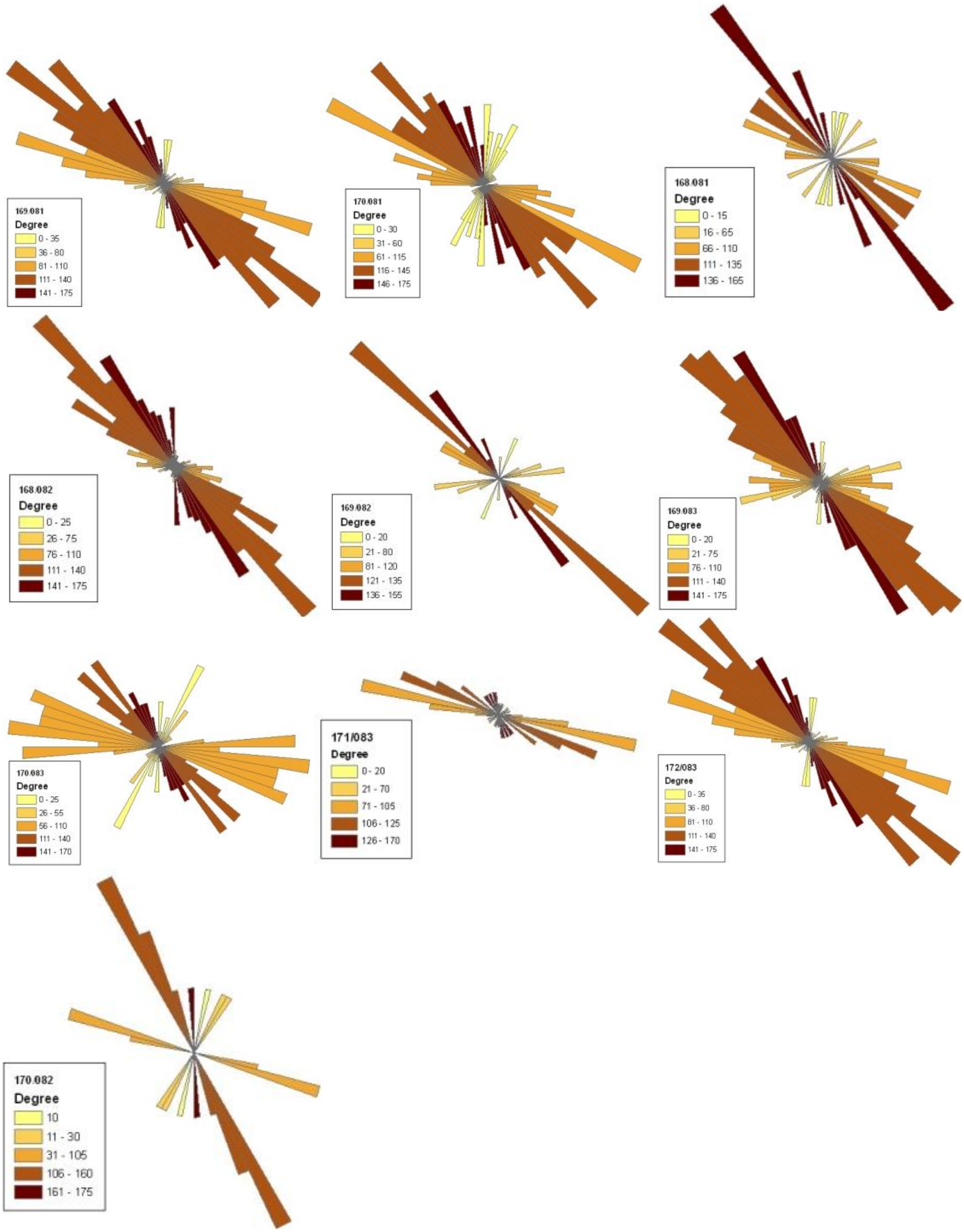

Figure 16. Rose plots derived from the lineament maps in the neotectonic belts.

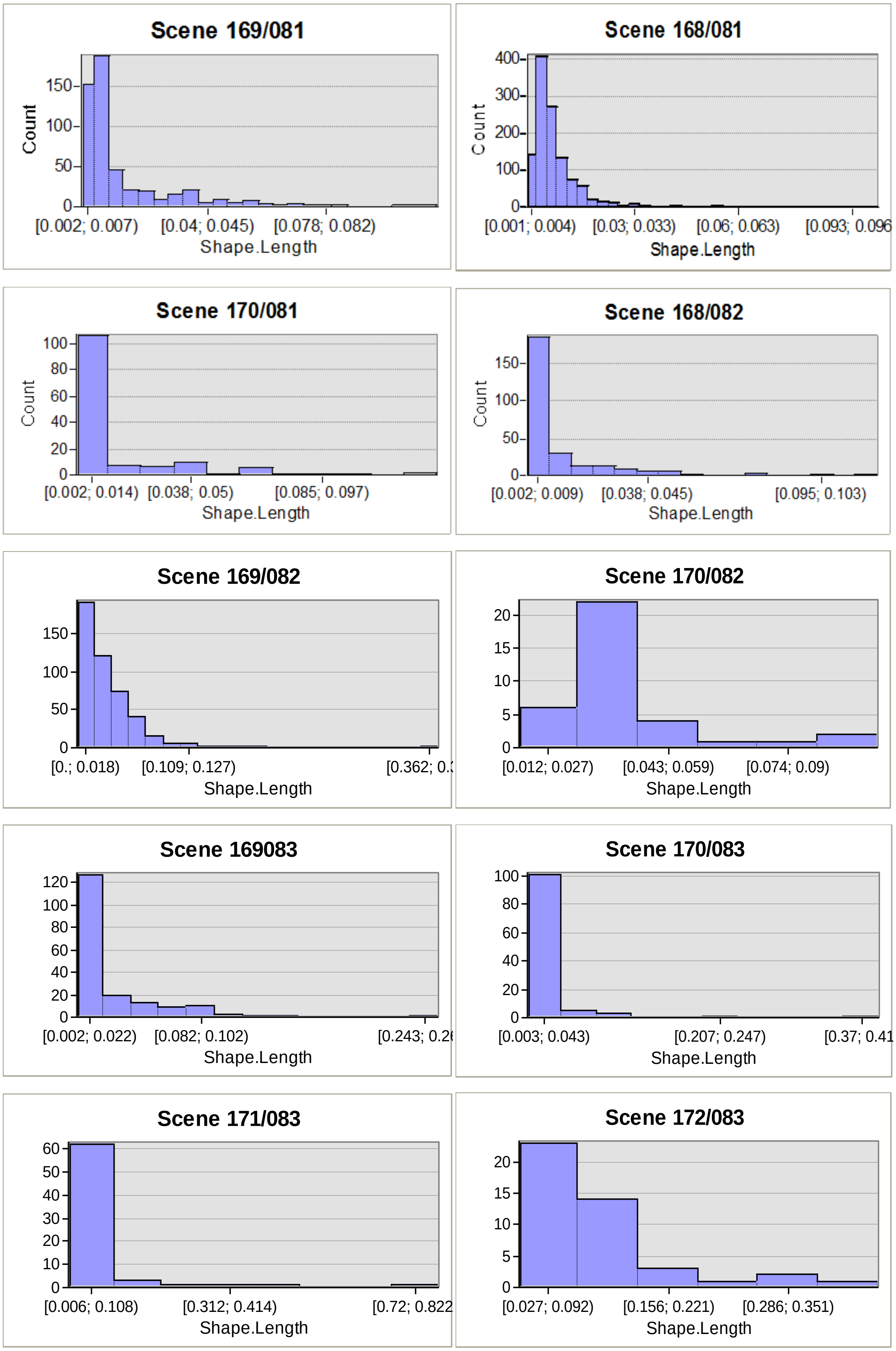

Figure 17. Histograms deduced from lineament maps in the Eastern Cape neotectonic belts.

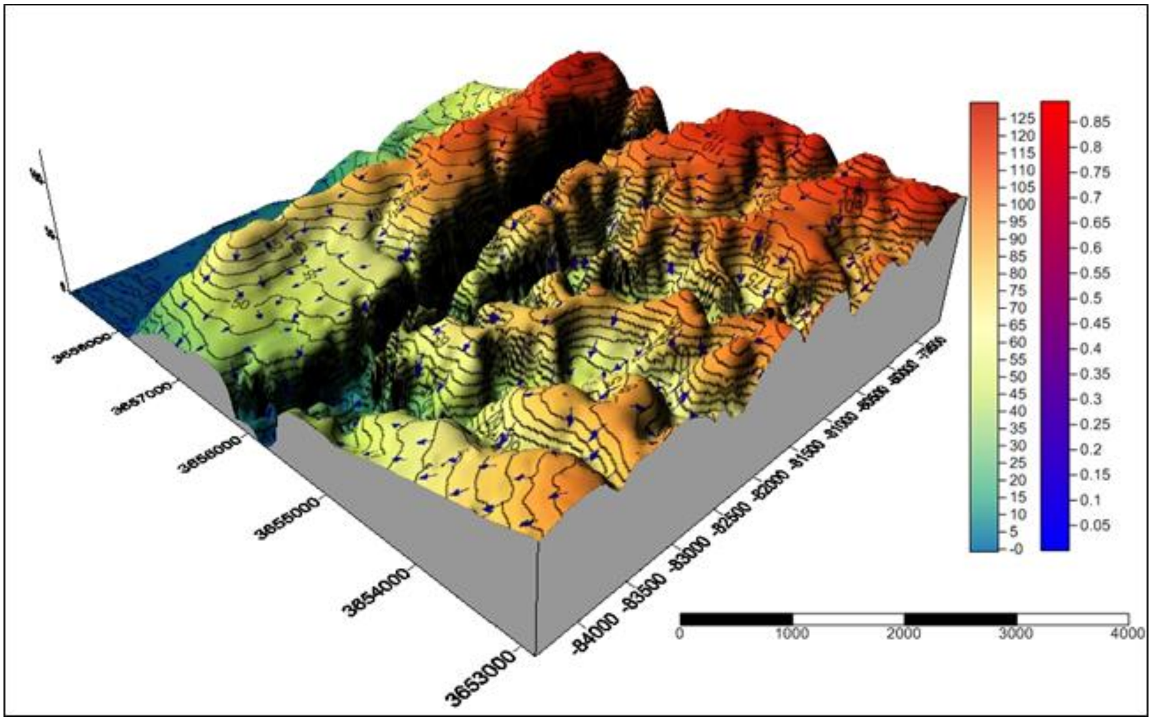

Figure 18. DEM from grid 3327d, note the E-W structure (ECGL).

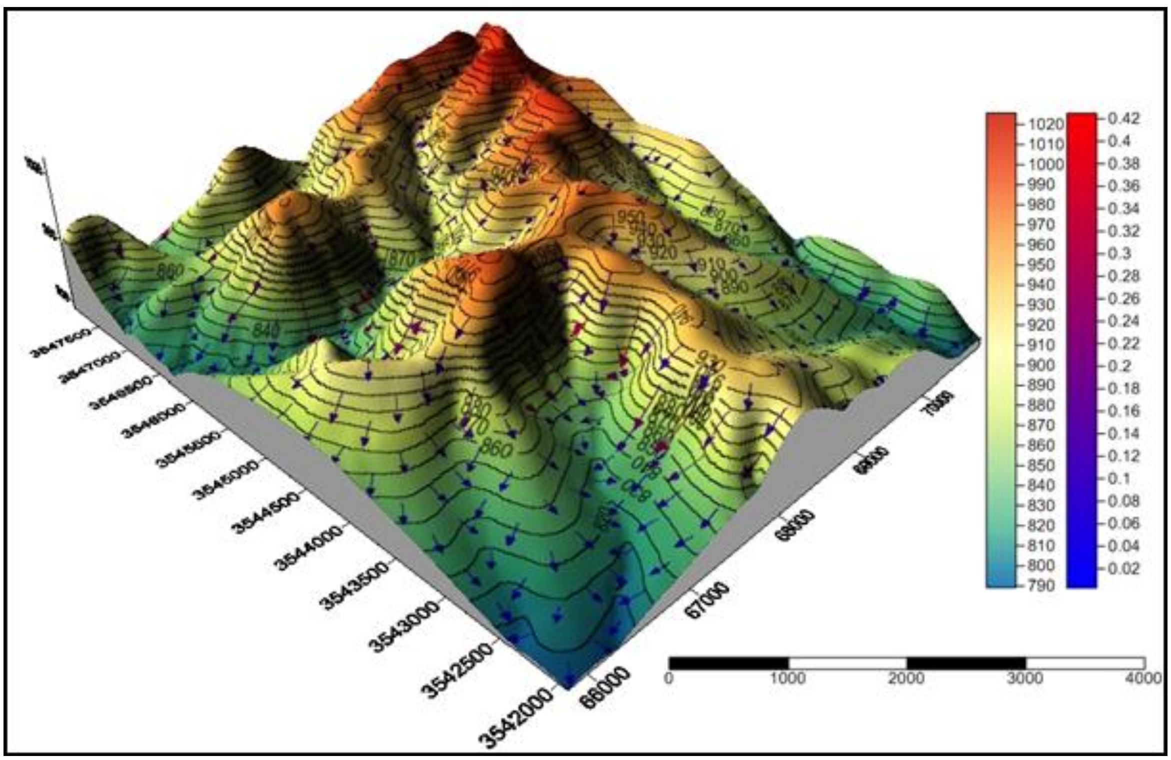

Figure 19. DEM from grid 3228.

an altidue, but the hypothesis of uplift is more and more favoured. It can be noted that in the eastern neotectonic belt, altitudes are not uniforms changing from 190 m, to 500 m, 700 m and 1020 m. The vector gradients indicate that the surface water would flow from west to east in general.

Samples of Digital Elevation Model in the northern neotectonic belt near the country of Lesotho were taken from the grid 3028, the grid 3028 is subdivided in four areas (ABCD), the vector gradients have an orientation mostly in the east-west and north-south direction (Figure 20), this orientation of vector gradients in a quasi east-west trend would be an important factor to consider for future hydrogeological works because it indicates the possible water flow direction. The Digital Elevation Model clearly shows that high altitude that can reach 2000 m characterize the northern neotectonic belt. The legend scales indicate the contour lines and magnitudes of different vector gradients.

DISCUSSION

In the exploration and characterization of potentially high yield aquifers, remote sensing has always played an important part; first because it can be used to find the maximum lineament density, this can be in turn correlated with the strike; which is useful in the exploration of groundwater. Most of the lineaments that were depicted using remote sensing have a predominant NW-SE orientation. The greatest lineament is an important feature to be reckoned with in the Eastern Cape in as far as works related to groundwater is concerned, mostly because of alignement of seismic epicenters related to earthquakes, which can reactivate the structures to allow movement of groundwater. The eastern neotectonic belt has high density of lineament, which makes it another important neotectonic domain.

In continental intraplate configuration like the case of South Africa, seismic epicenters are located on lineaments; these lineaments can be targeted for groundwater exploration. Lineaments can be in form of neotectonic faults, the works of Holford et al. (2011) showed that the southern Australian continental margin has been undergoing mild levels of deformation over the past ~10 Myr, manifested today by high levels of seismicity for a stable intraplate region. However, this deformation is partitioned, with zones of abundant neotectonic faults with evidence for Pliocene–Quaternary displacement.

On the geomorphologic point of view, the modeling of surface topography has indicated that elevations at the western side of the province (for example, grid 3327) do not exceed 450 m. To the contrary the grid 3228 which is more in the east has elevations that can reach 1020 m; though the elevations are not uniform in this grid, the higher surface topography of 1020 m can be related to Cenozoic uplift (Esthuizen, 2008). In the northern neotectonics belt near the country of Lesotho the elevation can reach 2000 m; this higher topography is the source of increasing stress in the lithosphere triggering earthquakes (Steinberger et al., 2001). The east-west big seismic belt that stretches from the east coast to Koffiefontein is located in this area, and belongs to the Senqu seismotectonic belt, better known as the Kokstad-Koffiefontein seismic belt.

The Sobel operator has been proved to be efficient technique in remote sensing to extract lineaments. From lineament extraction the eastern neotectonics belt can be considered as the second neotectonics domain of the province because of the intensity of lineaments, Kumanan (2001) has found that lineament density maxima zones and lineament intersections were buffered out as possible neotectonics zones. This can be a good highlight from the present project that can help to target productive aquifers. On the other hand what has been called the Eastern Cape great lineament north of the town of Grahamstown, has a geomorphology that is highly favourable to be considered as a major catchment; the seismic epicenters present within it has possibly reactivated faults and fractures, and thus contribute to the circulation of groundwater. The Grahamstown fracture is considered as a splay of the structure, which is qualified as a graben.

The neotectonics belt near the country of Lesotho is also known for the occurrence of many hot springs, which are indicative of circulation of groundwater at great depths, the occurrence of these springs indicate that they are connected by a major neotectonics fault that stretches from west (Aliwal North) to east (Polile Tshisa). The flooding that occurred in an abnormally well developed fissure zone, through which lot of water gushed out during the construction of the Orange-Fish tunnel (Olivier, 1975) is a proof that neotectonics is at work in the northern neotectonics belt. (Whittingan pers. com.) noted that the flow of the thermal spring at Badsfontein increased markedly for a period of at least three months after a local earthquake.

Conclusion

Neotectonics is active in the Eastern Cape Province as can be seen from the recent map of seismic epicenters. It is an important tool in targeting potentially high yield aquifers for two reasons: 1) it can reactivate old fractures or faults; 2) it can create new fractures or faults. All these two reasons imply more opportunities for the circulation of groundwater.

Surface topography modeling in this study has highlighted the flow direction of water, it was found that most vectors are oriented in the E-W direction; this can be taken into consideration during groundwater target and exploration. The eastern neotectonics belt is a good target for groundwater, it is characterized by a high density of lineaments, most of them are oriented NW-SE, on the other hand the normalized difference vegetation index (NDVI) performed on some satellite images clearly

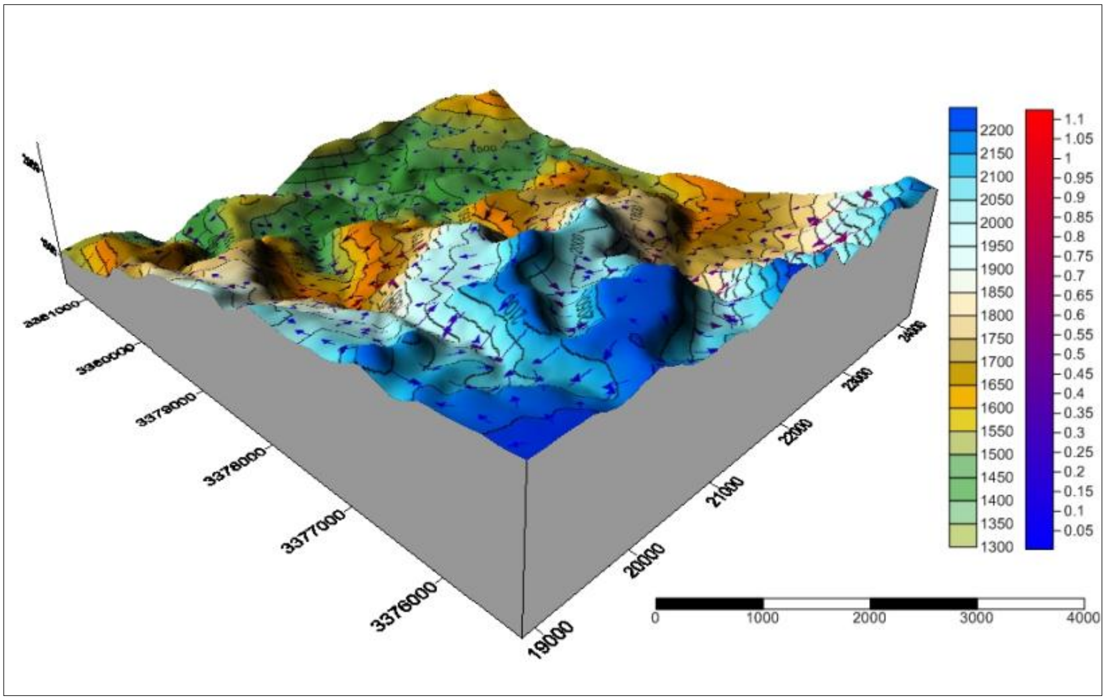

Figure 20. Digital elevation model sample and vector gradients of Grid 3028DB.

indicate that the quality of chlorophyll is higher, this can only be related to a healthy vegetation, which is in turn connected to more groundwater percolation favoured by the occurrence of lineaments.

The hot springs in the Eastern Cape northern neotectonic belt are connected or occur along an E-W neotectonic fault, a regional structure.

This project has given fundemental highlights to characterize the major and potential good yield aquifers by examining the neotectonics, the seismicity, and the structures. This project is important since it has also brought in the environmental impact through examination of seismic risk assessment, which can help in targetting place for dumping nuclear wastes so that the groundwater may not be contaminated.

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