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*RESEARCH ARTICLE*

# INVESTIGATION OF HEAVY-MINERAL DEPOSITS USING MULTISPECTRAL SATELLITE IMAGERY IN THE EASTERN COASTAL MARGIN OF BANGLADESH

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**ABSTRACT**

Sea beaches are always a good source of heavy minerals around the world. Cox's Bazar has 120 km of unbroken sandy sea beach. The study includes the sea beaches of 5 upazilas (Moheshkhali, Kolatoli, Ramu, Ukhia, Teknaf) in Cox's bazaar district for studying the concentration, identification and investigation of heavy mineral deposits along the sandy beaches. This study has concentrated on the physical properties, identification, and abundance of the heavy minerals fraction in sediments collected from the study area. Satellite imagery Landsat-8 OLI was used for remote sensing verifications. The image processing and crucial analysis carried out using Environment for Visualizing Images (ENVI), Arc GIS and Erdas Imagine software. Coastal areas adjacent to Teknaf upazila has a very significant amount of heavy mineral reserves, almost 16%. The study has identified around nineteen variety of heavy minerals from the collected samples in the study area. Ilmenite, Kyanite, Garnet, Rutile, Zircon, Magnetite, Augite, Hornblende, Enstatite, Epidote, Andalusite, Hypersthene, Diopside and Cassiterite have been found the most abundant in the entire study area. The Coastline of Bangladesh was surveyed completely to map the heavy minerals which are potential resources for our national economy.

**KEYWORDS**

Mineral Deposits, Heavy-Minerals, Satellite Imagery, Easterns Coastal Margin, Bangladesh.

## 1. INTRODUCTION

Heavy mineral sands generally contain high specific gravity (SG > 2.9) and occurring as detrital minerals such as rutile, sillimanite, monazite, xenotime, chromite, tourmaline, garnet, staurolite, zircon, ilmenite, magnetite, and kyanite. These heavy minerals are resistant to abrasion, chemically stable, and can endure diagenetic modification [1]. Most commonly referring to dense components [2]. Minerals are considered as non-renewable resource which can be taken out by several mining techniques [3]. Utilizations of heavy minerals in the industrial and geological purposes play an important role in the economy of a country [4,5]. Developing countries like Bangladesh need to focus on the detail mapping and rigorous exploration activities in the coastal areas of the country. In the coastal areas of Bangladesh, heavy minerals with beach placer deposits are abundant specially in the southern and eastern margin of the coastal belt [6-9].

Beach placer deposits generally comprise up to 23% (by weight) heavy minerals that is much higher than the low-grade river concentrated (1-2%) heavy minerals [10,11]. The concentration of heavy minerals in terrigenous sediments may vary significantly due to several factors together with provenance, sedimentary processes and post-depositional dissolution [12,13].

A sufficient mineral deposit formed by mechanical concentration of mineral particles from weathered debris. Beach placer and alluvial placer are the two main types of placer minerals [3]. Beach placers are formed when the mechanical or chemical weathering of rock masses and their redistribution along a continental shelf [14]. The sediments are sorted by gradual movement of the sea water, directing the coarser materials towards the shore and the finer materials into deep water [15]. The heavy minerals are gradually resistant to weathering and hence become concentrated. Long time upward movement of the coastal areas, change in sea level and the migration of sands dune blown by the wind over long distance has converted some of these sediments to land and consequently many beach placers occurs a considerable distance inland from the present coast line [16,17]. Several authors in Bangladesh outlined the heavy minerals properties, radioactivity, prospect and identification from different parts of the country, specially in the southern part (Coastal area) and northern part (River basin) of the country [18-24].

The beach in Cox Bazar is sandy and has a gentle slope; with an unbroken length of 120 km (75 mi), it is the longest natural sea beach in the world [25]. The heavy mineral deposits along the coastal belt of Bangladesh contain potential resources. The fore dune deposits areas also contain noticeable amount of heavy minerals, which are being accumulated within the intertidal zone. This part is very dynamic and exposed subject to wave, current and wind actions. Mineral sands on those deposits contain some important metallic minerals mainly ilmenite, magnetite, rutile, zircon, garnet, monazite, kyanite and leucoxene. The heavy mineral concentration along the recent fore dune deposit of Bangladesh ranges from 13% to 70%, which is quite significant [26]. Development in remote sensing or satellite image and GIS lead to identifying and locating the heavy mineral resources and also essential for proper mapping of mineral resources. Nowadays, remotely sensed data are frequently used for mineral exploration around the world [27-30]. This study will open up new areas for inland heavy mineral exploitation and leads to eco-friendly exploitation of natural resources along the study area. The study utilized the high potential of multispectral satellite data for exploration and mapping of mineral resources in the study area. These heavy minerals can be used in different industries, nuclear power plants, meters and scientific apparatus, welding, rod coating and others. These minerals can be commercially extracted and produced to increase the national income.

## 2. STUDY AREA

The Cox's Bazar coastal areas is situated at the south eastern belt of Bengal basin. It is bordered on the west by the Bay of Bengal, on the north by the Bakkhali estuary and Maheshkhali channel, on the east by low elevated hill ranges (~100m), and on the south by the headlands (**Figure 1)**. The beach area is totally exposed to the long shore current and episodic tidal oscillations. The beach area can be subdivided into: dunes, tidal creeks and beach. The width of the main beach plain is 200-300m at the mean sea level [31].

The study includes the sea beaches of Moheshkhali, Kolatoli, Ramu, Ukhia, Teknaf upazila in Cox's bazaar district. Samples were collected from these 5 upazilas for the identification and investigation of heavy mineral deposits along the sandy beaches of the study area. During fieldwork conducted on the beach area, surface and subsurface samples were collected extending from the surface to ~1 m depth (using hand auger). Total 30 samples were taken from 30 different locations: Four from Kolatoli, three from Ramu, eleven from Teknaf; seven ukhia, and five samples from Moheshkhali.

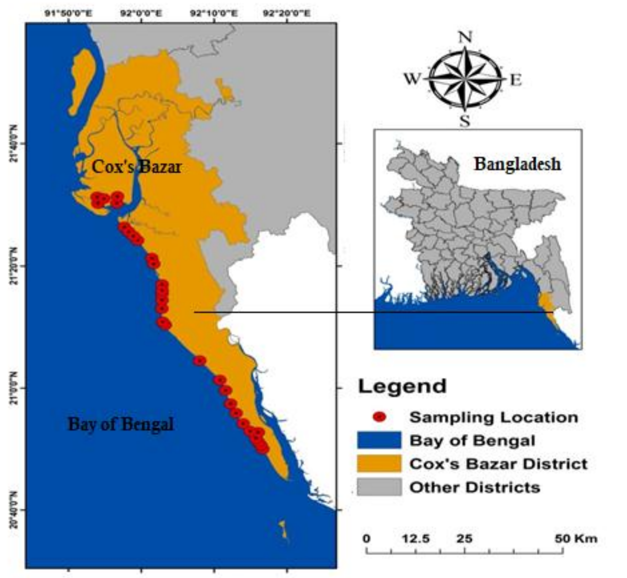


**Figure 1:** Study area map showing the sample locations

## 3. MATERIALS AND METHODS

The entire study workflow consists of four steps apart from field investigation including sample collection: a) Sieving, b) Heavy and light mineral separation technique, c) Thin section and d) Identification by a petrographic microscope and processing of satellite image for remote sensing verification.

### 3.1 Grain size analysis

Collected samples were dried and run through some physical separation techniques. Grain analysis was employed for the collected samples by using sieving techniques with different US standard mesh >500 µm, 250µm, 125µm, 63 µm and <63 µm was used (Ingram 1971). For this, 50 gm of the dry samples weight were taken and each was carefully recorded the weight of each sieve with its retained samples.

### 3.2 Separation of Heavy Minerals

Gravity separation was employed in this study for heavy mineral separation. The procedure was carried out under a well-ventilated hood; here bromoform was used as a heavy liquid, which has a specific gravity 2.89 at 20°C. 50 -60ml bromoform was used for 50 gm raw / previously sieved sand. Another beaker was placed beneath the separating funnel and a filter paper labeled was placed on a glass funnel over the beaker. After pouring the bromoform one of the raw samples were poured and stirred with a glass rod until the heavy and light minerals are separated completely. It was allowed to stand undisturbed for some time so that separate layer of light minerals, bromoform and heavy minerals are formed.

### 3.3 Slide preparation for optical study

Slides were prepared for investigating the optical properties of the heavy minerals in the samples. Canada balsam stick was melted on glass slide on hot plate and heavy mineral grains were dropped into it, removed the slide from hot plate and allowed cement to harden by cooling, cover slip was placed onto the glass slide before the microscopic study. The percentage, amount, concentration of valuable minerals can be identified by three different point counting methods [32]. In this study, Line counting method was used for the determination heavy mineral percentages. Properties of heavy minerals studied and identified under polarizing microscope (Figure 9).

### 3.4 Remotely sensed data and techniques

For this purpose, ENVI 5.1 version with the ArcGIS 10 and Erdas Imagine 9.2 has been used for mapping heavy minerals from satellite imagery. Landsat 8 OLI image dated 18th May, 2017 has been collected from the website https://earthexplorer.usgs.gov. Before identifying the mineral deposits, radiometric correction and fast line-of-sight atmospheric analysis of spectral hypercube (FLAASH) were employed to remove the effect of aerosols, clouds and cloud shadows (Figure 2). The reflectance calibration of the Landsat ETM data was performed with pre-launch gains and offsets calculated for Landsat sensors [33]. After preprocessing, the data is subjected to hourglass spectral analysis. The MNF transformation was applied to the atmospherically corrected and calibrated data and it generates six MNF-transformed bands which can be viewed and analyzed (Figure 3). It mainly reduces the computational requirements for subsequent processing.

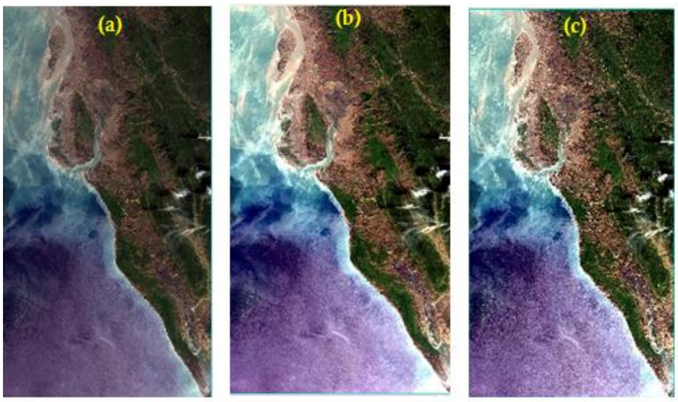


**Figure 2:** (a) Landsat-8 OLI before image corrections (b) Image after radiometric calibration (c) After atmospheric correction (FLAASH)

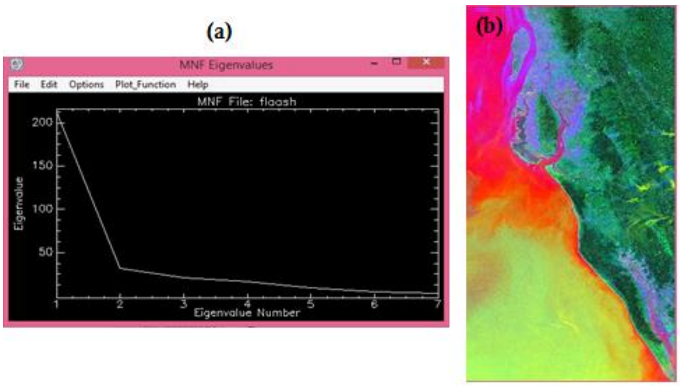


**Figure 3:** (a) Eigenvalue plot for different MNF bands of ETM data (b) MNF Result display

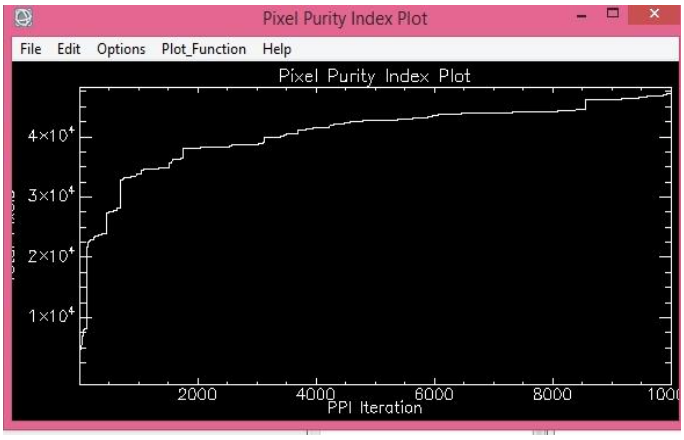


**Figure 4:** Pixel purity index plot

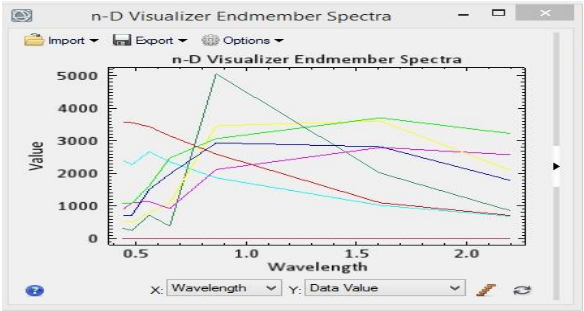


**Figure 5:** n-D Visualize Endmember Spectral plot.

In this work the PPI analysis was performed on the MNF bands with 10000 iterations and a threshold value of 3. Pixel purity index ENVI's pixel purity index (PPI) is a way of finding the most spectrally pure or extreme pixels in images (Figure 4) [34,35]. ENVI's n-dimensional visualizer used for finding endmembers by locating and clustering the purest pixels in n-dimensional space (Figure 5).

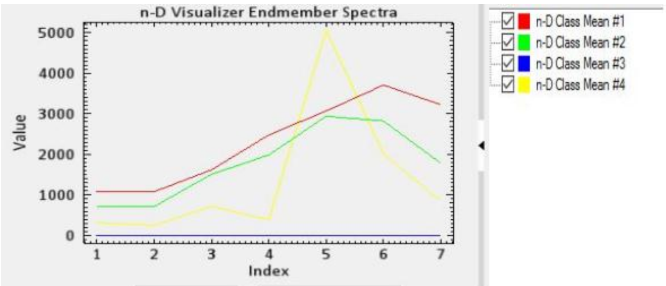


**Figure 6:** Selected endmembers from the spectral plot.

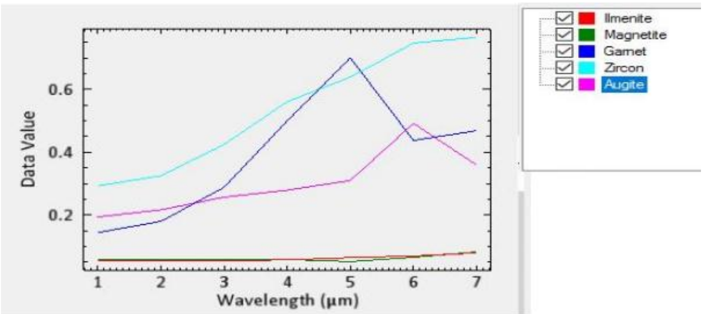


**Figure 7:** A Spectral plot of minerals obtained from the USGS spectral library.

### 3.5 Mapping of Minerals Using Spectral Angle Mapper

The selected and verified target endmembers present in the data are mapped with ENVI's spectral angle mapper (SAM). SAM is the most-used mapping method for minerals using hyperspectral data [36]. SAM is an automated method for comparing image spectra to individual spectra (Figure 6). By calculating the spectral angle between them, the similarity between two spectra is determined, treating them as vectors in a space with dimensionality which is equal to the number of bands (Figure 7).

## 4. RESULTS AND DISCUSSION

### 4.1 Result of Grain Size Analysis

Grain size distribution pattern identified from Moheshkhali to Teknaf beach area in Cox's bazaar district. The amount of coarse sand and clay particles is higher in Moheshkhali than Kolatoli, Himcchori, Inani and Teknaf. The percentage of medium sand is higher in kolatoli (13.82-39.78%) (Figure 8). The Inani beach contains less medium grained sand (0.18-8.86%) than the other regions. Fine and medium sand are comparatively higher in some areas of Teknaf beach, which indicates that these areas may have higher percentage of heavy minerals. From the sampling areas, the weight percentage of heavy mineral varies from 0.6 to 72.62%. The weight of light mineral ranges from 25.79 to 99.72%. Size analysis of the samples also showing that grain size is decreasing from North to South direction. A group researchers also found that the grain size of heavy minerals decreases from north to south and the sediments transported from northern region [37].

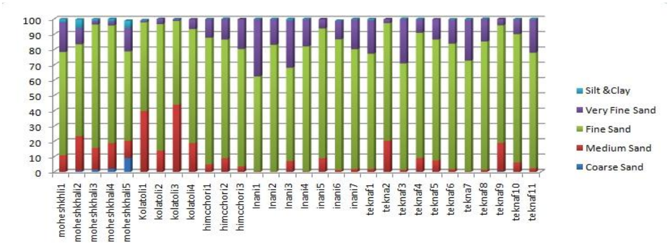


**Figure 8:** The Overall Grain Size Distribution of the collected samples from sea beaches in Cox's bazar district (Moheshkhali to Teknaf Beach).

### 4.2 Heavy Mineral Concentration

More than 19 types of minerals have found from the study area. Kyanite, Rutile, Zircon, Hornblende, Ilmenite, and Magnetite are very common and identified easily under microscope (Figure-9).

#### *4.2.1 Kolatoli (Cox's Bazar)*

In kolatoli, the weight percentage of heavy minerals varies between 10.88 and 15.36% (Table 1). kyanite has weight percentage of (0.25-0.48), garnet (0.1-0.59), rutile (0.12-0.59), andalusite(0.2-0.39), augite (0.37-1.17), ilmenite (4.40-5.50), magnetite (0.36-0.72), hornblende (0.20-0.48), enstatite(0.10-0.24), staurolite (0.25-0.39), hypersthene (0-0.39), cassiterite (0.12-0.39), diopside (0.12-0.25), zircon(0.2-0.30), epidote (1.2-3.5) (Table 1).

In kolatoli-1 (Hatchery point), the amount of garnet, Hypersthene and augite are higher than the other areas of kolatoli. The amount of magnetite is higher in kolatoli-4 (Diabetes point). The abundance of ilmenite is more abundant (~5.50) in kolatoli-3 (Laboni point). In area of kolatoli-4, the percentage of magnetite is higher. Comparatively the subsurface sediment of Kolatoli-1 (Hatchery point) contain more heavy minerals than other areas of Kolatoli region. Because there is no disturbance of the sediment due to tourist and other human intervention in kolatoli-1 (Hatchery Point). Laboni point contains fewer heavy minerals than other areas of Kolatoli, Cox's Bazar.

**Table 1:** The weight percentage (%) of light & heavy minerals at kolatoli region

| Sl.NO. | Heavy Weight (%) | Light Minerals (%) | Kyanite | Garnet | Rutile | Andalusite | Augite | Ilmenite | Magnetite | Hornblende | Enstatite | Staurolite | Hypersthene | Cassiterite | Diopside | Zircon | Epidote | Others | Unidentified |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Kolatoli-1** | 15.36 | 84.64 | 0.39 | 0.59 | 0.59 | 0.39 | 1.17 | 4.50 | 0.59 | 0.20 | 0.20 | 0.39 | 0.39 | 0.39 | 0.2 | 0.30 | 3.50 | 1.37 | 0.20 |
| **Kolatoli-2** | 12.52 | 87.48 | 0.25 | 0.10 | 0.20 | 0.20 | 0.37 | 5.50 | 0.49 | 0.37 | 0.10 | 0.25 | 0.00 | 0.30 | 0.25 | 0.20 | 2.10 | 0.49 | 1.35 |
| **Kolatoli-3** | 10.88 | 89.12 | 0.48 | 0.24 | 0.12 | 0.20 | 0.48 | 5.10 | 0.36 | 0.24 | 0.24 | 0.30 | 0.24 | 0.12 | 0.12 | 0.30 | 1.50 | 0.12 | 0.72 |
| **Kolatoli-4** | 12.58 | 87.42 | 0.36 | 0.36 | 0.24 | 0.24 | 0.60 | 4.40 | 0.72 | 0.48 | 0.24 | 0.50 | 0.12 | 0.24 | 0.24 | 0.24 | 1.20 | 0.12 | 2.28 |

#### *4.2.2 Himchari*

The percentage of heavy mineral varies between (15.61-22.33%) in different areas of Himchari region (Table 2). In every sampling area in this region, amount of ilmenite, hornblende and Enstatite are higher than other minerals. The percentage of major minerals found in these areas are ilmenite (4.43-6.11%), hornblende (2.11-3.22%), Enstatite (1.14-1.23%). The amount of heavy minerals is comparatively higher in Himcchari-3 (Mangala Para)

**Table 2:** The weight percentage of light & heavy minerals at Himchari region

| Sl.NO. | Heavy Weight (%) | Light Minerals (%) | Kyanite | Garnet | Rutile | Andalusite | Augite | Ilmenite | Magnetite | Hornblende | Enstatite | Cassiterite | Diopside | Zircon | Epidote | Topaz | Unidentified | Others |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Himchari-1** | 15.61 | 84.39 | 0.02 | 0.01 | 0.19 | 1.12 | 0.01 | 4.43 | 0.01 | 2.11 | 1.14 | 0.98 | 1.11 | 0.01 | 1.17 | 1.15 | 2.11 | 0.04 |
| **Himchari-2** | 20.86 | 79.14 | 0.07 | 0.02 | 0.06 | 1.54 | 0.16 | 5.43 | 0.18 | 3.21 | 1.22 | 0.44 | 0.92 | 0.05 | 1.98 | 1.12 | 4.44 | 0.02 |
| **Himchari-3** | 22.33 | 77.67 | 0.12 | 0.12 | 0.98 | 1.69 | 0.91 | 6.11 | 0.18 | 3.22 | 1.23 | 0.68 | 1.14 | 0.15 | 1.89 | 1.66 | 2.23 | 0.02 |

### *4.2.3 Inani Beach*

Overall 7 subsurface samples were collected from 7 different areas of Inani beach. Study shows 7 different mineral content patterns. The Inani beach contains (11.35-19.71%) heavy minerals. The most abundant minerals in these areas are Garnet (0.13-1.22%), Ilmenite (3.3-5.5%), Magnetite (0.11-1.88%) and Zircon (0.04-1.22%) (Table 3). In the samples of Inani-3 and Inani-5, heavy mineral concentration is higher than other areas of this region.

**Table 3:** The weight percentage (%) of light & heavy minerals at Inani Beach

| SI.NO. | Heavy Weight (%) | Light Minerals (%) | Kyanite | Garnet | Rutile | Andalusite | Augite | Ilmenite | Magnetite | Hornblende | Enstatite | Staurolite | Hypersthene | Cassiterite | Diopside | Zircon | Epidote | Topaz | Others | Unidentified |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Inani-1** | 16.54 | 83.46 | 0.18 | 0.71 | 0.53 | 1.14 | 0.89 | 4.4 | 0.89 | 0.71 | 2.11 | 0.11 | 0.45 | 0.12 | 0.36 | 0.36 | 1.45 | 0.36 | 0.53 | 1.24 |
| **Inani-2** | 18.83 | 81.17 | 0.49 | 1.22 | 0.49 | 1.57 | 0.49 | 4.2 | 1.71 | 0.24 | 2.44 | 0.24 | 0.24 | 0.11 | 0.44 | 1.22 | 1.19 | 0.11 | 0.97 | 1.46 |
| **Inani-3** | 19.71 | 80.29 | 0.13 | 0.52 | 0.26 | 1.89 | 0.26 | 5.5 | 0.64 | 0.39 | 3.12 | 0.98 | 0.88 | 0.26 | 0.88 | 0.39 | 2.18 | 0.14 | 0.26 | 1.03 |
| **Inani-4** | 18.15 | 81.85 | 0.57 | 1.13 | 0.57 | 0.98 | 0.76 | 3.5 | 0.76 | 0.57 | 2.13 | 0.14 | 0.97 | 0.12 | 0.11 | 0.57 | 1.88 | 0.18 | 0.19 | 3.02 |
| **Inani-5** | 19.34 | 80.66 | 0.79 | 1.09 | 0.03 | 2.11 | 0.05 | 5.1 | 1.88 | 0.78 | 3.33 | 1.11 | 0.04 | 0.13 | 0.44 | 0.05 | 2.13 | 0.03 | 0.03 | 0.22 |
| **Inani-6** | 12.68 | 87.32 | 0.28 | 0.25 | 0.45 | 1.18 | 0.11 | 3.9 | 0.35 | 0.2 | 1.17 | 0.98 | 0.77 | 0.11 | 0.05 | 0.15 | 1.18 | 0.11 | 0.25 | 1.19 |
| **Inani-7** | 11.35 | 88.65 | 0.04 | 0.13 | 0.07 | 0.67 | 0.76 | 3.3 | 0.11 | 0.04 | 1.54 | 0.12 | 0.67 | 0.02 | 0.67 | 0.04 | 2.65 | 0.07 | 0.11 | 0.31 |

### *4.2.4 Teknaf Beach*

Teknaf-1 and Teknaf-5 samples contain higher amounts of heavy minerals (13.29-20.68%) (Table 4). The major minerals of this regions are Garnet, augite, topaz, ilmenite, magnetite, staurolite, zircon, rutile and epidote.

**Table 4:** The weight percentage (%) of light & heavy minerals at Teknaf Beach

| Sl.NO. | Heavy Weight (%) | Light Minerals (%) | Kyanite | Garnet | Rutile | Andalusite | Augite | Ilmenite | Magnetite | Hornblende | Enstatite | Staurolite | Hypersthene | Cassiterite | Diopside | Zircon | Epidote | Topaz | Others | Unidentified |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Teknaf-1** | 14.21 | 85.79 | 0.21 | 1.14 | 0.22 | 0.14 | 0.06 | 1.18 | 0.65 | 0.56 | 0.53 | 1.53 | 1.53 | 0.91 | 0.13 | 0.89 | 0.06 | 1.53 | 1.12 | 1.82 |
| **Teknaf-2** | 13.86 | 86.14 | 0.58 | 0.87 | 0.87 | 0.21 | 0.87 | 1.74 | 2.61 | 0.58 | 0.29 | 1.09 | 0.34 | 0.12 | 0.45 | 0.32 | 0.35 | 0.14 | 0.98 | 1.45 |
| **Teknaf-3** | 13.83 | 86.17 | 0.48 | 0.31 | 0.21 | 0.11 | 0.21 | 3.41 | 0.51 | 0.31 | 0.81 | 1.12 | 0.11 | 0.12 | 0.45 | 0.31 | 0.34 | 0.23 | 3.56 | 1.23 |
| **Teknaf-4** | 15.09 | 84.91 | 0.12 | 0.45 | 0.23 | 0.3 | 0.15 | 3.04 | 0.89 | 0.32 | 0.15 | 1.12 | 0.43 | 0.06 | 0.34 | 0.15 | 0.15 | 0.15 | 6.45 | 0.59 |
| **Teknaf-5** | 16.72 | 83.28 | 0.34 | 1.38 | 0.38 | 0.45 | 1.07 | 2.07 | 1.07 | 1.69 | 0.32 | 1.69 | 0.34 | 0.09 | 0.69 | 0.11 | 0.13 | 0.38 | 1.83 | 2.69 |
| **Teknaf-6** | 16.57 | 83.43 | 0.32 | 0.32 | 0.87 | 0.56 | 0.32 | 4.32 | 0.32 | 0.32 | 0.11 | 0.11 | 0.21 | 0.11 | 0.21 | 0.43 | 0.21 | 0.32 | 6.54 | 0.97 |
| **Teknaf-7** | 20.15 | 79.85 | 0.86 | 2.58 | 0.72 | 0.86 | 1.01 | 0.44 | 1.58 | 1.29 | 0.43 | 0.43 | 0.86 | 0.43 | 0.86 | 1.01 | 0.86 | 0.12 | 0.65 | 5.16 |
| **Teknaf-8** | 14.94 | 85.06 | 0.76 | 0.95 | 0.89 | 0.76 | 0.95 | 3.71 | 0.95 | 0.71 | 0.76 | 0.48 | 0.24 | 0.11 | 0.34 | 0.48 | 0.48 | 0.71 | 0.71 | 0.95 |
| **Teknaf-9** | 12.77 | 87.23 | 0.04 | 0.14 | 0.06 | 0.03 | 0.13 | 4.14 | 1.19 | 0.15 | 0.04 | 0.45 | 0.04 | 0.06 | 0.04 | 0.78 | 0.06 | 0.04 | 5.14 | 0.24 |
| **Teknaf-10** | 13.29 | 86.71 | 0.07 | 0.12 | 0.89 | 0.21 | 0.18 | 4.23 | 0.25 | 0.07 | 0.05 | 0.05 | 0.02 | 0.05 | 0.05 | 0.02 | 0.07 | 0.07 | 6.14 | 0.75 |
| **Teknaf-11** | 20.68 | 79.32 | 0.78 | 3.11 | 0.65 | 3.11 | 0.78 | 3.78 | 1.56 | 0.21 | 0.78 | 0.34 | 0.78 | 1.56 | 0.78 | 0.78 | 0.14 | 0.11 | 0.67 | 0.76 |

### *4.2.5 Moheshkhali*

In Moheshkhali region, heavy mineral content ranges from 7.76 to 18.42% (Table 5). In Moheshkhali-1 and Moheshkhali-2, heavy minerals concentration shows more enriched than other areas of this region. Hornblende, Zircon, Ilmenite, Magnetite, Garnet are found abundantly.

**Table 5:** The weight percentage (%) of light & heavy minerals at Moheshkhali region.

| SL.NO. | Heavy Weight (%) | Light Minerals (%) | Kyanite | Garnet | Rutile | Andalusite | Augite | Ilmenite | Magnetite | Hornblende | Enstatite | Staurolite | Hypersthene | Cassiterite | Diopside | Zircon | Epidote | Topaz | Others | Unidentified |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Moheshkhali-1** | 18.42 | 81.58 | 0.33 | 1.18 | 0.23 | 0.43 | 1.18 | 4.36 | 1.77 | 1.18 | 0.89 | 0.57 | 0.12 | 0.59 | 0.57 | 1.18 | 0.59 | 0.59 | 1.18 | 1.48 |
| **Moheshkhali-2** | 13.63 | 86.37 | 0.37 | 0.92 | 0.26 | 0.44 | 0.55 | 3.29 | 1.11 | 0.18 | 0.18 | 0.55 | 0.14 | 0.55 | 0.37 | 1.11 | 0.66 | 0.56 | 0.18 | 2.21 |
| **Moheshkhali-3** | 15.05 | 84.95 | 0.31 | 0.77 | 0.15 | 0.35 | 0.46 | 5.92 | 0.77 | 0.47 | 0.46 | 0.15 | 0.40 | 0.67 | 0.78 | 0.15 | 0.31 | 0.67 | 0.15 | 2.11 |
| **Moheshkhali-4** | 8.11 | 91.89 | 0.33 | 0.19 | 0.19 | 0.36 | 0.22 | 3.31 | 0.39 | 0.09 | 0.58 | 0.13 | 0.57 | 0.13 | 0.04 | 0.13 | 0.92 | 0.09 | 0.26 | 0.18 |
| **Moheshkhali-5** | 7.76 | 92.24 | 0.03 | 0.04 | 0.03 | 0.01 | 0.06 | 3.09 | 0.98 | 0.14 | 0.35 | 0.56 | 0.03 | 0.78 | 0.03 | 0.02 | 0.87 | 0.67 | 0.06 | 0.01 |

The identification and concentration of heavy minerals showing that North Moheshkhali and some areas of Teknaf sea beach contains more heavy minerals consecutively (max. 18.42%) and (max. 20.68%). The most abundant heavy minerals found in the study area are Ilmenite (max. 6.11%), Magnetite (max. 2.61%), and Zircon (max. 1.22%), Garnet (max. 3.11%), Augite (max. 1.18%), Hornblende (max. 3.22%), Rutile (max. 0.98%) (Table 5). However, percentage of heavy mineral assemblages ensure that it is an economically important resource and feasible for exploitation. A researcher also found that there are five major minerals named as Zircon, Rutile, Ilmenite, Garnet and Magnetite in his study [3].

Heavy minerals are concentrated in some specific areas mainly in Chor-para (Teknaf-11) beach, Numberi (Teknaf-7) beach, Jahajchora (teknaf-1) beach and Raja-chorav (Teknaf-5) beach in Teknaf upazila containing 20.68%, 20.15%, 14.21% and 16.72% heavy minerals respectively. Imam Del (Inani-5) and Royal tulip resort (Inani-3) area in Ukhia Upazila contains 19.34% and 19.71% heavy minerals respectively. Coastal areas near Himchari region contain 22.33% heavy minera

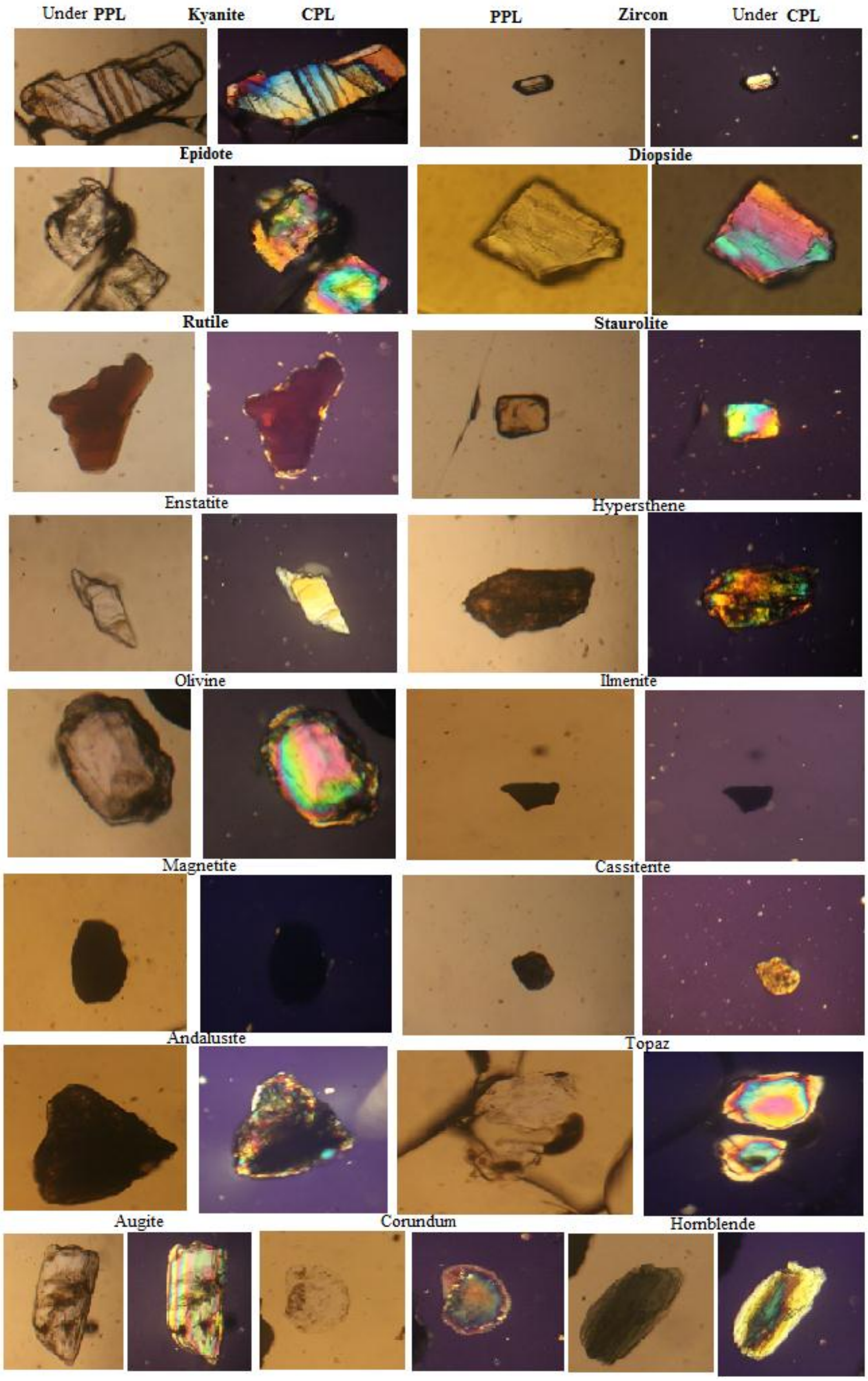


**Figure 9:** Some identified Heavy minerals under microscope both in Plane and cross polarized light.

### 4.3 Result of Remote Sensing Verification

For satellite image verification, the Lansat-8 OLI image was analyzed. The Analysis confirms that the major heavy mineral deposits are in the sandy long beach of Cox's bazar, Moheshkhali Island, Kutubdia Island, Inani beach, Himchari beach and also the beautiful sandy beach of Teknaf which validate the result obtained from laboratory analysis (Figure 10). The 30 samples analyzed in this study were collected from these major deposit's areas mainly from the Moheshkhali, Inanni, Himchari, long sandy beach of Cox's bazaar and Teknaf.

Result from the image analysis in ENVI shows that the heavy minerals are mostly found in Moheshkhali, Kutubdia, the entire sandy beach area of Cox's Bazar district (Cox's bazaar- Teknaf) and the region between Myanmar and Bangladesh near the Naf River and in Teknaf region. The distribution of ilmenite and magnetite are higher in coastal areas of Bangladesh [38]. The most important minerals which are identified from the research, are Zircon, Garnet, Ilmenite, Augite and Magnetite are also matched with the result of satellite image analysis (Figure 11). The result from the remote sensing study only showing the relative predicted gross distribution of heavy minerals along the eastern coastal belt of Bangladesh. In some places, results can not be correlated with the finding from field and laboratory analysis due to the coarser resolution of the satellite images.

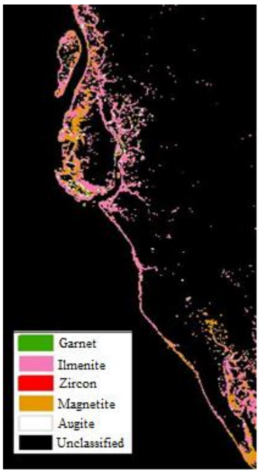


**Figure 10:** Distribution of heavy minerals along the eastern coastal margin of Bangladesh.

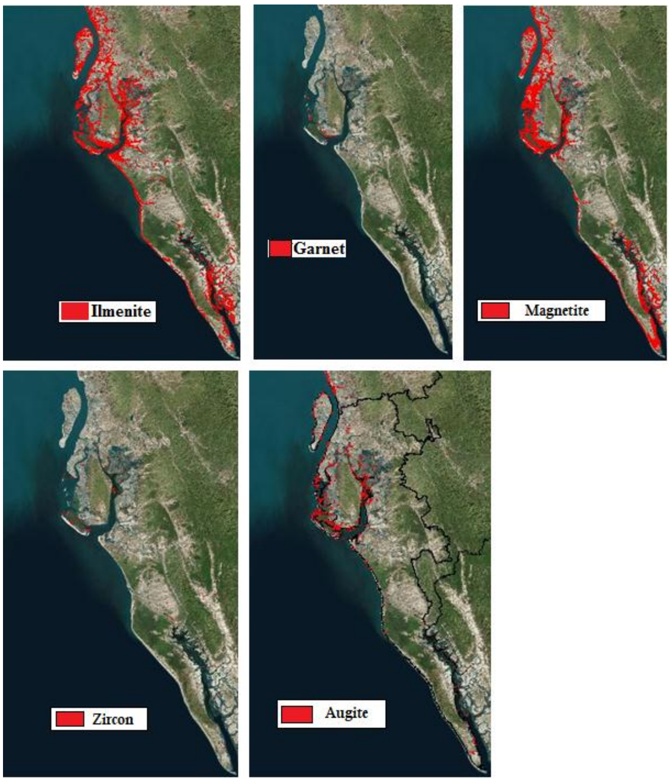


**Figure 11:** Showing image-based concentration of heavy minerals in the study area. From top (Ilmenite, Garnet, Magnetite, Zircon and Augite) to bottom.

## 5. CONCLUSION

The coastal belt of Bangladesh is very potential for heavy mineral exploitation that would contribute to the economy of Bangladesh. There are many valuable minerals found in the study area such as Zircon, Ilmenite, Augite, Rutile, Magnetite and Garnet. The Teknaf sea beach, Kolatoli and Moheshkhali are comparatively more resourceful in heavy minerals. In this study, heavy minerals mapping from satellite images has given a gross idea of specific mineral concentration in different parts of the area. However, heavy mineral concentration and distribution in the study area was verified with the satellite data and analyzed results are somewhat similar to the findings from geospatial analysis.

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