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Geobotanical and geomorphological approach to map the surface lithology using remote sensor data

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ABSTRACT

The objective of this research was to evaluate the potential of ASTER imagery for lithologic mapping in the heavily vegetated area using digital image processing. This study used geobotanical and geomorphological approach to identify the underlying surface lithology of the study area. Two lithologic maps were produced: the first lithologic map based on the combination of vegetation and drainage pattern was done using knowledge base classification and the second lithologic map based on GIS analysis of drainage pattern. Results of both of these two lithologic maps show that shale is dominant in the axial part of anticlines, sandstone in the outer flank of anticlines and alternation of sandstone and shale in the middle flank of anticlines. Accuracy of classification derived from knowledge-based classification was checked against field data and this shows an agreement of about 36% for sandstone, 92% for sandstone-shale alteration and 55% for shale units. Similar accuracy analysis yielded about 34% agreement for sandstone, 98% for sandstone-shale alteration and 77% for shale for the litho map derived on the basis of drainage pattern. Methodologies and findings of this study showed that remotely sensed ASTER imagery is a good tool for mapping lithology of a heavily vegetated area like this study area.

Keywords: Satellite image, ASTER, Knowledge base classification, Image processing.

1. Introduction

Chittagong Hill Tracts, a large hilly region of neogene clastic sedimentary rock in the southeastern part of Bangladesh, lies in the youngest structural province along the western flank of Indo-Burman range (Reimann K.A., 1993). Currently available geologic map of this area has been prepared on the basis of limited fieldwork along several road sections, stream sections supplemented by interpretation of aerial photographs carried out jointly by Geological Survey of Bangladesh (GSB) and United States Geological Survey (USGS). The units in these maps were at the broad formation level and lack many details. Inaccessibility, dense forest cover, poor infrastructure, lack of initiative by local organizations and frequent disruption of law and order restricts conventional geological field mapping in this region. Considering the current status of the lithologic mapping in the Chittagong Hill Tracts region, the present research work is carried out with the hypothesis that the multispectral satellite-borne imagery from ASTER sensor would be able to provide more usable information to augment the currently available lithologic map of this region. It would also provide a quantitative assessment of the capability of this sensor to map the lithology of an area covered with thick tropical vegetation.

Chittagong Hill Tracts area of Bangladesh comprises of lower Miocene to Recent sediments (Reimann K. A., 1993). The major rock types are sandstone and shale; the subordinate rock types include siltstone, sandy shale and conglomerate are also present. The synclinal troughs

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mainly comprise of alluvial sand, silt and clay. Structures of the study area are characterized by a series of parallel to subparallel ranges of hills with doubly plunging folds trending roughly NNW-SSE. Most of these structures are generally affected by longitudinal faults and have maximum throws near the anticlinal crests (Guha, 1978; Ganguly, 1983). The Bhuban, Bokabil, Tipam, Dupi Tila formation of Mio-Pliocene age and recent alluvium form the stratigraphic succession in this region. (Reimann K. A., 1993). Shale of the Bhuban formation occupies the flat central part of anticlines. Alternation of sandstone and shale of the Bokabil formation occupies flanks of the anticlines and sandstone of the Tipam and Dupitila Formations occupy outer flanks of the anticlines and synclinal trough. Recent piedmont deposits in broad synclinal valleys cover the Tertiary succession.

The entire study area is in the early to late youthful stages of the geomorphic cycle of erosion and is characterized by hills, spurs, ridges, valleys, escarpments and pockets of plain lands (Ali K.M., and Hasan K., 2002). The elevation of study site ranges from 430 m to 1918 m. Various types of drainage patterns are available in this area. It is established that drainage pattern results from geomorphic processes on the rock types and is strongly influenced by the rock characteristics to a degree that the underlying rock lithology can be inferred from it. It is developed through time on a landscape provides clues about the bedrock lithology. Drainage patterns vary in density, shape, extension, the lithologic character and tectonics of the material on which it forms and develops. The main influencing factors of the formation of drainage are rock type and its hardness/softness, the degree of consolidation and the tectonics of the material (Horst, F. and Bandat V., 1960). For an example, dendritic drainage pattern develops in regions underlain by homogeneous material reflecting similar resistance to weathering and there is no apparent control over the direction of tributaries (Strandberg C.H., 1967).

The soil of the study area is developed from sandstone and shale of Mio-Pliocene age. Soils developed on shale are clay and silty clay loam while those derived from sandstone are sandy loam to sandy clay loam (Hasan, M.M., 1999). The organic matter content of soil derived from shale is 0.98% whereas soil derived from sandstone was 0.64% to 0.85% (Hasan, M.M., 1999), thus organic matter content indicates higher fecundity of soil originated from shale over sandstone. The natural vegetation climax of Chittagong Hill Tracts is tropical evergreen and deciduous forest. It consists of a mixture of many tropical and deciduous species occurring in association with each other and with some patches of bamboo and sungrass. The anticlinal structures expressed as broad hill ranges, are covered by thick vegetation that obscures the exposed rock type. The narrow valleys on the synclinal structures are almost bare with few patches of vegetation. Despite the ubiquitous occurrence of these plants across all lithologic types, plants are different in their chlorophyll content, water content, canopy, biomass and vigour due to different underlying rocks.

Vegetation and its characteristics changes depend on the soil and its composition that is derived from parent rock materials. The geobotanical approach hypothesizes that underlying rock type controls natural vegetation due to different types of soil development (Figure 1). The explanation and understanding of this hypothesis mainly rests on the relation between natural vegetation, underlying soil, soil-water content and underlying rock type. The climate and relief of the area might also affect both soil and vegetation (Warner et al, 1994). Variations of vegetation are expressed through canopy, vigour, chlorophyll content, biomass, rate of evapotranspiration and plant water content. These parameters depend on the underlying soil moisture content, organic matter content, grain size and porosity. Therefore, changes in vegetation indicate the changes in underlying rock type. Spectral region of green, red, infra red and near infrared of ASTER imagery are sensitive to chlorophyll, biomass and water content of vegetation (Jensen J. R., 1983) which justifies the ability of ASTER image data for lithologic mapping using spatial discrepancy of natural vegetation as an indicator. As most of the areas of Chittagong Hill Tracts are covered with thick vegetation, the discrimination of difference in plant's characteristics helped to identify the rock type. Shale contains higher percentage of organic matter than sandstone (Hasan M.M., 1999). Therefore, soil over the shale has higher fertility than that of sandstone. Soil over the shale is able to produce healthier vegetation than soil over sandstone. However, human interactions have changed the original vegetation pattern of some areas through deforestation at first and later through replanting of exotic varieties of trees that may create confusion in interpreting the underlying soils and rocks.

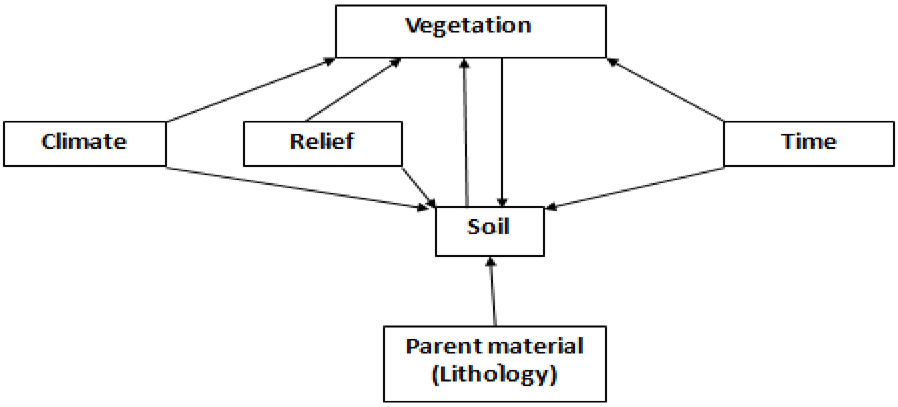

Figure 1: Relation between parent rock, soil, climate and vegetation (Warner et al, 1994)

2. Study area

The study area (latitude 22° 26´ 5.4969´´N – 22° 49´ 58.5912´´N and longitude 91° 51´ 5.7852´´E – 92° 21´ 50.5798´´E) lies in the northern part of the Chittagong Hill Tracts (part of Arakan Yoma Mountain Range), in the southeastern part of Bangladesh (Figure: 2). It covers nearly 2369 sq. Km. The Study area belongs to greater Rangamati district, which includes thanas namely Rangamati Sadar, Barkal, Mahalchari, Naniarchar, Langadu, Kawkhali, Rangonia, Raozan, Kaptai and Rajasthali.

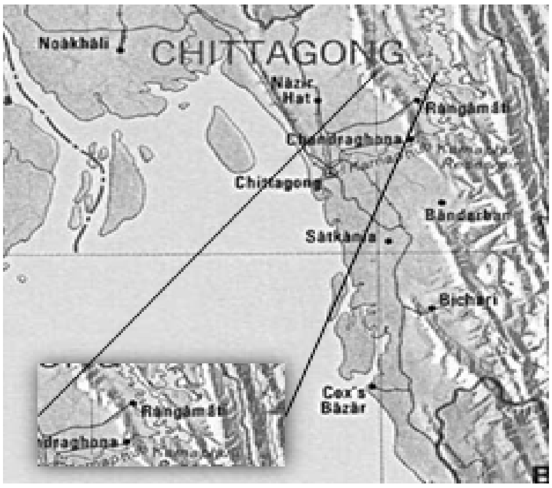

Figure 2: Location of the study area

3. Methodology

ASTER image (acquired on 16th February 2004) were processed using Erdas Imagine 9.1 software in this research work. Field collected data was used to digitally interpret the ASTER image and produce GIS layers, which were analyzed via GIS modeling. Geomorphological and geobotanical approach was used in this study. Vegetation was identified by unsupervised classification and drainage map was created by onscreen digitization of drainage pattern then field data and published data were used to identify the lithology. A knowledge based classification approach was conducted to produce a lithologic map based on two variables vegetation and geomorphology. Detailed literature survey about geological remote sensing and GIS, integrated field investigation, analysis of collected data, classification of ASTER data and spatial modelling for lithologic mapping and finally accuracy testing through field checking were carried out. Detailed fieldwork was restricted to selected sections only along Chittagong-Rangamati road section (Figure 3) due to inaccessibility and Security issues. Data of previous research work in this region about lithologic mapping using digital processing of Landsat 5 TM image was also used for this research work (Hasan T. M., 2002).

Drainage patterns within the study area were identified from ASTER image through their different orientation, tone, texture, linearity, and presence of water, dry and moist bare lands. These patterns were identified and digitized on-screen to create a drainage shape file and interpreted as different types of lithology. These findings were later verified through field investigations. Major drainage patterns, identified in study area are dendritic and parallel. Three types of dendritic drainage patterns were visually identified from satellite image subdivided based on the spacing density of the tributaries of the dendritic drainage in the study area; less dense, moderately dense and highly dense dendritic pattern. Relatively less dense dendritic drainage pattern developed on incompetent rock such as shale whereas moderately dense and highly dense dendritic drainage pattern developed on competent rock such as sandstone. Parallel drainage pattern were subdivided based on the length of the tributaries visually. Parallel short and medium length, sub-parallel short and medium length and parallel to sub-parallel short and medium length develop in the sandstone and shale alternation and Sub-parallel long length develops in the Shale.

3.1 Image analysis and interpretation

Analyses of the ASTER image of the study area were done by ERDAS Imagine 9.1 and ArcGIS 9.1 software with support of the corresponding field data to obtain lithologic maps. Systematic steps were taken for analysis of each classification.

3.1.1 Geomorphological analysis

Drainage patterns were identified visually by zooming in and out of image and by enhancing contrast and changing the band combinations. Two major types of drainage, dendritic and parallel were identified in the study area imagery. These two were subdivided based on the spacing density of the tributaries of the dendritic drainage and parallel drainage pattern were subdivided on the length of the tributaries visually. To create a lithologic map based on drainage patterns following steps taken in ArcGIS 9.1 and Erdas Imagine 9.1 software (Figure 4).

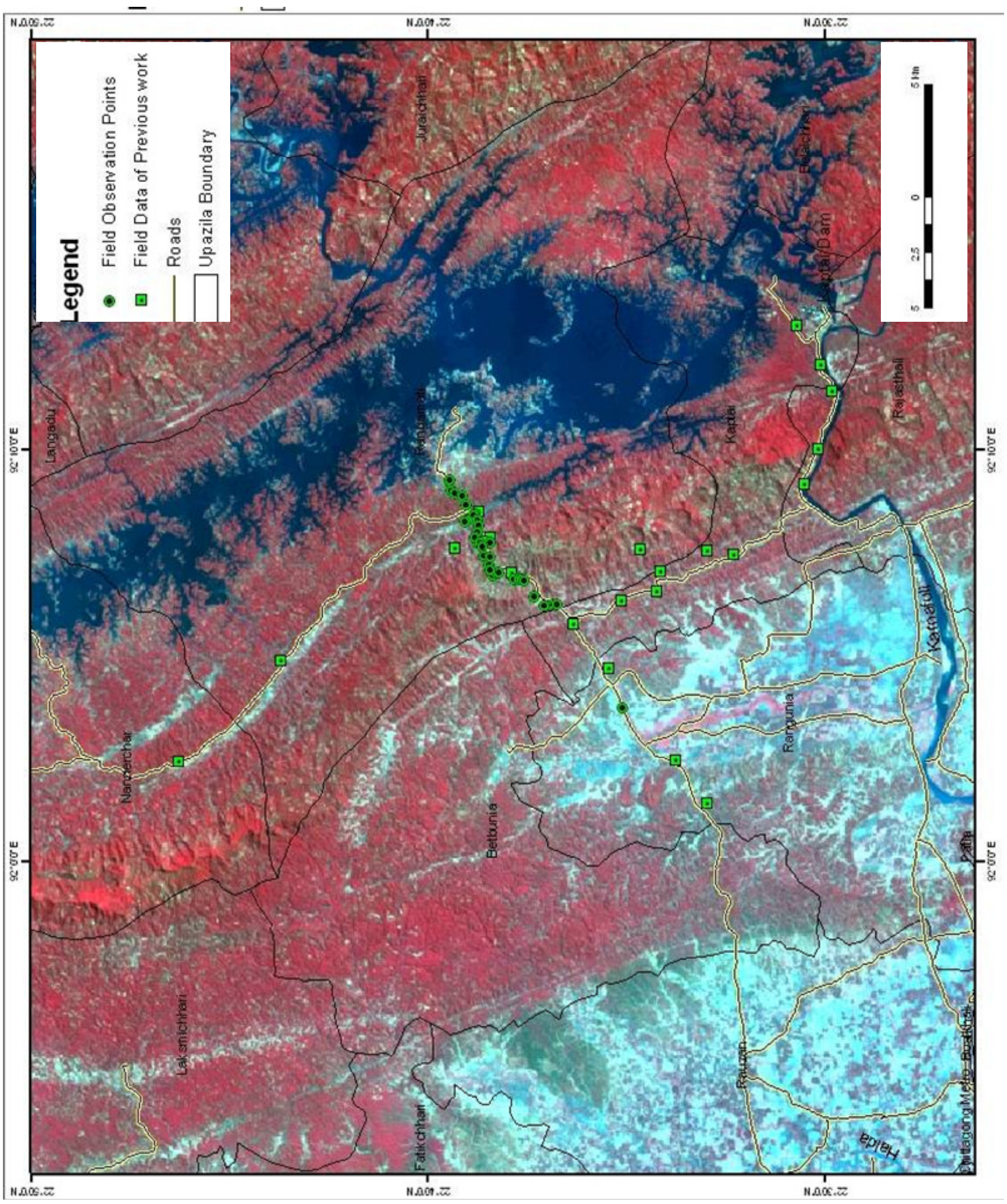

Figure 3: Field investigation locations along Chittagong-Rangamati road section

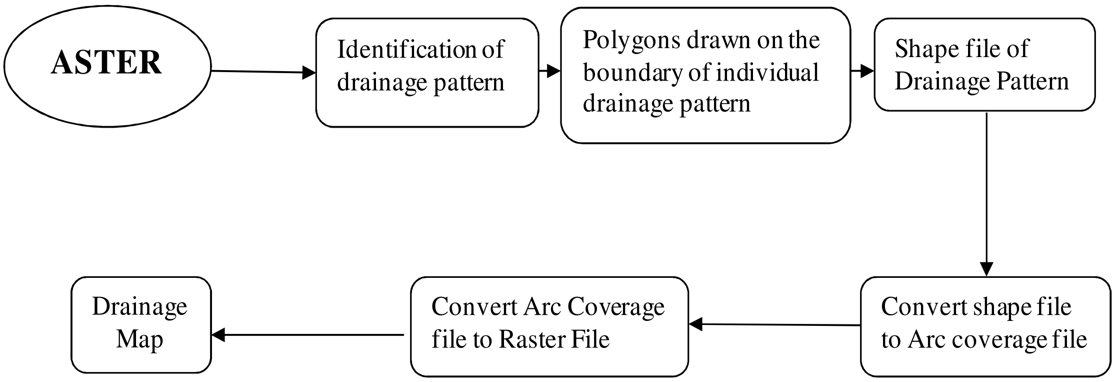

Figure 4: Flow chart of drainage map based on drainage patterns.

From the field and in image observation, it was observed that less dense dendritic pattern develops in the shale region where as moderately and highly dense dendritic pattern develops in the sandstone. And parallel short and medium length, sub-parallel short and medium length and parallel to sub-parallel short and medium length develop in the sandstone and shale alternation (Table 1). Drainage map was prepared based on the above data and merging the unsupervised classified image and drainage map created lithologic map.

Table 1: Image interpretation of drainage patterns and lithology based on field observations

	Categories	**Lithology**
Dendritic drainage pattern		
1	Less dense dendritic pattern	Shale
2	Moderately dense dendritic pattern	Sandstone
3	Highly dense dendritic pattern	Sandstone
Parallel drainage pattern		
1	Parallel short length	Alt. of sandstone and shale
2	Parallel medium length	Alt. of sandstone and shale
3	Sub-parallel short length	Alt. of sandstone and shale
4	Sub-parallel medium length	Alt. of sandstone and shale
5	Sub-parallel long length	Shale
6	Parallel to Sub-parallel short length	Alt. of sandstone and shale
7	Parallel to Sub-parallel medium length	Alt. of sandstone and shale

3.1.2 Geobotanical analysis

Vegetation of the study area was grouped into three types: category A: Low Biomass, category B: Medium Biomass and category C: High Biomass. Category C vegetation is much denser, greenish and healthier and category A vegetation is less healthy, denser and greenish. It was observed during fieldwork that the areas underlain by shale support vegetation of category C, category B, and areas underlain by sandstone support vegetation of category A.
Geobotanical Analyses were executed in several steps to obtain vegetation map using this satellite image of the research area in the following ways (Figure: 5): Iterative Self-Organizing Data Analysis Technique (ISODATA) algorithm was used to perform an unsupervised classification using Erdas Imagine 9.1 software for vegetation identification. The thematic image from the unsupervised classification was combined using overlay function with the all classified image to prepare a vegetation map using spatial modelling. Lithologic units obtained from conditional image were given the priority due to the direct relationship between overlying vegetation and underlying rock type. The final output from this process was a thematic map containing six classes: High Biomass, Medium Biomass, Low Biomass, Shadow, Other and Water. This biomass was co-related with lithology. Low to medium biomass developed in areas of sandstone, low to high biomass developed in areas of alternation of sandstone and shale and high and medium biomass developed in areas of shale.

3.1.3 Knowledge-based Expert classification

IMAGINE Expert Classifier™ in Erdas Imagine 9.1 software was used to perform another classification. It provides a rules-based approach to image classification. In easier terms, when the features in the image cannot be identified using only one variable but can be done so by using the relationship between more than one variable then this approach is often more suited. For example, the lithology is related to more than one variable such as drainage density and vegetation and certain types of lithology is a reflection of certain conditions in Both those variables. Then Knowledge Engineer can setup such conditions so that the feature that meets the both this criteria are identify using both rules simultaneously. Following data were used for creating the Knowledge Base:

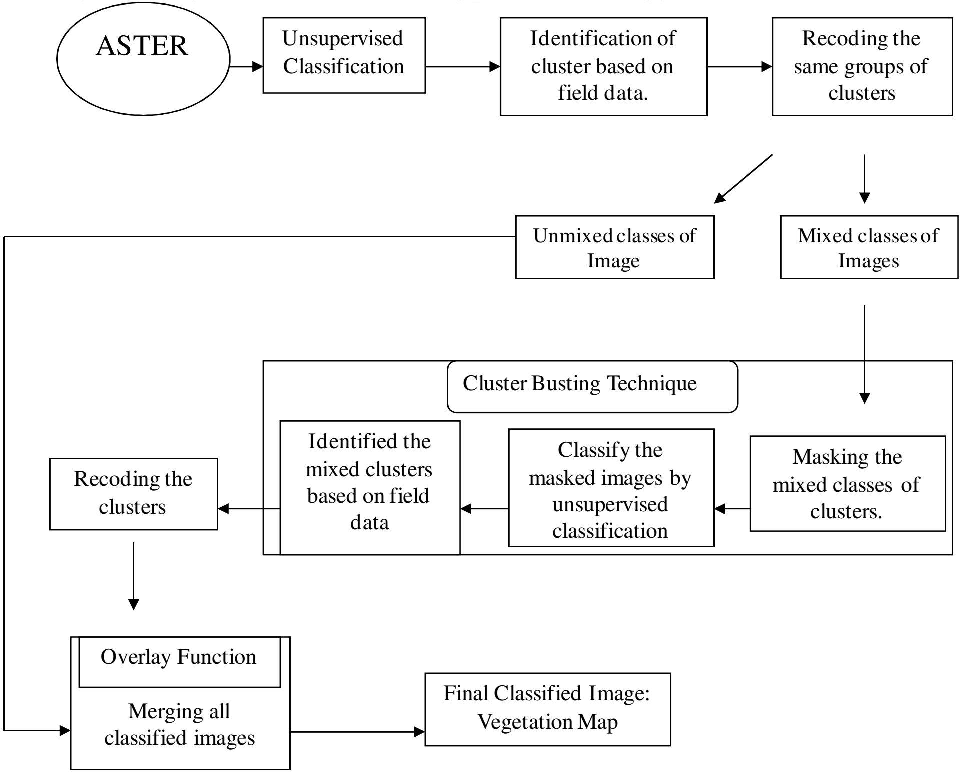

Figure 5: Flow Chart of ASTER Image Processing for Vegetation Map.

1. Vegetation data from classified ASTER image:
2. Drainage data: Dendritic drainage image and Parallel drainage image
    a. (Images show different types of drainage pattern and categories derived from ASTER image that represent different types of lithology).

Figure 6 shows the Knowledge Base (Decision tree) where green color represents the Hypothesis, yellow color represents the rules and blue color represents the conditions. Left side of the decision tree the green color hypothesis represents the output classes. The following output classes selected for the lithologic map

1. Water, 2. Other, 3. Shadow, 4. Alluvium, 5. Sandstone, 6. Alternation of sandstone and Shale, 7. Shale.

'Water' class is determined by the rule 'Water within the study area'. The rule compute the data from the condition 'Water = = 1' depicted on the right side which must be satisfied for the rule to be true. Here the condition contains variable, relation and value. The variable is a raster because the input is an image; value 1 represents the class number for water in the unsupervised classified image and the relation '= =' relates the variable to the value. The second hypothesis 'Other' where the expert rule is that bare-land and agricultural land in the study area represent other class and the rule is set accordingly. The third hypothesis 'Shadow' where the expert rule is that hill and tree shadows created by sunlight in the study area represents Shadow class.

The fourth hypothesis is the 'Alluvium' where the rule identifies the alluvium class in terms of low biomass, medium biomass and presence of sand, silt and clay. The fifth hypothesis is the 'Sandstone' where the expert rule is that the following drainage patterns: moderately densely spaced dendritic drainage pattern, highly densely spaced dendritic drainage pattern develops in areas of sandstone where low to medium biomass vegetation is supported. Some areas have low and medium biomasses in sandstone but the drainage pattern cannot be identified. The sixth hypothesis is 'Alternation of sandstone and shale' which is identified based on the following drainage patterns: Parallel, short and medium length, Sub-parallel, short and medium length, and Parallel to sub-parallel, short and medium length develops in areas of sandstone and shale alternation where low to high biomass vegetation is supported. In this area parallel to sub-parallel (short to medium length) drainage pattern is predominant. The seventh hypothesis is 'Shale' where the rule is that the less dense dendritic drainage and sub-parallel long length drainage pattern develops in areas of shale where high and medium biomass vegetation also grows.

The above knowledge base was constructed with the Knowledge Engineer and processed by the Knowledge Classification application. In Knowledge base, seven classes were selected to express the lithologic map. Many rules and conditions were linked with the seven classes, which are known as hypothesis. Then this knowledge base was run in Test Mode to access accuracy of the knowledge base during construction. After that, the final knowledge base was run in its regular mode to produce permanent output images.

4. Results

Two lithologic maps of the study area were the output of the image classification analysis: the first lithologic map based on the combination of vegetation and drainage pattern was done using knowledge base classification algorithm and the second lithologic map based on the analysis of drainage pattern. The resulting output of classified images and their details are given in following sections:

4.1 Results of knowledge base classification

A lithologic map was the output of classification derived from Knowledge base algorithm of ASTER image (Figure 7). It was the combination of geobotanical and geomorphological approach. The total study area is about 232453 hectares and total seven classes of this area have been classified. The following Table 2 shows the classes with areas.

Sandstone occupied areas were more than double than that of shale. Shale dominated in the axial region of the anticline and in the region of dense vegetation. Alternation of sandstone and shale was obtained by this classification because they are identified by both variables vegetation and drainage pattern. Sandstone decreases in the axial part of the anticline but increases toward the flank and dominates the outer flank region. An artificially built dam for hydroelectricity production caused the presence of huge amount of water. Major river Karnaphuli and its tributaries were also represented by water pixels. Other Class (Bare Land, Agricultural Land) was the second largest class in term of number of pixels and occupied large amount of areas in the map. Here, this bare land represented synclines, Jhum cultivated areas, bare lands. In most cases, N-S trending rivers drained these bare lands. Some of these lithologic classes could not be distinguished due to presence of shadow. Southwest side of the study area shows alluvium and other class. Alluvium contained sand, silt and clay.

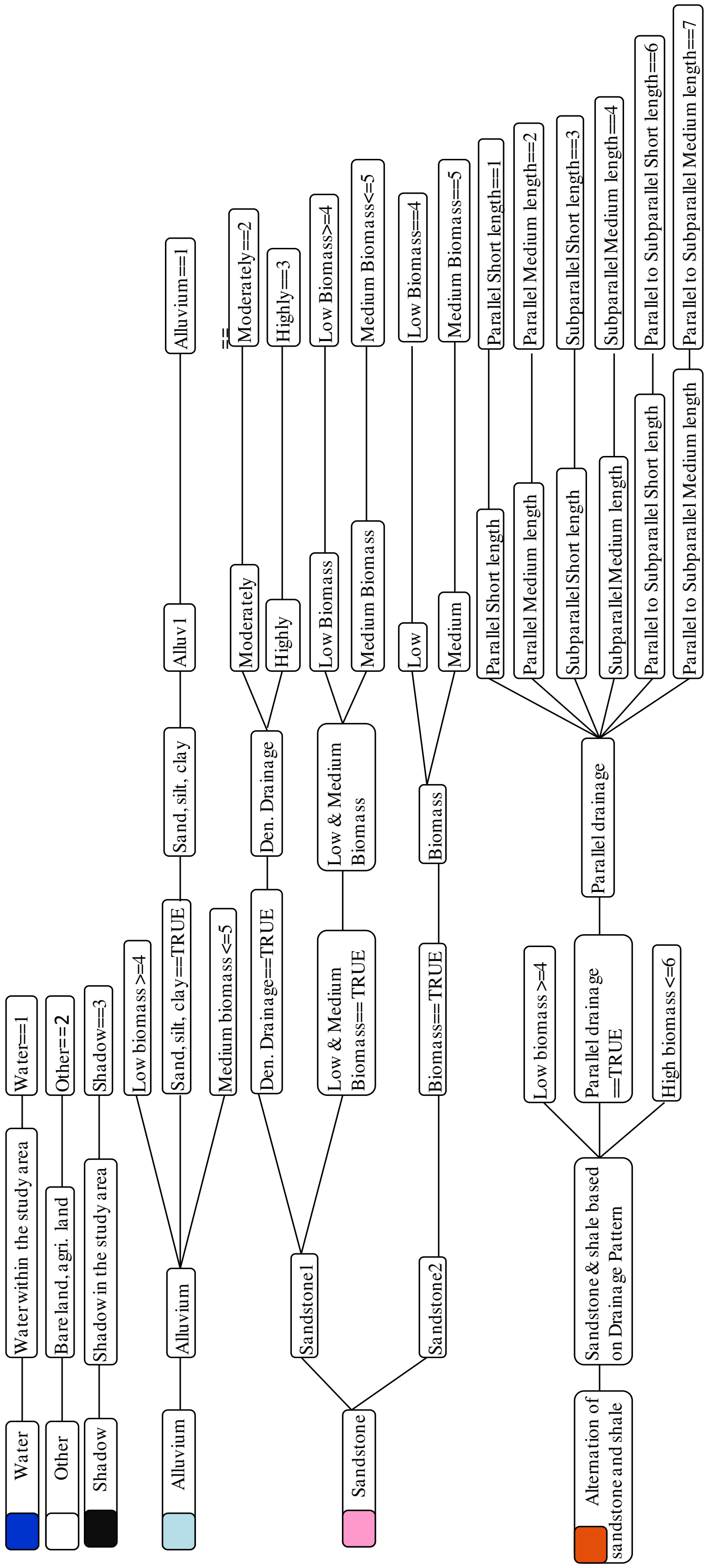

Figure 7: Knowledge Base presented as a Decision tree. Green, Yellow and Blue show Hypothesis, Rules and Conditions respectively

Table 2: Lithologic classes with area of ASTER image of the study area

Class Name	Area in Hectares	Area in Percentage
Water	30263.2	13.02
Other	39105.2	16.82
Shadow	922.275	0.397
Alluvium	9944.3	4.278
Sandstone	88387.5	38.02
Alternation of sandstone and Shale	20250.9	8.712
Shale	43580.3	18.75

4.2 Results of geomorphic analysis classification:

A lithological Map was produced from drainage pattern (Figure 8). The classes and their histogram, areas and percentage are given in the Table 3. Map produced from the drainage-based classification shows shale in the axial region and sandstone in the outer flank region of the anticlines and area covered by sandstone is double than that covered by shale. This method was also successful in identifying the alternating bands of sandstone and shale in middle flank of the anticlines due to the parallel drainage pattern.

Table 3: Lithologic classes with area of the study area based on drainage pattern

Class Name	Area in Hectares	Area in Percentage (%)
Water	21839.2	9.67
Other	28294.6	12.54
Shadow	175.275	0.07
Alluvium	9929.83	4.40
Sandstone	96763.3	42.88
Alternation of sandstone and Shale	20610.8	9.13
Shale	48004.2	21.27

4.3 Comparison between two lithologic maps

The figure 9 shows the comparison between two lithologic map produced by knowledge base classification and geomorphologic analysis classification. From the above data, it was observed that the area of water, other and shadow class is less in the lithologic map produced from drainage pattern then the map produce from using knowledge based classification. This was due to the merging of drainage map with the unsupervised classified image to get the lithologic map during which water, other and shadow class was merged with the lithologic units.

5.4 Accuracy analysis

Accuracy analysis was performed to calculate the percentages of areas occupied by individual rock type in the two classified image (from Knowledge Classification, Geomorphologic Classification) against each field polygon from data collection fieldwork (Table 4 and 5).

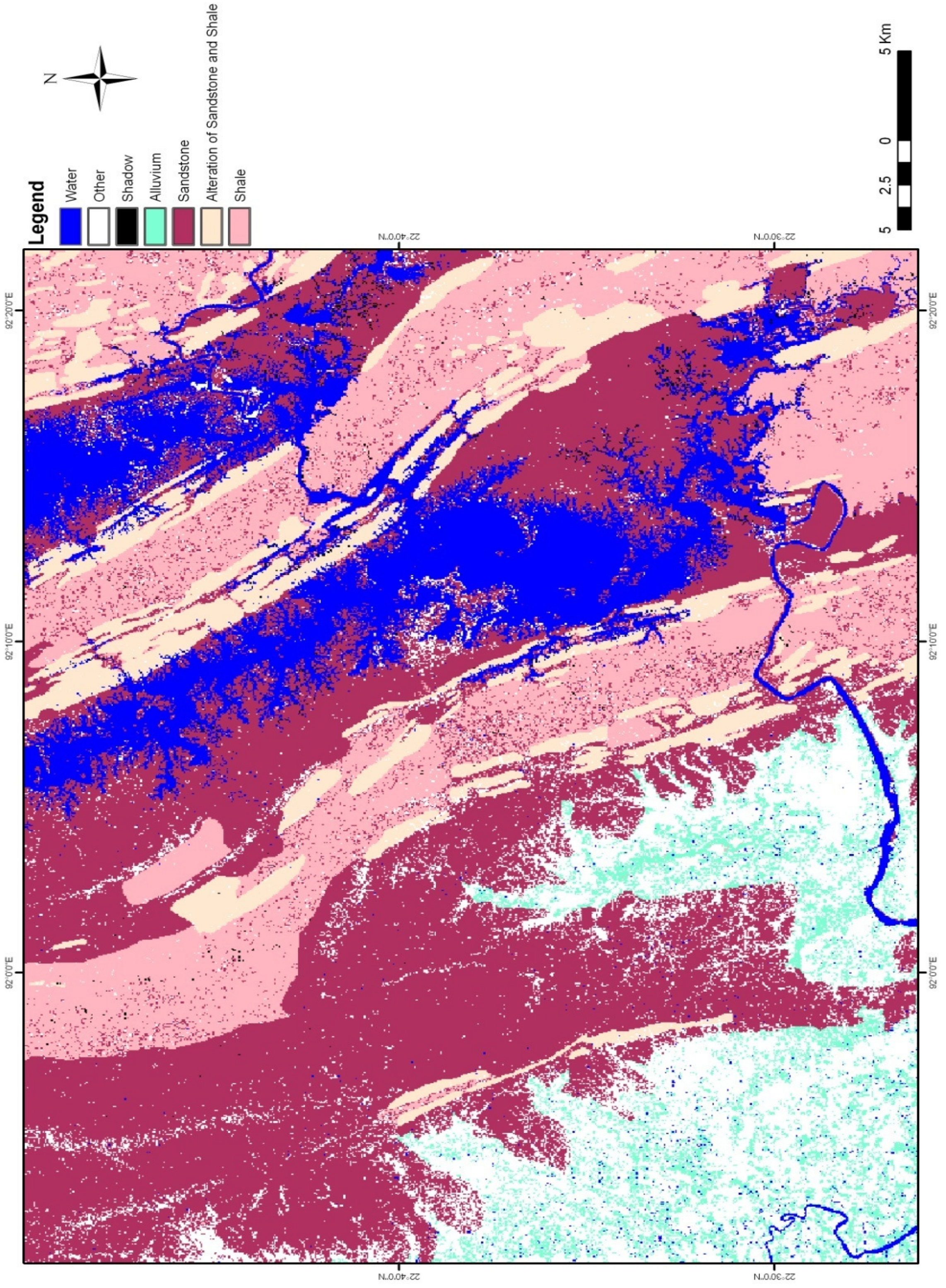

Figure 7: Lithologic Map produce by Knowledge Classification.

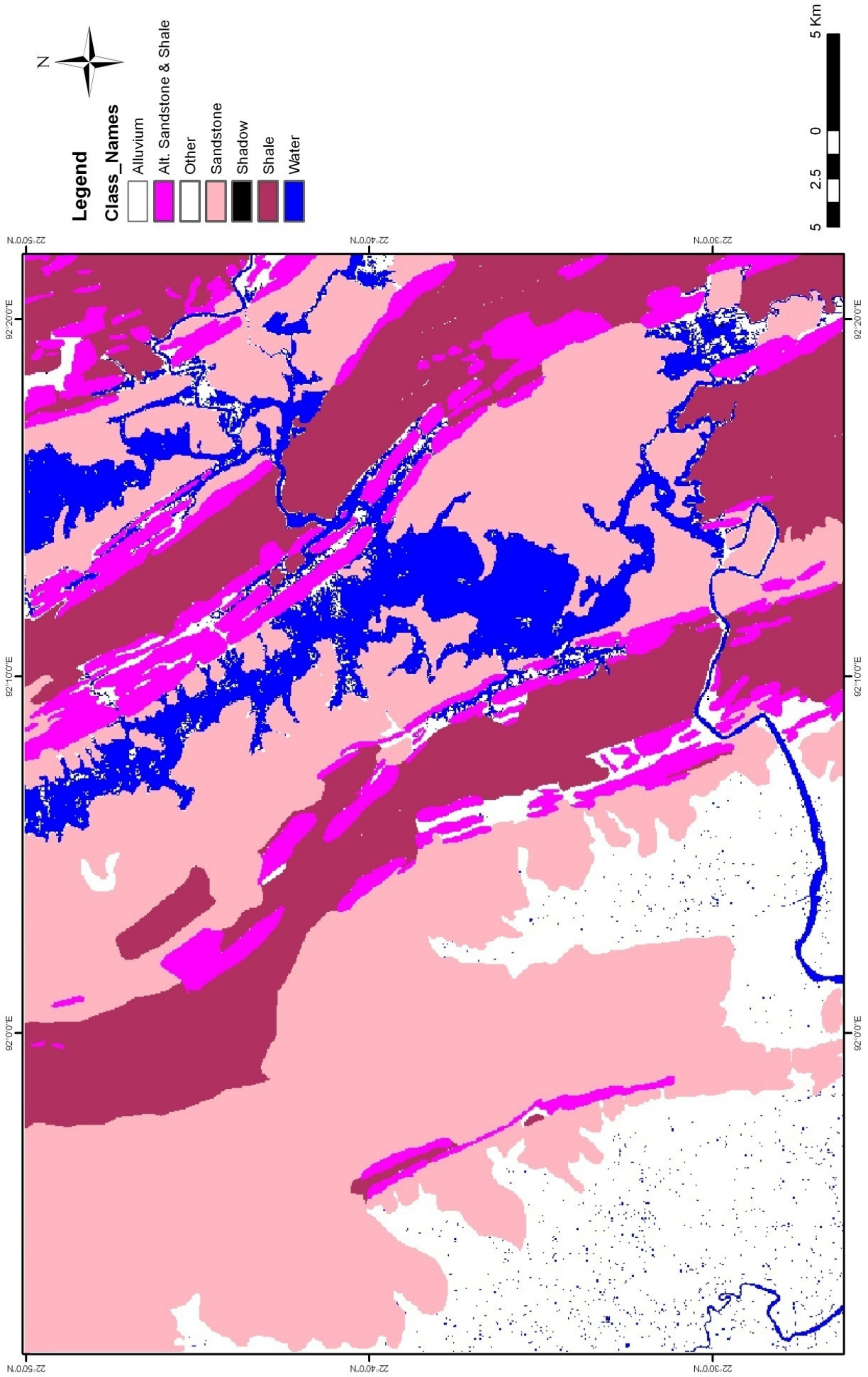

Figure 8: Lithologic map based on Drainage pattern.

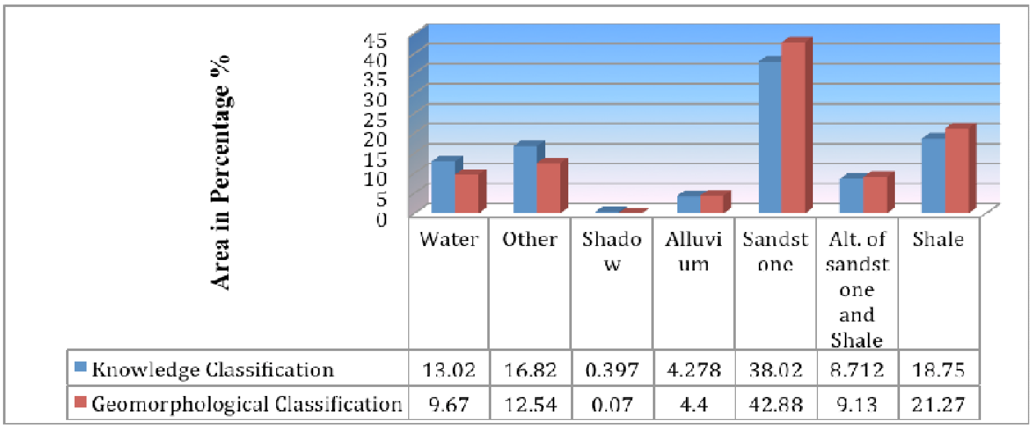

Figure 9: Lithologic classes with area in percentage for the two lithologic maps

Table 4: Results of accuracy analysis of Knowledge Classification against field polygons of data collection fieldwork

Polygon Name	Water (%)	Other (%)	Shadow (%)	Alluvium (%)	Sandstone (%)	Alt. sandstone and Shale (%)	Shale (%)
Sandstone	16.25	7.29	0.53	0.29	35.90	19.89	19.85
Alt. sandstone and Shale	0.31	1.56	0.94	0.00	4.69	91.88	0.63
Shale	4.42	4.93	0.88	0.00	22.49	12.13	55.15

Table 5: Results of accuracy analysis of Geomorphological Classification against field polygons of data collection fieldwork

Polygon Name	Water (%)	Other (%)	Shadow (%)	Alluvium (%)	Sandstone (%)	Alt. sandstone and Shale (%)	Shale (%)
Sandstone	17.60	2.74	0.61	0.33	34.11	23.89	20.72
Alt. sandstone and Shale	0.00	0.66	0.00	0.00	0.00	98.69	0.66
Shale	3.42	0.27	0.94	0.00	3.22	14.62	77.73

Accuracy of classification derived from knowledge based algorithm was checked against field data and this shows an agreement of about 35.90% for sandstone, 91.88% for sandstone-shale alternation and 55.15% for shale whereas 34.11% for sandstone, 98.69% for sandstone-shale alternation and 77.73% for shale for the lithologic map derived from drainage pattern. In both approaches, about 35% for sandstone, 95% for sandstone-shale alternation and 66% for shale were mapped as sandstone, alternation of sandstone and shale and shale respectively.

5. Conclusion

Applicability of satellite remote sensing tools using natural vegetation and drainage pattern as indicators proves potential lithologic mapping in the study area. In general, sandstone and shale can identify from the image using bio-indicator and drainage pattern and alternation of sandstone-shale can identify from the drainage pattern. Two lithologic maps of the study area have been prepared, the first one prepared based on the combination of Geobotanical and Geomorphological techniques through Knowledge classification and second one prepared based on only drainage pattern. The maps thus prepared generally indicate shale in the axial part and sandstone in the outer flank of anticlines. Alternation of sandstone and shale in the midflank of anticline was identified by these techniques. Different techniques were used in this study showing considerable amount of accuracy for lithologic mapping. Spectral values of vegetation on different rock types are significant for the identification of underlying lithology of the entire area. The lithologic maps prepared from drainage pattern and from the combination of geobotanical and geomorphological had an approximate agreement of about 35% for sandstone, 95% for sandstone-shale alternation and 66% for shale against the field collected data. The study shows that Satellite remote sensing tools has potential to produce lithologic map in the region of poor accessibility with field data of accessible region but its accuracy varies somewhat. A very reliable degree of accuracy is obtained for Sandstone-shale alteration class and a moderate accuracy is obtained for the shale class. However the accuracy for the Sandstone class is very low and suggests that this method was not very useful for this rock type. This poor accuracy could be due to the interference brought on by human settlement practices, which has altered the natural vegetation growth and undermined the relationship between lithology and vegetation growth. It was observed that sandstone has better accuracy in the Knowledge base classification but sandstone-shale alternation and shale have better accuracy in the classification based on drainage pattern. The main causes of this difference is that in knowledge base classification, lithology can not be identified in some areas due to the presence of water, bare-land and shadow and they are identified as water, other and shadow classes. But some pixel of these classes were identified as lithology in the classification process based on drainage pattern and most of the pixels of shadow, bare-land and water was identified in the sandstone-shale alternation and shale area during unsupervised classification. Therefore, the percentages of sandstone-shale alternation and shale were high in the accuracy result. And presence of water, bare-land and shadow was less in the sandstone area that's why accuracy of sandstone was less in the result based on drainage pattern.

In this research work, two types of variables such as vegetation and drainage pattern were used to delineate the underlying lithology. So, more variables can be used for the identification of lithology such as Digital elevation data. Digital elevation model (DEM) can provide slope gradient information of the area, which has a relationship with the underlying lithology and also has connection with the vegetation. Digital elevation data can be a valuable data for producing a lithologic map that was also suggested by Ingram et al, 2003. Higher spatial resolution sensor can be used to identify the lithology with narrow outcrop. Additionally, it can detect the smaller drainage basin, pattern and divide providing more information about underlying lithology. Extensive fieldwork in dry season needs to be carried out for a batter understanding of the geobotanical relationship with lithology. Hyperspectral remote sensing approach can be undertaken in order to identify micro-vegetation changes. Although the research work is confined to northern part of Chittagong Hill Tracts of Bangladesh, the methodology can be applied to other highly vegetated regions of Bangladesh.

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