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ACCUMULATION AND REPLENISHMENT OF HEAVY MINERALS IN THE BEACH SEDIMENTS OF TUTICORIN DISTRICT, SOUTHERN TAMIL NADU

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Abstract: India, endowed with a coastline of over 6,000 km, has some of the largest and richest deposits of heavy minerals. The study of heavy mineral placer deposits and of their replenishment in the coastal sediments of Tuticorin district from Vembar to Kandasamypuram reveals the presence of heavy minerals and their replenishment. Standard protocol was used in collecting and separating the heavy minerals, as well as in calculating the weight percentage and estimating the replenishment rate of heavy minerals. Ilmenite, garnet, rutile, sillimanite, zircon, and monazite are the predominant heavy minerals found in the beach sediments of these regions. The depth upto which they are found varies from 2 to 2.5 m along the coast. The beaches of Vembar and Vaippar consist of 5 tonnes of geological reserve per square meter, and in Periyasamipuram and Kandasamypuram the beaches have 4 tonnes. The average weight percentage of heavy minerals ranges from 53 to 58%, with the highest concentration of ilmenite in Vembar (36.03%) followed by Vaippar (35.83%), Periyasamipuram (33.38%) and Kandasamypuram (30.33%), whereas Kandasamypuram (18.16%) is enriched with more garnet than the other locations. The major source for the heavy minerals are charnockite, calc-granulites, gneisses and granites of Eastern and Western Ghats, and the Quaternary sediments and their accumulation is mainly controlled by the geological processes (i.e. weathering, climate, transportation and sorting, etc.). The width of the tidal zones of this region varies from 16 to 22m, those of the beach and berm zones vary from 10 to 38 m and 33 to 103m respectively. However, the Vaippar region exhibits narrower tidal, beach and berm zones than the other locations. Moreover, the beach zones of Periyasamipuram, Vembar and Vaippar are more enriched with ilmenite than the tidal and berm zones. The rate of replenishment of beach sediments is 100% in the tidal zone with the time period of 1½ to 3 hours, depending on the season, whereas the rates of replenishment of beach sediment in the beach and berm zones vary from 0.43 to 0.83% and 0.30 to 0.71% respectively for the time period of 24 hours. The rate of replenishment depends on the dynamic forces like monsoonal rainfall; the velocity of river flow; the quantity of weathered materials brought to the ocean floor; ocean current; and the velocity and direction of the wind. Hence, the available resources of heavy minerals in the beach sediments of Tuticorin district can be mined in a sustainable manner for the development of the country.

Key words: Heavy minerals, beach sediments, geological reserve, replenishment rate, Tuticorin district

INTRODUCTION

India is gifted with a coastline of over 6,000 km with the largest and richest shoreline placers. Rivers and streams carry sediments to coastal areas, where the detritus are deposited, and reworked by waves, tides, and winds, and thus concentrated in a variety of coastal deposits. Deposition can occur in deltas, beach face, sand dunes, behind the shore, offshore, in barrier islands, tidal lagoons as well as in the channels and floodplains of streams and rivers within coastal plains (Force, 1991; Frihy, 1994). The sediments so brought to the coast bring with them varying amounts of heavy minerals, which ultimately get deposited as beach placers (Oversteet, 1967; Rajamanickam, 2000; Gosen *et al*, 2010) and undergo a series of transformations depending on the nature of the shore.

The actions of waves, long-shore currents, wind and tides naturally sort and concentrate the heavy minerals into layers (Gosen *et al*, 2010).

These deposits are the principal global sources of several important industrial heavy minerals, in particular, the titanium-bearing ore minerals (ilmenite, leucoxene and rutile) and zircon. The other coexisting heavy minerals are often produced as co-products, such as monazite, sillimanite/kyanite, garnet and staurolite. Most of the coastal heavy minerals are mined and processed to extract heavy minerals; these deposits are referred to as industrial minerals in the business parlance and as heavy mineral sands in scientific literature (Gosen *et al*, 2010).

The Indian coastlines are marked by the accumulation of various types and grades of placer deposits (Rao *et al*, 2001). The exploration for and exploitation of beach placer minerals in India started in the 20th century after the accidental discovery of monazite in the beach sands of Travancore State by Schombery, a German scientist. Well-known beach placer deposits containing monazite, zircon, ilmenite, rutile, sillimanite and garnet occur in the Konkan coast (Siddique *et al*, 1979; Hegde *et al*, 2006) and Ullal in Karnataka in western India (Radhakrishna *et al*, 1993; Shalini *et al*, 2020); in the coasts of Kerala (Tipper, 1914; Viswanathan, 1957; Mallik, 1974; Mallik *et al*, 1987; Nayak *et al*, 2012) and Tamil Nadu (Kannan *et al*, 2002; Ramasamy *et al*, 2004; Gandhi and Suresh, 2016) in southern India; and along the coasts of Andhra Pradesh (Mahadevan and Rao, 1950; Ravi *et al*, 2001) and Orissa (Pascoe, 1950; Rao *et al*, 2001; Routray *et al*, 2017) in eastern India.

The coastal zone of Tamil Nadu is also endowed with beach placers. The coastal stretch from Nagore to Tirumullaivasal is rich in zircon, garnet and kyanite (Chandrasekar, 1992) Mineralogical assemblages in beaches vary from one region to another depending on a number of factors like the nature of the host rocks in the province, climate conditions subsisting in the area, agents and mechanism of transport in action and the hydraulic conditions prevailing during deposition (Rao and Lafond, 1958). Mineralogical assemblages enriched with radioactive minerals are of special interest because of their use in the nuclear industry (Alencar and Freitas, 2005; El Nahas *et al*, 2011).

Heavy minerals have economic value (Mohan *et al*, 2000) and contribute to the development of industrial economy of the country (Indian Mineral Year Book, 1999). Heavy minerals mined from beach deposit will be replenished by the transport of new sediment. The rate of replenishment is important for the continuous mining of these resources (Macdonald and Rozendaal, 1995). The present work quantifies the heavy mineral resources of Tuticorin District, in terms of their concentration, the tonnage of the current geological reserve and the rate of reserve replenishment for future management and exploration.

MATERIALS AND METHODS

The study area Vembar, Periyasamipuram, Vaippar and Kandasamypuram located in Tuticorin district (Fig. 1.) comprises a 100 km long coastal track with various geomorphic landforms like beaches, strandlines, sand dunes, mud flats, salt marshes, estuaries, and beach rocks. In total, 36 samples were collected (every month from the four locations) from the tidal, beach and berm zones from January 2018 to December 2018. Samples were collected with the help of hand auger upto a depth of 2 to 2.5m down to water table. Samples below the water table were collected by manually-driven Conrad bunka drill. The results of the four quarters namely January to March (Post Monsoon), April to June (Summer), July to September (Pre Monsoon) and October to December (Monsoon) were averaged in the present study. Three traverses with an interval of 100 m between were run across the beach at each location. Three samples were collected from each traverse. Collected sediment samples were dried and 1kg of sediment sample was taken for further processing which employed the coning and quartering method. Lighter and heavy fractions were separated using bromoform (Specific gravity – 2.89). Lighter fractions include silica, shells and other impurities. Low-power hand-magnet was used to separate magnetite. The other heavy minerals were separated into magnetic and non-magnetic fractions with the help of an electro-magnet set at 0.2 amperes. The weight of all the fractions was noted. The separated heavy mineral fractions were

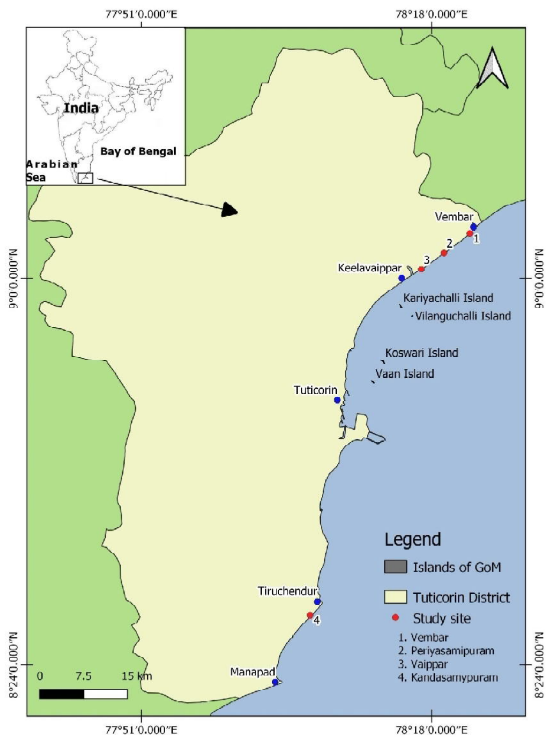

Fig. 1. showing the map of the study area (GoM – Gulf of Mannar)

mounted on a glass slide using Canada balsam and 300 grains were counted using a polarising microscope and weight percentages of each mineral were obtained by following standard method (Young, 1966). The chemical compositions of the heavy minerals were analysed using XRD method (PANalytical-Cubix^{3}Minerals).

The geological reserve was estimated by single block method

Geological Reserve (tonnes) = Area (sq m) x depth (m) x bulk density of heavy mineral (tonnes/cubic meter)

In order to evaluate the rate of replenishment of heavy minerals at the tidal, beach and berm zones of the locations, pits of 1 m x 1 m x 0.3 m were made at each zone, in which specially made steel boxes of 1 m x 1 m x 0.3 m were fitted. The distance between each box was measured. Box (A) was kept at the tidal zone, followed by box (B) in the beach and box (C) at the berm area. The initial weight of sand removed from the pit for keeping the steel box was measured. At the end of 24 hours, the amounts of sand collected in the steel boxes were measured, and the heavy minerals were separated from the sand and weighted. The rates of replenishment were then estimated.

RESULTS AND DISCUSSION

The colouration of beach sediments in the study locations was observed. Krynine (1948) pointed out four factors that determine the colour of the sediments: 1. The total mass of the colour of the component mineral grains of their own aggregates; 2. The colour of the fine-grained matrix or the content; 3. The colour of the thick enamel coating on the grains, if any; and 4. The degree of fineness of the sedimentary grains. In the present study, the colour factor is controlled by the total mass of the colour of the component minerals grains of their own aggregates and also by the fineness of the sedimentary grains. A similar observation has been made by Jayaraju (2004) in the heavy minerals of the southern tip of India. The present work observed patches of red and black beach sediments in the study locations. Red patches are due to the occurrence of garnet, which might have derived from the disintegration of host rocks such as charnockite, calc-granulites, gneisses, and granite of the Eastern and Western Ghats and the Quaternary sediments (Anguswamy and Rajamankckam, 2000; Chandrasekar and Murugan, 2001), which contain resistant garnet minerals deposited by the turbulent winnowing action of waves (Jayaraju, 1993 & 2004). The black patches are due to ilmenite and rutile of similar origin (Chandrasekar, 1992; Anguswamy and Rajamanickam, 2000).

Table 1 presents the data relating to the accumulation and distribution of heavy minerals during different seasons in the study locations. Accumulation of heavy minerals is to a depth of 2.5 m from the surface in the study locations. In Vembar and Vaippar locations heavy minerals are seen upto a depth of 2.5 m, whereas in Periyasamipuram and Kandasamypuram, they are seen upto a depth of 2 m. The average concentration of heavy minerals ranges from 53 to 58% (weight percentage), with the highest value in Vembar and the lowest in Kandasamypuram. Of these, Vembar (36.03%), Vaippar (35.83%) and Periyasamipuram (33.38%) show higher

Table 1. The depth of heavy mineral deposits and the seasonal concentration (wt %) in different locations at tidal, beach and berm zone

Location and depth	Minerals	Tidal				Beach				Berm				Average (%)
		Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul – Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul – Sep	Oct - Dec	
Vembar (2.5 m)	Garnet	16.63	17.46	19.9	19.35	17.38	17.45	18.64	17.31	17.84	18.44	18.62	18.07	18.09
	Ilmenite	34.96	33.56	38.52	38.43	36.02	35.87	38.06	38.39	34.29	34.59	35.05	34.6	36.03
	Rutile	0.4	0.68	0.51	1.02	0.48	0.57	0.64	0.67	0.87	0.53	0.5	0.32	0.6
	OHM	3.24	3.41	4.23	3.22	3.47	3.43	4.24	4.15	3.42	3.95	3.12	3.83	3.64
	Q & OM	44.77	44.89	36.84	37.98	42.65	42.68	38.42	39.48	43.58	42.49	42.71	43.18	41.64
Periyasamipuram (2 m)	Garnet	16.73	15.13	16.31	17.71	16.72	17.48	18.02	16.81	17.02	18.44	18.87	18.71	15.94
	Ilmenite	33.86	34.82	37.57	38.06	36.35	37.63	38.26	37.82	34.78	35.36	35.13	34.74	33.38
	Rutile	0.92	0.49	0.81	1	0.92	0.92	0.49	0.8	0.59	0.89	0.93	0.73	0.71
	OHM	3.72	3.51	4.47	4.15	3.86	3.16	3.06	3.46	3.03	3.93	3.37	3.35	3.28
	Q & OM	44.77	46.05	40.84	39.08	42.15	40.81	40.17	41.11	44.58	41.38	41.7	42.47	38.36
Vaippar (2.5 m)	Garnet	15.37	15.63	16.57	16.17	16.01	17.88	17.79	16.39	16.17	17.9	17.31	16.34	16.63
	Ilmenite	34.74	34.37	36.1	38.97	34.83	36.34	35.42	37.88	34.02	35.48	36.7	35.07	35.83
	Rutile	0.65	0.76	0.67	0.7	0.55	0.41	0.5	0.64	0.43	0.49	0.36	0.64	0.57
	OHM	3.44	4.48	3.96	3.81	3.68	3.23	3.65	4.24	3.54	3.3	3.33	3.61	3.69
	Q & OM	45.8	44.76	42.7	40.35	44.93	42.14	42.64	40.85	45.84	42.83	42.3	44.34	43.29
Kandasamypuram (2 m)	Garnet	16.37	17.03	18.98	18.88	16.92	17.61	18.24	18.58	18.44	18.09	19.84	18.91	18.16
	Ilmenite	28.17	29.6	32.63	32.81	28.58	28.65	31.51	30.22	29.38	30.25	31.35	30.85	30.33
	Rutile	0.67	0.6	0.59	0.38	0.49	1.01	0.62	0.5	0.57	0.82	0.96	1.01	0.69
	OHM	3.35	4.41	4.31	3.74	3.46	4.18	4.25	3.33	3.14	3.8	3.68	3.61	3.77
	Q & OM	51.44	48.36	43.49	44.19	48.55	48.55	45.38	47.37	48.47	47.04	44.17	45.62	46.89

OHM - other heavy minerals, Q & OM – Quartz and other minerals

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

Minerals	Chemical constituents
Garnet	Al_2O_3:24-36%; SiO_2:31-36%; FeO:29-30%; MgO:7-8%
Zircon	ZrO_2:64-66%; SiO_2:31-33%
Rutile	TiO_2:60-71%; SiO_2, ZrO_2, Fe_2O_3 1% each
Monazite	Phosphates of rare earth and Thorium
Ilmenite	TiO_2:51-55%; FeO:20.5-21%; Fe_2O_3:18.5-20%; V_2O_5:0.25%

Table 3. The available heavy mineral reserve in the study sites

Location	Area (sq.m)	Depth - (m)	Average bulk density of heavy minerals (tonnes/cu.m)	Availability of heavy minerals sand (tonnes)
Vembar	1	2.5	2	5
Periyasamipuram	1	2	2	4
Vaippar	1	2.5	2	5
Kandasamypuram	1	2	2	4

concentration of ilmenite than Kandasamypuram (30.33%). Kandasamypuram (18.16%) shows higher concentration of garnet than Vembar (18.09%), Vaippar (16.63%) and Periyasamipuram (15.94%) (Fig 2). It was also observed that the beach zones of Periyasamipuram (37.58%), Vembar (37.10%) and Vaippar (36.39%) contain a higher concentration of ilmenite deposits than the tidal and berm zones, which could be due to their higher specific gravity than the other heavy minerals.

Table 2 presents the chemical compositions of some of the heavy minerals found in the beach sediments of the study location. The almandine-rich varieties of garnets present in these locations are light pink to pink in colour, and anhedral in shape with a conchoidal fracture. Zircons are colourless and euhedral in shape. Rutile is translucent to opaque in nature. Monazite is well-rounded to ellipsoidal in shape and greenish yellow in colour, whereas ilmenites are opaque in nature and rounded to sub-

Table 4. The width of tidal, beach and berm zone and distance of boxes for replenishable reserve study

Location	Months	Tidal (A)			Beach (B)				Berm (BE)				Total length of the stretch (A+B+BE) m
		Width of zone (m)	Distance of box from LTL (m)	Distance of box from HTL (m)	Width of zone (m)	Distance of box from HTL (m)	Distance of box from Berm (m)	Distance of box from Box - A	Width of zone (m)	Distance of box from beach boundary (m)	Distance of box form land bound (m)	Distance of box from the Box - B (m)	
Vembar	Jan - Mar	20	10	10	34	19	15	29	66	7	59	22	120
	Apr - Jun	22	10	12	38	14	24	26	64	10	54	34	124
	July - Sep	22	9	13	36	18	18	31	62	11	51	29	120
	Oct - Dec	20	14	6	33	16	17	22	65	9	56	26	118
Periyasamipuram	Jan - Mar	17	9	8	22	12	10	20	33	25	8	35	72
	Apr - Jun	20	11	9	20	11	9	20	35	23	12	32	75
	July - Sep	19	10	9	20	10	10	19	34	20	14	30	73
	Oct - Dec	18	8	10	21	11	10	21	33	21	12	31	72
Vaippar	Jan - Mar	16	9	7	12	6	6	13	56	33	23	42	84
	Apr - Jun	20	10	10	10	6	4	16	53	30	23	32	83
	July - Sep	18	9	9	11	5	6	14	55	33	22	30	84
	Oct - Dec	17	10	7	12	7	5	14	56	31	25	31	85
Kandasamypuram	Jan - Mar	18	7	11	19	8	11	19	103	26	77	37	140
	Apr - Jun	21	9	12	22	11	11	23	100	30	70	41	143
	July - Sep	20	10	10	20	8	12	18	102	27	75	39	142
	Oct - Dec	19	9	10	20	11	9	21	101	29	72	38	140

Table 5. The rate of replenishment for a different period in the study locations

Location	Zone	ROM removed before fixing the box (kg)				Rom replenished in the box in kg				Duration taken for filling in hrs				Rate of replenishment (%)			
		Jan - Mar	Apr - Jun	July - Sep	Oct - Dec	Jan - Mar	Apr - Jun	July - Sep	Oct - Dec	Jan - Mar	Apr - Jun	July - Sep	Oct - Dec	Jan - Mar	Apr - Jun	July - Sep	Oct - Dec
Vembar	Tidal	837	842	823	809	811	816	806	799	3	2	1.3	1.3	100	100	100	100
	Beach	686	673	660	665	4.8	5.6	5.3	3	24	24	24	24	0.7	0.83	0.8	0.45
	Berm	640	650	636	632	3.2	4.6	4.3	2.1	24	24	24	24	0.5	0.64	0.68	0.33
Periyasa-mipuram	Tidal	839	828	842	830	796	801	809	812	3	2	1.3	1.3	100	100	100	100
	Beach	649	675	656	671	2.8	4.3	4.6	4.1	24	24	24	24	0.43	0.64	0.71	0.61
	Berm	634	628	631	626	2.5	4.1	4.5	1.9	24	24	24	24	0.4	0.65	0.71	0.3
Vaippar	Tidal	826	834	828	817	790	809	798	783	2.3	1.3	2	1.3	100	100	100	100
	Beach	645	654	670	657	3	5.3	5.1	4.4	24	24	24	24	0.47	0.81	0.76	0.67
	Berm	638	622	628	624	2.3	4.2	4	2.1	24	24	24	24	0.36	0.67	0.64	0.33
Kandasa-mypuram	Tidal	826	839	831	814	798	804	800	788	2.3	2	2	1.3	100	100	100	100
	Beach	652	644	671	656	2.5	5	4.8	3	24	24	24	24	0.46	0.78	0.72	0.46
	Berm	638	625	633	621	2.1	3.7	4	1.9	24	24	24	24	0.33	0.59	0.63	0.31

rounded in shape. The geological reserve of heavy minerals available in one square meter is 5 tonnes in Vembar and Vaippar, and 4 tonnes in Periyasamipuram and Kandasamypuram (Table 3). The coastal zones of Vembar, Vaippar, and Periyasamipuram possess larger reserves of ilmenite, while the garnet reserve is more in Kandasamypuram. In the study locations, the width of the tidal zone ranges from 16 to 22 m, the width of the beach zone ranges from 10 to 38 m and the width of the berm zone ranges from 33 to 103 m (Table 4). The Vaippar region exhibits the narrowest tidal, beach and berm zones.

The rate of replenishment in the tidal area reached 100 % within 2½ to 3 hours of time during January - March; in 1½ to 2 hours during April - June and July - September periods, and within or less than 1½ hours during October - December (Table 5). This

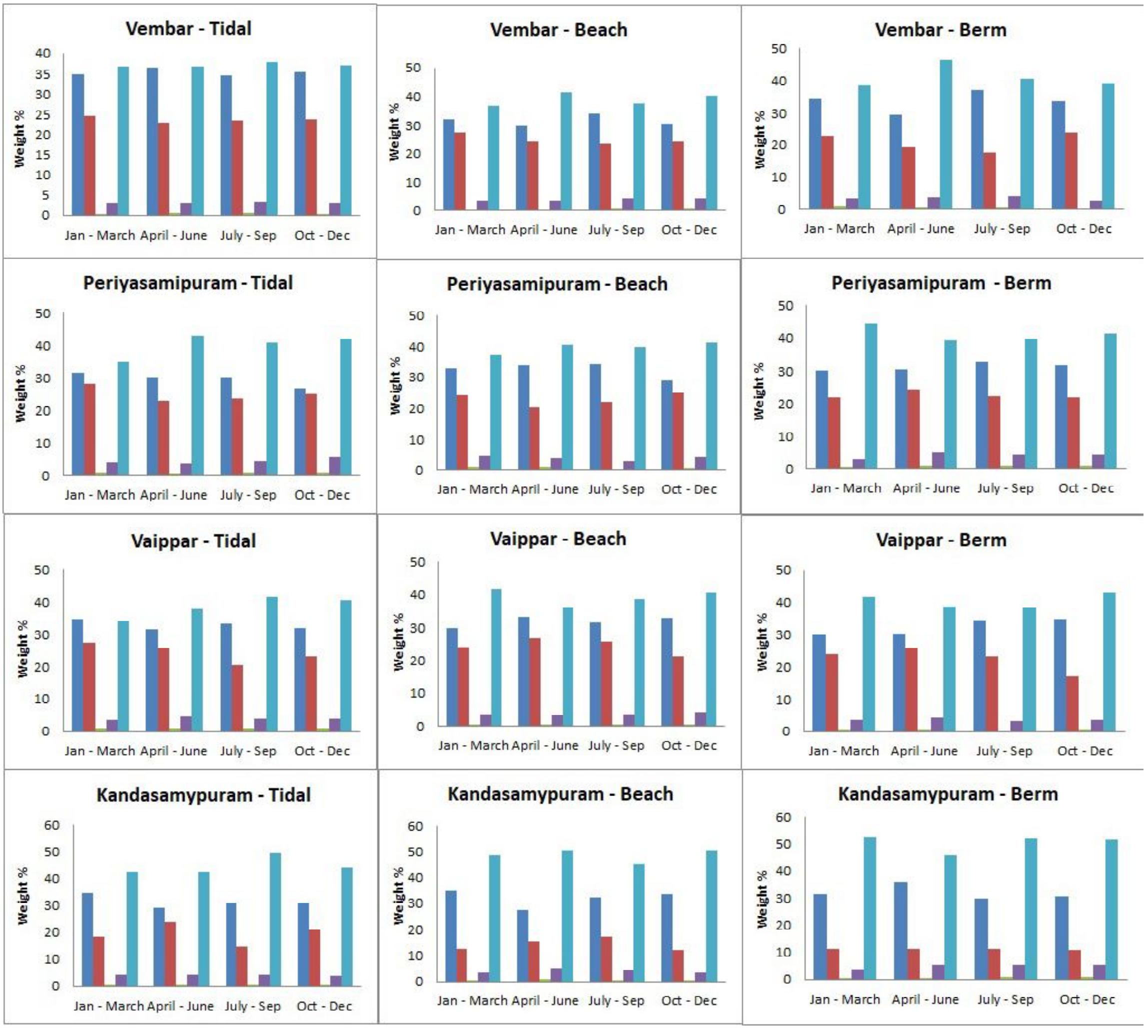

Fig. 2. The weight percentage of beach minerals of the study locations

clearly indicates that wave action in the tidal zone replenishes the beach sediments completely. Moreover, the composition of minerals in the replenished beach sand is similar to the composition of the 'original' beach sand, and this could be due to the reworking of sediment by the continuous wave action (Angusamy and Rajamanickam, 2000). The rate of replenishment in the beach zone varies from 0.43 to 0.83% over a period of 24 hours, which was higher during April to June and July to September than the other two quarters. The strong wind condition and rough nature of sea during southwest monsoon could be the reason for the higher replenishment rate. The rate of replenishment in the berm zone varies from 0.30 to 0.71% for 24 hours, which was higher during April to June and July to September, which could be due to the southwest monsoon wind. The rate of replenishment may not be uniform in the same coast because of the rapid changes from season to season in the dynamic forces such as monsoon rains, velocity of river flow, quantity of weathered materials brought to the ocean floor, ocean currents, and velocity and direction of wind, and sometimes these changes occur in the same

Fig. 3. Photographs showing a) beach placer deposit at Vaippar, b) measurement of zones c)steel box for replenishment study, d) pit for placing steel box, e) box placed in the tidal zone f) weighing of collected mineral sand

season engendered by various interrelated forces (Peterson *et al.*, 1986; Chandrasekharan and Murugan, 2001). Changes in one or two external factors may vary the rate of replenishment.

The coastal region of Tuticorin is enriched with deposits of heavy minerals such as ilmenite, garnet, rutile, sillimanite, zircon, and monazite. The Precambrian rocks such as charnockite, calc-granulites, gneisses, and granite of the Eastern and Western Ghats and the Quaternary sediments along the coastal region are the important sources of these heavy minerals**.** The depth of heavy mineral accumulation varies from 2 to 2.5 m in the study locations with a geological reserve of 4 to 5 tonnes/sq. m and the average heavy mineral concentration ranges from 53 to 58% (weight percentage). Vembar has a higher concentration of ilmenite, followed by Vaippar, Periyasamipuram and Kandasamypuram, whereas Kandasamypuram is enriched with more garnet than the other locations. Similarly, the beach zones have higher ilmenite deposits than the tidal and berm zone. The study on the rate of replenishment indicates the continuous supply of heavy minerals in the beach sediments. The present study comes to the definite conclusion that the heavy mineral resources available along the beach sediments of Tuticorin district can be mined in a sustainable manner for the development of the country. The combined effect of strong aeolian action and the winnowing effect of wave currents will continue to replenish the heavy minerals in the study area for a long time. There is no sign of an immediate decrease in the replenishment activity of the natural forces and hence there is no probability of any alarming problem arising for the mineral extraction in this region.

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