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PROSPECTING SAND RESOURCES AT THE CONTINENTAL SHELF IN OFFSHORE GALLE, SRI LANKA

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ABSTRACT

Depletion of inland sand reserves for the construction industry and occurrence of beach sand deposits rich with heavy minerals such as ilmenite, rutile, garnet, zircon and monazite around the coastal belt of Sri Lanka, lead to investigate the offshore potential for such minerals. The study carried out in the continental shelf offshore of the Galle region of Sri Lanka by sampling in a 500 m X 500 m grid using Nansen type grab sampler to identify the availability of construction sand and heavy mineral rich sand. Grain size, sorting, shell content, chloride content and heavy mineral content of sea bottom samples show the existence of sand deposits suitable for mining, without negative impacts to nearby beaches. Two distinct sand bands in the north and south of the Gin river mouth were identified at 1.5 to 2.5 km away from the coastline with the width of 1.0 to 1.5 km at the water depths between 18 m and 30 m. The mean grain size varies between 0.5 mm to 2.0 mm and the deposits can be classified as moderately well sorted, which are ideal for fine aggregates used for construction purposes. However, the chloride content (Avg = 0.64 %) is higher than the standard value of 0.075 %.Therefore chloride content needs to be removed either by mechanical washing or natural rain water draining. The shell content (0.89 %) is within the specified limits. In addition, the mineralogical analysis reveals that low concentration of heavy minerals with an average of 2.0 wt % within the study area. However, area around 'H1' near coastal zone show 16.86 wt % of heavy mineral content.

Keywords: Sri Lanka, Offshore, Continental shelf, Galle, Construction sand, Heavy minerals

INTRODUCTION

Sri Lanka owns its exclusive economic zone (EEZ) that runs up to 200 nautical miles which is more than eight times the land area of the country. Further, Sri Lanka is planning to expand its exclusive economic zone, and therefore it is natural to look forward to the ocean for country's mineral requirements to support the national development. However, exploration and mining in deep waters beyond the continental shelf requires advanced technology and high investments. But, exploration and mining within the continental shelf requires less effort due to shallow water depths. Therefore, small to medium scale investments with easily available technology can be utilized to recover the resources. Two most abundant resources in this sedimentary environments are construction sand and heavy minerals.

A rapid development in the construction industry of Sri Lanka since 2009 has increased the demand for construction sand, resulting illicit sand mining along major river banks (Ratnayake et al., 2012; Ilankoon et al., 2008; Ekanayake, et al., 2007). Although regulations stipulate, mining can only be done with necessary approval from the Geological Survey and Mines Bureau (GSMB), many sand miners carry on destructive mining, disregarding government regulations. Therefore, it is highly necessary to look into alternatives for construction sand such as crushed rocks and sea sand, which are presently used in small scale (Ratnayake et al., 2012; Ilankoon et. al., 2008; Ekanayake, et al., 2007).

Many countries use dredged sand from the ocean bed to reclaim land or elevate land levels to build new roads and railways (e.g. Sri Lanka Land Reclamation and Development Corporation). Singapore and Hong Kong have extended their land area by pumping sand from the sea bed (Glaser et al., 1991). Also, land areas around sea ports are expanded to set up warehouses and container yards. In addition, Britain and Japan use most of their sand requirements through sea sand resources (Sutton and Boyd, 2009).

Construction sand should be strong and clean with low content of organic matter, clay, shells and chloride. Chloride content is a significant disadvantage in sea sand if the absolute chloride content of construction sand goes beyond the permissible level of 0.075% (Dias et al., 2008).

In addition to sand as an economic mineral for the construction industry, heavy minerals with much higher specific gravity (>2.8) such as ilmenite, rutile, zircon, monazite, garnet and many others were found in the ocean bed. Modern and ancient beaches are one of the most important sources of heavy minerals and the beaches of Sri Lanka are rich in sands containing such minerals (Fernando, 1986).The occurrence of heavy mineral placer deposits on the southwestern coast of Sri Lanka has been identified for a long time and exploited economically since 1918. A number of studies (e. g. Coates, 1935; Wadia, 1945; Fernando, 1950, 1954; and several unpublished Geological Survey reports) have been made on heavy mineral deposits off southwestern Sri Lanka (Wickremeratne, 1986). Heavy minerals have a strategic place in the world mineral market.

This study is focused on, exploration for construction sand and to understand the heavy mineral distribution and their possible potential as a resource in the offshore region of Galle area.

METHODS AND MATERIALS

SAMPLING

The offshore field visits were carried out in March and April, 2012 during the inter monsoon period. Research vessel Baticlova I which belongs to the Ocean University of Sri Lanka has been used. Predetermined sampling locations (Figure1) were identified with the aid of the inbuilt GPS navigation system (FURUNO GP-1850 W C-Map NT). The Nansen type grab sampler was used to collect forty sediment samples from the surface of the seabed, from a 500 m×500 m grid. Approximately, 2 kg weight of each sample was collected from each point. The geographical coordinates of sampled locations are given in Appendix Table 1. The water depth of the each sampling point was recorded using an echo sounder.

LABORATORY METHODS

The collected samples were brought to the laboratory and kept in the deep freezer at -4^{0}C. Later, oven dried at 120^{0}C for 24 hours to remove moisture. Through, visual observation, samples were categorized as algal beds, clay, sand, shell, corals and rocks. 500 g of sand and clay rich samples were sieved according to the BS EN 933-1:2012, 2012 guideline using 2.00 mm, 1.40 mm, 1.18 mm, 850 μm, 500 μm,

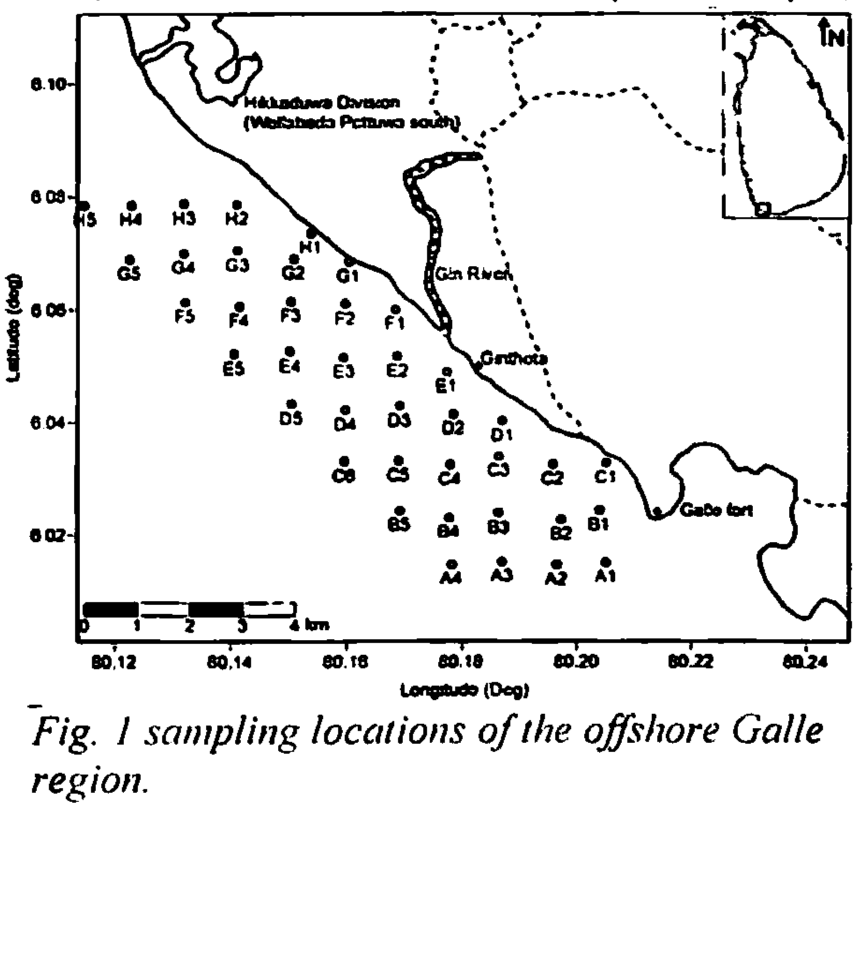

Fig. 1 sampling locations of the offshore Galle region.

355μm, 250 μm, 212 μm, 180 μm, 125 μm, 106 μm, 75 μm and 45 μm sieves for 10 minutes at constant vibration. Statistic package GRADISTAT version 4.0 (Blott and Pye, 2001) is used for data analysis. The grain size distribution, mean size, sorting [$(\sigma_g = \exp \sqrt{\sum f(\ln m_m - \ln \bar{x}_g)^2 / 100})$] and cumulative particle size distribution maps were generated.

The chloride content (BS 812: Part 117:1988) and the shell content (BS 812: Part 106: 1985) were also tested according to the British Standards. Studies on heavy mineral content were done using 200 g of each sample. These extracts were concentrated by panning using 36 inch diameter plastic pan. The concentrated portions of samples were examined through a petrographic microscope (Figure 2) and the individual grains of heavy minerals and gangue grains were counted.

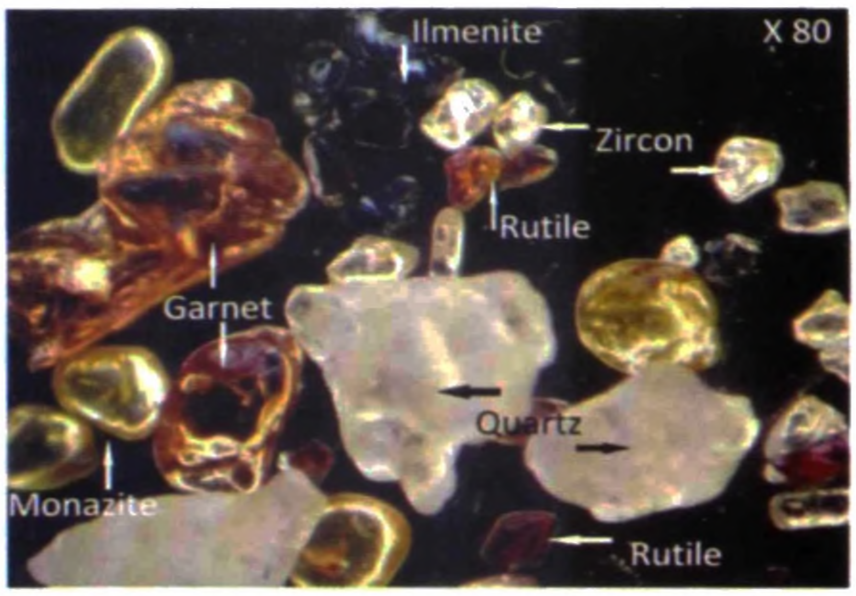

Fig. 2 A representative image of the identified heavy mineral through a gemological microscope.

Reproducibility of panning and microscopic grain counting methods used in this study was tested on the few samples by dense media separation (using bromoform) and magnetic separation, respectively. The result shows ± 2 % accuracy of this method compared to the dense separation and magnetic separation methods.

A bathymetry map (Figure 3) was generated using the depths obtained from the echo sounder at the grid points to understand the relationship

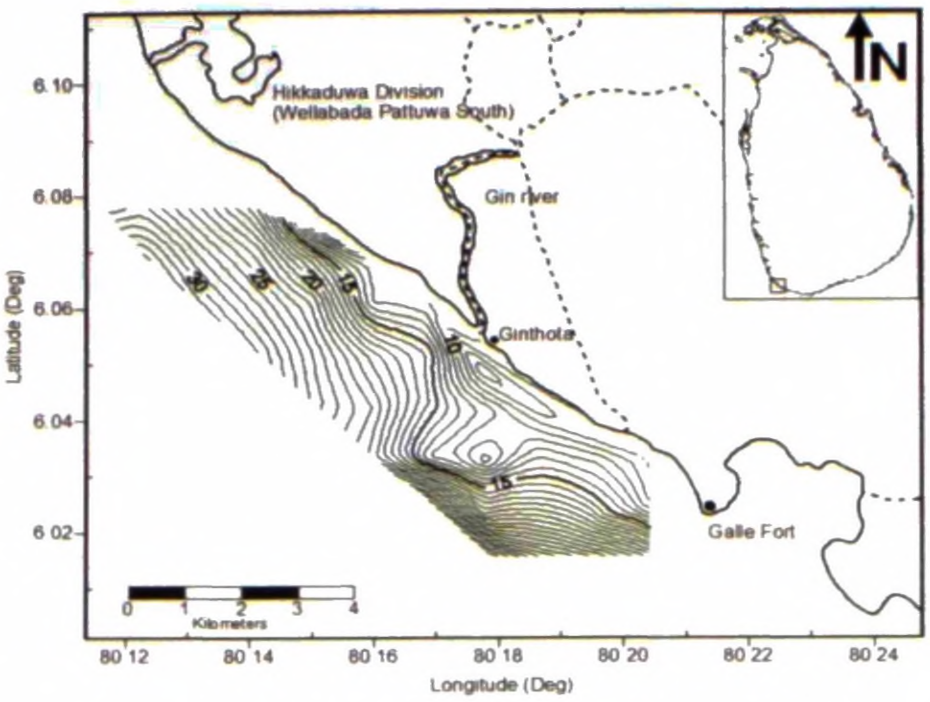

Fig. 3 Bathymetry of the offshore Galle region (in meter).

of the geology and the water depth. Surfer 8 software was used (natural neighbour gridding method) to plot the isobaths. Bathymetric data was re-corrected using the existing National hydrographic charts.

RESULTS AND DISCUSSION

Bathymetry of the mining area is an important factor in sea sand mining. It would help to identify the mineable area, schedule the mine plan, select an efficient mining method, select appropriate dredging equipment and plan transporting pipeline layout, etc. Thus, it is vital for evaluating the feasibility of the prospecting project in terms of technical, economic and environmental aspects.

Bathymetry of the study area of offshore Galle varies from 0 m to 9 m within 500 m from the coastline. However, within 2.5 km from the coastline 0 - 35 m depths were recorded (Figure 3). Contours are generally parallel to the coastal line in both northern and southern sections of Gin River. However, the depth of the continental shelf around Gin river mouth is much shallower, showing the influence of the Gin river sediment on the bathymetry. The average slope of the studied area of the continental shelf is 1°.

Geological mapping would give material distribution of the study area. It will illustrate the shape of the deposit, association of surrounding materials, extension of the area,

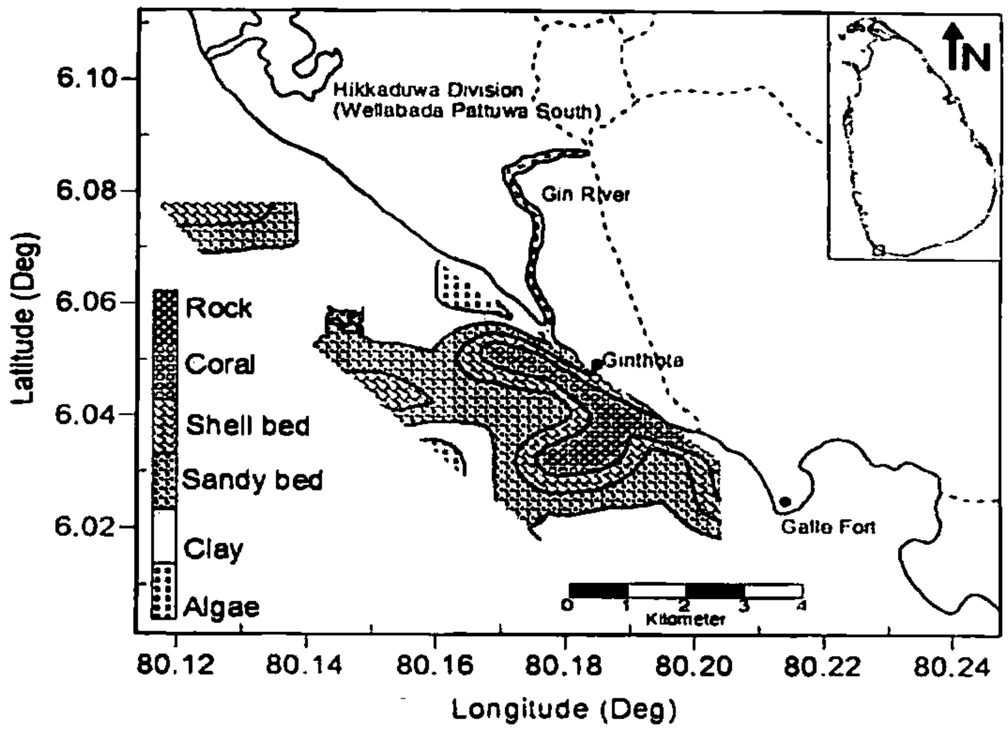

Fig.4 Surface geology of the offshore Galle region.

distance from the beach and etc. It will help to decide how to mine, which part to be dredged first, and understand the economic, environmental and technical difficulties on mining. Geology of the studied area illustrates two distinct bands of sand deposits in the north and south of Gin river mouth (Figure 4). Both were 1.5 to 2.5 km away from the coastline with the width of 1.0 to 1.5 km. The bathymetry confirms these deposits are located at depths varying from 18 m to 30 m. The Southern deposit could be a paleo channel of the Gin River. During the last glacial period global environment was different from the present environment and the global sea level was 125 m below than the present sea level (Fairbanks, 1989) creating similar paleochanels. Results show significant presence of potential construction sand in the studied offshore region. However, it is important to find out whether the properties of above sand are suitable for Sri Lankan construction purposes. The mean grain size of the present sea sand samples and sorting are important specifications for construction sand (Table1). Both will assure the suitability for different applications, strength and durability. The mean grain sizes vary from 0.5 mm to 2.0 mm, which is the best range for quality sand (Fig. 5). A median size (D_{50}) of sand around 0.6 mm is most suitable for concrete production (Dias et al., 2008). The median size of sand in this study also shows similar values. Sorting level of sand demonstrates the strength and appropriateness for different usage. Since this sand deposit is classified as moderately well sorted it could be recommended for utilizing in the construction industry (Figure 6).

Moreover, the chloride content of the sea sand is a very critical aspect for the steel reinforcement in concrete because it could cause corrosion of reinforcements and enhance soluble salt efflorescence in concrete (Kayali and Zhu, 2005). Several researchers have expressed concern about this and safe limit of the allowable chloride ion content. For Ordinary Portland Cement based reinforce concrete it was arrived as 0.075 % of chloride content by weight of sand (Dias et al., 2008). However, the results obtained (0.64 %) from this work have a higher

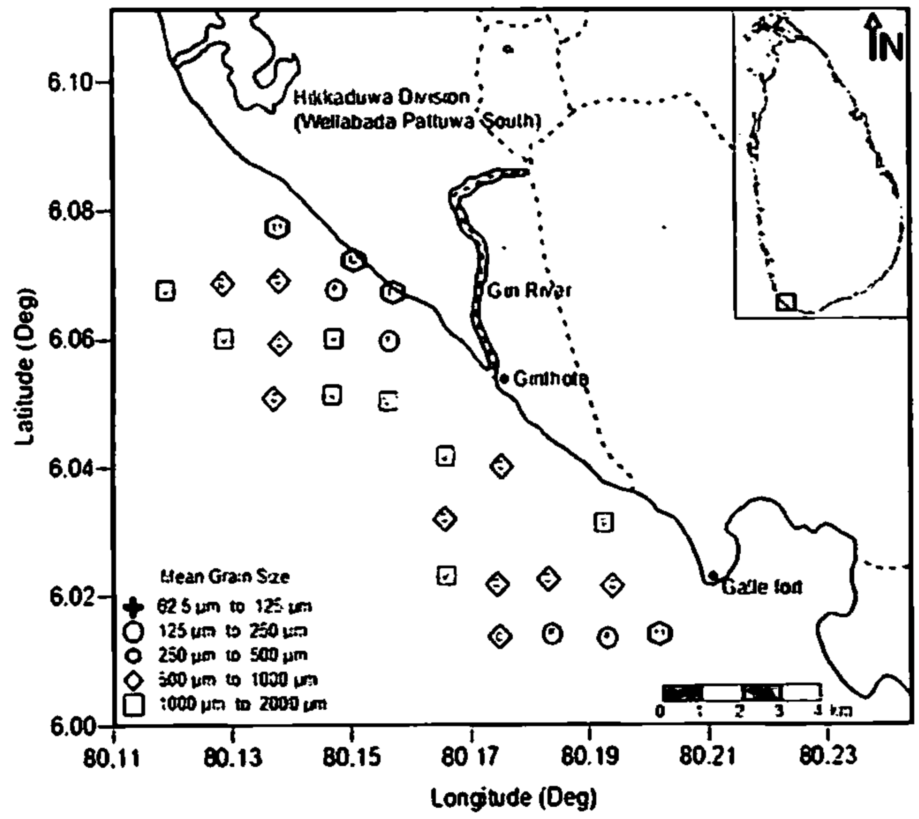

Fig. 5 Mean grain size distribution of the offshore Galle region (in mm).

percentage of chloride than the stipulated values. But, when the sand loses its sea water through draining out from a heap, then the chloride content would be reduced to almost acceptable limit. Further flushing via rain or artificial washing would easily reduce the chloride level to acceptable values. The moisture content of the sand during draining out would depend on the median size of the sand. Sands with fine

Table 2 Textural information and heavy mineral percentages for the bottom sediments of each locations at the offshore Galle region

Location	Mean Grain Size (µm)[1]	Soil Type[2]	Sorting[3] Description	SD[4]	Tot HM%[5]	Heavy mineral volumetric % Il	Rt	Zr	Gt	Mo	Other
A1	274.3	Clay	Moderately Well Sorted	1.6659	1.28	26.19	0.20	32.14	0.60	0.00	9.33
A2	172.7	Clay	Well Sorted	1.4801	0.26	78.13	0.64	11.46	1.91	0.00	0.64
A3	233.7	Clay	Moderately Well Sorted	1.4807	2.09	45.16	1.72	35.05	0.00	0.00	1.08
A4	909.9	Sand	Moderately Sorted	1.7247	0.86	63.84	1.88	17.70	0.19	2.26	1.13
B2	591.9	Sand	Moderately Well Sorted	1.6230	1.35	70.53	1.71	17.87	0.00	0.76	1.14
B3	900.2	Sand	Moderately Sorted	1.7070	6.62	72.82	2.76	12.31	3.82	0.85	0.00
B4	726.0	Sand	Moderately Well Sorted	1.5757	0.60	66.78	2.42	14.53	1.56	1.38	0.00
B5	1195.0	Sand	Moderately Sorted	1.7393	0.19	46.97	1.70	24.62	0.00	1.89	8.33
C2	1168.0	Sand	Moderately Well Sorted	1.5038	0.25	61.17	0.37	23.81	0.55	0.92	0.00
C5	578.2	Sand	Moderately Well Sorted	1.5066	1.57	72.88	4.32	15.03	0.69	0.86	0.00
D2	559.6	Sand	Moderately Well Sorted	1.4519	1.15	72.58	3.46	14.75	0.00	1.61	0.00
D3	1308.0	Sand	Moderately Well Sorted	1.5152	0.21	58.78	1.17	17.80	0.00	1.17	3.98
E3	1245.0	Sand	Poorly Sorted	1.9599	0.03	-	-	-	-	-	-
E4	1283.0	Sand	Poorly Sorted	2.4992	-	-	-	-	-	-	-
E5	927.8	Sand	Moderately Sorted	1.9546	7.38	46.79	1.24	31.47	1.45	0.21	2.07
F2	201.8	Clay	Moderately Well Sorted	1.5909	1.18	64.36	0.25	17.82	3.22	0.99	2.72
F3	1042.0	Sand	Poorly Sorted	2.1935	2.81	57.98	1.57	27.64	1.12	0.67	0.67
F4	891.2	Sand	Moderately Sorted	1.7277	1.07	61.00	4.15	23.86	0.00	0.41	1.04
F5	1424.0	Clay	Moderately Sorted	2.1091	0.07	60.39	0.86	14.99	16.06	0.21	0.43
G1	256.5	Clay	Well Sorted	1.5271	1.36	63.18	4.26	22.29	0.00	0.00	0.97
G2	177.2	Clay	Well Sorted	1.4994	0.39	54.85	0.00	23.02	2.26	0.00	3.39
G3	691.4	Sand	Well Sorted	1.3950	3.39	65.84	2.04	19.91	0.23	0.00	2.04
G4	837.3	Sand	Moderately Sorted	1.7948	-	-	-	-	-	-	-
G5	1118.0	Sand	Poorly Sorted	2.2670	0.29	47.39	1.88	20.88	0.84	0.42	10.23
H1	492.6	Sand	Well Sorted	1.4212	16.86	63.55	3.97	19.16	1.64	0.00	2.34
H2	306.4	Clay	Very Well Sorted	1.3509	2.35	66.30	0.36	21.01	0.00	0.00	1.45

[1]Mean — Method of Moments - Arithmetic (µm)
[2]Soil Type — Soil Classification - Visual examination
[3]Sorting — Method of Moment - Geometric (µm)
[4]SD — Standard deviation of the mean grain size (µm)
[5]Tot HM% — Total heavy mineral weight percentage

Il – Ilmenite
Rt – Rutile
Zr – Zircon
Gt – Garnet
Mo – Monazite

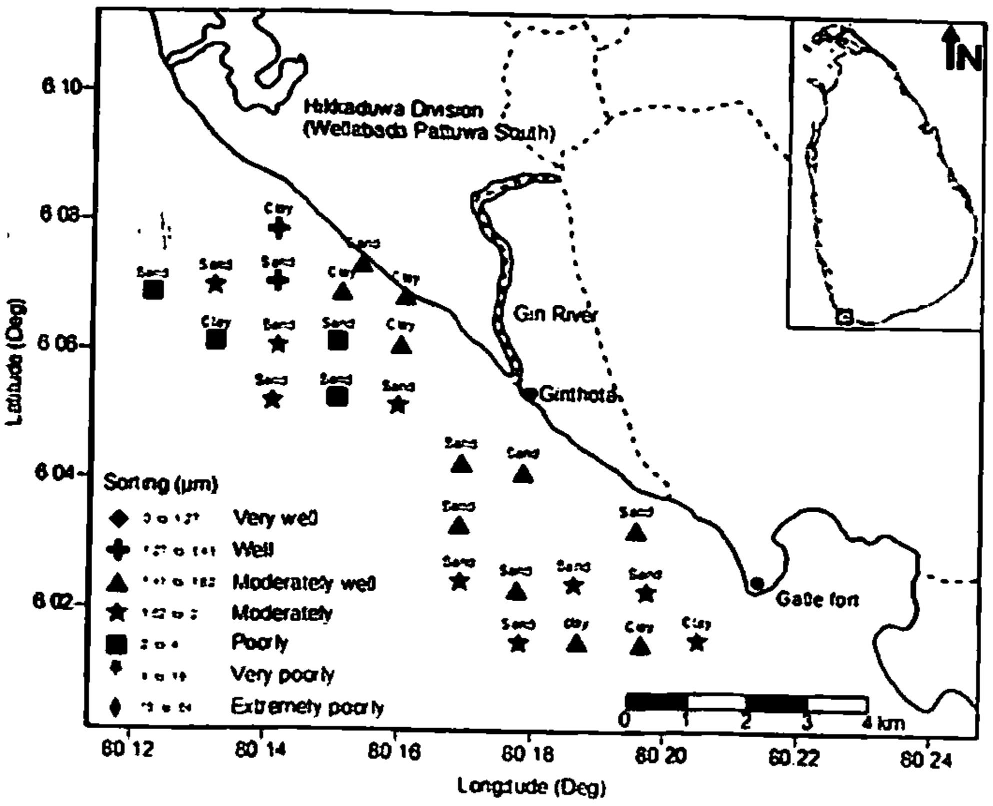

Fig. 6 Variation of Sorting Index in the offshore Galle Region.

fraction would have greater capillary action and retain more moisture. However, grain size analysis reveals that they have a median size of greater than 0.500 mm which will not enhance the capillary action. However, if moisture is lost from the sand through evaporation the chloride content will be higher. This could occur in hot and dry environments (Gutt and Collins, 1987). The area around Galle features a tropical rainforest climate with heavy rains. Hence, it is suitable to use natural rain water for chloride leaching in this area. Even where moisture is trapped by capillary action, a small amount of rain water (i.e.80 mm) will be sufficient to reduce chlorides to acceptable levels in a 2 m high stockpile (Dias et al., 2008).

In addition, the shell content was also measured and it was found that shell content is within the specified limits. According to Dolage et al., 2013, shells have no adverse effect on strength, but the workability is reduced if the concrete is made out of aggregate having a large shell content. However, since the coarse aggregate content in a concrete mix will rarely be less than fine aggregate content when offshore sand is mixed with coarse aggregate, the shell contents by weight of the coarse aggregate will be less than those by weight of the fine aggregate and hence well below the acceptable limits (Table 2).

Another important aspect to be discussed is the dredging of deposits at suitable depths and suitable distance from the coast. Here it is mandatory to check availability of sand at right depths and distance from the Mean Sea Level to mine without affecting the coastal area. Shallow water dredging (< 30 m) causes large environment effect to the sea ecosystem and coastal morphology. Dredging far away from the coast and in deeper zones has an impact on selection of dredging equipment and mining method, influence on the economic and technical aspects of the project. The location with water depths greater than 50 m raises technical challenges for the operation of aggregate dredgers (Sutton and Boyd, 2009).

Table 2 British Standard values (BS) and study area results of shell content (wt %)

Size (mm)	BS Limits	Results
> 10	8	1.58
5 – 10	20	0.89
< 5	No requirement	-

More than the impacts on coastal geomorphology, the marine ecosystem could be changed physically, biologically and chemically due to dredging. Extraction of sediment from offshore borrow sites can result in modifications to physical processes in and around the dredging zone and near shore areas. The rate of extraction and total quantity of material removed is particularly relevant to the physical impact on the coastline of marine aggregate dredging (Byrnes et al., 2004). The impact of a pit in middle shore face zone (15 to 25 m depth contour) has negligible impact on near shore wave climate, near shore littoral drift and no measurable shoreline changes (Van Rijn et al., 2005).

It should be noted that offshore sand extracted below 15 m of ocean depth (i.e. beyond the surf zone) would not affect the coastal sediment budget (Dias et al., 2008). Therefore, mining of discovered deposit was not going to affect the coastal geomorphology.

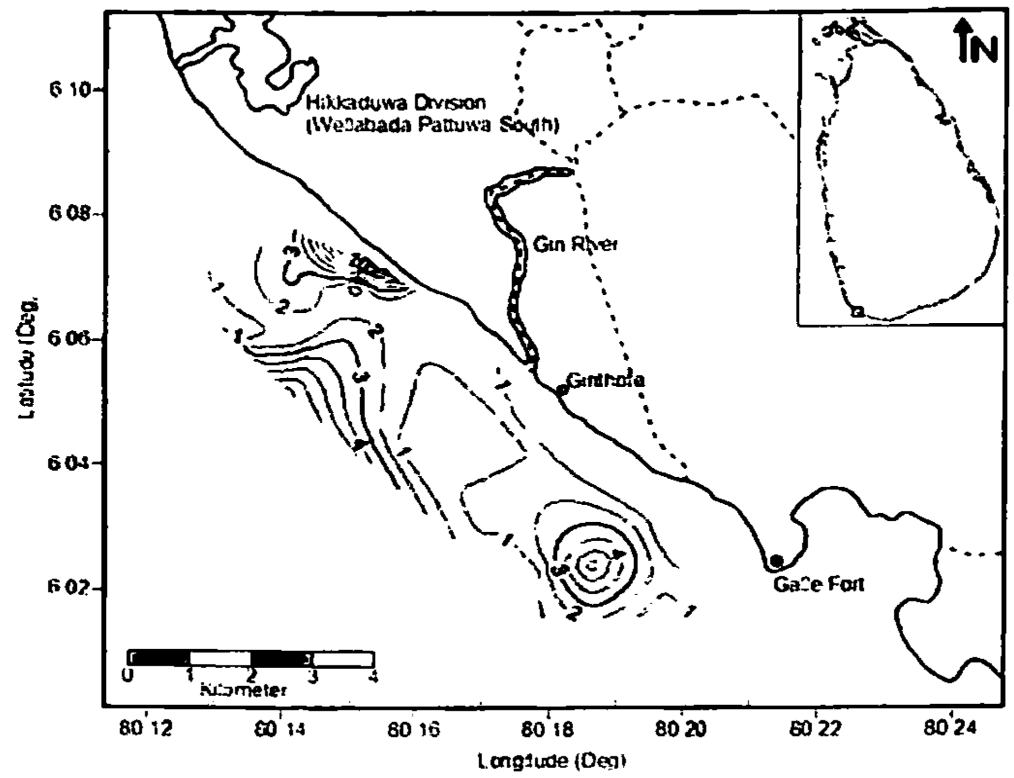

Fig. 7 Total heavy mineral distribution at offshore Galle.

The development projects such as expansion of Mahamodara hospital, building complex of Ministry offices, Galle port development project and Southern expressway extension project in the Galle region will be benefited by this deposit. Transport costs from the stockpile would not be excessive as Galle area which is just 12 km away from the farthest distance of deposit.

In addition to construction sand the weight percentage of total heavy mineral sand was studied. The percentage of heavy minerals of each sample vary in the range of nil to 16.9 %, though it's made a very low average and only a few locations consist more than 3.0 % of heavy minerals (Figure 7). However, location (H1) showed 16.9 wt % of heavy minerals, indicating prospective area for detailed investigations. Most of these heavy mineral rich locations, including H1 with 16.9 wt % is associated with clay. Volumetric percentage of ilmenite is above 50 % of the total heavy mineral content in many samples. However, few samples with 80 % garnet have been identified. Rutile and monazite are found up to 2-3 % in almost all the samples.

This study is limited only to the surface sediments and, the results of this study can be used for a detailed exploration program. It is essential to carry out drill core analysis or sub bottom profiling data to determine the proven reserve estimation.

CONCLUSIONS

The following conclusions are drawn;

- Discovered sand deposits are economically and technically feasible for exploiting for construction purposes.
- The possible environmental effects due to dredging of these sand deposits are minimum.
- Exploration for heavy minerals in the area around location "H1" is recommended for detailed investigation.

ACKNOWLEDGEMENTS

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APPENDIX

Appendix Table 1 Coordinates of sampling locations in offshore Galle region

No	Name	Latitude	Longitude
1	A1	6^0 00.910'	80^0 12.306'
2	A2	6^0 00.885'	80^0 11.788'
3	A3	6^0 00.917'	80^0 11.222'
4	A4	6^0 00.887'	80^0 10.696'
5	B1	6^0 01.462'	80^0 12.239'
6	B2	6^0 01.369'	80^0 11.837'
7	B3	6^0 01.435'	80^0 12.184'
8	B4	6^0 01.388'	80^0 10.669'
9	B5	6^0 01.460'	80^0 10.155'
10	C1	6^0 01.969'	80^0 12.304'
11	C2	6^0 01.954'	80^0 11.746'
12	C3	6^0 02.041'	80^0 11.184'
13	C4	6^0 01.947'	80^0 10.680'
14	C5	6^0 01.993'	80^0 10.145'
15	C6	6^0 01.984'	80^0 09.577'
16	D1	6^0 02.416'	80^0 11.223'
17	D2	6^0 02.486'	80^0 10.716'
18	D3	6^0 02.572'	80^0 10.155'
19	D4	6^0 02.526'	80^0 09.594'
20	D5	6^0 02.592'	80^0 09.032'
21	E1	6^0 02.934'	80^0 10.648'
22	E2	6^0 03.100'	80^0 10.136'
23	E3	6^0 03.088'	80^0 09.581'
24	E4	6^0 03.149'	80^0 09.023'
25	E5	6^0 03.120'	80^0 08.438'
26	F1	6^0 03.602'	80^0 10.122'
27	F2	6^0 03.656'	80^0 09.598'
28	F3	6^0 03.681'	80^0 09.033'
29	F4	6^0 03.630'	80^0 08.497'
30	F5	6^0 03.673'	80^0 07.933'
31	G1	6^0 04.103'	80^0 09.634'
32	G2	6^0 04.137'	80^0 09.061'
33	G3	6^0 04.220'	80^0 08.481'
34	G4	6^0 04.193'	80^0 07.921'
35	G5	6^0 04.129'	80^0 07.354'
36	H1	6^0 04.405'	80^0 09.242'
37	H2	6^0 04.713'	80^0 08.474'
38	H3	6^0 04.720'	80^0 07.924'
39	H4	6^0 04.708'	80^0 07.375'
40	H5	6^0 04.709'	80^0 06.891'