ENVIRONMENTAL IMPACTS OF DREDGING RECLAMATION AND COASTAL MODIFICATIONS IN CORAL REEF ISLANDS, A CASE STUDY FROM MALDIVES *

MAHMOOD RIYAZ

Environment Research Centre, Ministry of Home Affairs and Environment, Jamaaludheen building, Nikgas Magu Male`
Maldives

MOHAMED ALI

Environment Research Centre, Ministry of Home Affairs and Environment, Jamaaludheen building, Nikgas Magu Male`
Maldives

Assimilation, concentration and dispersion rate of dredged material in an elongated coral reef (faro) was investigated to study the environmental impacts of an ongoing dredging, reclamation and coastal modification (creation of artificial headlands, bays and a marina) project in Reethi Rah Resort North Male atoll. Sediment transport pattern around the island and concentration of dredged material was quantitatively measured in 10 locations. Two sets of sea surface water samples were collected, one while dredging and another set three hours after dredging stopped, to study the assimilation, dispersion rate and behavior of sediment plume within the house reef. Wave, current, wind and tide data was utilized to interpret results of the quantitative data. The study showed that bottom sediment movement around Reethi Rah Falhu was slow; the highest rate recoded was 50gram $m^{-1}d^{-1}$ in westerly direction. Concentration of dredged material on the eastern and northern side is (3%) while on the southwestern and southeastern end is (7-9%). Turbidity level within the house reef falls from 17.5NTU to below 1 NTU, similarly concentration of suspended solids in sea surface water falls from 44 mg/l, to 5-1 mg/l three hours after dredging stops. The results reveal that the sediment plume travels west and southwest directions and it is very much confined, locally dispersed very rapidly and disappears from the surface after traveling approximately 750m, concentration of silt content in seabed gradually increases southwest and westwards. The material is carried away from the source very rapidly due to the strong wave and current action within the house reef, hence sedimentation is minimal on the reef flat. Longer period data collection would enable to model the sediment movement pattern within the house reef and changes in the beach profile more accurately and consequent long to medium-term impact of coastal structures on islands.

1. Intorduction

The Atolls of the Maldives are located midway stretching about 800km on the Indian Ocean's 3000 km long Laccadive-Chagos submarine ridge. Small low-lying reef islands of the Maldives are precariously situated on narrow reef platforms within the atolls/atoll rims. Almost all the islands are formed of accumulations of biogenic material provided exclusively by the local reef platform. There are 26 atolls, 1190 islands of which 201 island are inhabited and more than 80 islands are developed as tourist resort. Islands of Maldives are developed on shallow reef flats due to hydrodynamic deposition of biogenic material produced by the surrounding reef during the final phase of Holocene development Gourlay (1988), Woodroffe and McLean (1994). Number of islands occurring in a single reef (house reef) may vary from one to many islands.

Dredging and land reclamation in coral reef environment has been identified as the outright obliteration of coral reefs through removal of reef substrate and increased sedimentation, Bryant (1998). Despite the devastative impact dredging and reclamation has on the delicate coral reef environment, sometime such activates becomes a necessity when livelihood and well-being of the community is concerned. In the tourism industry of Maldives, which has a substantial contribution for the country's economy, development of access channels and harbours are necessary for easy navigation and for mooring in all weather conditions.

This paper presents the environmental impacts of dredging reclamation and coastal modification in coral reef islands from an ongoing dredging and reclamation project in Reethi Rah Resort reef north Male atoll, Maldives. The paper provides a quantitative assessment of assimilation, concentration and dispersion rate of dredged material in an elongated coral reef and identifies the environmental and aesthetic impacts of the activity on the coral reef and neighboring Ziyaaraiyfushi Island.

1.1. Study area

Reethi Rah Resort lies on the northwestern rim of North Male atoll, latitude of 4°31' N and longitude of 73°22'E, in an elongated house reef (Figure 1). Besides Reethi Rah, two small sand cays shares the house reef, Madivaru Island approximately 0.75 km, to the south and Ziyaaraiyfushi resort, 1.7 km to the north of Reethi Rah Island. The three islands and the house reef is N-S orientated. The islands are separated from each other by a shallow channel.

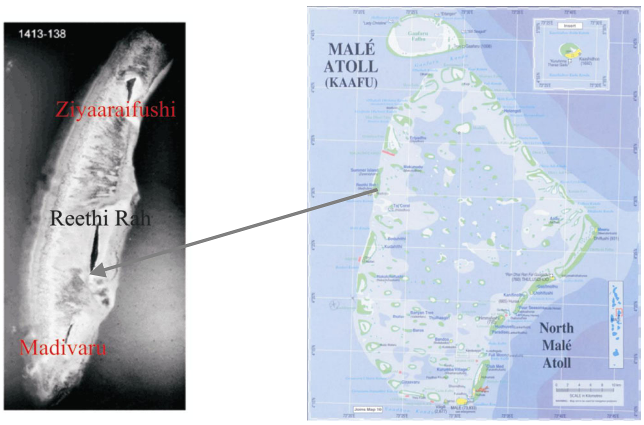

Figure 1. Location map showing North Male Atoll and an aerial photograph of Reethi Rah Falhu (left).

Reethi Rah reef (Reethi rah Falhu) is approximately 5.4km long and 1.4km wide. Depth and composition of the “shallow sandy lagoon” Purdy (1974), of Reethi Rah reef is very uniform, depth ranges between 0.5-1.5m, and consists of fine to medium grained coral sand mixed with coral rubble.

Reethi Rah has been operating as a tourist resort for more than 10 years. The management of the island decided to upgrade the resort to sell for the upper tourism market. The upgrading process involved creation of, more land by reclamation, artificial bays, private beaches, a harbour and a marina in the island and number of other luxurious facilities in the island. The plan is to dredge a harbour, an access channel and a marina, and to use excess material from dredging to undertake, reclamation, beach replenishment, and shape the whole island in an amoebic shape, with number of artificial bays and headlands (figure 2).

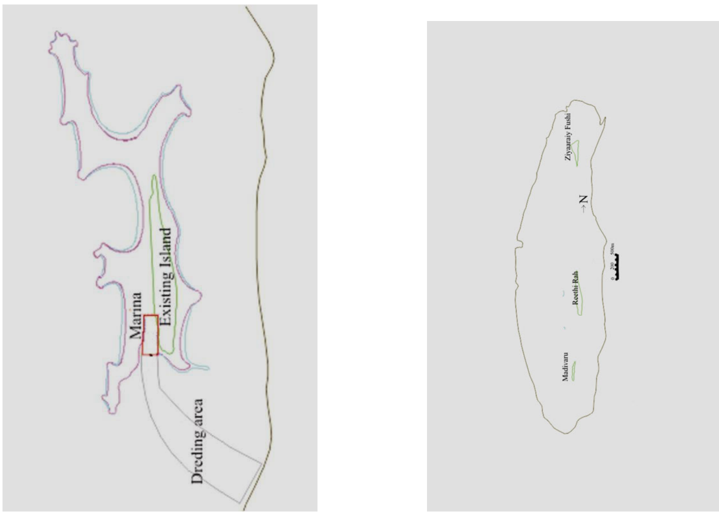

Figure 2. Existing shape of shape of Reethi Rah within the Falhu (right) note the elongated shape of the island, proposed amoebic shape of the island (left), size of the island will be increased, number of artificial bays and headland will be created.

2. Methods

2.1. Surface water and bottom sediment sampling

Sea surface water and bottom sediment sampling size and amount was determined based on the (OSPAR 1998, EPA 2001, IADC/CEDA, 1997) guidelines for the Management of Dredged Material. The amount of dredging in Reethi Rah ranges 100,000 – 500,000 m^3, which requires minimum number of sampling stations to be between 7 and 15 OSPAR (1998), IADC/CEDA (1997). Two sets of surface water samples were taken from the lagoon. The first set was taken while dredging is ongoing, Dredging Water Samples (DWS), and the second set of samples was taken thee hours after dredging stopped, No Dredging Water Samples (NDWS) (Figure 3). A total of 33 water samples were collected, 15 NDWS and 18 DWS, and analysed in the laboratory for turbidity and suspended sediment concentration.

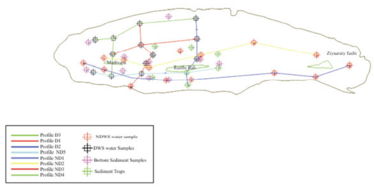

Figure 3. Sampling, instrumentation and profile lines.

A total of 10 bottom sediment samples were taken by snorkeling in the shallow lagoon (by scooping the upper 5cm in to the sampling bag). Bottom samples were analysed for silt/mud concentration (dredged material). Each sample was weighed, washed and left in a 30cm deep settling pond for 6 hours. After 6 hours water was drained off and the settled sediment at the bottom of the pond was reweighed. Percentile difference in weight of pre and post settling was taken as the percentage concentration of mud in the sample.

2.2. Sediment Transport

Quantitative measurement of sediment transport was accomplished by measuring the total volume change over a known time: $Q = \Delta V/\Delta t$. Twenty eight cloth traps were deployed offshore around Reethi Rah Falhu in seven stations (figure 3). The traps were constructed of steel, rectangular in shape 20cm long and 5cm wide. At each station four traps were fixed by steel stakes. These traps are aligned in four directions at 90^{o} intervals.

The traps were first recovered after 24 hours and redeployed and recovered after 72 hours. Trapped sediment were weighed and analysed to study the volumetric change in sediment transport over a known time, and nett movement and direction.

2.3. Current and tide

Sea surface current velocity and directions measurements were taken by injecting dye into the water and measuring the distance moved by currents centroid of the injected dye is divided by the time of injection and measurement: $V = D/t_2 - t_1$.

A temporary tide staff was installed approximately 20 meters east of the eastern shore. Tide measurements were recoded every 30 minutes manually for two days. The tidal data collected from the temporary station was reduced to the reference level of the nearest standard tidal station located at the Hulhule International Airport approximately 25 miles south east of Reethi Rah resort.

Daily weather records of Hulhule weather station for the surveyed period obtained from the Department of Meteorology was used to interpret and correlate sea surface current and tide measurements of the field.

2.4. Dredging and reclamation methodology employed at Reethi Rah Resort

Dredging in Reethi Rah is carried out by a suction dredger. Reclamation and leveling is carried out by excavators. Two settling ponds were constructed on the western side of the island prior to dredging. Settling ponds receives the dredged material trough the outfall pipes. The two ponds are connected through a large pipes. The exit opening of the is on the southern end of Reethi Rah Resort. These two ponds function to trap most of the sediments and sorts coarse and fine materials by gravity, also serve to reduce the amount of suspended material carried into the surrounding shallow lagoon. Sorted material from the first settling pond is used for reclamation and beach fills.

3. Results

3.1. Sediment Transport

On the first recovery period sediments were only trapped at stations 5, 1 and 4 only. In both locations, stations 1 and 4, sediments are moving southwest wards. Station five is near the eastern shore of Reethi Rah, showed slow eastwardly movement.

Recovered traps after 72 hours at stations 1, 5 and 3 was the highest and the rate of sediment transportation was more than 50 grams $m^{-1}day^{-1}$. The results also show that the total amount moved each day decreased in absolutes total over the period. At station 2, on both recoveries traps were empty. For the whole period the greatest mobilization of sediment was found at station 5, where the quantity of sediment trapped was almost equal in all four traps.

3.2. Concentration of mud/silt in the seabed

Concentration of dredged material in seabed is low at the eastern and northern side of Reethi Rah (3%), while the concentration is high on the southwestern side of Reethi Rah particularly on the SW and SE end of Madivaru, (7-9%). Concentration of silt/mud content in seabed gradually increases SW and westwards.

3.3. Current and tide

Surface current at the measured location was 0.3m/sec and moving southwesterly direction.

Recorded tide levels at Reethi Rah was related to the nearest tidal station in Hulhule (Figure 4). Daily weather records for the period obtained from the Department of Meteorology shows that calm conditions prevailed for the period of the study, 7-12 April 2003. Winds were in the range of 3-7kts and NNW-ENE in direction.

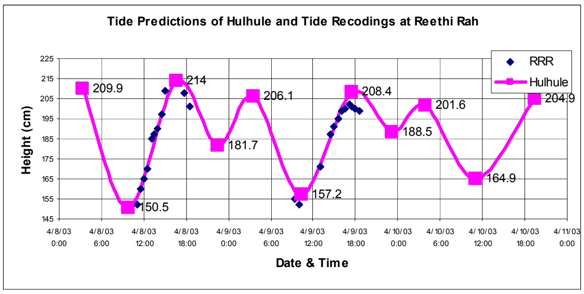

Figure 4. Comparison tide measurements at Reethi Rah and predicted tide at Hulhule International Airport.

3.4. Suspended sediment concentration and turbidity level

Concentration of suspended solids in sea surface water samples of NDWS ranges between 1-5 milligram/liter. The highest concentration was found in sample NDWS1, few meters away from the dredger and the lowest was in samples NDWS2, 5, 6, 8, and 13. DWS showed a wide range of suspended sediment concentration between 1-44 mg/l.

Turbidity measurement recorded from both sets of samples clearly shows that turbidity level within Reethi Rah reef falls below 1 Nephelometric Turbidity Units (NTU) three hours after dredging stops. The turbidity level of 15 NDWS ranges between 0.07-0.96, NTU and 18 DWS samples ranges between 0.11-17.5 NTU. The highest turbidity level was recorded in sample DWS Extra 17.5 NTU.

4. Discussions

4.1. Sediment transport

Present study based on field measurements within Reethi Rah reef has shown a slow rate of sediment movement around the island. Nevertheless the study enabled to get a clear idea about the sediment movement directions. Hence a broad general description of sediment transportation pattern around the island can be obtained from the study. In the eastern side of Reethi Rah sediment is moving east and south easterly and on the western side south westerly direction. This is reasonable because the wind is blowing from the North and NW direction, therefore the fetch waves generated by the wind is approaching the reef on northern directions and dissipating through the reef. Similarly the impact of surface current would have greater role here, due to the shallow depth of the lagoon. Hence the sediment is transported to the south by the combined effects of wave, current and wind. The process is expected to reverse in the SW monsoon period.

4.2. Assimilation and dispersion rate of suspended material within Reethi Rah Falhu

Dominant wind was from NNW direction, hence the sediment plume produced by the dredging and reclamation activity in Reethi Rah is expected to move south and southwest. The results obtained from the field measurements confirms that the sediment plume was moving on SW direction.

DWS and NDWS water sample analyzed and seabed sediment samples were plotted in a map of Reethi Rah by using Surfer® software to study the behavior of the sediment plume produced by the ongoing dredging and beach fill activity (Figure 5A-D).

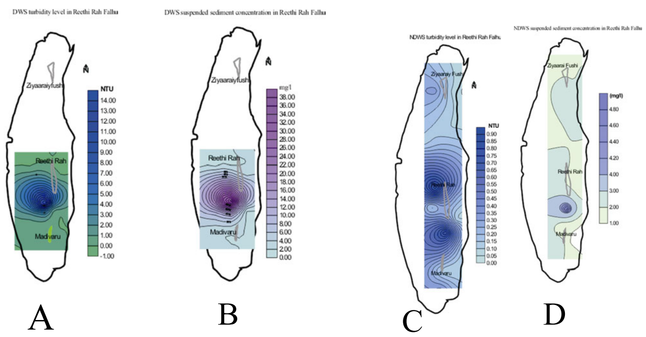

Figure 5. Assimilation and dispersion of turbidity level and suspended sediment while dredging is ongoing (DWS) maps A&B, (NDWS) maps C&D.

Present study clearly showed that silt/mud generated from dredging activity disperses very fast. Turbidity level and suspended sediment concentration falls from 17.5-1 NTU and, 44 mg/L, to 5-1 mg/L three hours after dredging stops, respectively. The rate of dispersion here could partly be attributed to the arrangement of dredging activity and partly to the surface current flow within the channels. Since the dredging is conducted on the southern channel (Madivaru-Reethi Rah channel), at high tide, and the outfall of settling ponds are on the northern channel (Reethi Rah- Ziyaaraiyfushi channel), strong current in these two channels disperses the sediment fast. High tide generates more water flow through the reef, hence contributes for faster dispersion of sediments produced from dredging and reclamation activities.

Silt/mud concentration in bottom sediment similarly increases in the southwestern part of Reethi Rah Falhu (Figure 6). However, observation of corals on reef flat southwestern side of Reethi Rah Falhu showed a little evidence of sedimentation. This could be attributed to the strong wave action in this part of the reef, where ocean swells continuously breaks on to the reef flat or other factors, Rogers (1990), Anthony (2000), Anthony and Fabricius (2000) .

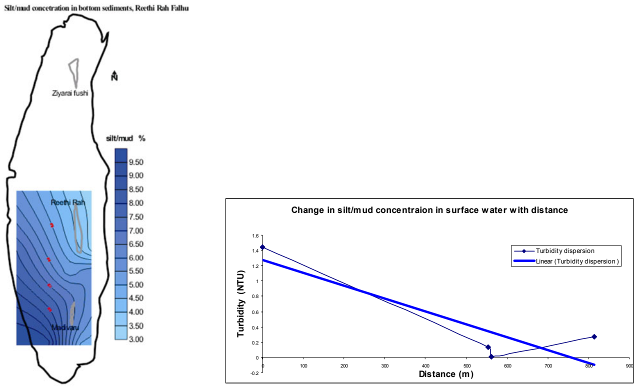

Figure 6. A map showing assimilation of silt/mud concentration in bottom water sediment Reethi Rah Falhu (left). Relationship between change in turbidity level with distance, NWDS water samples showing that turbidity level in surface water falls below 1NTU, at 750m radius from the source, 3 hours after dredging stops.

Assimilation of silt/mud is inversely proportional to the distance, and sea surface turbidity level reaches below 1NTU at 750m from the source (Figure 6).

4.3. Environmental Impacts

The objective of the present study was to assess the impacts of dredging, reclamation and coastal modification activities in Reethi Rah on the neighboring tourist resort (Ziyaaraifushi). Particularly to study the behavior of the sediment plume, and beach erosion issues that may trigger due to coastal modifications in Reethi Rah Resort. The study clearly showed that the sediment plume is moving southwest, hence, neither suspended sediment nor turbidity level is expected to increase in Ziyaaraiyfushi. However, the movement of plume will reverse with the reversal of monsoon and might increase suspended sediment concentration and turbidity level in Ziyaaraiyfushi lagoon in the SW monsoon period.

Proposed modification has not taken place at the time of the present study. Therefore it is extremely complex to predict the magnitude and extent of anticipated impacts of coastal modification Hoply (1981), in terms of erosion and accretion on Ziyaaraifushi, with the little data this study has obtained on current, wave and sediment movement within the Reethi Rah Falhu. Although the study enabled to quantify the amount and direction of sediment transport within the reef, but the quantification is insufficient to predict the long-term trend in sediment movement pattern around the island.

Observations on coral reefs (patch reefs), within 700-900m radius, indicated that they are heavily sedimented, while corals on the reef flat show little evidence of sedimentation. This can be attributed to the strong wave action and current of removal associated with the ocean swells as well as other processes related with sediment and coral, Rogers (1990), Anthony (2000), Anthony and Fabricius (2000).

5. Conclusions

Environmental impact of dredging and reclamation in coral reefs can be reduced if appropriate methods and technology is employed. Dredging methodology, timing, seasonality, environmental setting, wave, current, and tide level are crucial factors that contribute to minimize much of the impacts anticipated from dredging and reclamation activities in coral reef environment

The study clearly indicated that the sediment plume produced by dredging and reclamation is moving southwest wards, hence will not increase the turbidity level and suspended sediment concentration within Ziyaaraiyfushi lagoon in NW monsoon period.

Greater mobility of sediment is observed near shore areas than far shore. This might be due backwash effect of waves approaching the shore.

Reclamation by direct dumping of material into the water produces higher concentration of suspended sediment and turbidity level than dredging by suction dredger, but the impact of the earlier is more localized than the later.

References

Anthony, K.R.N. (2000) “Enhanced particle-feeding capacity of coral on turbid reefs (Great Barrier Reef, Australia)”. *Coral Reefs*, 19, 59±67.

Anthony, K.R.N. and Fabricius, K.E. (2000) “Shifting roles of heterotrophy and autotrophy in coral energy budgets under varying turbidity”. *J. Exp. Mar. Biol. Ecol*., 252, 221±253.

Bryant D. B urke L., McManus J. and Spalding M. (1998). “Reefs at Risk, A map based Indicator of threats to the world’s Coral Reefs” *A joint publication by World Resources Institute (WRI), International Center for Living Aquatic Resources Management (ICLARM), World Conservation Monitoring Centre (WCMC), United Nations Environment Programme (UNEP)*, ISBN 1-55963-257-4

Environment Protection Authority (2001) “Best practice Environmental Management, Guidelines for Dredging”, *Victoria, AUSTRALIA*

Gourlay M.R. (1988). “Coral cays: products of wave action and geological processes in a biogenic environment”. *Proc 6th Int. Coral Reef Symp*. 2:491-496

Hoply.D. (1981) “Sediment movement Around A Coral Cay, Great Barrier Reef, Australia” Pacific Geology vol 15 p17-36.

International Association of Dredging Companies (IADC)/Central Dredging Association (CEDA) (1997). “Environmental Aspects of Dredging” Guide 3 (Investigation, Interpretation and Impact). ISBN 90-75254-08-3.

International Association of Dredging Companies (IADC)/Central Dredging Association (CEDA) (1997). “Environmental Aspects of Dredging” Guide 4: Machines, Methods and Mitigation ISBN 90-75254-08-3.

John D.D. and Scott M. (1990) “Environmental Consideration for port and Harbour Development” World Bank Technical paper no 126.

OSPAR (1998). “Guidelines for the Management of Dredged Material Summary Record” OSPAR 98/14/1-E, Annex 43:PP 34

Rogers C.R. (1990) “Response of Coral Reefs and Reef Organisms to Sedimentation” Marine Ecology Progress Series Vol 62: p 185-202

Purdy E.G. (1974). “Reef configurations: cause and effect”. *In: Laporte LF (ed) Reefs in time and space - SEPM Spec Publ* 18: 9-76

Woodroffe C.D. and McLean R.F. (1994) “Reef islands of the Cocos (Keeling) Islands” *In: CD Woodroffe (ed) Ecology and geomorphology.*