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Research Paper

Morphotectonic Studies Of Area Around Lanja, District Ratnagiri: Remote Sensing Technique

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ABSTRACT

Major aspects of morphotectonics such as lineaments, river valleys, basins, coastlines, isolated hills etc. can be studied with the help of remote sensing techniques. By applying various methods of remote sensing enhancement techniques, geomorphological, lineament and lithological maps can be prepared. For this purpose, LANDSAT ETM+ images are used as a base data. The lineament analysis indicates that the most dominating lineaments are N-S and NW-SE while others are ENE-WSW. The geomorphic analysis of the study area indicate that presence of two distinct geomorphic areas; 1) western plateau region and 2) east-west trending ridge and valley landforms east of curvilinear lineaments. Lithologicallythe area is covered by basaltic lava flows of Deccan Traps and its western part is covered by lateritic caps of varying sizes and shapes. The outcrops of older Kaladgi sedimentary quartzite occur as small inliers in the centre of the study area.The spatial distribution and arrangement of geomorphic features and their correlation with lineaments and lithology is successfully applied to decipher the morphotectonic studies of the area.

Keywords: Remote Sensing, Lineaments, lithology, geomorphology.

INTRODUCTION

The study of surficial geomorphic, structural and morphometric evidences of long– and short– term tectonic activity is morphotectonics. The endogenous mechanism operate and control the tectonic activities which is represented by relative movements, such as uplifting, subsidence and translation of the crust. Multi-sensor digital images and DEMs along with advanced digital image

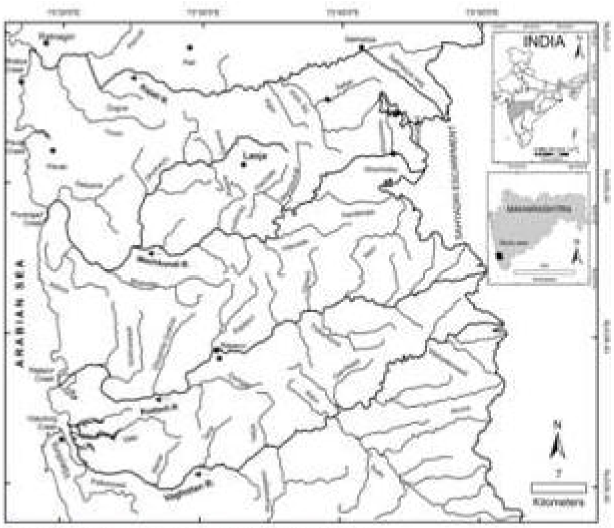

Fig.1: Location map of the study area

processing techniques, supported by field evidences are extremely useful to observe and map morphotectonic features. The analysis of these morphotectonic indicators gives a synoptic view of the (neo)tectonic activities of the region. Most of the tectonic activities dates current or geological recent times, and those can be considered as neotectonic activities. The relationship between geomorphometric elements and neotectonic landscapeis believed to be mainly indicated by bedrock joints in the area of questions.

The continental scale passive west coast margin of India representing one of the rifted margins of world has attracted many researchers because to its unique spatial position and its major role in shaping the tectonic characteristics of India. Still there is ample of scope to dive in the research in tectonics of west coast margin of India. Northern part of this west coast margin of India is covered by voluminous Deccan basaltic lava flows, covering an area about half a million square kilometres erupted 65Ma representing K-T boundary, marked by mass extinction on a global scale. Coast parallel precipitous escarpment (Western Ghat Scarp) trending nearly about N-S direction recedes eastward due to intense weathering and generates a narrow lowland at its west and a plateau at its east forms three distinct morphotectonic units from west to east are Konkan lowland(Konkan Coastal Belt), Western Ghat Scarp (called Sahyadri in local Indian language) and Deccan plateau. Formation of these morphotectonic units, their evolution, seismic events, view of mantle plume theory in its formation as well as recent trends in remote sensing are source of this research.

Major aspects of morphotectonic studies are lineaments, river valleys, basins, coastlines, isolated hills etc. (Scheidegger, 1980). The processes, structures and landforms associated with tectonic deformation of the earth's crust modify the relief and rate of erosion of the affected regions. Study of topography gives a first hand and indispensable indication of the distribution and arrangement of morphological features within a region. Remote sensing is the useful tool to identify geomorphic and tectonic features and therefore it helps to understand morphotectonics of the study area. In this paper, remote sensing data of LANDSAT ETM+ were used to recognize geomorphic features, lineaments and prepared maps of lithology and lineaments of the area around Lanja, District Ratnagiri, Maharashtra state, India (Fig.1)

DATA USED AND METHODOLOGY

In the present study, LANDSAT – 7 Enhanced Thematic Mapper (ETM+) digital data was used. Landsat-7 ETM+ is a multispectral scanner that provides a multispectral image data set in eight spectral bands. The Landsat images are relatively of higher spectral resolution and appropriate spatial resolution. The spatial resolution for the visible and near-infrared is 30m; while for panchromatic (band 8) and thermal infrared (band 6) resolution is 15m and 60m respectively. The Landsat-7 ETM+ image set was obtained from the Global Land Cover Facility (GLCF), Earth Science Data Interface (ESDI). Morphotectonic elements and lithology can be discriminated in these spectral regions and hence ETM+ imageries are employed for geological and tectonic mapping purposes. Table 1 describes the characters of Landsat ETM+ imageries.

Table 1: Characteristics of Landsat ETM+ channels.

Channel	Spectral Range (µm)	Spatial resolution (m)
TM 1	0.45 – 0.52 (blue)	30
TM 2	0.525 – 0.605 (green)	30
TM 3	0.63 – 0.69 (red)	30
TM 4	0.76 – 0.90 (NIR)	30
TM 5	1.55 – 1.75 (SWIR)	30
TM 6	10.4 – 12.50 (TIR)	60
TM 7	2.09 – 2.35 (SWIR)	30
TM8	Panchromatic	15

Map Data:

Survey of India topographic maps (No. 47 H/5, 6, 9 and 10) of the study region of the scale 1:50000 and published District Resource Map – Ratnagiri District, Maharashtra (G.S.I., 2001) were used for geo-information and geo-referencing.

Ground Data:

During fieldwork 200 Ground Control Points (GCPs) were collected with attributes using a handheld Global Positioning System (GPS) receiver with an expected error of 3-4m. Most of the GCPs are the intersections of rivers and roads, bridges etc. This data was used for georeferencing and ground truthing, as well as for accuracy assessment of the imagery.

Preliminary pre-processing of images for digital image processes includes several techniques which are carried in three general steps for the treating of digital data by computers:

- Image restoration,
- Image enhancement and
- Information extraction.

Figure 1 displays the flowchart of the digital image processing methods used. Digital image analyses were carried by processing digital image data of ETM+ bands of 1 to 5 and 7 using IDRISI and ArcGIS softwares, to generate lithologic and lineament maps as well as to delineate geomorphic features.

The raw data contains flaws and deficiencies. To overcome these flaws and deficiencies and to retain the originality of the data, it has been processed by several steps of image restoration. It is then followed by processes of image enhancement and information extraction.

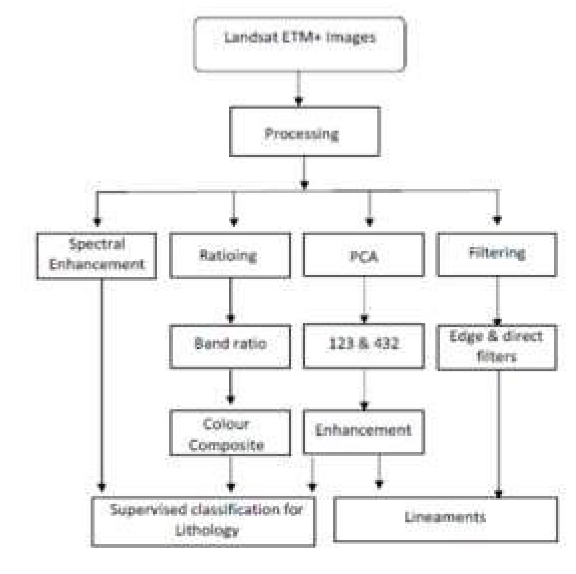

Fig. 2: Flowchart for digital image processing methods used.

•Image Restoration and Ortho-correction:

The raw image data has been geometrically corrected and resampled using ArcGIS software. The process of ortho-correction was achieved by using GCPs recorded at the time of field visits and with the help of scanned Survey of India topographic maps. The image was then de-noised using MATLAB functions of wavelet toolbox.

•Image Enhancement:

In this technique the original data was modified so as to improve the contrast of an image and hence sharpness of some features was increased. The methods used of enhancement technique are linear stretch and non-linear contrast stretch, wherein histogram of frequency of digital numbers (DN) was observed. Histogram provided the information of frequency of DN values of available brightness range. In the case of linear contrast stretch the average low and high frequency of histograms were assigned to extreme black and white respectively and remaining DN values were redistributed linearly between these extremes.

•Information Extraction:

Feature Extraction is a tool for extracting information from multispectral imagery based on varied spatial, spectral, and texture characteristics. Feature extraction uses the object-based approach to classify imagery. Lithology in the region of interest can be discriminated with the help of spatial, spectral (brightness and color), and/or texture characteristics of various rock types. It is possible to extract multiple lithological features at a time. The Landsat ETM+ band 7 has proved to be most suitable for lithological discrimination whereas ETM+ band 4 gives better information about the vegetation cover and land water contrast. The band 3 has proved to be useful for delineation of soil-boundaries as well as geological-boundaries. Band 3 also exhibits more contrast than bands 1 and 2 because of the reduced effect of atmospheric attenuation. Figures 2,3 and 4 are images of ETM+ 3, 5 and 7 bands respectively. Processed and enhanced bands were employed for information extraction, such as ratioing, Principal Component Analysis (PCA), filtering and False Colour Composites (FCC).

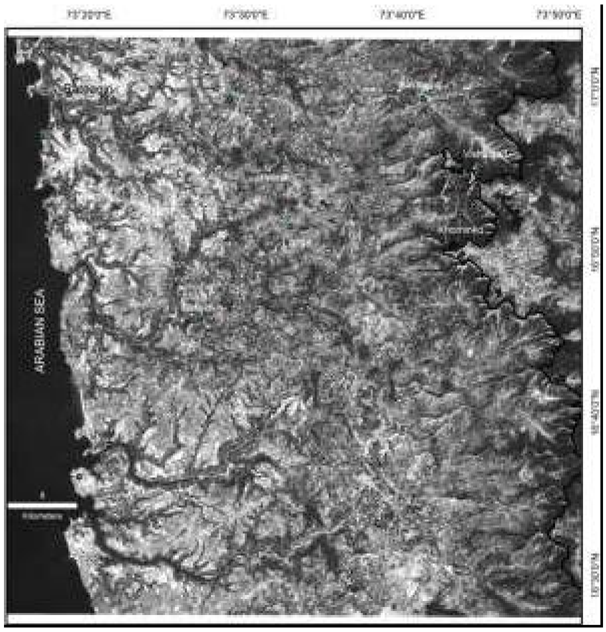

Fig. 3: Image of LANDSAT ETM+ band – 3. Arrow shows turbidity currents released by promontories.

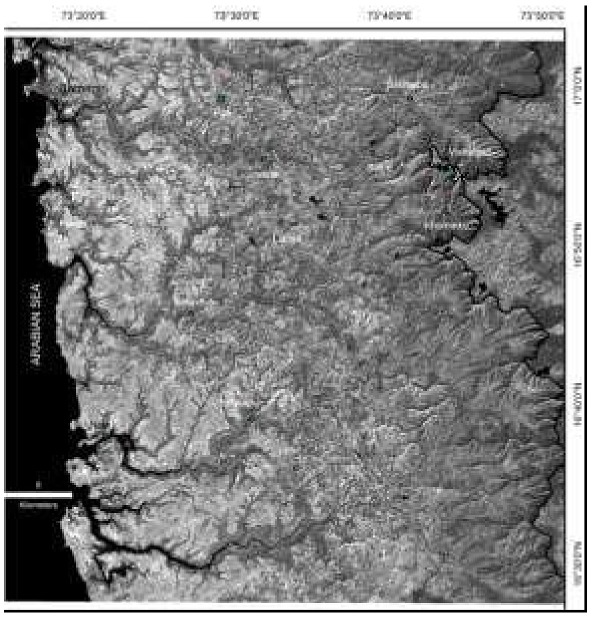

Fig.4: Image of LANDSAT ETM+ band – 5.

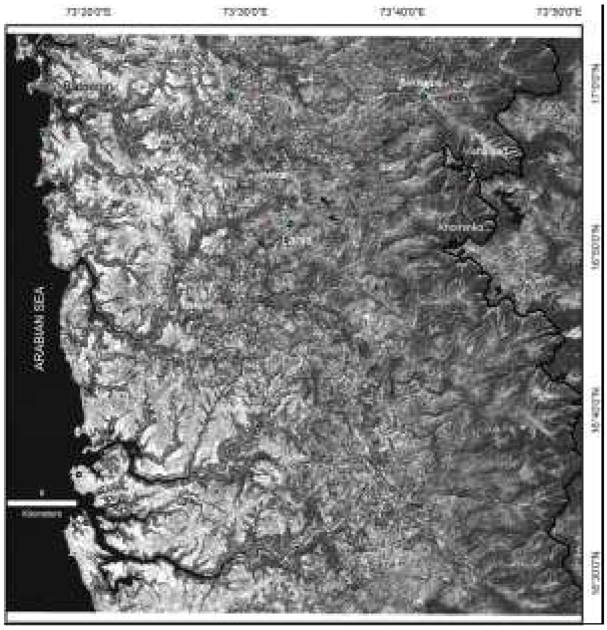

Fig. 5 Image of LANDSAT ETM+ band – 7.

Ratioing:

The technique of ratio is carried out by dividing the gray level of pixels in one band by gray levels of another band. It is a significant process by which some of the features are enhanced. It proved to be important in the case of ferruginous and limonitic cappings. Figure 5 represent the spectral reflectance curves for laterite and other iron minerals (Hunt and Ashley, 1979). These curves indicate that the values of spectral reflectance of laterite and iron minerals are different. The reflectance of laterite is relatively low in band 5 than band 7 than other iron minerals. According to Hunt and Ashley, 1979, the band ratio 5/7 enhances the rocks which are rich in Al-OH and laterite. Figures 2.8 and 2.9 are ratio images generated by a ratio of the bands 5/7 and 5/4 respectively.

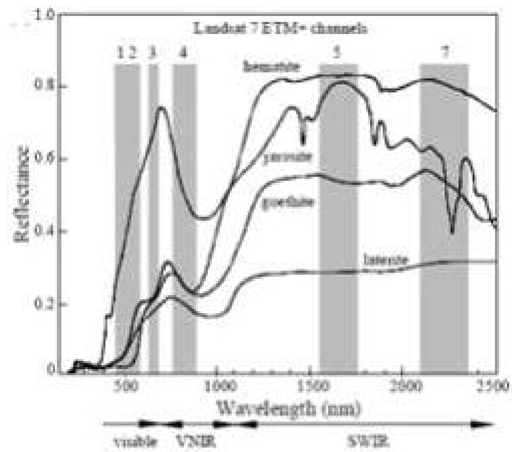

Fig. 6: Spectral reflectance of laterites (After, Hunt and Ashley, 1979)

Principal Component Analysis (PCA):

In the PCA technique, multi-band data sets can be used to reduce its dimensionality, and compress as much of the information in the original bands into fewer bands. The useful information about the units in the image can be compressed properly into three components. The technique of PCA was applied to six bands (1, 2, 3, 4, 5 and 7) of Landsat ETM+ to compress the information in three bands. Table 2 shows the image statistics of the principal components (PCs) performed using ETM+ bands. The eigenvalues indicate the decreasing variance in successive principal components. The first component of the PCA consists of infrared information of Bands 3, 5 and 7. The second and third components of PCA consist of information of 4, 5 and 7 bands and 5, 7 and 3 bands respectively. The first principal component contains 88.391% of the total variance. The first three components contain 99.13% of the total variance within the whole volume of data of six bands. The image of PCA-2 shows good lithological discrimination (Fig. 11). Lineaments also have been identified and demarcated manually using PCA-2 image.

Table 2: Eigen vectors and Eigen values of the Principal Component Analysis of the bands of Landsat ETM+ data.

	ETM1	ETM2	ETM3	ETM4	ETM5	ETM7	Eigen Values %
PC1	0.2971	0.3595	0.5346	0.1175	0.5247	0.4557	88.3910
PC2	-0.1833	-0.1450	-0.3170	0.8280	0.3944	-0.0619	7.5107
PC3	-0.3276	-0.3823	-0.3163	-0.4604	0.4887	0.4423	3.2334
PC4	0.5922	0.3023	-0.6867	-0.0183	-0.0829	0.2812	0.5161
PC5	-0.2388	-0.1187	0.0962	0.2875	-0.5685	0.7168	0.2650
PC7	-0.6025	0.7734	-0.1812	-0.0756	0.0168	-0.0047	0.0839

Merging operations:

FCCs are generated by merging various combinations of bands from visible spectra and IR spectral regions. According to Das, 2009, colour composite of bands 3(red), 5(green) and 7(blue) is useful to delineate the lineaments, laterite capping as well as the extent of vegetation and soil cover in the region. The FCC of the study area was produced by a combination of (RGB) 3, 5 and 7 bands (Fig. 12). The Cyan, Magenta, Yellow and Black (CMYK) mode of colour composite (Fig. 7) was also prepared using bands 3, 5 and 7.

Filtering operations:

Spatial frequency is one of the characteristic features of the satellite images. It is defined as the number of changes in the brightness value per unit area for any particular part of an image. Low frequency areas means there are very few changes in the brightness value over a given area in the image. Conversely, if the brightness values change abruptly over short distances, this is an area of high frequency detail (Jensen, 1996). Therefore, filtering operations are used to emphasize or deemphasize spatial frequency in the image. This frequency was attributed to the presence of the lineaments in the area because the filtering operation sharpens the boundary between adjacent units. The main disadvantage of filtering operation is effective extracting lineaments in low-contrast areas, where features extend parallel to the sun directions and in mountain shadows (Koike et al., 1995).

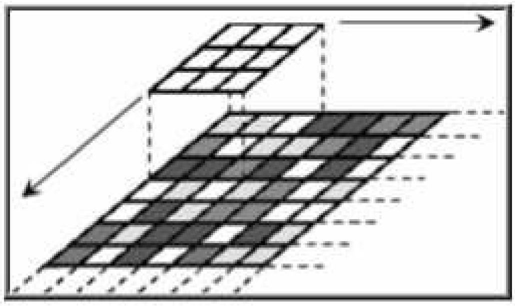

Fig. 7: Generation of a new image by filtering operation; selected window moves both row-wise and column-wise and calculates new values.

A moving window of certain kernel size of 3x3, 5x5 or 7x7 over an area is commonly used filtering operation. The moving window calculates new DN value for each pixel and replaces the central pixel of the kernel to generate resultant image. The High Pass filter selectively enhances the small scale features of an image (high frequency spatial components) while maintaining the large-scale features (low frequency components) that constitute most of the information in the image. Directional filters (edge detection filters) are designed to enhance features which are oriented in specific directions. Gradient-Sobel and Gradient-Prewitt are commonly used for edge detection filters. Hence, Prewitt and Sobel filters were applied to all six bands of the image in N-S, E-W, NE-SW and NW-SE directions and forty eight images were generated.

Four principal directional filters used are given in table 3. These images were visually examined and most effective subset of images are shown in figure 7 A, B, C and D.

Table 3: Sobel and Prewitt filters applied in four main directions.

	N-S			NE-SW			E-W			NW-SE		
SOBEL	-1	0	1	-2	-1	0	-1	-2	-1	0	1	2
	-2	0	2	-1	0	1	0	0	0	-1	0	1
	-1	0	1	0	1	2	1	2	1	-2	-1	0
PREWITT	-1	0	1	-1	-1	0	-1	-1	-1	0	1	1
	-1	0	1	-1	0	1	0	0	0	-1	0	1
	-1	0	1	0	1	1	1	1	1	-1	-1	0

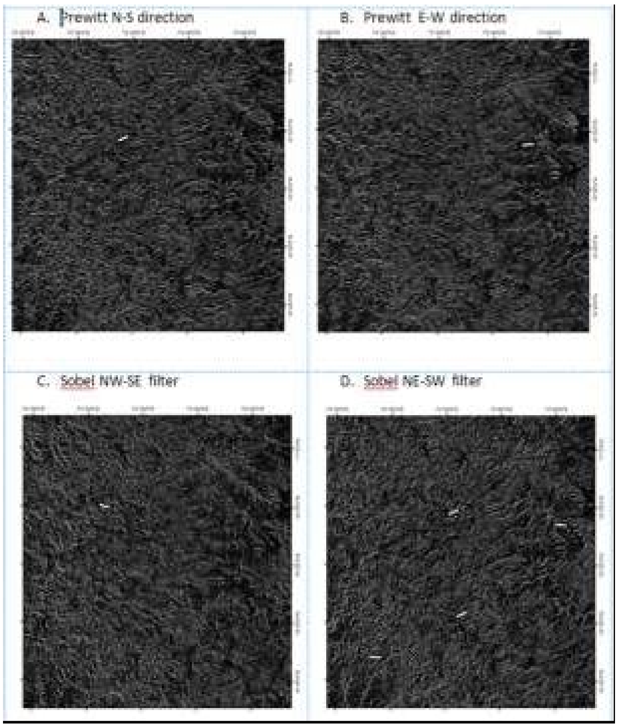

Fig.8: Subset images generated by Sobel and Prewitt filters, Arrows: enhanced lineaments

RESULTS AND DISCUSSION:

Geologic Analysis:

Lithological units, lineaments and geomorphic features were recognized using elements of photo or image recognition from processed images of individual bands, ratio, PCA-2 and FCCs. The object based approach was used to recognize lithological units. Tone, texture, association in the images and the published geological map were used for lithological discrimination and mapping. Lineaments were recognized on thebasis of topographic and tonal contrast, linear river valleys, alignment of vegetation etc., while size, shape, pattern and association were used to recognize various geomorphic features. Lineaments were manually digitized in ArcGIS environment using images of PCA-2 (Fig.11), enhanced Sobel and Prewitt filters (Fig. 5), FCC 357 (Fig. 12) and CMYK (Fig. 13). Duplicate and minor lineaments were deleted.A final lineament map was prepared by overlaying lineament layers generated by each analysis.

Images of enhanced ETM+ bands and FCCs, CMYK and PCA-2 were used to recognize and differentiate various lithological units and geomorphic features in the study area. Table 4 shows the nature of image signatures and their relative ability to discriminate lithounits, lineaments and geomorphic features in ETM+ bands, while Table 5 shows that of FCC (357), CMYK, ratio images (5/7 and 5/4) and PCA-2. ETM+ images of 3, 5, 7. ETM+ images of bands 3,5 and 7 and PCA-2 found most useful for geologic studies. All of the ETM bands were found useful to recognize Western Ghat scarp. CMYK image also exhibit huge scarps, westward extending ridges and small to large scale amphitheatrically shaped valley heads. Drainages, water

Table 4: Terrain characteristics in image of Landsat ETM+ bands.

Band	Escarpment	Water bodies	Drainages	Lineament	Ridge/valley	Basalt flows and laterite	Sedimentary quartzite	Beach alluvium	Mudflats
1	ID	ID (G)	ID (G)	ND	ND	ND	ND	D (W)	D (MG)
2	ID	MD (DG)	D (G)	ND	ND	ND	ND	D (W)	D (MG)
3	D	D (B)	ID (G)	ID	ID	ND	D (with basalt and laterite)	D (W)	D (MG)
4	ID	D (B)	D (DG)	D	ID	D (LG and MG)	ND	ND (LG)	D (DG)
5	D	D (B)	ID (DG)	MD	D	D (LG and MG)	D (MDG)	D (W)	D (DG)
7	MD	D (B)	ID (DG)	ID	D	D (LG and MG)	D (MDG)	D (W)	D (DG)

D: Distinct, MD: Moderately Distinct, ID: Indistinct, ND: Not Demarcation, D: Dark Grey, MDG: Moderately Dark Grey, LG: Light Grey, MG: Medium Grey, G: Grey, W: White

water bodies and lineaments were distinctly recognized in the bands of 5 and 7, while beaches and other alluvium areas were recognized easily in the bands of 3, 5, and 7. Areas of basaltic flows and laterite caps were easily demarcated in 5 and 7 bands, while Kaladgi sedimentary quartzite inliers were delineated from 3, 5 and 7 bands.

Table 5: Colour or tonal signatures and readability of features in FCC, CYMK ratio images, and PCA-2 images.

No.	Features	FCC 357	CMYK	Ratio images		PCA-2
				5/7	5/4	
1	Agri. fields	Pink, violet,	Not recognized	Indistinct	Indistinct	Indistinct
2	Town villages	Distinct	Not recognized	Indistinct	Indistinct	Indistinct
3	Road	Distinct	Not recognized	Indistinct	Indistinct	Distinct
4	Water bodies	Brownish black, Distinct	White	Black	Shades of grey	Light grey
5	Vegetation	Green	Not recognized	Light grey	Dark grey	Shades of grey
6	Alluvium	Red	Not recognized	Grey	Moderate grey	Moderate grey
7	Mud flats	Pink	Not recognized	Grey	Dark grey	Dark grey
8	Drainage	Distinct	White Distinct	Distinct	Distinct	Grey Distinct
9	Escarpment	Distinct	Distinct	Distinct	Distinct	Distinct
10	3D effect, Deep valley, Ridge, slope	Moderate	Distinct	Not recognized	Not recognized	Not recognized
11	Basalt	Pink, violet		Shades of grey	Shades of grey	Shades of grey
12	Laterite	Pink, violet	Light oliverite to olive green	Shades of grey	whitish	whitish
13	Sedimentary quartzite	Not recognized		Indistinct	Indistinct	Indistinct
14	Lineaments	Indistinct	Distinct	Indistinct	Indistinct	Indistinct

Enhanced images such as ratios of 5/7 and 5/4 (Fig. 9 and Fig.10) were found most significant for discrimination of lithological units. The FCC 357 (Fig. 12) discriminates various man made features such as agricultural fields, roads, towns, water bodies as well as lithological units such as basalts, laterite covered areas and alluvium. However, this image was not found useful to discriminate inliers of Kaladgi sedimentary quartzite. The CMYK (Fig. 13) composite is one of the best enhanced images, which was found useful to discriminate most of the lineaments and geomorphic features.

Lithological Mapping:

Studies of enhanced images of ETM+ bands indicate that the lithological boundaries between basalt and laterite, basalt and sedimentary quartzite, basalt and alluvium were easily demarcated in images of ETM bands 5 and 7, PCA-2, FCC (357), ratio images of 5/7 and 5/4 and CMYK mode. Alluvium deposits such as beaches, mud flats, alluvial deposits and point bars along rivers were easily recognizable by using ETM band 3 and FCC (357). Boundaries between basalt and laterite as well as Kaladgi sedimentary quartzites were easily recognized and demarcable with the help of images of FCC (357), ratio 5/4, PCA-2 and CMYK. The lithological map (Fig.14) prepared with the help of images of FCC (357), ratio 5/4 and PCA-2 indicates that the most of the study area is covered by basaltic flows. The flows on the plateaux in western regions are covered by laterite caps, which represent the planar surfaces. Laterite outcrops are extending most of the plateaux regions. Kaladgi sedimentary quartzite inliers were marked mainly in the middle part of interbasinal areas of Machkundi and Kodavli rivers. Beach deposits in the images are linear and narrow tracks along the coast lying between river mouths whereas estuaries are wide and exhibit alluvium deposits in the form of mud flats.

Lineament Extraction:

Most of the lineaments were recognized by using linear deep valleys, topographic and tonal contrast criteria. These are easy to recognize in images of ETM bands of 3 and 5, PCA-2, FCC (357) and CMYK. Most of these are either continuous or discontinuous linear features while few of them are curvilinear (Fig. 15). The number azimuth frequency rose (Fig. 15 B, inset) indicate that, these are oriented in three distinct trends, such as, 1) N-S, 2) NW-SE and 3) ENE-WSW directions. Other than these directions, NE-SW is also observed only in the escarpment region. N-S lineaments are linear and curvilinear while NW-SE and ENE-WSW are linear. Curvilinear N-S lineaments occur along the deep valley of streams in between the Kajali and Machkundi rivers, whose concave traces (L1 to L2) are towards the west. L1 and L2 curvilinear lineaments follow the stream valleys of Agav-Mandavkar and Palu respectively. The L6 curvilinear lineament whose concave trace is towards the east which follows Phuphere stream, tributary of Kodavliriver. L4 lineament is sinus, whose southern segment is concave towards east. The trend of curvilinear lineaments changes from NW-SE to NE-SW through N-S. Linear N-S lineaments (L5) control the linear coast lines and linear deep valleys of stream segments in the study area. The L3 lineament follows the N-S deep Khorninko valley, tributary of Machkundiriver and also traverses the projection of upland region, west of Vishalgad.

NW-SE lineaments (L7 and L8) appear to be continuous and discontinuous at their southeastern and northwestern segments respectively. Most of them control the moderately deep linear valley segments in the eastern region of the study area. L8 extends up to the coastal region while others are intersecting the escarpment regions recognized by linear topographic contrast. Out of southeastern segments of L7 lineament has been controlled valley segments of Panhale and Vilavade, while L8 has controlled the valley segment of Sukhriver. ENE-WSW lineaments are relatively indistinct and are controlled by relatively shallow and linear Kajali river segment and Salpe stream in the north and Aruna stream in the south. It is interesting to note that the angles between NW-SE and ENE-WSW lineaments are acute and obtuse. The acute angle between them is nearly 600 which represent the dihedral angle between conjugate lineaments. The trend axis of bisecting dihedral angle orients in WNW-ESE direction, which is a maximum principal palaeo-stress (? 1) direction.

Recognition of Geomorphic and Drainage characters:

Geomorphic features and drainage network have been recognized in the images of ETM+ bands of 3 and 5, PCA-2, FCC (357) and CMYK image mode. Large scale features recognized are escarpment, amphitheatrically shaped valley heads, ridges and their slopes, valleys, plateaux, mesas, rivers and their meandering segments, drainage patterns and creeks. Small scale features recognized are deep valleys or channels, point bars, beaches, estuaries and mud flats. Western Ghat escarpment separates eastern main plateau upland and narrow coastal plains at its west. CMYK image distinctly exhibits escarpment, sub-ghat constituting valley heads and ridges and western dissected plateau region covered by laterite caps representing the planar surfaces. CMYK and PCA-2 images show relic upland that has separated by streams controlled by N-S and NE-SW lineaments near Vishalgad. In general, the rate of scarp retreat in the southern escarpment is more than the northern. Ridges are originating from steep escarpment. The sub - Ghat section has numerous parallel sharp ridges and deep 'V' shaped valleys which are mostly trending in E-W. These ridges terminate at L2 and L6 lineaments. The dominating N-S trending ridge and valleys are located east of Lanja region in between curvilinear N-S lineaments indicating structural control. Deep 'V' shaped valleys are associated in the escarpment and western plateau regions. The planar surfaces in the western region of the study area are of different size and shapes, however, most of them are irregular and some are rectangular in shape. The deep 'V' shaped valleys dissected plateau region are of varying depths and steeper slopes in comparison to those valleys in sub-Ghat section. The narrow region between L1 and L4 lineaments in the north is relatively leveled region, which has lower absolute and relative relief while southern region has number of isolated hills.

The study region has westerly flowing narrow and elongated four major river basins namely; Kajali, Machkundi, Kodavli and Vaghotan. The drainage pattern in the study area is mostly dendritic to sub-dendritic. The drainage pattern east of L1 is parallel, asymmetrical and trellis while the drainage pattern east of L6 is parallel. Thus eastern parts of these lineaments are highly structurally controlled. The local sharp bends along rivers or streams are seen. The Kajali river segment in its lower reach region near Ratnagiri makes a sharp bend to its westerly flow direction. Similarly, Panhale and Vilavade streams have sharp bends controlled by NW-SE trending lineament (L7). The widths of river channels in the coastal regions are wider to form creeks in their mouth. Fewer numbers of islands and mud flats have been identified in these creeks.

CONCLUSION:

Image signatures and their readability indicate that the images of CMYK, PCA-2 and ratioing as well as different spectral bands of ETM+ are not only useful to demarcate lithological units, lineaments, major geomorphic features and normal and abnormal drainage characters but also useful to recognize small scale geomorphic features such as relative channel depth, point bars, mud flats etc. However, CMYK image is more suitable for recognizing most of the geomorphic features and lineaments.

Remote sensing analysis of Lanja region underlines the fact that most of the area is covered by basaltic lava flows of Deccan Traps and its western part is covered by lateritic caps of varying sizes and shapes. The outcrops of older Kaladgi sedimentary quartzite occur as small inliers in the centre of the study area. The recent alluvium deposits occur along upper and lower reaches of major rivers while mud flats and beach deposits seen in the mouth of rivers at creeks and along the coast respectively.

The lineament analysis indicates that the most dominating lineaments are N-S and NW-SE while others are ENE-WSW. The N-S is a group of lineaments include linear as well as curvilinear NNW-SSE to N-S trending lineaments. Pattern of N-S curvilinear lineaments expresses presence of listric normal faults. The L3 lineament controls the deep valleys and also it intersects the relic upland. L4 lineament coincide with the line of hot-springs indicates deep seated weak zone. L5 lineaments coincide with the linear coastal segments and linear N-S inland stream/river channels adjacent to the coastlines. N-S lineaments are parallel to the major tectonic features in KCB, such as West Coast Fault, Panvel flexure and horst and graben structures in the offshore regions. NNW-SSE lineaments coincide with weak zones of the Dharwarian trend exposed immediately to south of southern Deccan Traps. NW-SE and ENE-WSW lineaments are intersecting with each other making an acute angle of 600, indicating they are conjugate and are of the same system. The ENE-WSW lineaments are subordinate in comparison to NW-SE that can be recognized by degree of incision and dominance.

The remote sensing analysis of the study area indicate that presence of two distinct geomorphic areas; 1) western plateau region and 2) east-west trending ridge and valley landforms east of curvilinear lineaments (L1 and L6). These ridges and valleys originate in escarpment region and diminish and terminate at curvilinear lineaments. The higher degree of incision and deep 'V' shaped valleys mainly occurs in the plateau region indicate rejuvenation. The valleys in the plateau region are deeper than the valleys adjacent to the escarpment. The study area has a number of abnormal drainage characters such as sharp bends, linear and curvilinear deep valleys as well as trellis and asymmetrical drainage patterns indicate structural control. The trellis and asymmetrical drainage pattern is mainly seen in the inter-basinal region between Kajali and Machkundi rivers. The curvilinear ridge lying between Agav-Mandavkar and Palu curvilinear lineaments also indicate structural control.

Thus, the lineaments in this region can be divisible into two groups: 1) N-S lineaments which are parallel to major structures in the KCB and in offshore region and 2) NW-SE and ENE-WSW lineaments exhibit the conjugate relationship. The conjugate pattern of lineament discerns the maximum principal compressive stress ($\sigma 1$) in WNW-ESE direction. The N-S linear and curvilinear patterns of lineaments and the conjugate relation between NW-SE and ENE-WSW lineaments are indicative of complex tectonics.

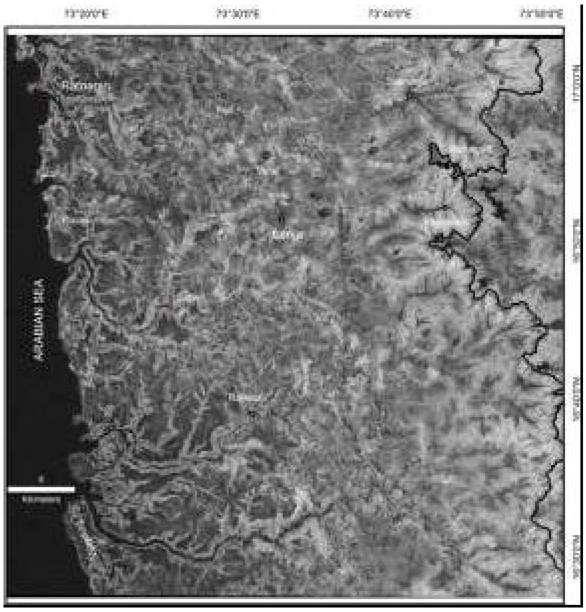

Fig.9: Image of ratio 5/7

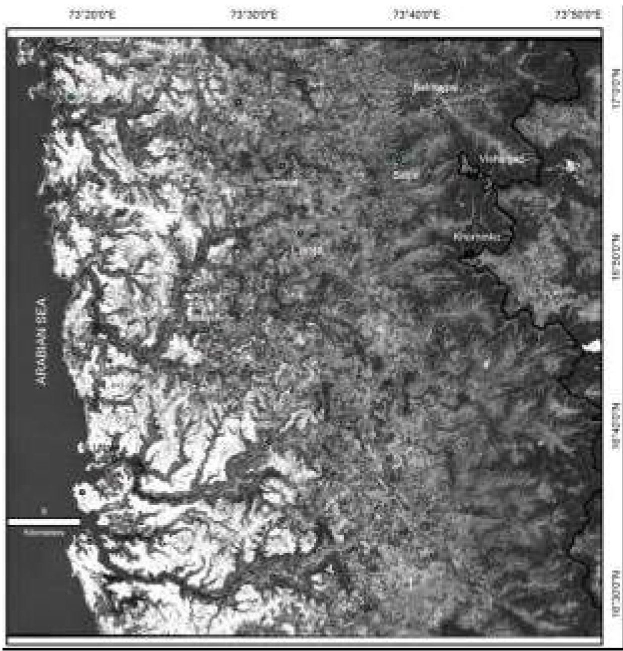

Fig.10: Image of ratio 5/4 which enhances ferrous minerals, Laterites.

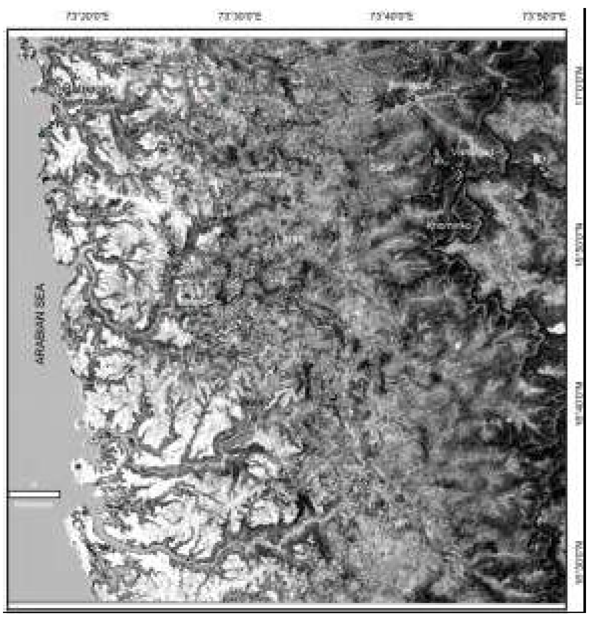

Fig.11: Image of PCA-2.

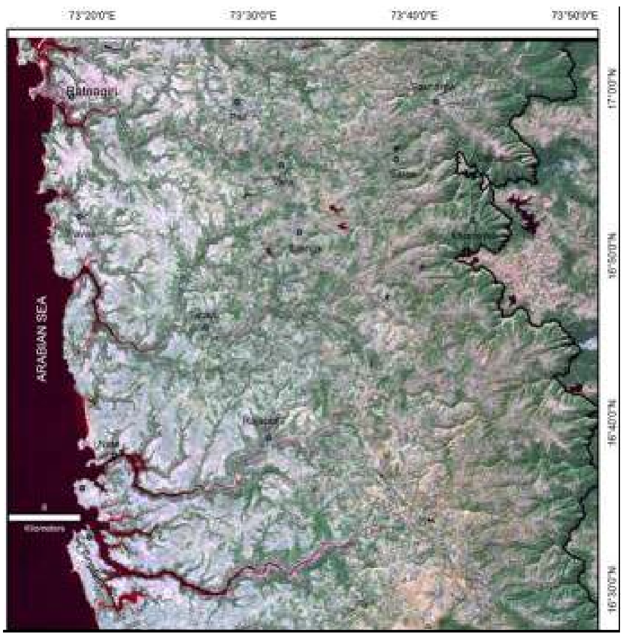

Fig. 12: False Colour Composite of bands 3(red), 5(green) and 7(blue).

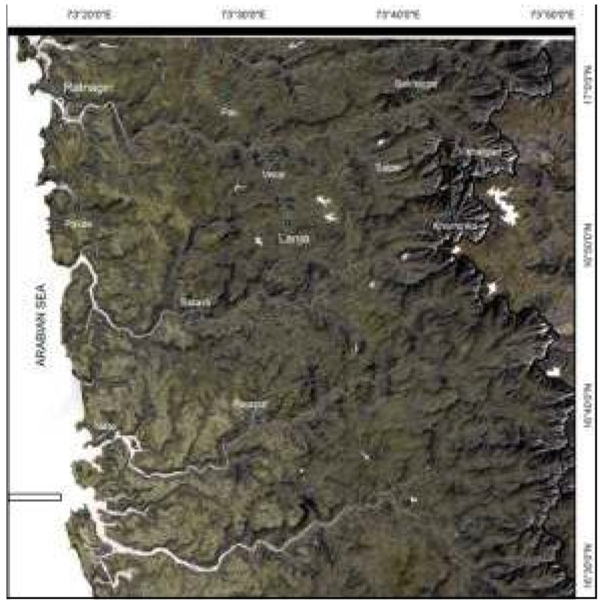

Fig.13: FCC of 3,5and 7 in CMYK colour mode.

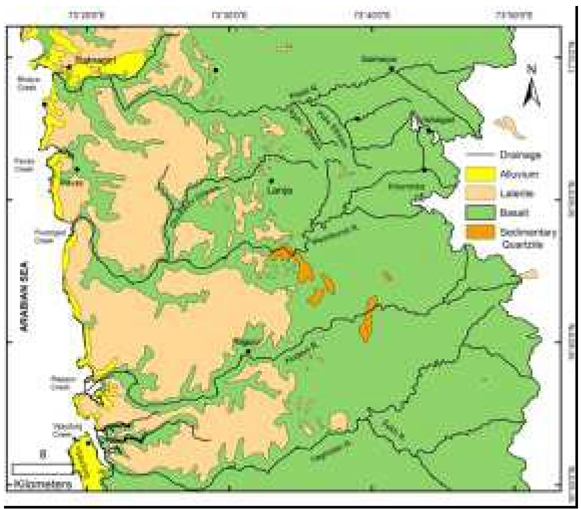

Fig. 14: Lithological map of the area.

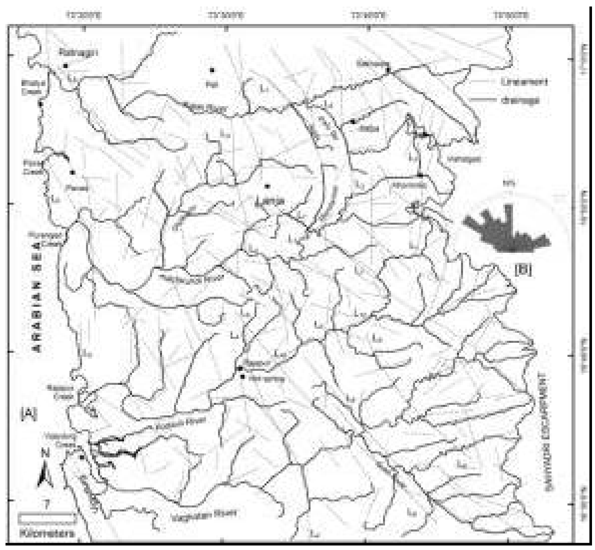

Fig.15: A) Lineament map B) Rose of number azimuth of lineaments.

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