GIS Based Index Overlay Method in Targeting Heavy Mineral Deposits, Southern Kerala Coast, India

Melwyn Joshua R, Palanivel K, Rajaperumal R

Abstract: Owing to the strategic importance in defence and the other industrial applications, the heavy minerals have attracted the attention of the geoscientists since long time. But they have been using mostly the traditional techniques for a long time for targeting the heavy mineral deposits. Later, the scientists have started employing modern techniques like scintillometer based field surveys, remote sensing and the laboratory based sedimentological and heavy mineral studies. But since the traditional techniques are more cumbersome and would be very difficult to cover the vast length of the Indian coasts of over 7500 km, faster and effective techniques are necessary. So, the information value method was accomplished in the present study to demonstrate the targeting of heavy minerals in parts of Kerala extending from 76° 41' - 08° 53' in NNW and 77° 13' - 08° 17' in SSE (1.811sq.km).

In this study five geosystem maps, viz; Lithology, Lineament Frequency, Lineament Density, Lineament Intersection density and Geomorphology were prepared using the raw and digitally processed LANDSAT ETM 7 and IRS LISS IV FCC data sets. These geosystem maps were firstly prepared as vector GIS layers and then converted into raster maps using ARC GIS software with the pixel size of 100x5.m and the total pixels of 1,64,358. On the basis of the contribution of the above five main geosystem variables towards the heavy mineral potentials, weightages were assigned (Wi) to each of them. Similarly, depending upon the heavy mineral possibilities of the sub variables of the above five main geosystem variables, scores were assigned (Si) to each sub variable of the 5 main geosystem variables. Then, the Wi values were multiplied with the corresponding Si values of each of the sub variables of the 5 main geosystem variables and those were considered as final weightages (HMP-Heavy Mineral potentials) and assigned for the corresponding pixels of each sub variable of the five main variables. Followingly, the each WiSi weighted values of the 1,64,358 pixels of the lithology main geosystem variable were added with corresponding pixels of the remaining 4 main geosystem variables using ADD function menu of ARC GIS and integrated raster GIS database was generated with all the 1,64,358 pixels having the cumulative WiSi values (∑WiSi). Then, on the dynamic range of the ∑WiSi values, these pixels were classified into Very High, High, Moderate, Low and Very Low zones of heavy mineral concentrations. This was validated with heavy mineral weight percentage data derived from the field samples collected from the study area during survey.

This study was basically undertaken to replicate it for the rapid appraisals of the probable heavy mineral target areas along the Indian coasts. However this can be replicated anywhere.

Keywords: Remote Sensing and GIS, Index Overlay method, heavy mineral targeting, Southern Kerala coast

I. INTRODUCTION

Due to the fast emerging needs of heavy minerals in various industrial and defense sectors, the inventory for the heavy minerals have galloped all over the world. These heavy minerals, though originally occur as disseminated minerals in the hard crystalline rocks, due to subsequent weathering, long transport by the river systems and the intensive panning action by the waves and tides along the coasts, these get concentrated along the coasts and also in the fluvial sediments [1]. India having more than 7500 km long coasts both along its west and east, a hierarchy of agencies and institutions have embarked in the race of heavy mineral search in India [2]. The academic and research institutions while concentrate mostly in understanding the mode of origin, occurrence and the processes involved in the concentration of heavy minerals, the other exploration agencies mainly focus on hunting these deposits to meet out the national needs [3]. Duly considering the vast area to be covered along the Indian coasts, and the need for developing faster and precise methods, a technique called Index Overlay method was attempted in the south western part of Kerala coast “Fig. 1”. Covering an area of 1,811 sq.km (90 km long in NW - SE and 25 km broad in E-W directions) to locate the probable zones of heavy mineral concentrations.

In the said study, maps on various geosystem parameters were prepared using remote sensing and GIS on raster formats and weightages were assigned for the individual geosystem parameters and the final weightages for the integrated geosystem layer using Arc GIS. From the integrated layer, on the basis of the weightages, the heavy mineral target areas were identified. The study has brought out encouraging results as evidenced from the validations done by the field based sampling and the assessment of the weightage percentages of the heavies.
II. MATERIALS AND METHODS

In the study, “Fig. 2”. raw and digitally processed satellite data were interpreted and GIS maps were prepared on Lithology, Lineament Frequency, Lineament Density, Lineament Intersection density and Geomorphology of the study area. These 5 geosystem maps prepared on vector GIS formats using ARC GIS were converted to raster maps with the pixel size of 100 sq.m and the total pixel of 1,64,358 for the study area of 1,811 sq.km. Depending upon the heavy mineral potentials of the above 5 geosystem maps / variables, weightages (Wi) were assigned. Similarly, on the basis of the heavy mineral possibilities, independent scores (Si) were given to each sub variables of the above 5 main geosystem variables. Then, the weightage (Wi) of the each geosystem data were multiplied with Si values of the each of the corresponding sub variables and Wi x Si values (HMP –Heavy mineral potential values) were worked out for each sub variables of the 5 geosystem variables. These were assigned as the final weightages for each pixels of all the sub variables. Then, such WiSi values (HMP) of each pixel of lithology main variable were added with corresponding pixels of the remaining four main geosystem raster maps and cumulative WiSi values (∑WiSi) were worked out for each pixels in the final integrated raster GIS data. Then, on the basis of the dynamic range of the ∑WiSi values of 1.64,358 pixels, the study area was classified into heavy mineral prospects of Very High, High, Moderate, Low and Very Low zones. This was also validated from the heavy mineral weight percentage data of the 10 samples collected from the field.

III. RASTER GIS DATABASES ON GEOSYSTEMS

A. Lithology

- **Image interpretation and mapping:** Various types of image processing techniques were used by using ENVI image processing software and LANDSAT ETM data was subjected to Minimum Noise Fraction processing, De correlation Stretching, Principal Component Analysis and other digital processing techniques “Fig. 3”. From these, the rocks belonging to the Precambrian period, younger sedimentary and recent sands were mapped.

Fig. 1. Study Area

Fig. 2. METHODOLOGY

Fig. 3. Digitally Processed Satellite data showing various Lithology
**Precambrian Crystallines:** In the study area, Garnet-Biotite-Silimanite gneiss with or without Graphite, Garnet Biotite Gneiss with associated Migmatites, Quartz Feldspathic Gneiss / Biotite Gneiss, Pyroxene Granulite and Charnockites were interpreted by duly referring the published maps and updating them using the image processing techniques “Fig. 4”. These rock types in general have heavy minerals in disseminated form and on weathering these could get released out as boulders blocks and further subjected to the fluvial action.

**Younger Sedimentaries and Recent Sands:** Similarly through these image processing techniques, Sandstones, Pebble beds, Sand - Silt - Clay admixture (Fluvial), Palaeo - Beach deposits (Marine) and Beach Sand (Marine) were interpreted. These younger sedimentary rocks and mostly the coastal deposits and the fluvial sediments have better probability for heavy minerals because of the long transport of the heavy mineral bearing rocks and the sedimentary differentiation and panning due to fluvial and fluvo – marine actions. Such vector based lithology and the raster converted lithology maps are shown in “Fig. 4 A – B” respectively. The pixel wise coverage of the 10 lithological sub variables are tabulated and shown in Table – I.

### Table - I: Pixel wise coverage of Lithology

| S. No | Lithology Sub Variables                                                                 | No. of Pixels |
|-------|----------------------------------------------------------------------------------------|---------------|
| 1     | Garnet- Biotite- Silimanite Gneiss with or without Graphite                             | 95616         |
| 2     | Garnet Biotite Gneiss with associated Migmatites                                         | 32609         |
| 3     | Quartz Feldspathic Gneiss / Biotite Gneiss                                              | 2821          |
| 4     | Pyroxene Granulite                                                                      | 148           |
| 5     | Charnockite                                                                             | 5344          |
| 6     | Sandstone                                                                              | 16959         |
| 7     | Pebble bed                                                                             | 505           |
| 8     | Sand - Silt - Clay admixture (Fluvial)                                                  | 1139          |
| 9     | Palaeo - Beach deposits (Marine)                                                        | 8967          |
| 10    | Beach Sand (Marine)                                                                     | 250           |
|       | **Total no. of pixels**                                                                 | **1,64,358**  |

**B. Lineament and their derivatives**

*Lineament Fabric:* On the basis of the above digitally processed data the lineaments were interpreted on the basis of tonal, textural, soil tonal, vegetational, topographic and drainage linearities and curvilinearities “Fig. 5”. The lineaments thus interpreted generally fall in NW – SE, NE – SW and WNE – WSE [4] “Fig. 5”. In the interpretation of lineaments the SRTM shaded relief data was also used “Fig. 5”.

**Lineament Frequency:** From the lineament fabric map, the total numbers of lineaments per 1 sq.km were counted, plotted in the respective grid centers and contoured using GIS [5]. These numbers of lineaments have varied from 2 to 12 per grid. On the basis of this the lineament frequency was classified into 5 zones such as, Very High (8 -12), High (6-8), Moderate (4-6), Low (2-4) and Very Low (<2). Such classified raster data on lineament frequency is shown in “Fig. 6 – B”. The total numbers of pixels covered by these 5 sub variables of lineament frequency are shown in Table – II.

### Fig. 4. Lithology

- **Fig. 4.** Lithology

- **Fig. 5.** Lineament Fabric of the Study Area

- **Fig. 6.** Lineament Frequency
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Table - II: Pixel Wise Coverage of Lineament Frequency

| S. No | Lineament Frequency Sub Variables | Pixel   |
|------|---------------------------------|--------|
| 1    | Very High (VH)                  | 32660  |
| 2    | High (H)                        | 33293  |
| 3    | Moderate (M)                    | 33002  |
| 4    | Low (L)                         | 32606  |
| 5    | Very Low (VL)                   | 32797  |

Total no. of pixels 1,64,358

- **Lineament Density:** In the same way, total length of the lineaments per 1 sq.km were measured, plotted in the respective grid centers and contoured [5] “Fig. 7 – A”. This has also varied from 100 meters to over 7000 meters “Fig. 7 – A”. This was classified into five classes as shown in Fig.7A. Such lineament data having 5 sub variables are also shown as raster data in “Fig. 7 – B” and the numbers of pixels covered by these 5 sub variables are also shown in Table – III.

![Fig. 7. Lineament Density](image)

Table - III: Pixel Wise Coverage of Lineament Density

| S. No | Lineament Density Sub variables | Pixel |
|------|--------------------------------|-------|
| 1    | Very High (VH)                 | 32155 |
| 2    | High (H)                       | 33519 |
| 3    | Moderate (M)                   | 33085 |
| 4    | Low (L)                        | 32888 |
| 5    | Very Low (VL)                  | 32711 |

Total no. of pixels 1,64,358

- **Lineament Intersection Density:** In the same way, total number of lineament intersections per 1 sq.km were counted and contours were drawn, classified into 5 zones depending upon their dynamic range, converted into raster GIS data and these are shown in “Fig. 8 – A & B”. The 5 sub variables of the lineament intersection density and their pixel wise coverage are shown in Table – IV.

![Fig. 8. Lineament Intersection Density](image)

Table - IV: Pixel Wise Coverage of Lineament Intersection Density

| S. No | Lineament Intersection Density Sub variables | Pixel |
|------|---------------------------------------------|-------|
| 1    | Very High (VH)                             | 32381 |
| 2    | High (H)                                   | 32702 |
| 3    | Moderate (M)                               | 33227 |
| 4    | Low (L)                                    | 33177 |
| 5    | Very Low (VL)                              | 32871 |

Total no. of pixels 1,64,358

C. Geomorphology

- **Image interpretation and Mapping:** As geomorphology plays a vital role in the heavy mineral concentration, fine resolution geomorphology map was prepared using IRS LISS IV FCC data, digitally processed LANDSAT ETM 7 data such as Minimum Noise Fraction, Decorrelation Stretching output and Principal Component Analysis images “Fig. 9”. Overall 17 landforms were mapped belonging to the denudational, fluvial and fluvio-marine parentage “Fig. 10”.

- **Denudational land forms:** Under denudational landforms residual hills, dissected hills and pediments were interpreted. While residual hills may not have the heavies, the dissected hills could be the source for the supply of debris to the fluvial systems. Similarly, the pediments may also have disseminated heavy minerals which on erosion could supply them.

- **Fluvial Landforms:** Over 6 landforms were mapped under fluvial geomorphology, amongst which the valley fills are the landforms occurring just below the mountains. Since the blocks and boulders that have been disintegrated by geological processes, slide down the hills by fluvial action, hence the valley fills are found at the bottom of the foot hills. The cobbles and pebbles are the main deposits of valley fills and hence can form potential zones for the heavies. But there may not be any concentration and it will be too much disseminated. However, the flood plain and channel island are the areas where heavy minerals can get concentrated.
Fig. 9. Digitally Processed Satellite data showing Geomorphology

- **Fluvio-Marine and Marine Landforms**: Fluvio-Marine Landforms like relict beach ridges, planated beach ridges and beaches are highly promising areas for heavy minerals because of the natural sedimentary differentiation by the rivers and the interface dynamics between the marine and fluvial actions which cause intensive panning. Thus, over 17 geomorphic landforms interpreted were vectorized and then rasterized as shown in “Fig. 10 – A & B” and the pixel wise coverage is shown in Table – V.

Table - V: Pixel Wise Coverage of Geomorphology

| S. No | Geomorphology Sub Variables | No. of Pixels |
|-------|-----------------------------|---------------|
| 1     | Residual Hill               | 2             |
| 2     | Dissected Hill              | 128845        |
| 3     | Valley Fill                 | 25421         |
| 4     | Pediment                    | 2             |
| 5     | Flood Plain                 | 71            |
| 6     | Channel Island              | 13            |

Fig. 10. Geomorphology of the Area

IV. INDEX OVERLAY METHOD AND HEAVY MINERAL TARGETTING

A. Assignment of weightages (Wi) and Scores (Si) to geosystems and estimation of $\sum WiSi$

These 5 geosystems were analyzed in conjunction for their heavy mineral prospects. Hence from it, the weightage (Wi) 4 was assigned to lineament frequency and lineament density and 5 was assigned to lineament intersection density because amongst these three, the zones of lineament intersection have comparatively higher possibility of disintegration and the release of heavy minerals Table – VII. Similarly, the highest weightage (Wi) of 8 was assigned to geomorphology Table – VIII followed by 6 to lithology Table – VI.

- **Lithology**: For lithology, different scores (Si) were assigned depending upon the heavy mineral potential for each of the 10 sub variables. Wi and Si were worked out (HMP) and the same is shown in Table – VI.

Table - VI: Index Overlay weightages (Wi) and Scores (Si) & $\sum WiSi$ for Lithology

| SL. No. | Lithology                          | Weightage (Wi) | Scores (Si) | HMP (Wi x Si) |
|---------|------------------------------------|----------------|-------------|---------------|
| 1       | Garnet – Biotite Gneiss with Migmatites | 5              | 30          |               |
| 2       | Garnet – Biotite – Sillimanite Gneiss | 5              | 30          |               |
| 3       | Quartz – Feldspathic Gneiss / Biotite Gneiss | 4              | 24          |               |
| 4       | Pyroxene Granulite                 | 4              | 24          |               |
| 5       | Charnockite                        | 4              | 24          |               |
| 6       | Sand Stone                         | 5              | 30          |               |
| 7       | Pebble bed                         | 6              | 36          |               |
| 8       | Sand – Silt – Clay admixture       | 7              | 42          |               |
| 9       | Palaeo Beach deposit               | 9              | 54          |               |
| 10      | Beach Sand                         | 10             | 60          |               |

- **Lineaments and Derivatives**: Similarly, different scores (Si) were assigned to lineament frequency, lineament density and lineament intersection density depending upon their heavy mineral potential and WiSi were worked out which are shown in Table – VII.
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Table - VII: Index Overlay weightages (Wi) and Scores (Si) & \(\sum \text{Wi} \times \text{Si}\) for Lineament Derivatives

| Sl. No | Sub Variables | Lineament Frequency | Lineament Density | Lineament Intersection Density |
|--------|----------------|---------------------|-------------------|-------------------------------|
|        |                | Wi | Si | Wi | Si | Wi | Si |
| 1      | Very High (VH) | 5  | 20 | 6  | 24 | 7  | 35 |
| 2      | High (H)       | 4  | 16 | 5  | 20 | 6  | 30 |
| 3      | Moderate (M)   | 3  | 12 | 4  | 16 | 5  | 25 |
| 4      | Low (L)        | 2  | 8  | 3  | 12 | 4  | 20 |
| 5      | Very Low (VL)  | 1  | 4  | 2  | 8  | 3  | 15 |

- Geomorphology: Similarly, the scores (Si) were assigned depending upon the heavy mineral potential for each of the 12 geomorphic landforms and the WiSi were worked out from them which are shown in Table – VIII.

Table - VIII: Index Overlay weightages (Wi) and Scores (Si) & \(\sum \text{Wi} \times \text{Si}\) for Geomorphology

| Sl. No | Geomorphology | Weightages (Wi) | Scores (Si) | HMP (Wi x Si) |
|--------|---------------|-----------------|-------------|---------------|
| 1      | Residual Hill | 2               | 16          |               |
| 2      | Dissected Hill| 5               | 40          |               |
| 3      | Valley Fills  | 6               | 48          |               |
| 4      | Pediment      | 3               | 24          |               |
| 5      | Flood Plain   | 5               | 40          |               |
| 6      | Channel Island| 7               | 56          |               |
| 7      | Coastal Plain | 6               | 48          |               |
| 8      | Relict Beach Ridge | 8 | 64 |          |
| 9      | Planated Beach Ridge | 8 | 64 |          |
| 10     | Creek         | 4               | 32          |               |
| 11     | Swale         | 4               | 32          |               |
| 12     | Beach         | 9               | 72          |               |

- B. Heavy Mineral Targeting

Subsequent to the working out of the WiSi values for each sub variables of each of the 5 geosystem maps, these were integrated using ADD function menu of Arc GIS and integrated raster GIS map was prepared “Fig. 11”. This integrated raster map was having the cumulative WiSi values of each pixel of the entire study area (\(\sum \text{Wi} \times \text{Si}\)). These \(\sum \text{Wi} \times \text{Si}\) values have varied from 4 to 72. These were linearly stretched and normalized from 0 to 10 by using modified linear stretching algorithm of [4] and [6]. Now, on the basis of dynamic ranges these were classified into 5 zones of heavy mineral probabilities as Very High (8 – 10), High (6 – 8), Moderate (4 – 6), Low (2 – 4) and Very Low (< 2) “Fig. 11”.

C. Validation

10 samples were collected from surface and sub-surface in these 5 identified provinces and weight percentages were worked out in the laboratory by using hand magnet, bromoform separation and other standard procedures. These weight percentages were compared with heavy mineral probability areas brought out from the study. This has shown that the higher heavy mineral percentages were found in Very High and High zones Table – IX. Hence, this index overlay method is best suitable for the rapid appraisal of the heavy mineral probability.

Table - IX: Heavy Mineral Probable Areas (HMPA) and Average Heavy Mineral (AHM) Percentage

| Sl. No | HMPA | AHM % |
|--------|------|-------|
| 1      | Very High (VH) | 8.72  |
| 2      | High (H)       | 5.32  |
| 3      | Moderate (M)   | 3.66  |
| 4      | Low (L)        | 2.35  |
| 5      | Very Low (VL)  | 0     |

V. CONCLUSION

The state of Kerala is a unique geological province of 600 km long in NNW – SSE and 35 to 120 km broad in EW. In this linear stretched up state the Western Ghats Mountains occur all along the east of the state rimmed by sequentially and sub parallelly by the composite slopes, marginally raised uplands and the coastal plains. So, the drainages that rushes down from the more deformed and more fractured Western Ghats ranges rush down ferociously and enters the sea. This phenomenon provides the possibility of removal of the
heavy mineral baring rocks, dump them in the foot hills as debris and valley fills; further carry on and deposited and fluvial landforms; finally these sediments that are brought from the Western Ghats by these drainages are subjected to panning by the waves and the tides; thus the heavy minerals are possibly concentrated along the beaches and beach ridges. Thus, the coastal areas forms the high probability zones, followed by fluvial systems and then by the foot hills. Though geodynamically the system is very clear to understand the origin of the heavy mineral concentrates; hence, not only Kerala state, but also the entire east and west coasts of India are favorable locals for heavies; but the precise mapping of the heavy mineral concentrates demands suitable technologies so that the entire coast of India can be scanned for the heavy mineral probability. Under this scenario the present study of information value method which involves fine resolution of mapping of various geomorphic, tectonic and lithological parameters; assign weights and scores depending upon their heavy mineral potentials and integrate them using GIS has stand out to be a very good methodology for heavy mineral targeting. The sampling and the heavy mineral analysis has also confirmed the areas identified in this study. Hence, this can be replicated not only along the Indian coast but the entire global coast as well.

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AUTHORS PROFILE

R. Melwyn Joshua (31 yrs) is from the Geosciences discipline after acquiring his 5yr integrated degree in Geosciences from Bharathidasan University, Tiruchirappalli, he has joined as a Project Fellow in the Centre for Remote Sensing, Bharathidasan University. In his academics and as research fellow he has acquired extensive knowledge and wide range of exposure on the principles of satellite borne remote sensing, digital image processing of most of the global satellite data, principles and applications of GIS including development of spatial and non – spatial data in earth sciences related issues, development of Cartosat DEM using photogrammetry tools and its analysis, analysis of SRTM data and its interpretation using shaded relief maps for geological mapping etc. All these concepts, he has used in rock type identification, tectonic modeling and mapping, geomorphology appraisals and natural resources etc. On acquiring efficiency he has joined as a research scholar in Centre for Remote Sensing and distilled his experience in studying the general geology, Western Ghats tectonics, geomorphology and morphodynamic processes of Kerala and developed concepts using spatio – statistics for placer minerals along Kerala coasts. In addition to locating the probable areas of placer minerals, for which he developed scientific protocols which are also validated by ground sampling and determination of heavy mineral percentages and radioactive levels of Uranium, Thorium and Potassium. He has also brought out number of reports and participated in various workshops and conferences.

Dr. K. Palanivel (45 yrs) is presently the Professor and Head, Department of Remote Sensing, Bharathidasan University, Tiruchirappalli, is a Geologist. His Post Graduate in Applied Geology and acquiring his Ph.D degree on Remote Sensing and GIS related to geosystem based development planning of parts of Western Ghats region of Madurai, Theni and Dindigul districts of Tamil Nadu, India. He has specialized in application of remote sensing and GIS, later, to the advanced level of 3D visualization, village level informatics leading to decision support system for development planning. He was associated and also executed large number of projects funded to be more than 10 corers during his research carrier of over 20 years. His studies have brought out new packages of information’s in earth sciences on lithological mapping, fold dynamics, lineament modeling and geomorphology leading to mineral resources. Identification of hydrocarbon baring deep seated structures through GIS based 3D visualization, spatial modeling of aquifer system, development of functional model on hard rock aquifer system, reservoir siltation and management studies, interface dynamics of floods and geosystems and landslides. He has published over 75 research articles and guided over 10 Ph.Ds.

R. Rajaperumal (34 yrs) after getting his M.Sc., Geo – informatics post graduate degree from Centre for Remote Sensing, he has involved himself as a research fellow in number of projects. His M.Sc., Geo – informatics program itself is a new of its kind which has the direct focus in understanding the general geosystem mapping and convert them into spatial information’s using GIS. Thus he possesses deserving expertise both in remote sensing and GIS in preparation of various thematic maps and their modeling for natural disasters. Synthesizing his expertise he has carried out a hierarchy of scientific methodology involving lithological mapping, geomorphological mapping of various landform of denudational processes, fluvial processes and coastal process and integration of all in targeting the heavy minerals along the Kerala coast. He has developed a hierarchy how lithological and geomorphological mapping could be done in relation with the targeting of heavy mineral parentage, accumulation, degree of physical disintegration and their occurring landforms; the geomorphic processes and the possible accumulation of heavies in hill slopes regions of the fluvial dynamics and landforms of the denudational processes, the interface dynamics between the fluvial systems and the marine systems and the development of the fluvio-marine landforms which have the possibility of heavy minerals. He has demonstrated a methodology for the central sector of Kerala and also validated it through ground based sampling along the Kerala coasts.