The Role of Remote Sensing in Mapping Swelling Soils

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Abstract

The use of satellite images during the early stages of mineral exploration has been very successful in pointing out the presence of minerals such as smectites and kaolinite important in the identification of hydrothermal alterations. These same minerals are key to the soil swelling properties and their identification from space makes remote sensing a good tool in the characterization of soils in terms of swelling potential. Here several methods used for spectral enhancement of multispectral images are used on an Enhanced Thematic Mapper image (ETM+) in order to detect these minerals on soils, in an area in the central Kenya, where swelling soils are a major problem in the ever-expanding urban centres surrounding the Nairobi city. The techniques were based on separation of the areas based on the presence of iron oxides, hydroxyl bearing minerals and vegetation cover. The imagery was subjected to several data enhancement techniques before interpretations that included; principle component analysis, band rationing and minimum noise fraction. Interpretations were done based on observations made after these manipulations which gave characteristic differences between the heavily vegetated terrain consisting of high iron oxides and thus red soils and the low lying scarcely vegetated grasslands consisting of dark grumosolic soils. Spatially varying micro-topography consisting of gilgai topography and evident in the ETM+ panchromatic band 8 was used to further identify areas with swelling soils. This micro-relief complimented the spectral interpretations. The results were confirmed by field surveys and reveal a new method of integrated image interpretation in terms of spectral and spatial resolutions in identifying soils physical/chemical properties.

1. Introduction

Study of soil swelling has been necessitated by the extensive damage worldwide caused by the phenomenon on infrastructure. Methods of its estimation have been developing over the years with the aim of establishing faster and less expensive ways of estimating the swelling potential of engineering soils. Such methods have mainly consisted of laboratory tests that are laborious and expensive. However new methods for their study and identification from remote sensing has recently been the subject of research. Chabrillat et al., (2002) found it possible to distinguish between the spectral response of three swelling potential indicator clay minerals i.e. smectites, illites and kaolinites based on airborne sensor data. However, access to such high-resolution data is still limited and study on the applicability of multispectral systems is still important.

Geologic mapping using multispectral imagery has been a major goal for earth scientists since the launch of Landsat 1 in 1972 and the series of Landsat thematic Mapper (TM) has provided extensive mapping capabilities (Goetz and Rowan, 1981) with reported successes in esti-

mation of soil constituents such as organic matter (Ishida and Ando, 1999), surface geologic materials (Bittick et al., 1994) and stages of iron and clay weathering (Riaza et al., 2000). Others include Ruiz-armenta and Prol-ledesma (1998) use of TM to obtain the spectral response of hydroxyl and iron oxides and Agbu et al. (1990) establishment of the fact that most surface soil properties pertinent to soil classification can be predicted from satellite data. With improving spectral resolution and the introduction of spaceborne hyperspectral sensors such as the Hyperion and ENVISAT, the capacity to resolve small spectral features from remote sensing in the future for such soil property mapping is becoming a reality.

Vibrational transitions in hydroxyls produce reflectance anomalies in the near infrared region of the electromagnetic spectrum. The middle infrared region 1.65 μm (Thematic Mapper (TM-5) contains high reflectance anomalies and high absorption at approximately 2.2 μm (TM-7) for the three swelling indicator minerals (Goetz and Rowan, 1983) while iron oxide and vegetation have similar reflectance in TM bands 1 and 2. Band 3 shows high reflection for iron oxides and a strong absorption from vegetation (strong

presence of iron oxides in clay mineralogy is associated with kaolinite). Band 4 includes the typical feature for vegetation identification, and contains absorption feature for iron oxides at 0.9 μm making vegetation and iron oxides to share a lot in terms of spectral information. TM band 5 and 7 are helpful in differentiating vegetation from hydroxyl and iron oxides because they have distinct reflectance curves. Table 1 is a summary of the important bands in the TM that can be used to differentiate between these materials. Small height differences on the other hand, referred to as gilgai micro-relief (20-50 m in diameter) within swelling soils and resulting from repeated swelling and shrinking could be another source of information on the soil differences from the image.

Gilgai is an Australian word which describes a terrain of low relief on a plain of heavy clay soil characterised by the presence of hollows, rims, and mounds, as formed by alternating periods of expansion during wet weather and contraction (with deep cracking) during hot, dry weather. It is common in Vertisols and results in an irregular land surface with alternating mounds and depressions. The soil on the mounds has properties, which are more like subsoils (i.e. lighter colour, more alkaline, presence of carbonate and higher salinity) a characteristic that brings about vegetation differences. This topography has been widely mapped in Australia, and is recognized as a surface expression of high swelling soils. Several workers have given different models as to their formation.

Eldelman and Brinkman (1962) related them to shearing force in the underlying clay while Knight (1980) suggested that the micro highs form from cumulative internal vertical movements along small oblique slips immediately associated with major crack zones. Newman (1983) described them as "chimney" or "diapir" structures due to plastic extrusion resulting from large disparities in the densities of two adjacent materials. White and Bonestell (1960) suggested gravity as the cause and Beckmann et al. (1973) and Elbersen (1983) attributed the linear type to immature rill erosion.

Recognition of these differences from imagery could add a new method of using the ever-increasing spatial resolution in satellite imagery as a tool for mapping swelling soils and the spatial resolution of the ETM+ panchromatic band offers such a possibility.

Future applications of remote sensing could include the use of IKONOS and Interferometric SAR (InSAR). Differential interferometry that enables the measurement of changes or displacements of the surface over large temporal and spatial scales with centimeter accuracy (van der Meer, 1999) could also be applied.

This paper reports the combined use of the spectral enhancement techniques and the ETM+ panchromatic band visual interpretations of the gilgais to establish a swelling soil locations map.

1.1 Study Area

The study area (Figure 1) is bounded by 1° 00' to 1° 30' S latitudes and 36° 30' to 37° 30' E longitudes. The climate is pleasant with temperatures ranging between 14 and 28°C and rainfall is moderate and uniform throughout the year.

The soils to the northwest are products of weathering of the mainly volcanic rocks under relatively high temperature and rainfall coupled with good drainage. They consist of strong brown to yellow-red friable clay and red friable clays with high humus layer overlying clay, having developed from lava, volcanic tuff and ash in humid conditions with a rainfall of more than 1000 mm per year. This gives way southeastwards to red friable clays developed on similar rock types in areas where annual rainfall is slightly lower 762-1000 mm (Saggerson, 1991). These conditions have resulted in soils rich in both kaolinite and iron oxide, attributed to the leaching of soluble bases and silica leaving aluminium in the form of the kandite clay minerals and the iron oxides (Dumbleton, 1967; Sherwood, 1967). The leached components accumulate in the plains in the middle and stretching southwards, which coupled with poor internal drainage due to impermeable underlying rocks, has resulted in development of black to dark grey soils comprising of *vertisols* with calcareous and non-calcareous variants dominated by smectite as the clay mineral. To the east are soils that are products of the basement system of rocks subjected to low rainfall and good drainage resulting in kaolinite as the major clay mineral.

The soils range in depths from a few centimeters to several meters dependent on the physiographic position in the landscape. The red soils in the highlands are deep with well-developed profiles while those in the low-lying plains vary in depth dependent on their position within the plain i.e. the soils are more shallow on the convex buff slopes than on the flat mid plains. In some areas, the concept of litho-morphic versus topomorphic characteristics could be applied as the controlling factors in the soil development. In both cases though, the neo-formation of smectites clay is important with the *Vertisols* best developed where the thickness of the solum is thicker than 90 cm. Shallow stony soils characterize the east-southeast trending valleys and have been described to derive from various soil types that have been subjected to accelerated erosion.

In terms of cover, heavy healthy vegetation characterize the red soils in the higher grounds to the east and northwest, where intense farming is carried out due to the soil fertility. The plains, whose main soils are the vertisols, comprise of scarce vegetation cover making it ideal for remote sensing data applications, with the main landuse being grazing. Attempts to cultivate adapted crops like millet, maize etc. often fail because of unreliable and insufficient rains in addition to the workability of these soils. They are very hard when dry and very sticky and plastic when wet. Expansion

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of the city of Nairobi towards the plains has caused construction problems for the foundation of structures, sewage, road construction etc, because of the swell/shrink properties of these soils. Special provisions need to be taken to prevent collapse of walls, drainage channels, etc in such constructions, making their study even the more important.

Table 2 provides a relative classification of the soils by Scott (1963)/Sombroek et al. (1980) and a modified classification (Siderius and Kariuki, unpublished, 2002) based on geomorphology. It shows the high swelling vertisols to form zone 2 (midsection) categorized in the classification as of generally flat to undulating topography, of grey to black colour with poor drainage. The soils flanking the plain to the northwest consist of *Ando-humic Nitisols, Humic Nitisols and Eutric Nitisols* (zone 1) and those to the east/southeast *Eutric Nitisols, Ferrasols, Ferric Acrisols, and Ferralic Arenosols* (zone 3).

2. Materials and Methods

The materials used in this analysis consisted of a Landsat 7 enhanced TM+ imagery acquired on 21 February 2000 during which period the weather is relatively dry. The six none thermal bands were used for the spectral analysis, whereas the panchromatic band (with a spatial resolution of 15 m) was used for the visual interpretation of the topographical differences in the area. Field verification exercise was also carried out at a similar time of the image acquisition.

Several data enhancement techniques were employed in the analysis, with both Univariate and Multivariate statistics used to reduce redundancies in the data for all the visible and infrared bands. Band ratios, minimum noise fraction (MNF) and principal component analysis (i.e. both standard and Crosta technique (Crosta and Moore, 1989)), together with Tasseled cap transformation (TCT) were the other enhancement methods used.

2.1 Band Ratios

Band ratios are assumed to overcome the shadow and topography effects, though for this particular case, the fact that most of the study area was in a generally flat topography could be said to have made this a small problem. However, other information on spectral differences could have been enhanced by this manipulation.

2.2 Minimum Noise Fraction (MNF)

The minimum Noise Fraction (MNF) transformation is used to determine the inherent dimensionality of image data especially so in hyperspectral data, to segregate noise in the data, and to reduce the computational requirements for subsequent processing (Boardman and Kruse, 1994).

The MNF transform is essentially two cascaded principal component transformations (Green et al., 1988)

where the first transformation based on an estimated noise covariance matrix decorrelates and scales the noise in the data. This first step results in band-to-band correlations. The second step is a standard principal component transformation of the noise-whitened data. For further spectral processing, the inherent dimensionality of the data is determined by examination of the final eigenvalues and the associated images. The data can be divided into two parts: one part associated with large eigen values and coherent eigen images, and a complimentary part with near unity eigen values and noise dominated images. By using only the coherent portions, the noise is separated from the data, thus improving the spectral processing results.

2.3 Principal Component Analysis

In Principal Component (PC) analysis, one can use either the standard or selective analysis, the difference being that in the former, while in the later, only certain bands are chosen (Crosta and Moore, 1989). The later is otherwise known as the Crosta technique or Feature Oriented Principal Components Selection (FPCS) whose analysis of eigenvector values allows identification of the principal components that contain spectral information about specific materials, as well as the contribution of individual original bands in relation to the spectral response of the materials of interest. This technique indicates whether the materials are represented by bright or dark pixels based on the sign and magnitude of the eigenvectors.

2.4 Tasseled Cap Transformation

The Tasseled Cap Transformation (TCT) is used to enhance separation between soils and vegetation through the determination of three indices namely; soil brightness, greenness and a third feature associated with soil moisture. TCT is an orthogonal transformation (Crist and Cicine, 1984) where the first index is a weighted sum of all bands in the direction of principle variation in soil reflectance that includes more soil reflectance or brightness information. The second index is the greenness axis that describes the contrast between the near infrared and the visible bands whereas the third component contrasts mid infrared reflectance with visible and near infrared reflectance and is important in confirming the separation of areas into vegetated and bare soil units.

2.5 Visual Interpretation

Visual interpretation of the panchromatic band 8 was used to delineate areas with gilgai micro topography based on the observation of their spatial patterns where the structural homogeneity factor (K) (Russell and Moore, 1972) that measures the tendency of repeatability was used over a 1 km radius. Vegetation differences on the mounds and depressions were also studied to try and further enhance the information content on this micro-relief.

Validation of the obtained results was through field visits and laboratory analysis of samples collected from areas interpreted to consist of the swelling soils.

3. Results

3.1 Univariate and Multivariate Statistics

The results of the univariate analysis are as shown in Table 3. They show that band 2 has the smallest variance due to its low contrast and band 5 has the largest variance due to the large differences in the spectral response in this band, of the various materials contained in the image.

The correlation matrix (Table 4) represents the multivariate statistics and indicates that bands TM-1, TM-2, and TM-3 are highly correlated, and therefore their information is redundant. The lowest correlation is obtained for bands TM-4 and TM-7 (49%) making them the most important in establishing differences on the basis of spectral information. Band 7 returns low radiance in the presence of hydroxyl minerals whereas band 4 return high values in the presence of vegetation. Thus areas with high values for the band 4 were assigned to heavy vegetation cover whereas areas with lower radiance for this band were assigned to low vegetation cover. Dark areas in the band 7 but high reflection for Band 5 were assigned to strong hydroxyl presence.

3.2 Band Rationing

The important band ratios for the problem at hand are 3/1, 4/3, 5/4 and 5/7. NDVI obtained from the ratio between band 4 and 3 gave the heavily vegetated terrain as bright pixels and was found to be mainly in the high grounds. The ratio between 3 and 1 known to reflect iron content (Rowan et al., 1977) was found to show high values in wide areas. The ratio between bands 5 and 7 is conventionally used to show the clay mineral content (Riaza et al., 2000) in the absence of vegetation and this was evident in most parts of the low lying areas though not as explicate as with the vegetation NDVI ratio. The ratio between band 5 and 4 gave differences between iron oxide dominance and hydroxyl with areas of high oxides giving brighter pixels due to stronger absorption of the band 4. Figure 2 shows a color composite of three of these band ratios (4/3, 5/4 and 5/7 red, green and blue respectively). In the image, areas with heavy vegetation is represented by red and magenta, areas presumed to be of high iron oxides are forest green and strong presence of hydroxyls appear blue.

3.3 Minimum Noise Filter (MNF)

Table 5 gives summarized statistics of the MNF transformation. From the statistics it is apparent that the first four bands, with large Eigen values would be the most

useful to represent the spectral information, contained in the images. The first MNF image consisted of the highest variance and was interpreted to represent variation in albedo among the surface materials. The second MNF had strong negative loading from band 5 and thus was assigned to information on bare soil. Figure 3 shows an inverse image of the 2nd MNF transformation clearly marking out the vegetated terrain as bright pixels and the scarcely vegetated to bare areas as grey to black. The 3rd MNF image gave a strong negative loading from band 4 and was assigned to vegetation. Other MNF images were found to consist of noise and thus were not considered in the proceeding analysis.

3.4 Principal Component Analysis

Principal component transformation results, using as inputs six of the seven TM bands (TM-1, TM-2, TM-3, TM-4, TM-5, and TM-7) are as shown in Table 6. The first principal component (PC1) was assumed to consist of information on the albedo the major contribution being from TM-5 (66.7%). The second principal component (PC2) gave a stronger contribution from the band 5 and gave built up areas as bright pixels. PC3 had strong loadings from TM-4 (91%) thus showing was assigned to healthy vegetation as bright pixels. PC4 was thought to map hydroxyl as bright pixels due to the higher negative contribution by TM-7 (61%) as seen in Figure 4. PC5 and PC6 were incoherent and were therefore not used.

3.5 Crosta Technique

This technique was applied to four bands 1, 4, 5 and 7 selected based on the spectral characteristics of the OH, and the vegetation (Table 2) and the results are given in Table 7. PC1 had high loadings from band 5 (83% of the data variance) and thus assigned to albedo whereas PC3 gave vegetation as dark pixels due to the negative contribution from band 4 and positive from band 1. PC4 gave strong positive loadings for TM-7 and a relatively strong negative for PC-5, and thus was therefore assumed to show hydroxyl pixels as dark pixels.

3.6 Tasseled Cap Transformation (TCT)

Areas with high values for the soil brightness assignment band were those established in the other analysis to consist of low vegetation cover. The greenness index also gave clear indication of vegetated terrain.

Field visits and subsequent analysis of soil samples collected in this exercise established areas assigned to heavy vegetation and iron oxides presence to consist of mainly red kaolinitic soils. Areas assigned to hydroxyl richness were established to consist of dark grumosolic soils with scattered acacia gall and in places grass cover where the dominant clay mineral consisted of notronite a
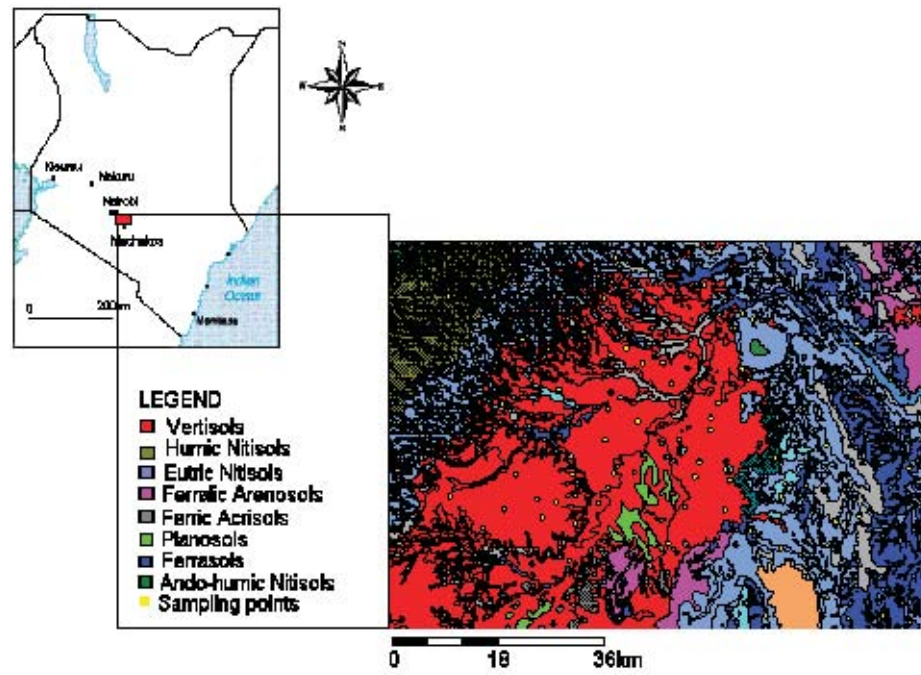
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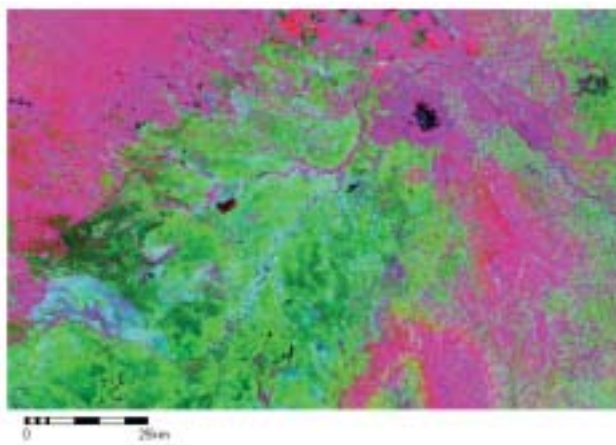Figure 1: Soil map of the study area (after Scott, 1963)

Figure 2: Color composite of the ratios 5/4 (red),
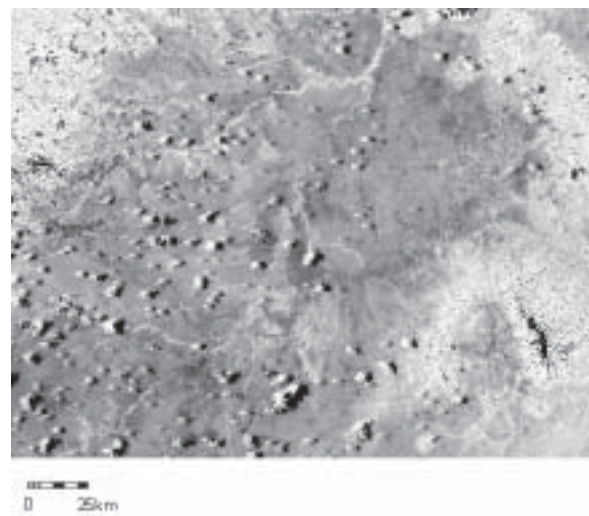4/3 (green) and 5/7 (blue).

Figure 3: An inverse of the 2nd MNF Image showing highly
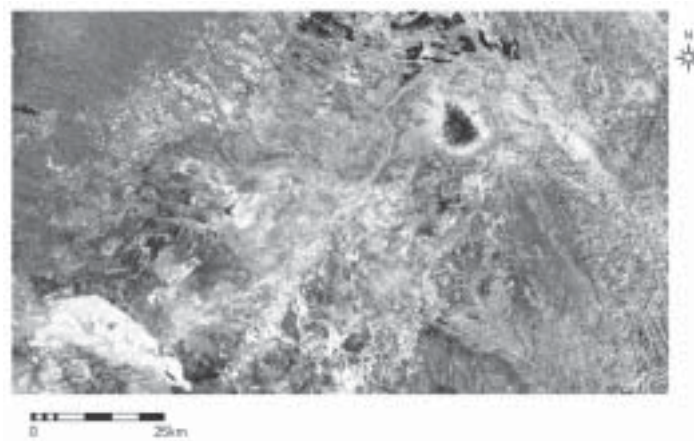vegetated terrain as bright pixels

Figure 4: Fovrth principal component showing hydroxyl as bright pixels
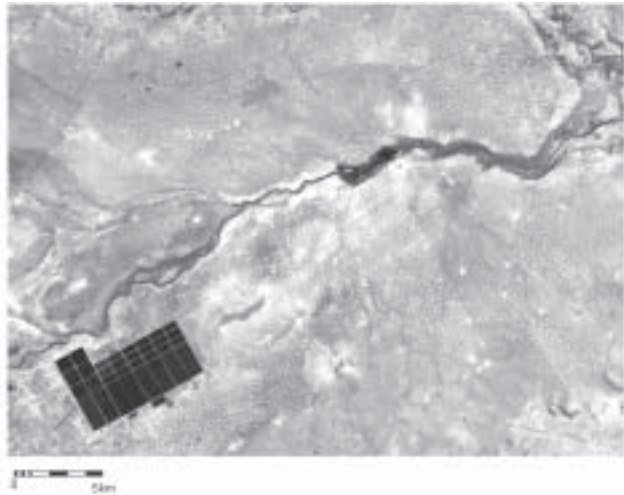
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Figure 5: Close up look of gilgai topography on ETM+ band 8
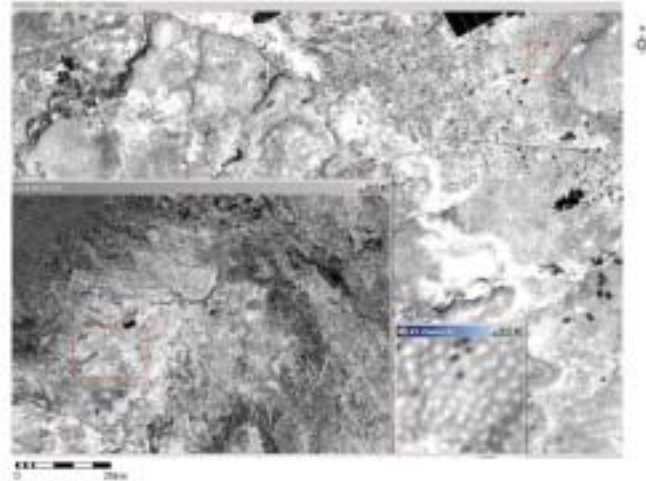

Figure 6: Entire study area (inset) and zoomed sections to represent the gilgai topography
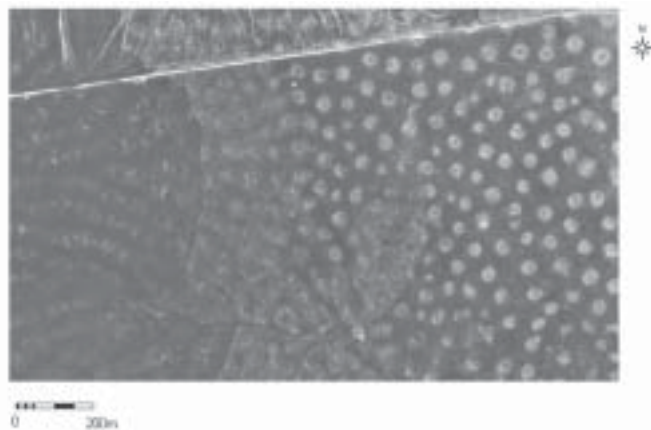

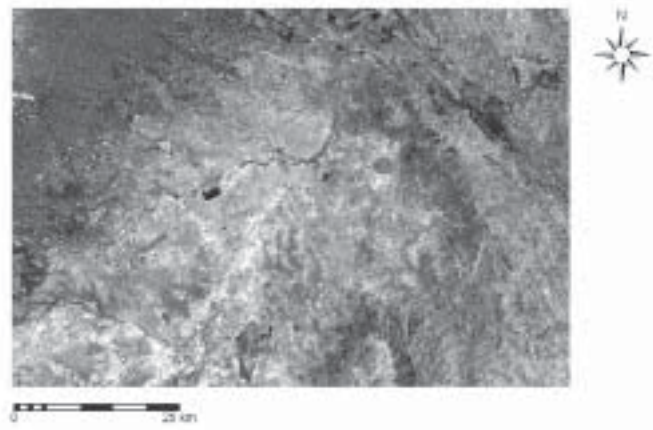Figure 7: A 1:20 000 aerial photograph showing the gilgai topography

Figure 8: Distribution of gilgai topography in the study area marked in green
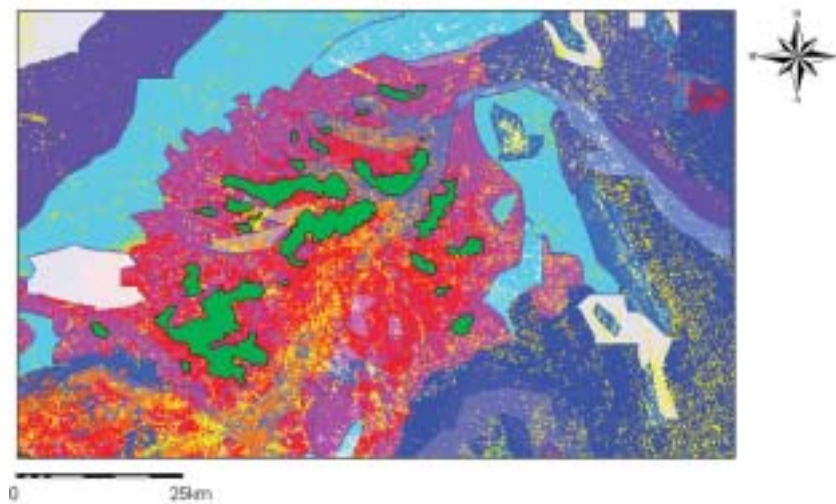

Figure 9: Overlain layers of gilgai soil and interpreted swelling based on spectral data (soil map 50% transparent)

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Table 1: Characteristic features for iron oxides,
hydroxyl and vegetation

Material	High reflectance	Absorption
Iron oxide	TM-3, 5&7	TM-1&2
Hydroxyl	TM-5	TM-7
Vegetation	TM-2&4	TM-1,3&7

Table 2. Geomorphological classification of the major soil units

Scott (1963)	Sombroek (1980)	Kariuki/Siderius (2002)
Zone 1; high ground eastern flank Rift Valley (dissected narrow, broad very broad) (Northwest of study area)	R: volcanic foot ridges (dissected lower slopes of major older volcanoes and mountains; undulating to hilly (R1, R2, R3)	Volcanic foot ridges; interfluves, valley sides and valley bottoms
Zone 2; Athi-Kapiti plains (flat to gently undulating) (Midsection)	L: plateaus and high level structural plains (flat to gently undulating; L11, L17, L15) and minor valleys	Structural and denudational plains; lava flows (buffs and mesa's); inclusive of alluvium
Zone 3; Central Hill Mass East of the Machakos District inclusive individual hills (East south east of area)	H: hills and minor scarps (H13, H15) and U: uplands on various levels (Uh15, Uu3) and plain remmants (L1, L14)	Hills and hill land (summit shoulder complex; back slope; foot slope; toe slope; associated with remmants of old peneplains (mainly basement system of rocks)

Table 3: Univariate analysis on the six bands of the TM image

Band Number	TM1	TM2	TM3	TM4	TM5	TM7
Mean per band	89.88	42.06	56.74	71.97	133.90	64.11
Std. per band:	20.93	13.77	19.53	15.98	33.96	20.38
Variance	437.95	189.55	381.32	225.37	1153.46	415.15

Table 4: Correlation matrix for study area

	TM1	TM2	TM3	TM4	TM5	TM7
TM1	1.00	0.95	0.93	0.56	0.67	0.76
TM2	0.95	1.00	0.96	0.66	0.68	0.79
TM3	0.93	0.96	1.00	0.60	0.81	0.89
TM4	0.56	0.66	0.60	1.00	0.51	0.49
TM5	0.67	0.68	0.81	0.51	1.00	0.95
TM7	0.76	0.79	0.89	0.49	0.95	1.00

Table 5: Statistics of the MNF transformation Images

Band	Min	Max	Stdev	Eigenvalue
1	-51.38	81.83	12.69	161.15
2	-15.19	73.69	6.11	37.33
3	-26.55	30.16	4.24	17.95
4	-64.92	22.92	3.6	12.94

Table 6: Principal component analysis of the study area

	TM1	TM2	TM3	TM4	TM5	TM7	Eigen values (%)
pcs1	0.371	0.249	0.383	0.206	0.667	0.408	82.30
pcs2	0.546	0.360	0.297	0.307	-0.601	-0.168	10.87
pcs3	0.315	0.061	0.167	-0.914	-0.104	0.151	5.39
pcs4	0.562	-0.209	-0.369	-0.029	0.360	-0.611	0.93
pcs5	0.368	-0.262	-0.569	0.136	-0.213	0.639	0.39
pcs6	0.113	-0.832	0.527	0.093	-0.091	0.013	0.12

Table 7: PCA on four bands for hydroxyl mapping

Input Bands	TM1	TM4	TM5	TM7	Eigen values
PC1	0.389	0.222	0.767	0.459	82.52
PC2	0.682	0.568	-0.448	-0.103	10.21
PC3	0.574	-0.786	-0.161	0.163	6.33
PC4	-0.232	0.098	-0.429	0.867	0.95

member of the smectite group of minerals.

3.6 Visual Interpretation of the Images

The above interpretations though giving an indication of the differences in spectral signature between vegetated and scarcely vegetated areas does not give compositional differences and thus gives little information on the soil physical/chemical properties. However by adding a spatial dimension to the interpretations we could obtain differences within the scarcely vegetated areas in terms of gilgai micro-topography on the swelling soils at the centre of the study area. Figure 5 gives a close up view of the ETM+ band 8 (with a spatial resolution of 15 m), whereas Figure 6 gives the entire study area and zoomed sections to represent the gilgai micro-topography. The image clearly show the micro topography which is in the range of 20-50 m in diameter in the study area with those of the higher value diameter dominant. Figure 7 show this micro-topography from aerial photographs at a section of this area, clearly marking out the characteristic differences within the area while Figure 8 shows the mapped gilgai micro-relief in the study area.

The interpretations enabled confirm further classification of the area into units of high and low swelling potential characteristics based on the presence or absence of this topography and the previously established spectral differences. Verification on the ground established the areas mapped as of high swelling potential based on gilgai topography to consist of the high swelling soils variety as is shown in the overlay with the soil map in Figure 9.

A transect taken along the depressions and mounds in the area shown on the aerial photographs gave some subtle differences in the exchangeable bases between the mounds and depressions. A spectral profile in the transect was observed not to give strong characteristic differences, which was attributed to there being little influence of the exchangeable bases on the spectral characteristics.

4. Discussion

The uses of Landsat TM images for soil mapping has always been hindered by vegetation cover (Ruiz-armenta and Prol-ledesma, 1998) and complex methods are required to remove vegetation influence. However, the results of this study demonstrate instead the use of vegetation differences to obtain soil properties variations through application of different processing techniques. The clear separation can be attributed to the good internal drainage in the higher grounds resulting in soils rich in iron oxides and kaolinite and thriving vegetation. Poor internal drainage in the plains has led to development of soils rich in smectites and thus poor vegetation making separation based on vegetation cover possible.

Improvements on these separations were made by the application of different statistical analysis methods to decorrelate the image bands and enhance the spectral response. The higher order principal components retained most spectral features typical of clay minerals i.e. the anomalous high reflectance and absorption of band 5 and 7 respectively that are distinctive of hydroxide bearing minerals and was evident in the bare soil areas. The spectrally enhanced information yielded relatively good results more so the TCT where assignments to vegetation and soil brightness could be made. Introduction of a spatially discernible dimension to the interpretations added a new tool in the characterization of the soil properties. The observed gilgai topography compensated for the lack of clear separation from the spectral band analysis on the basis of the soils physical chemical properties by showing areas of high contents of the smectite group thus helping identify areas requiring field visits for confirmations of their potential to swell.

Driese et al. (2000) established significant differences in soils physical-chemical properties at the micro-highs and micro-lows in the gilgai topography, which they attributed to overall wetter soil conditions and variable reduction/oxidation potential under micro-lows promoting greater depths of leaching. They described the micro-highs as evaporative "wicks" that draw moisture and soluble phases towards the soil surface, resulting in precipitation of among others carbonates that could probably explain the differences observed in the exchangeable bases. Mac-donald et al. (1999) on the other hand established the micro-high/low vegetation growth to be uneven due to soil moisture variations a fact that could explain the clarity in the contrast of the two in the image.

Continuous reworking on the soils seems not to obli-terate this micro-relief probably indicating rejuvenation, which could probably attest to Wilding and Tessier (1988) conclusions that the phenomenon is a dynamic process. This confirms the phenomenon as important for swelling soils mapping from remote sensing imagery, thus providing

another use of spaceborne sensors in the identification and mapping of soil physical properties. It probably calls for the re-interpretation of data from sensors such as the InSAR, in terms of what the variation in micro-topography represents more so in areas where these soils are abundant.

The results show the potential application of TM data in classifying soils into swelling potential classes based on spectral and spatial analysis and make a preliminary case for combined use of the microrelief differences and the spectral analysis to assign soils to swelling potential classes. Future work will include detailed studies to establish whether there are marked differences in the soils in the micro highs/lows in a more detailed analysis to further test the applicability of the method.

5. Conclusions

This study has established that the combined use of spatial and spectral resolution of satellite data could result in the identification and location of soils susceptible to swelling. The spectral information of the Landsat 7 ETM+ was useful in establishing differences in the signature of heavy vegetation and scarce vegetation cover and to some extent, the hydroxyl. The resolving factor of the satellite data was improved further by use of the higher spatial resolution panchromatic in establishing micro topography differences in the swelling soils. This was concluded to show the imagery potential in characterising the soils physicochemical properties, thus providing a tool for establishing the soil properties at a wider scale. The sea-sonal changes in the soil morphology should be taken into consideration in any future study.

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