International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 16s,2025
https://theaspd.com/index.php

Heavy Mineral Assemblages And Distribution Between Kooduthalai And Midalam, Southern Tamil Nadu, India

Nithiya Kalyani, K.[1,2]*,Patterson Edward, J.K.[1]
[1]*Suganthi Devadason Marine Research Institute, 44-Beach Road, Tuticorin 628 001, India*
[2]Registration No:17217022052002, Manonmaniam Sundaranar University
*Corresponding author: Email: k.nithiyakalyani@gmail.com

Abstract
In this work, we studied the heavy-mineral placer deposits in the sediments of the coastal stretch between Kooduthalai and Midalam, Southern Tamil Nadu. For the present assessment, we collected a total of 187 samples from six sites viz. Kooduthalai, K. Uvari, Navaladi, Thiruvembalapuram, Vattakottai and Midalam. Sediment samples were collected down to a depth of 6m.We used a hand auger and a manually-driven Conrad banka drill for sampling. The collected samples were sub-sampled for every 0.5m depth interval. Samples were weighed, sieved and separated for different heavy minerals and identified with the help of a polarizing microscope. We followed standard protocol in sample processing and identification. We estimated the quantity of geological reserve of heavy minerals for one square meter. Pink, black and greenish yellow sediment patches occur in the study area. The heavy minerals present in this region include both the opaque and non-opaque varieties, the dominant minerals being ilmenite and garnet with small amounts of zircon, rutile, sillimanite, leucoxene and monazite. The average concentration of heavy minerals varies from 62.59 to 66.54%. We find the spatial distribution of ilmenite increasing from Kooduthalai (east coast) to Midalam (west coast), whereas garnet exhibits a reverse pattern. Monazite is confined to Vattakottai and Midalam (south to west coast). The assemblages of heavy minerals are concentrated in the fine and very fine sand fractions. The formation and concentration of these deposits are governed not only by the characteristics of the host rock in the Peninsula, Western Ghats and Quaternary sedimentary deposits but also by weathering processes, geological agents and coastal hydrodynamics. The concentration of heavy minerals in this region varies from 5 to 12 tonnes per square meter. Hence, the various heavy minerals occurring in the coastal tracks of the study area can be safely mined.
Keywords: *Heavy mineral assemblages, concentration, geological reserve, Kooduthalai to Midalam, southern Tamil Nadu*

1 INTRODUCTION

Tamil Nadu,the second largest coastal state in India, is gifted with a 1,076 km long coastline (DADF, 2014). The southern part of the Tamil Nadu coast is well known for the occurrence of various types and grades of heavy mineral deposits. The common minerals found are ilmenite, garnet, zircon, rutile, sillimanite, monazite, and leucoxene (Chandrasekar, 1992; Ramasamy *et al.*, 2004; Gandhi and Solai, 2010; Kalyani *et al.*, 2019). These minerals are derived from the weathering of rocks such as Khondalites, Charnockites, gneiss, granites, lateriteis, sandstone etc. by physical, chemical and biological processes, transported by rivers, streams and wind processes and deposited in the flood plains of streams and rivers, deltas, lagoons, beaches, sand dunes, hind shores, offshore and islands in the coastal plain (Force, 1991; Frihy 1994; Angusamy and Rajamanickam, 2000; Gosen *et al.*, 2010). The concentration of heavy minerals in layers depends on the nature of the shore, regular actions of waves, longshore currents, and wind and tide action (Gosen *et al.*, 2010; Akaram *et al.*, 2015). Several important heavy industrial minerals, particularly titanium-bearing ore minerals (ilmenite, rutile and leucoxene) and zircon occur here. The other coexisting heavy minerals, such as sillimanite/kyanite, staurolite, monazite and garnet are often found as co-products. Heavy minerals are commonly extracted from coastal deposits; these deposits are called 'industrial minerals' in the business world and 'heavy minerals sand' in the scientific literature (Gosen *et al.*, 2010). The main objectives studied in the present work are to identify and quantify the current status of the coastal region's heavy mineral resources of the coastal area between Kooduthalai and Midalam, Southern Tamil Nadu, India.

2 MATERIALS AND METHODS

The study area of the present work extends to a length of 120 km along the coastal track from Tirunelveli district in the Gulf of Mannar to Kanyakumari district in the Bay of Bengal of South Tamil Nadu. The coastal track is endowed with various geomorphic landforms like sandy beaches, dunes, teri sand, wave-cut notches, beach terraces, rocky shores, estuaries, beach berms and sand bars (Castro *et al.,* 2021). Six sites were selected in the study area: Kooduthalai (Latitude: N 08°18'12.76" and Longitude: E 77°56'5.51"), K Uvari (Latitude: N 08°16'15.38" and Longitude: E 77°53'4.05"), Navaladi (Latitude: N 08°14'57.529" and Longitude: E 77°49'40.30") and Thiruvembalapuram (Latitude: N 08°13'29.12" and Longitude: E 77°47'09.54") from Tirunelveli district, Vattakottai (Latitude: N 08°07'24.74" and Longitude: E 77°33'48.56") and Midalam (Latitude: N 08°12'41.88" and Longitude: E 77°11'58.77") from Kanyakumari district. Total 187 samples were collected from six locations during January and February 2021. At each location, samples were collected from 3 travers, each with an interval of 50 m parallel to the coast. In each traverse, 3 samples were collected at an interval of 50 m landward from the shoreline. Sampling was done with the help of hand auger down to the water table, while samples underneath the ground water table were collected by manually-driven Conrad banka drill. Each borehole sample was sub-sampled with an interval of 0.5m depth. The collected sediments were dried and weighed for further processing. Lighter and heavier fractions were separated using bromoform (specific gravity – 2.89). Lighter fractions, including silica, shells and other impurities were removed. The magnetic and non-magnetic minerals were separated with the help of an electro-magnet set at 0.2 amperes (Kalyani *et al.,* 2019). The weight of all the individual fractions was noted. The heavy minerals of individual fractions were mounted on glass slides using Canada balsam, and grains were counted using a polarising microscope, and the weight percentage of each heavy mineral was estimated by following the standard method (Young, 1966). XRD method was used to obtain the chemical compositions of the heavy minerals (PANalytical-Cubix^{3}Minerals). The geological reserve of the study area was estimated by single block method

Geological Reserve (tonnes) = Area (sqm) x depth (m) x bulk density of heavy mineral (tonnes/cu m) (Kalyani *et al.,* 2019).

3 RESULTS AND DISCUSSION

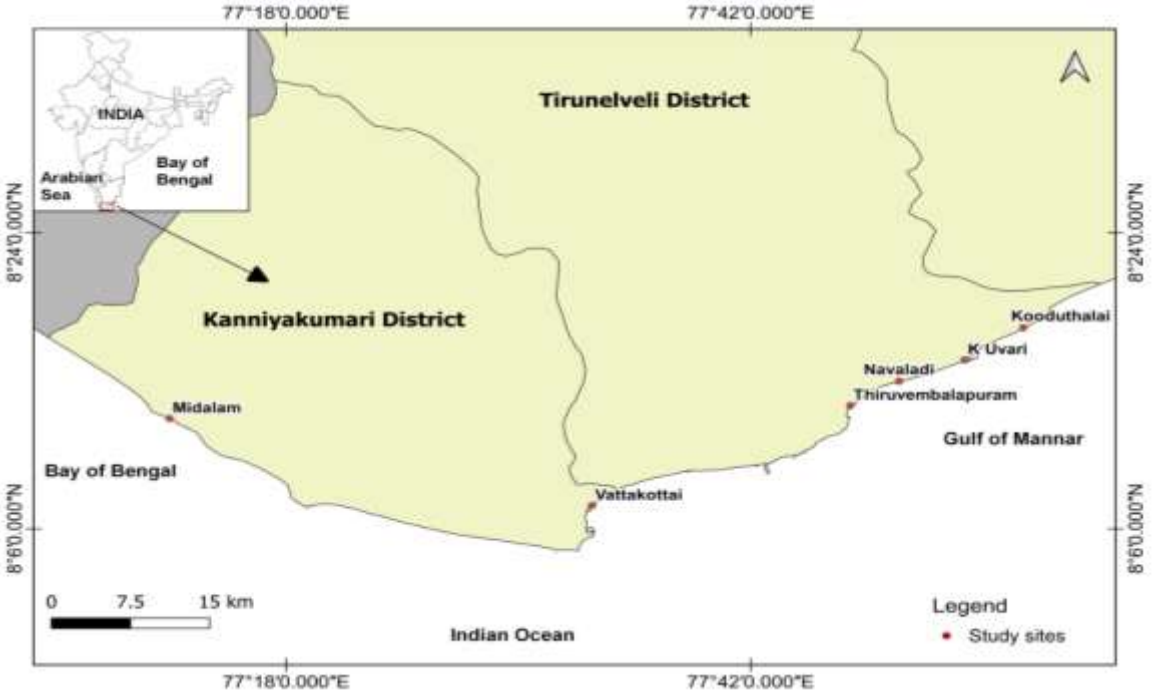
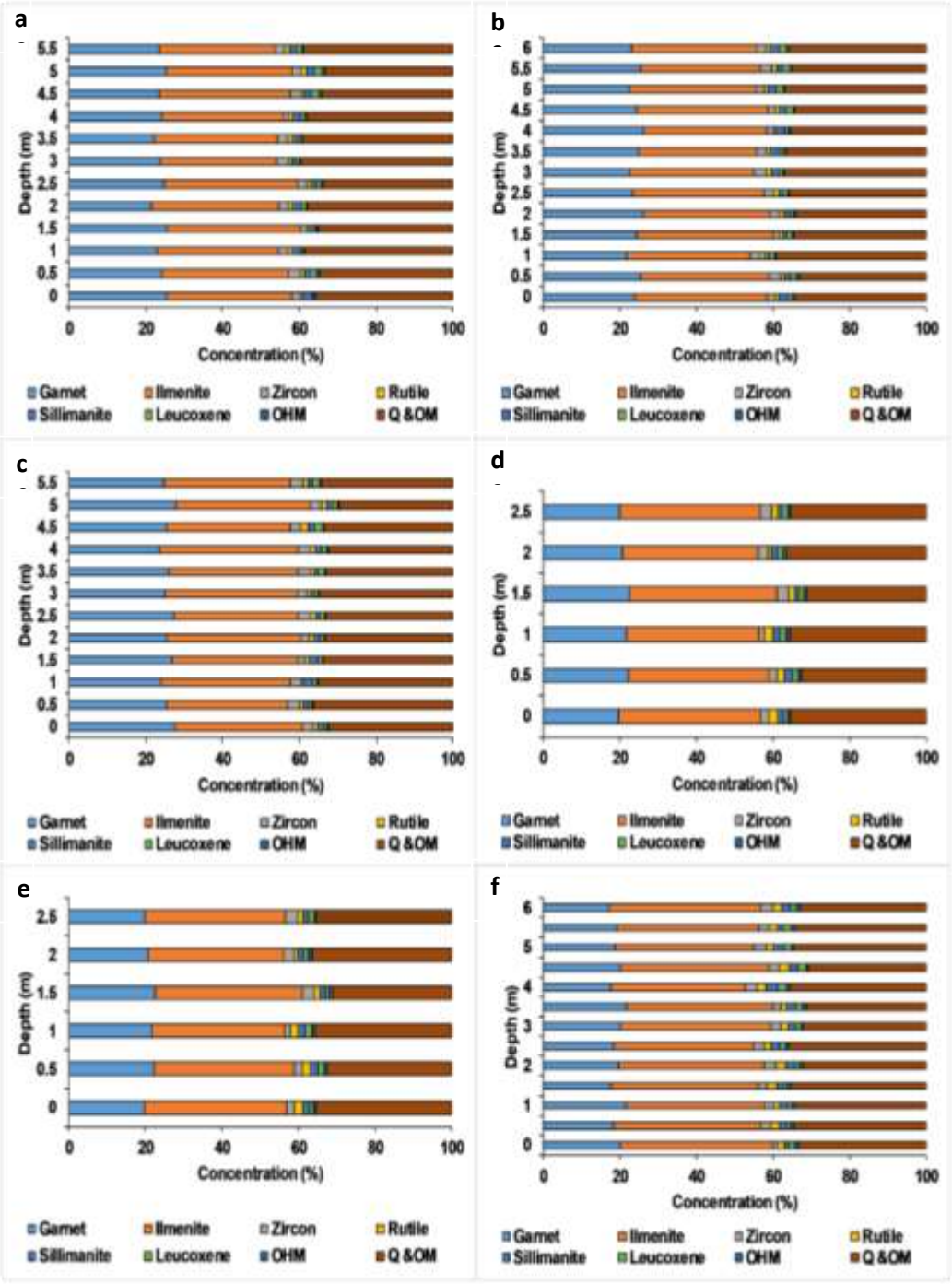


Fig. 1: Map showing the study locations along the southern coast of Tamil Nadu

All six study sites are located along the coastal track (Fig. 1).The depth of samplings was 6 m at K. Uvari and Midalam, and 5.5 m at Kooduthalai and Navaladi. On account of the presence of basement rock at Thiruvembalapuram and Vattakottai, sampling at these sites was done at 3 m and 2.5 m, respectively. The colouration of beach sediments was observed in all the study locations. The beach sediments of Kooduthalai, K. Uvari, Navaladi, Thiruvembalapuram and Vattakottai are pink and black in colour. The transition of colour is not abrupt but gradual. At Midalam, sediments exhibit pink, black and greenish yellow colours, and the transition of colour is not abrupt but gradual. The total mass of the colour of the component mineral grains of their own aggregates, the fineness of the sedimentary grains, and the thick enamel coating on the grains all influence the colour of the beach sediments (Krynine, 1948; Kalyani *et al.,* 2019). The red patches are due to the presence of garnet, which might have formed as a result of the disintegration of host rock such as charnockite, calc-granulites, gneisses, and granite from the Western Ghats, as well as Quaternary deposits (Anguswamy and Rajamanickam, 2000; Chandrasekar and Murugan, 2001; Kalyani *et al.,* 2019); the presence of ilmenite and rutile of similar origin is the reason for black patches (Chandrasekar, 1992; Anguswamy and Rajamanickam, 2000). The greenish yellow patches could be due to the presence of monazite, which might have been derived from charnockites, granitic and pegmatitic rock from the Western Ghats (Akaram *et al.*, 2015). These sediments are deposited as beach placers by the turbulent winnowing action of waves (Jayaraju, 2004). The beach sediment from the study area contains both heavy minerals and light minerals (Fig. 2). The heavy mineral assemblage present in the study area includes both opaque and non-opaque minerals. The opaque mineral includes ilmenite (stable mineral). The non-opaque mineral consists of zircon and rutile (ultrastable minerals), monazite (stable mineral), garnet and sillimanite (moderately stable minerals), and leucoxene (Pettijohn *et al.,* 1973). The average concentration of heavy minerals in the beach sediments of the study area ranges from 62.59 to 66.54% (weight percentage), with the highest value in Navaladi,and the lowest value in Thiruvembalapuram. The concentration of ilmenite is the highest, followed by garnet. Midalam has the highest concentration of ilmenite(37.83%), while Kooduthalai contains the lowest concentration(32.67%). In contrast, Midalam contains the lowest concentration of garnet (19.24%) and Navaladi has the highest concentration (25.7%). These variations are clearly indicated in the spatial distribution map (Fig. 3). The average concentration of zircon in the study area ranges between 2.34 and 2.72%. Rutile concentration ranges between 1.10 and 2.11%, sillimanite between 1.42 and 2.13%, leucoxene between 0.91 and 1.58 %; whereas other heavy minerals have a presence of less than 1%, of which monazite is observed in Vattakottai and Midalam sediments. The other heavy minerals include hornblende, hypersthenes, kyanite, tourmaline and mica. The chief constituent of light minerals is quartz, the other minerals. Earlier studies also report similar heavy mineral deposits of ilmenite, garnet, rutile,

zircon and monazite from the coastal tracks of the southern tip of India (Jayaraju, 2004) and also from the coastal Teri sand of southern India (Chandrasekharan and Murugan, 2001). The present study does not observe any significant vertical variation of heavy minerals concentration in the locations.



International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 16s,2025
https://theaspd.com/index.php

Fig. 2: Concentration of various heavy and light mineral (wt%) for different depth at a) Kooduthalai, b) K. Uvari, c) Navaladi, d) Thiruvembalapuram, e) Vattakottai, f) Midalam

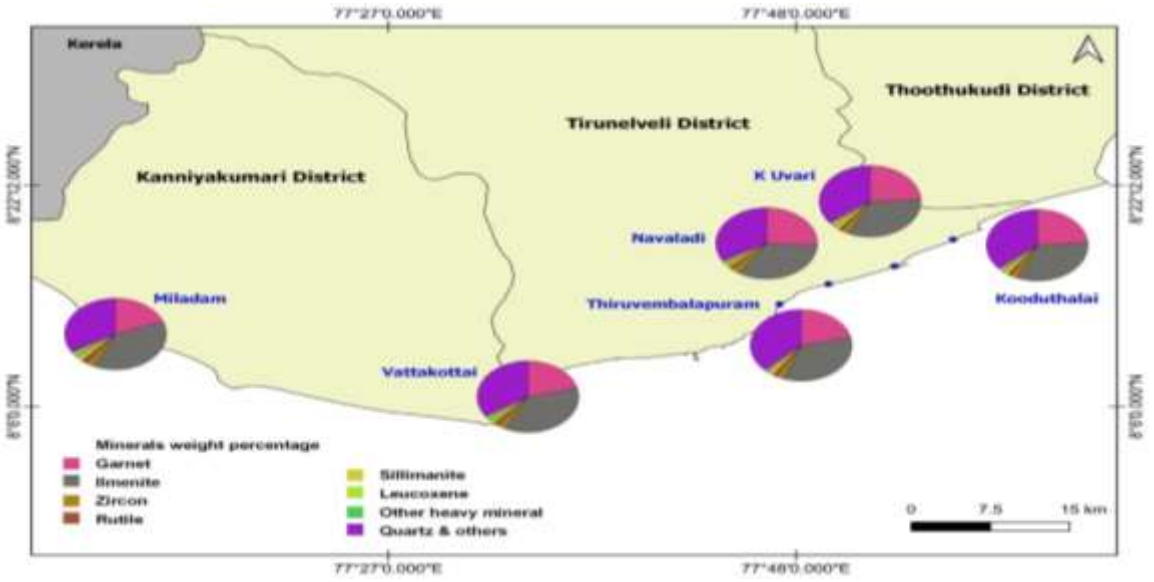


Fig. 3. Map showing the spatial distribution of weight percentage of heavy and light minerals in the study sites

The examination of grain size indicates that the fine sand fraction receives more concentration of heavy minerals than the very fine sand fraction in the study area (Table 1). At Navaladi and Thiruvembalapuram significant amounts of heavy minerals are seen in medium sand fraction also in contrast to the other locations. Garnet concentration is higher in fine fractions ranging between 5 and 25%. At Kooduthalai, fine fraction is followed by medium sand fraction, whereas from K. Uvari to Midalam, the fine fraction is followed by a very fine fraction. The garnet mineral varies from light pink to pink in colour, irregular in shape (subangular to subrounded) with conchoidal fracture and is of almandine-rich variety. The specific gravity of garnet is 4.1 and the mineralogical composition for the study stations shows minor variation (Table 2; Fig. 4). Ilmenite concentration is higher in fine sand fraction followed by a very fine sand fraction. It is opaque and subrounded in nature with a specific gravity of 4.7. The mineralogical composition of ilmenite in the study stations shows minor variation (Table 2). The concentration of zircon is higher in fine sand fractions at Kooduthalai and K. Uvari, whereas at Navaladi, Vattakottai and Midalam, both fine and very fine sand fractions have equal concentrations. At Thiruvembalapuram, very fine fraction dominates in zircon concentration.Zircon in the beach sediment is colourless or light brown,

and is rounded to subrounded(subhedral with rounded terminations, occasionally with iron oxide coated rims) in shape, which indicates the transportation of sediment before deposition. The specific gravity of zircon is 4.7 and the mineralogical composition shows minor variation. Zircon is considered to be the most common accessory mineral in the granitic terrain (Jayaraju, 2004). Higher rutile concentration is shared by fine and very fine sand fractions. Rutile is translucent to opaque in nature with brownish red to reddish black colour. The rounded to subrounded nature of rutile indicates that the sediment has been transported well before deposition. Rutile might have been derived from ancient sediments which have undergone recycling (Gandhi and Raja, 2014). Monazite is concentrated in very fine sand fraction followed by fine sand fraction. It is yellowish to reddish brown or greenish in colour with a rounded to subrounded shape, and the specific gravity is 5.2. Sillimanite is distributed significantly in all the sediment fractions. Similarly, leucoxene is found in all the sediment fractions. They vary from yellow to brown in colour. The lighter minerals are enriched in medium sand and fine sand, followed by a very fine sand fraction.

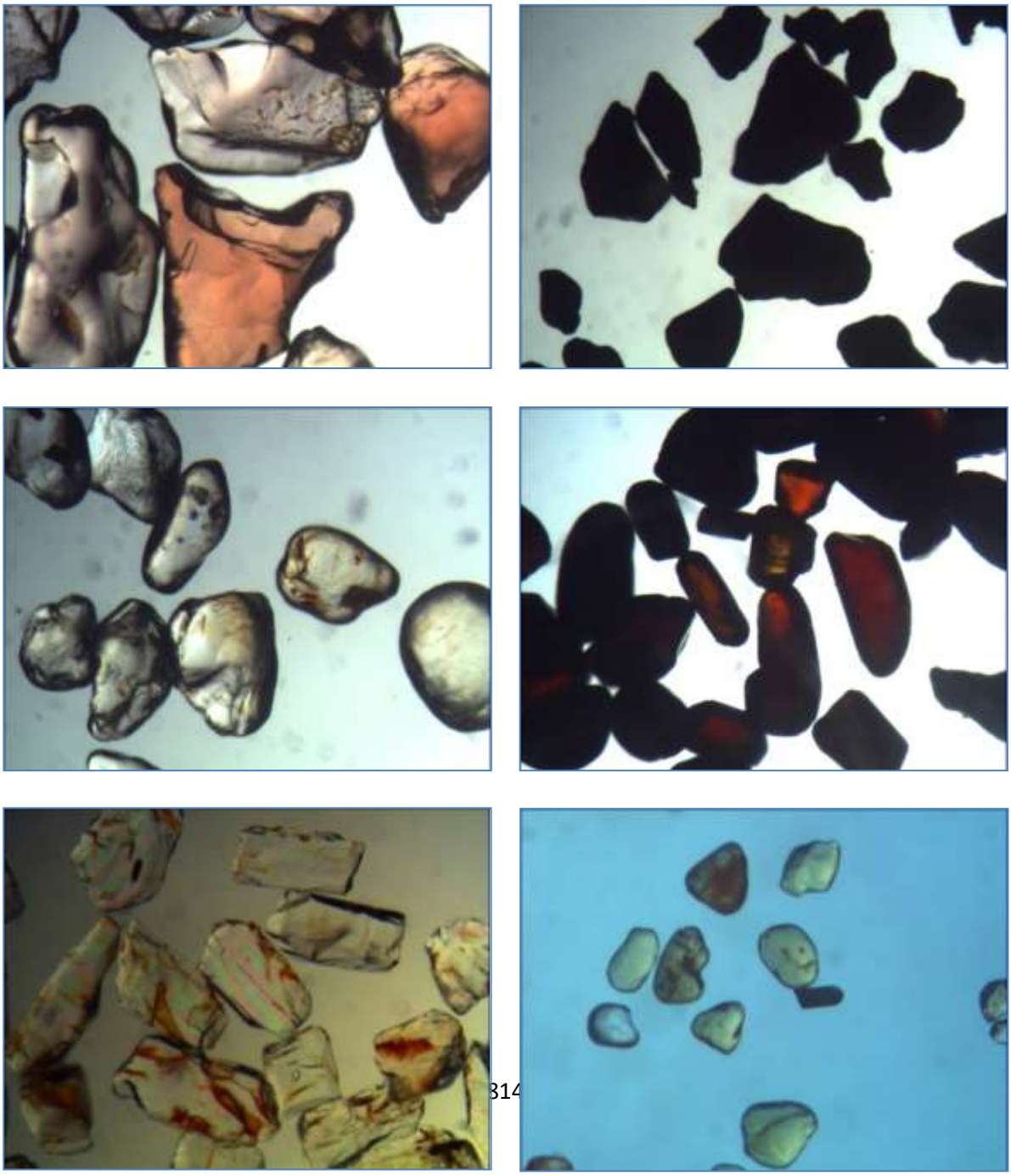


Fig. 4: Microphotograph of a) garnet; b) ilmenite; c) zircon; d) rutile; e) sillimanite; f) monazite

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 16s,2025
https://theaspd.com/index.php

Table 1. Grain size characters of heavy and light minerals for the study locations

Location	Kooduthalai				K. Uvari				Navaladi			
Sieve(ASTM)	0 to 60	60 to 120	120 to 230	>230	0 to 60	60 to 120	120 to 230	>230	0 to 60	60 to 120	120 to 230	>230
Garnet	0 ~ 10	10 ~ 20	0 ~ 5	0 ~ 3	0 ~ 8	5 ~ 20	0 ~ 10	0 ~ 5	0 ~ 12	5 ~ 24	0 ~ 16	0 ~ 7
Ilmenite	0 ~ 2	5 ~ 20	3 ~ 15	0 ~ 5	0 ~ 5	0 ~ 15	0 ~ 10	0 ~ 3	0 ~ 8	0 ~ 20	0 ~ 10	0 ~ 5
Zircon	0 ~ 1	0 ~ 2	0 ~ 1	0 ~ 1	0 ~ 0.5	0 ~ 2	0 ~ 1	0 ~ 1	0 ~ 0.3	0 ~ 1	0 ~ 1	0 ~ 0.5
Rutile	0 ~ 1	0 ~ 1	0 ~ 1	0 ~ 1	0 ~ 0.5	0 ~ 1	0 ~ 1	0 ~ 1	0 ~ 0.5	0 ~ 1	0 ~ 1	0 ~ 0.5
Sillimanite	0 ~ 1	0 ~ 2	0 ~ 1	0 ~ 1	0 ~ 1	0 ~ 1	0 ~ 2	0 ~ 1	0 ~ 1	0 ~ 2	0 ~ 1	0 ~ 1
Leucoxene	0 ~ 1	0 ~ 1	0 ~ 1	0 ~ 1	0 ~ 0.5	0 ~ 0.5	0 ~ 1	0 ~ 0.5	0 ~ 0.4	0 ~ 0.8	0 ~ 1	0 ~ 0.4
OHM	0	0 ~ 0.01	0 ~ 0.05	0 ~ 0 .01	0	0 ~ 0.01	0 ~ 0.02	0 ~ 0 .01	0	0 ~ 0.01	0 ~ 0.03	0 ~ 0 .02
Q & OM	0 ~ 15	5 ~ 20	0 ~ 15	0 ~ 5	0 ~ 20	5 ~ 25	0 ~ 10	0 ~ 8	0 ~ 18	5 ~ 24	0 ~ 15	0 ~ 6

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 16s,2025
https://theaspd.com/index.php

Location	Thiruvembalapuarm				Vattakottai				Midalam			
Sieve (ASTM)	0 to 60	60 to 120	120 to 230	>230	0 to 60	60 to 120	120 to 230	>230	0 to 60	60 to 120	120 to 230	>230
Garnet	0 ~ 10	5 ~ 20	0 ~ 20	0 ~ 5	0 ~ 8	5 ~ 25	0 ~ 15	0 ~ 4	0 ~ 6	5 ~ 20	0 ~ 12	0 ~ 5
Ilmenite	0 ~ 10	0 ~ 22	0 ~ 15	0 ~ 6	0 ~ 7	0 ~ 25	0 ~ 10	0 ~ 5	0 ~ 8	0 ~ 20	0 ~ 20	0 ~ 10
Zircon	0 ~ 0.2	0 ~ 0.5	0 ~ 1	0 ~ 0.4	0 ~ 0.1	0 ~ 0.8	0 ~ 0.8	0 ~ 0.6	0 ~ 0.1	0 ~ 0.6	0 ~ 0.6	0 ~ 0.4
Rutile	0 ~ 0.3	0 ~ 0.80	0 ~ 0.6	0 ~ 0.7	0 ~ 0.2	0 ~ 0.70	0 ~ 1	0 ~ 0.5	0 ~ 0.2	0 ~ 0.50	0 ~ 1	0 ~ 0.4
Sillimanite	0 ~ 0.5	0 ~ 1	0 ~ 2	0 ~ 0.5	0 ~ 0.6	0 ~ 0.8	0 ~ 1	0 ~ 0.6	0 ~ 0.5	0 ~ 0.8	0 ~ 1	0 ~ 0.5
Leucoxene	0 ~ 0.2	0 ~ 0.2	0 ~ 0.6	0 ~ 0..5	0 ~ 0.4	0 ~ 0.6	0 ~ 0.8	0 ~ 0.3	0 ~ 0.3	0 ~ 0.8	0 ~ 0.4	0 ~ 0.2
OHM	0	0 ~ 0.02	0 ~ 0.04	0 ~ 0 .03	0	0 ~ 0.01	0 ~ 0.03	0 ~ 0 .02	0	0 ~ 0.02	0 ~ 0.04	0 ~ 0 .02
Q & OM	0 ~ 20	5 ~ 25	0 ~ 20	0 ~ 10	0 ~ 15	5 ~ 24	0 ~ 18	0 ~ 10	0 ~ 15	5 ~ 30	0 ~ 15	0 ~ 10

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 16s,2025
https://theaspd.com/index.php

Table 2. Chemical constituents of some heavy minerals from the study locations

Mineral	Kooduthalai	K. Uvari	Navaladi	Thiruvembalapuarm	Vattakottai	Midalam
Garnet	Al_2O_3:24-35%;SiO_2:31-37%; FeO:29-30%; MgO:7-8%	Al_2O_3:25-35%; SiO_2:32-37%; FeO:29-31%; MgO:7-8%	Al_2O_3:24-35%; SiO_2:32-36%; FeO:29-30%; MgO:7-8%	Al_2O_3:25-35%; SiO_2:31-37%; FeO:29-31%; MgO:7-8%	Al_2O_3:24-35%; SiO_2:31-36%; FeO:29-30%; MgO:7-8%	Al_2O_3:25-35%; SiO:32-37%; FeO:29-31%; MgO:7-8%
Ilmenite	TiO_2:52-53%; FeO:32-38%; Fe_2O_3:5-15%; V_2O_5:0.25%	TiO_2:52-53%; FeO:32-38%; Fe_2O_3:5-15%; V_2O_5:0.25%	TiO_2:52-53%; FeO:32-38%; Fe_2O_3:5-15%; V_2O_5:0.25%	TiO_2:52-53%; FeO:32-38%; Fe_2O_3:5-15%; V_2O_5:0.25%	TiO_2:55-56%; FeO:25-35%; Fe_2O_3:7-17%; V_2O_5:0.15%	TiO_2:57-58%; FeO:25%; Fe_2O_3:13-19%; V_2O_5:0.3%
Zircon	ZrO_2:65-66%; SiO_2:31-32%	ZrO_2:65-66%; SiO_2:30-32%	ZrO_2:65-66%; SiO_2:31-32%	ZrO_2:65-66%; SiO_2:31-32.5%	ZrO_2:65-66%; SiO_2:30-32.5%	ZrO_2:65-66%; SiO_2:30-32%
Rutile	TiO_2:60-71%; SiO_2,ZrO_2,Fe_2O_3:1% each	TiO_2:60-71%; SiO_2,ZrO_2,Fe_2O_3:1% each	TiO_2:60-71%; SiO_2,ZrO_2,Fe_2O_3:1% each	TiO_2:60-71%; SiO_2,ZrO_2,Fe_2O_3:1% each	TiO_2:60-71%; SiO_2,ZrO_2,Fe_2O_3:1% each	TiO_2:60-71%; SiO_2,ZrO_2,Fe_2O_3:1% each
Monazite	Phosphates of rare earth and Thorium	Phosphates of rare earth and Thorium	Phosphates of rare earth and Thorium	Phosphates of rare earth and Thorium	Phosphates of rare earth and Thorium	Phosphates of rare earth and Thorium

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 16s,2025
https://theaspd.com/index.php

Table 3. Available heavy mineral reserve in the study sites

Name of the location	Geological Reserve for 1 sq m	Depth of heavy minerals (m)	Bulk density (tonnes/cu.m)	Total volume (tonnes)	Garnet (tonnes)	Ilmenite (tonnes)	Zircon (tonnes)	Rutile (tonnes)	Silimanite (tonnes)	Leucoxene (tonnes)
Kooduthalai	1	5.5	2	11	2.62	3.59	0.26	0.12	0.20	0.14
K. Uvari	1	6	2	12	2.90	3.97	0.29	0.14	0.21	0.18
Navaladi	1	5.5	2	11	2.83	3.71	0.30	0.14	0.16	0.15
Thiruvembalapuarm	1	3	2	6	1.28	2.06	0.14	0.08	0.11	0.05
Vattakottai	1	2.5	2	5	1.06	1.82	0.12	0.09	0.08	0.07
Midalam	1	6	2	12	2.31	4.54	0.31	0.25	0.26	0.19

It is observed that beach sediments are enriched with heavy minerals in fine and very fine sand fractions. This enrichment could be mainly due to the selective removal of fine light minerals by high wave energy and leaving behind the coarser light fraction, the high-density fine and very fine fractions (Mahadevan and Ramadas, 1954; Hanamgond and Nayak, 2011; Gandhi and Raja, 2014). The grain size investigation of the present study, as well as that of Nallusamy *et al.* (2015), indicates the existence of a mixed energy environment in this region. In this environment, the concentrations of heavy minerals do not show any typical trend in the process of sedimentation, which could not concentrate more heavy minerals by the removal of more light minerals. The dominant shape of the heavy minerals is angular to subangular, but a few grains are subrounded to rounded in nature. The angular to subangular nature could be mainly from the primary igneous and metamorphic rocks, whereas the subrounded to rounded nature could be mainly from meta-sedimentary and sedimentary rocks (Garzanti and Ando, 2007; Akaram *et al.,* 2015). We estimated the amount of geological reserve of heavy minerals available in one square meter of the study area. It varies from 5 to 12 tonnes (Table 3). Ilmenite ranges between 1.82 and 4.54 tonnes, garnet between 1.06 and 2.9 tonnes, zircon between 0.12 and 0.31 tonnes, rutile between 0.08 and 0.25 tonnes, sillimanite between 0.08 and 0.26 tonnes and leucoxene between 0.05 and 0.19 tonnes. Earlier studies also indicate the replenishment of heavy minerals by the aeolian and wave actions in the adjoining coastal area (Kalyani *et al.*, 2019).

4. CONCLUSION

The southernmost coastal region of Tamil Nadu is endowed with beach placers. The distribution of different types of minerals determines the heavy mineral assemblages of this region. Both opaque and non-opaque heavy minerals are present, of which opaque minerals include ilmenite and non-opaque minerals include garnet, zircon, rutile, sillimanite, leucoxene and monazite. The spatial distribution of ilmenite increases from east to west, whereas the distribution of garnet exhibits an opposite trend. Similarly, monazite is confined to the region between the down-south to the west i.e. from Vattakottai to Midalam. Heavy minerals are concentrated in fine and very fine sand fractions. Water and wind are the chief geological agents that play a main role in the concentration of heavy minerals in the coastal region of the study area. Selective removal of light minerals during accelerated retrogression by high waves plays a major role in the concentration of the beach sediment, whereas the prevailing wind removes the lighter minerals in the coastal dune region. The main source of heavy minerals could be the metamorphic and igneous rocks of the Western Ghats and the Quaternary sedimentary deposits along the coastal track. The current geological reserve of heavy minerals in the beach sand of the study area ranges between 5 and 12 tonnes/m^2. The available heavy mineral reserves along the coast from Kooduthalai to Midalam can be mined for the development of the country.

ACKNOWLEDGEMENTS : The authors express their thanks to Suganthi Devadason Marine Research Institute, Tuticorin for the research facilities.

5. REFERENCES

1. Akaram, V., Das, S.S., Rai, A.K. and Mishra, G. 2015. Heavy mineral variation in the deep sea sediment of southeastern Arabian Sea during the past 32 kyr. Journal of Earth System Science. 124: 477-486. doi:10.1007/s12040-015-0546-0
2. Anguswamy, N. and Rajamanickam, G.V. 2000. Distribution of heavy minerals along the beach from Mandapam to Kanyakumari, Tamil Nadu. Journal of the Geological Society of India, 56:199-211.
3. Castro, A.J.A., Kumar, R.S., Antony, J.K., Pagare, N.S., Kumar, P.R. and Raj, R.P. 2021. Delineation of coastal geomorphology along the coast of Kanyakumari district, southernmost coast of India. Turkish Online Journal of Qualitative Inquiry. 12: 6981-7002.
4. Chandrasekar, N. 1992. Beach Placer Mineral Exploration along the Central Tamil Nadu Coast, Ph.D Thesis (Unpublished), Madurai Kamaraj University, Madurai, 293.

5. Chandrasekharan, S. and Murugan, C. 2001. Heavy minerals in the beach and the coastal red sands (Teris) of Tamil Nadu.Special Issue on "Beach and Inland Heavy Mineral Sand Deposits of India" – 2001. Exploration & Research for Atomic Minerals, 13: 87-109.
6. DADF. 2014. Handbook on Fisheries Statistics, Department of Animal Husbandry, Dairying and Fisheires, Ministry of Agriculture, Government of India. Available online at http://www.dahd.nic.in/dahd/handbook-on-fisheries-statistics-2014.aspx
7. Force, E.R. 1991. Geology of titanium-mineral deposits: Geological Society of America Special Paper 259: 112.
8. Frihy, O.E. 1994. Discrimination of accreted and eroded coasts using heavy mineral compositions of the Nile Delta beach sands, Egypt: Sedimentology, 41: 905–912.
9. Gandhi, M.S., and Raja, M. 2014. Heavy mineral distribution and geochemical studies of coastal sediments between Besant Nagar and Marakkanam, Tamil Nadu, India. Journal of Radiation Research and Applied Sciences. 7: 256-268. https://doi.org/10.1016/j.jrras. 2014.06.002
10. Gandhi, M.S, and Solai ,A. 2010.Textural and heavy mineral characteristics surface and buried sediments along the coast between Cuddalore and Pondicherry, Tamil Nadu, India; Int. J. Earth Sci. Eng. 3(6): 886–892.
11. Garzanti, E. and Ando, S. 2007. Heavy mineral concentration in modern sands: Implications of provenance interpretation; In: Heavy minerals in Use (eds) Manage M and Wright D K, Dev. Sedimentology. 58: 517-545.
12. Gosen, B.S.V., Fey, D.L., Shah, A.K, Verplank, P.L. and Hoefen, T.M. 2010. Deposit Model for Heavy-Mineral Sands in Coastal Environments: Mineral Deposit Models for Resource Assessment, Scientific Investigations Report 2010-5070-L,USGC.1-51.
13. Hanamagond, P.T., and Nayak, G.N. 2011. Geochemistry of heavy minerals of beach sediments at Arge, West coast of India. International Journal of Earth Science and Engineering. 52-60.
14. Jayaraju, N. 2004. Controls on formation and distribution of heavy minerals along southern tip of India. Journal of Indian Geophysical Union, 8(3): 191-194.
15. Kalyani, K.N., Asir, N.G.G. and Edward, J.K.P. 2019. Accumulation and replenishment of Heavy minerals in the beach sediments of Tuticorin District, Southern Tamil Nadu. Journal of Aquatic Biology & Fisheries. 7: 64-72.

16. Kannan, V., Rajan, M.P., Iyengar, M.A.R. and Ramesh, R. 2002. Distribution of natural and anthropogenic radionuclides in soil and beach sand samples of Kalpakkam (India) using hyper pure germanium (HPCe) gamma ray spectrometry. Applied Radiation and Isotopes, 57: 109-119. doi:10.1016/S0969-8043(01)00262-7.
17. Krynine, P.D. 1948. The megascopic study and field classification of sedimentary rocks, Journal of Geology, 56: 130-165.
18. Mahadevan, G. and Ramadas, S.A. 1954. Effect of high waves on the formation of coastal black deposits, Memoir in oceanography, Andhra University, 1: 57-62.
19. Mahadevan, C. and Rao, N. B., 1950. Black sand concentrates in Vizagpatnam coast. Current Science 19: 48-49.
20. Nallusamy, R., Rajamanickam, M. and Thenmolli, K.L. 2015. Coastal sediment transport study between Vembar-Kanyakumari. International Journal of Engineering and Management Research. 5: 409-414.
21. Pasocoe, E.H. 1950. A manual of the Geology of India and Burma; Government of India Press, Calcutta, 1: 483.
22. Pettijohn, F.J., Potter, P.E. and Siever, R. 1973. Sand and Sandstone. Springer-Verlag, New York. 600p.
23. Ramasamy, V., Dheenathayalu, M., Ravisankar, R. and Ponnusamy, V. 2004. Natural radioactivity measurements in beach-rock samples of southeast coast of Tamil Nadu, India. Radiation Protection Dosimetry, 111: 229-235. doi:10.1093/RPD/NCH328.
24. Young, E.J., 1966. Analysis of Beach sediments, Journal of Sedimentary Petrology, 36: 57.