MAURITIUS RESEARCH COUNCIL

TOWARDS BETTER UNDERSTANDING OF THE HYDRODYNAMICS AND MORPHODYNAMICS AROUND FRINGING BARRIER REFFS

Final Report

March 2015

MAURITIUS RESEARCH COUNCIL

Address:

Level 6, Ebène Heights,
34, Cybercity,
Ebène 72201,
Mauritius.

Telephone: (230) 465 1235
Fax: (230) 465 1239
Email: mrc@intnet.mu
Website: www.mrc.org.mu

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PI Name: AZIE Jean Lindsay

Address: Eau Clair
Rodrigues Island
Republic of Mauritius

MAURITIUS RESEARCH COUNCIL FINAL REPORT

PART I- PROJECT IDENTIFICATION INFORMATION

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PART II - SUMMARY OF COMPLETED PROJECT

This project aimed at better understanding the hydrodynamics and morphodynamics around a fringing reef system where a newly established Marine Protected Area has been implemented. The project site is at the SEMPA in the south of Rodrigues Island which forms part of the republic of Mauritius. The present study is in straight line with one of the SEMPA's objective of having a strong scientific understanding of its existing ecosystem for better follow-up.

Field data collection campaigns have been undertaken for collecting water depth within the SEMPA which were further processed for obtaining the existing bathymetry. Wind, tide and wave data have been collected and altogether included in the Delft3D-FLOW model for deeper analysis. An insight has been obtained about the existing hydrodynamics within the SEMPA whereby the water movement in and out of the lagoon during the flooding and ebbing phases of the tide have clearly been demonstrated. An idea has also been obtained about the water velocity pattern that exist in the SEMPA. Furthermore, the field data collection campaign had enable to obtain the coastal morphology along the SEMPA sandy beaches and to look into its variation.

This study can further by pushed forward in view of deepening the understanding of the hydrodynamic effect combined with sea level rise prediction over the coastal morphology especially under extreme weather conditions.

PART III - TECHNICAL INFORMATION

1 Introduction

The rising concern about threats coming from the sea towards Small Island Developing States as laid down in the IPCC report of 2007 has made it very essential to make predictions beforehand in order to consider remedial actions in case of extreme surges. Also, the increasing economic activities along coastal areas, has made it essential to forecast any unforeseen threats so as to lessen any damage to be caused. In that perspective, the Republic of Mauritius which also forms part of the SIDS has taken some steps ahead in order to be up to date on the issue. Among various measures taken, an Integrated Coastal Zone Management (ICZM) office has been established during the last ten years and an ICZM plan has been developed for better coastal management. Furthermore, various studies and coastal adaptation measures have been carried out along the coastlines of the islands forming part of the Republic of Mauritius.

This piece of research work has proposed as main idea to better understand the hydrodynamics and morphodynamics around a fringing reef in one of the island of the Republic of Mauritius called Rodrigues Island where the largest Marine Protected Area of the Republic has been set up. A field data collection campaign took place for further analysis using models including DELFT3D-Flow and XBEACH. Further details are provided through this report.

2 Background and objectives of research

The research has been carried out on the site of a Marine Protected Area (MPA) namely the South East Marine Protected Area (SEMPA) located in the Southern part of Rodrigues Island. The aim of the SEMPA is to restore the depleted marine habitat, and also to maintain the still existing marine ecological values. Furthermore, the SEMPA project has the innovative approach of considering the social, economic and environmental background of the project site and its vicinity. Thus the well-being of the inhabitants bordering the SEMPA is being given vital consideration.

2.1 Problem definition and project motivation

The IPCC report 2007 has stressed on the threats facing Small Island Developing States (SIDS) regarding danger coming from the sea (Mimura, *et al.*, 2007). There is increasing concern about rise in storminess around the globe. More efforts are being committed in order to better understand those risks and to forecast their impacts so that mitigating measures can be considered beforehand.

For instance, some studies have been carried out on Rodrigues Island in view of analyzing climate change impact on its territory. It is however a fact that not much has been done in order to better understand the hydrodynamic processes within Rodrigues' lagoon. For illustration, (Lynch, *et al.*, 2002) in their report recommended that further research be undertaken to extend data sets on current patterns and wave spectra and that a more precise bathymetric survey of the lagoon be carried out in order to produce a comprehensive hydrodynamic model of the Rodrigues lagoon.

This piece of research work is therefore coming forward with an extension of the data sets for the bathymetry of the lagoon in the south of the island and to come up with a pilot demonstration of the hydrodynamic model of the Southern lagoon of Rodrigues Island. Added to this, the morphodynamics pattern along the sandy beaches within the South Eastern part of the Island is also being proposed. Such a study would help to consolidate the recommendation meant by (Lynch, *et al.*, 2002). A hydrodynamic model will be available for further analysis within the SEMPA and also the morphodynamics analysis can be used as a guideline for decision making purposes.

2.2 Aim and objectives of the research

The main objective of the research work has been ***to better understand the hydrodynamics and morphodynamics around the existing reef system within the South East Marine Protected Area boundaries in Rodrigues Island via a demonstration process***. A set of specific objectives were devised as laid down below:

- To analyze the morphodynamics evolution along the South East Marine Protected Area sandy beaches from Mourouk to Graviers
- To come up with a precise bathymetry for the SEMPA lagoon that would be used for hydrodynamic analysis
- To use available and appropriate coastal analysis software for analysis of the current pattern due to tidal and wind forcing along the sandy beaches and within the SEMPA.

2.3 Research questions

Base on the specific objectives a set of research questions were established and which have been dealt with through the whole research works so as to meet the main objective. The research questions are developed below.

- What is the change in beach morphology with time along the SEMPA sandy beaches?
- What are the implications for the setting up of a proper bathymetry of the South East Marine Protected Area lagoon that could be further be used for further hydrodynamic analysis?
- What is the water current circulation pattern that exist within the SEMPA during tide rise and tide fall?

2.4 Study Area

Forming part of the Republic of Mauritius, Rodrigues Island is located in the South Western Part of the Indian Ocean around latitude 19.7 degrees South and longitude 63.42 degrees east. This research work was focused around the South East Marine Protected Area (SEMPA) boundaries found in Rodrigues Island. The main aims of the SEMPA are to rehabilitate the degraded marine ecosystem, to reduce the pressure on the marine biota and to maintain the still existing ecological web around the reefs and within the lagoon. The area is well known for the presence of artisanal fishermen and fisherwomen. The commonly practiced fishing techniques are basket trap, line fishing and octopus fishing which is widely being done by fisherwomen in the area. This has proven to be a good source of income for the inhabitants in the past but has caused lots of pressures on the fishery and marine habitat. Nowadays, the catches from the fishers are much lower as compared to some years back (Kaly, *et al.*, 2007). At times when they are not at sea, the fishermen/ women who are mainly settled along the coastline, use to practice farming activities. They grow vegetables and nurture animals for personal consumption and the excess are sold at the local market. Also in the area, there exist sandy beaches located in the South-Eastern part of the island. Hotels have been built and the area is well known for water related activities such as diving, kite surfing, sailing among others. The beaches are also greatly visited by local inhabitants for leisure activities.

The SEMPA boundaries include partly a lagoon area, a part of fringing barrier reef and also an off-lagoon fraction. There exists a natural channel known as Grande Passe which heads its way from the outer lagoon to as far as about 2.5 km in-lagoon (Kaly, *et al.*, 2007) and further citations therein). The recent report, by (Kaly, *et al.*, 2007) described the existing biota within the SEMPA boundaries consisting of rocks, cobbles, sand, reef crest, corals, and sea grasses among others. The map below shows a résumé of those components within the SEMPA.

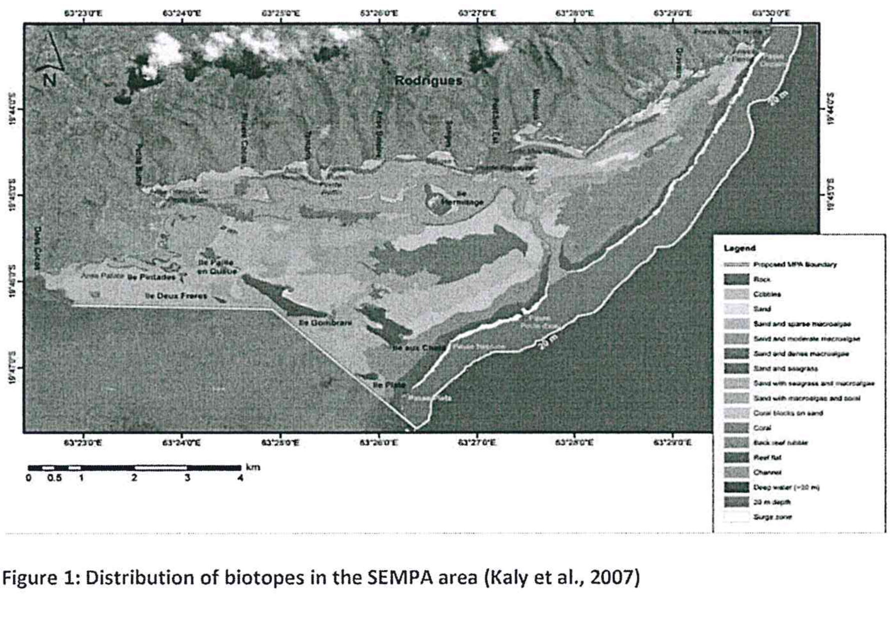


Figure 1: Distribution of biotopes in the SEMPA area (Kaly et al., 2007)

3 Methodology used

The methodology process for this whole piece of research work is summarized through the process flow diagram below

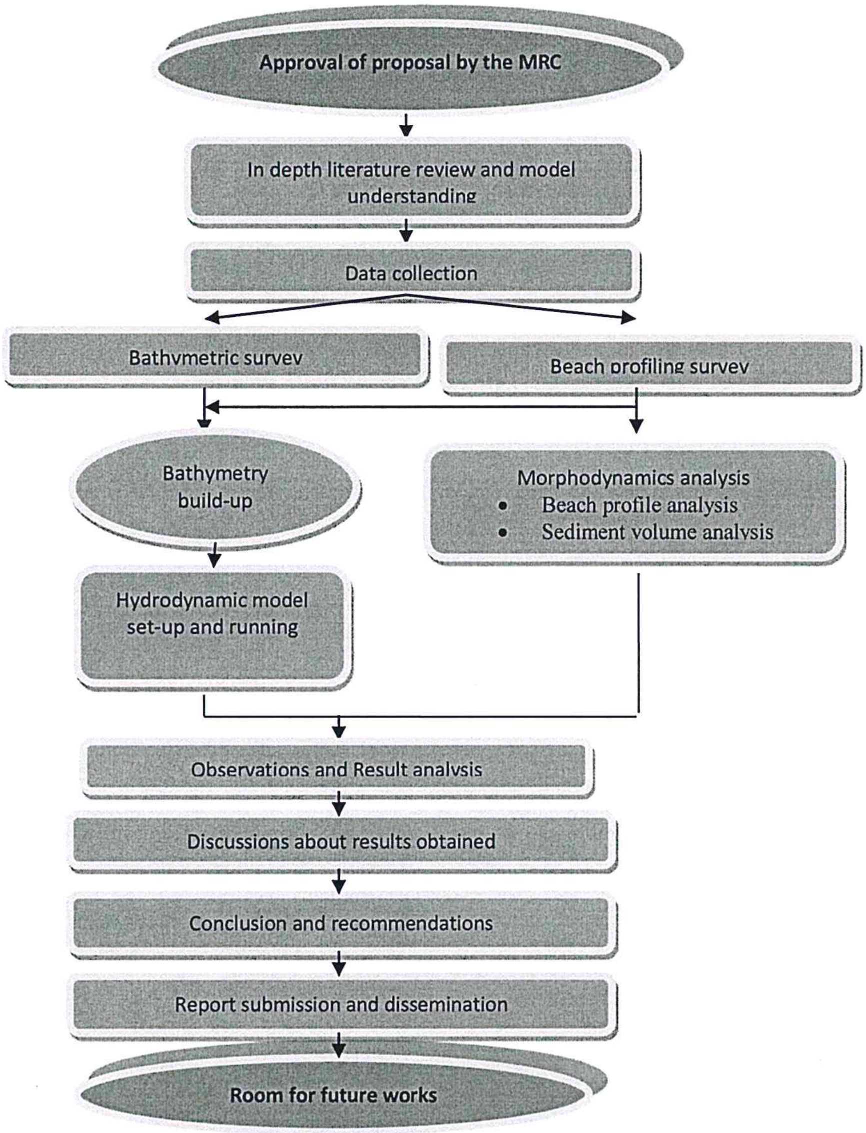


Figure 2: Process flow chart for research and Methodology

The whole process of the research has started with submission and approval of proposal. The several steps that took place afterwards include looking for data sources, to analyze the data available, to make a morphodynamics analysis along the sandy beaches and to interpret the results obtained, to run hydrodynamic model and to understand outcome results. Appropriate conclusion has been made and future works proposed. The entire above are further explained through the remaining part of the report.

4 Rodrigues Island and its vulnerabilities

Rodrigues Island forms part of the Republic of Mauritius and is located at around 560 km in the North East of the mainland Mauritius. The island is of volcanic origin with the highest point at around 355 m above mean sea level. Rodrigues has a steep slope whereby severe run-off usually occurs after torrential rains which increase its vulnerabilities to erosion problem leading to silting of its surrounding lagoon covering a surface area twice as that of its land mass. This same lagoon is enclosed by 90 km of the most well-developed fringing barrier reef of the Mascarene Islands of which Mauritius and Reunion Island also form part (Wilkinson, 2008). (Lynch*, et al.*, 2002) further describes the Rodrigues lagoon to be relatively shallow with some remote deeper pools at some point.

The Island of Rodrigues which forms part of the Small Island Developing States (SIDS) is highly vulnerable to effects of the climate change, extreme events and sea level rise as described (Mimura*, et al.*, 2007) in the IPCC report 2007. The same report highlights the high probabilities that worse inundation, storm surges, erosion and other coastal peril will occur on the SIDS due to sea level rise. Several socio-economic impacts are due to occur ranging from increase in property lost to negative impacts on agriculture and fisheries as detailed by (Pelling & Uitto, 2001). (Mimura*, et al.*, 2007) also deplored that there is high possibility that coral reefs community, fisheries habitat and other marine-based resources be affected by climate change thus affecting the Gross Domestic Product (GDP) of many island states. In the same line, tourism industry which is also a major contributor of the GDP and employment for many small islands, has high confidence of being jeopardize either directly or indirectly by climate change.

4.1 Coastal dynamics in Rodrigues

The Republic of Mauritius including Rodrigues Island is highly influenced by the climate variability and extreme weather events. For instance, the predominant climatic condition in that part of the globe are large ocean-atmosphere interactions such as trade winds and are greatly affected by tropical cyclones and other extreme weather conditions (metservice, 2016). According to reconstructed tide gauge data and Topex/ Poseidon altimeter for the period 1950-2001 there has been a rise in sea level in the South West Indian Ocean of around 1.3 mm/yr at Rodrigues, (Church, et al., 2006). The National Environment Strategies (NES) for the Republic of Mauritius and the National Environmental Action Plan (NEAP) II published in 1999 put forward the challenges faced by Mauritius as a country and proposes strategic actions centered, amongst others, on Integrated Coastal Zone Management. The preservation of the coastal zone and the marine biodiversity, therefore, is recognized as being of utmost importance. Due to threats of accelerated sea level rise, increased storminess, anthropogenic impacts due to increased sedimentation in the lagoons, and overexploitation of natural resources the Government has decided to implement remedial actions so as to recover from marine degradation. In that line, a project was launched in the year 2003 in collaboration with the United Nation Development Programme (UNDP) and the Global Environment Facility (GEF) in order to restore the marine habitat at various places within the Republic itself. Thus the Partnership for Marine Protected Areas in Mauritius and Rodrigues project was set up whereby a demonstration site has been established on Rodrigues Island in order to set the South East Marine Protected Area (SEMPA).

4.2 Prevailing climatic conditions in Rodrigues

The prevailing climatic condition in Rodrigues Island is a mild tropical maritime climate with persistent South East trade winds blowing throughout the year. The summer season extends from the month of September to March of the following year with a mean temperature of about 25.9 degrees Celsius and winter starts from April to August with a mean temperature around 22.3 degrees Celsius. There is a temperature difference between summer and winter of about 3.6 degrees Celsius. The hottest months are January to March and August is the coolest one (metservice, 2016). According to the local Meteorological station, the long term annual mean rainfall from 1961 to 2007 over the island is 1116 mm with a mean summer rainfall of 729 mm which is 65 % of the annual total. Comparatively, the winter rainfall is only 392 mm. February is the wettest month while September and October are the driest ones. Base on the same report, the island receives about 8.9 hours of bright sunshine daily and the average wind speed on any day is 18.1 km/h.

5 Morphodynamics and Hydrodynamics analysis around reef systems

The predominant forcing that can affect the nearshore hydrodynamics along an open coast are tides, short waves, Infragravity waves, local winds, and river/estuary inlets. However in areas where coral reefs with steep faces and wide platforms exist there is a significant modification of nearshore circulation and waves (Sheremet, *et al.*, 2011). The contrast in the intensity and localization of processes during wave transformation from deep to shallow water over a gentle slope varying beach as compared to a steep reef although they acknowledge some similarities has thus been described. In the former situation (Sheremet, *et al.*, 2011) mentioned about the wide surf zone and small wave breaking dissipation rate over a smooth area whereby the waves keep almost the same shape and loose energy slowly as they approach the coast. On the other hand, for a steep reef the surf zone is narrow and restricted at specific places as laid down in the report. They explained this to the fact that the deep and shallow-water regions are very close together leading to huge wave breaking dissipation rate. Furthermore, there is quick shoaling of waves and the development of large frontal accelerations.

When waves break on the reef crest, the wave energy gets dissipated before it approaches the shore, thus providing a protection to the shore and the back reef lagoon. (Symonds, *et al.*, 1995) in their report mentioned that the percentages of the momentum flux being transferred into wave setup and a cross-reef flow depends largely on some phenomena such as wave height, reef geometry, and reef crest depth.

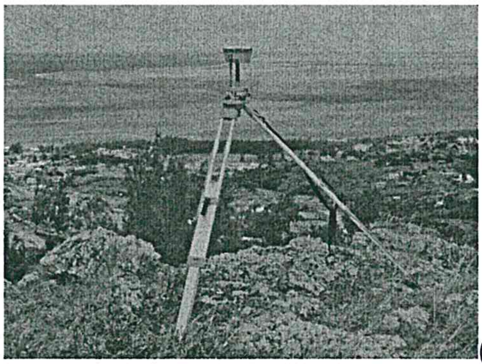
In the same line the main parameters found to most affecting the morphology of a beach are wave climate, tide and sediment characteristics (Bernabeu, *et al.*, 2003) and other citations therein). The same paper also mentioned that beach morphodynamics are influenced mainly by wave height and tidal range.

6 Morphodynamics analysis within SEMPA

In order to better understand the morphology change along the sandy beaches of the SEMPA coastlines, there had had a field data collection campaign at three time intervals where the elevation of the beach was recorded along transects set at regular distances along the beach. The cross-shore profiles along each transect was plotted for the two survey. Further to that, the beach was classified into cells whereby sediment budget was done by calculating sediment volumetric changes along each transect. The idea was to determine the flow of sand in or out or along a specific cell as explained further in the report.

6.1 Beach profiling survey

Three beach profiling survey were carried out along the Mourouk to Anse Fémie sandy beaches. A GPS was used to carry out the survey. Measurements were made along cross-shore transects from the end of sand deposition in direction of the sea up to distances of around fifty (50) meters behind the high water marks. All transects were made at approximately one hundred (100) meters interval and levels were recorded at approximately ten (10) meters interval along transect. The pictures below provide a visual recap about the beach profile survey carried out.


(a)


(b)

Figure 3: Map showing (a) Fixed Global Positioning System (GPS) apparatus used as reference point for beach profile survey and (b) Man at work using Global Positioning System (GPS) instrument during beach profiling survey

6.2 Observations made during beach profile surveys

Fine sand deposits extending from the water marks up to a distance varying from around thirty to hundred meters in the cross-shore direction were noticed lying on various parts of the sandy beaches. At other areas calcareous rock was predominantly found anchored into the beach profile while very little or no sand lying on it. ***Casuarina equisetifolia*** commonly known as filao trees are very frequent all along the beaches. There also exists a grass canopy that forms part of the system just under the filao trees. At some areas gravels were noticed just after the sandy beach strip in the seaward direction, while sea grasses were observed close to the seashore in other areas.

During the first survey some signs of erosion were noticed to have occurred along the Mourouk beach more precisely along the sand spit as can be seen in the picture below. The roots of the filao trees lying along the water mark were hanging in the air as compared to well-rooted roots further inland.

Figure 4: Trees roots above soil level showing signs of erosion

Along other beaches, there were sand accumulation and at some places a berm typed beach was observed. The sandy beach patches vary from around thirty to hundred meters wide in the cross-shore direction.

No major change was noticed after the second survey.

During the third survey (which was carried out after a heavy rainfall) some variations were observed along different part of the beaches. For instance along the sandy spit along Mourouk beach, it was noticed that sand moved away especially below the grass canopy along the water line. Also, at the mouth of two river streams present along Var Brule and Petit Graviers beach strips respectively, sand has been washed away by stream flow during the cyclone. Furthermore, more erosion was noticed along different part of the beaches, leaving a sand cliff of less than fifty centimeters.

6.3 Beach profile graphical plot and beach sediment budget

The graphical representation of the cross-shore profile was made along each transect where the elevations, h measured in meters were plotted against cross-shore distance, x measured in meters. The two different profiles from each subsequent survey were plotted for each transect.

The sandy beaches along the SEMPA coastline heading from Mourouk to Graviers were subdivided into four cells namely Mourouk cell, Var Brule cell, Graviers cell and Petit Graviers cell is shown below.

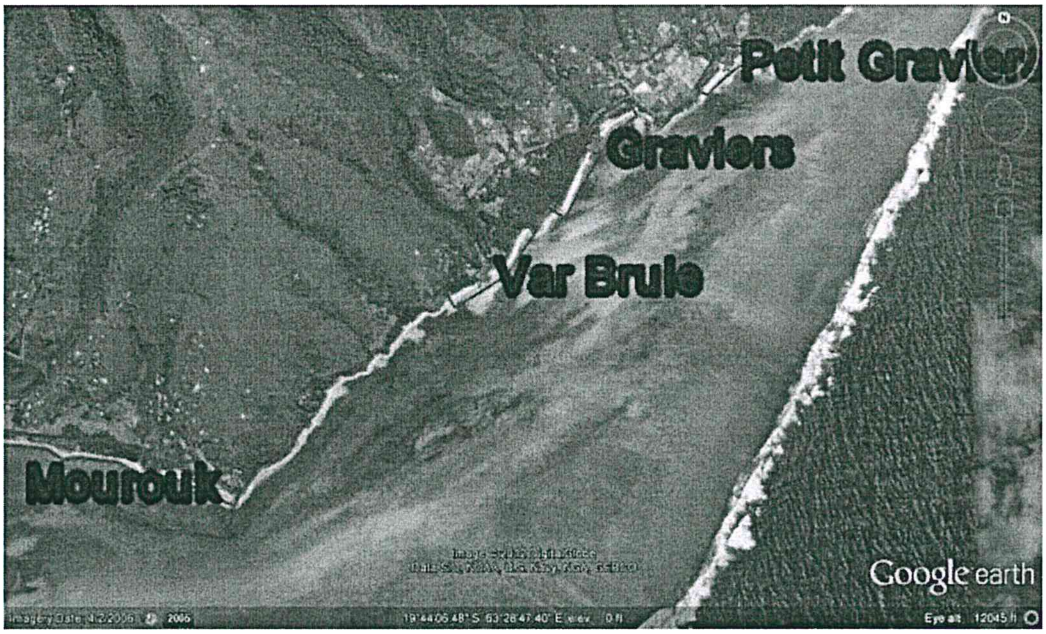


Figure 5: SEMPA coastline sand strip subdivided into four cells

Transects with Mourouk cell were named ML, those in Var Brulé cell were named VL, those in Graviers were GL and for Petit Graviers were PGL. Each transect in each cell were then attributed with a respective number.

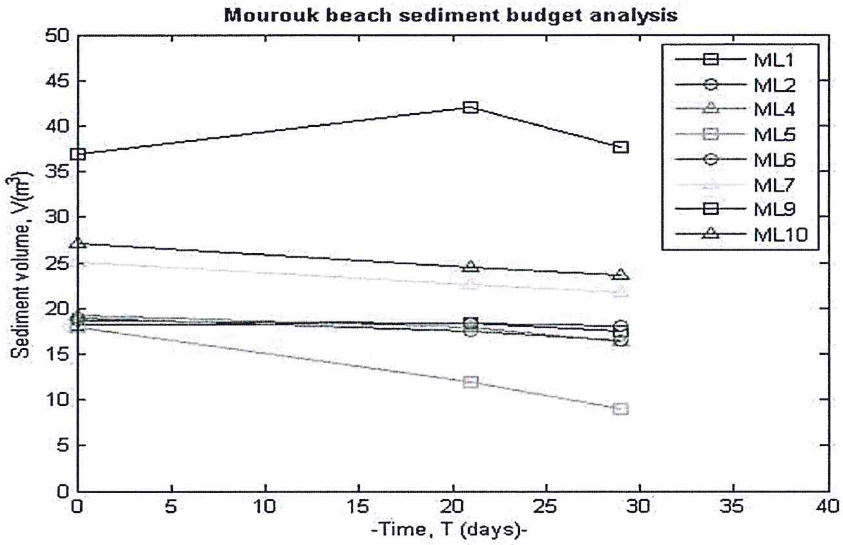
A sediment budget has been carried out for better understanding the morphological change during the period of observation along the beaches.

The sediment volume for each survey was calculated at the high-water line for each transect. A reference point was set during the first survey at beach elevation of 1 m and the sediment volume was calculated over a distance of 20 m along transect towards the land. The distance of 20 m represents the minimum distance of sandy strip that could be obtained along one transect and was therefore chosen as basis. The reference point set was kept for calculations during the second and third surveys also. The volume was calculated by multiplying the area under graph (area under profile) by 1 m (which represents width of strip along a specific transect). The area under graph was obtained by using the Trapezoid formula where the upper limit (surface) was the beach profile, the lower limit (bottom part) was set to 0.3 level which represents the lowest elevation along one of the transects.

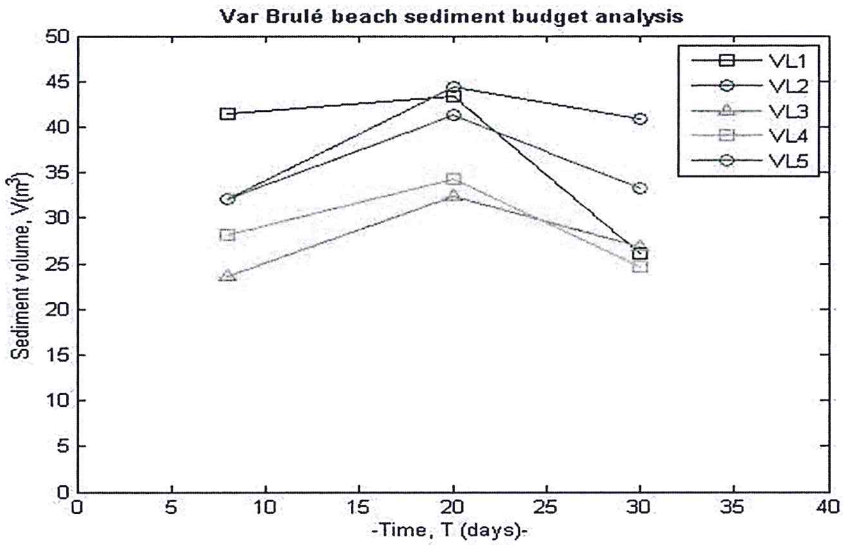
6.3.1 Results and observations made

The sediment budget analysis was made in order to assess any accretion/ erosion or stability along the various transects. It is also meant to identify any possibility of longshore sediment transport along the beaches.

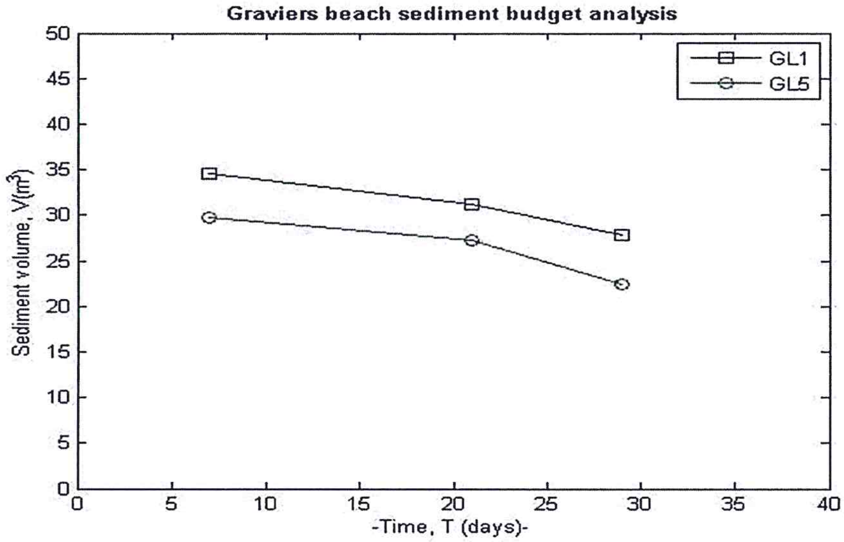
The outcome results have been plotted in graphical representations as per the figures below. The volume of sediment present along transect was plotted against time in days.



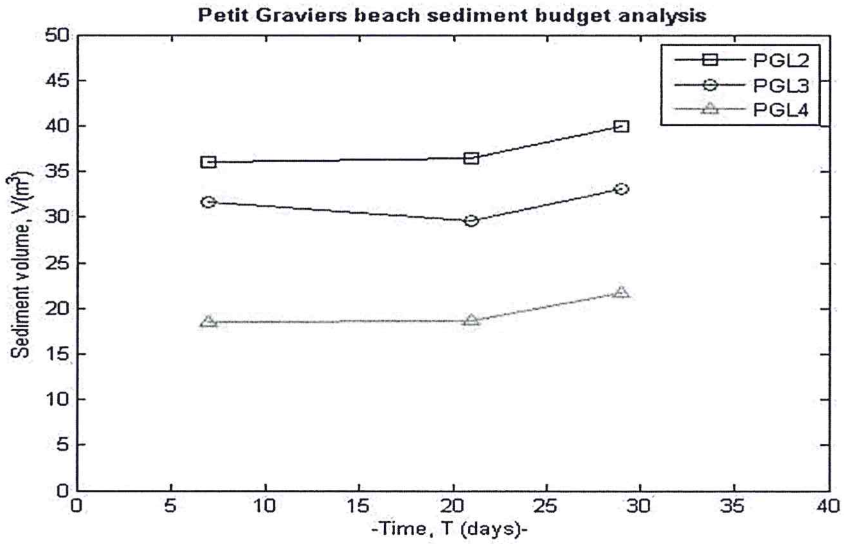
(a)



(b)



(c)



(d)

Figure 6: Graphs showing sediment volume change along each transect for (a) Mourouk; (b) Var Brule; (c) Graviers and; (d) Petit Graviers beach respectively

From plot (a) above, it can be observed that two transects (ML7 and ML10) in Mourouk cell undergone a slight decrease in sediment volume after the second and third survey. The profile plot analysis for those two transects are confirmed although a sign of stability was assigned to the ML10 transect. Here the change in sediment volume is very little if not to say stable. The highest decrease occurred for transect ML5 both for the second and third survey as compared to the others within the same cell. A sign of erosion is clear here and this has also been confirmed in the profile analysis. A stable sediment volume was noticed along transects ML1, ML2, ML4 and ML6 after the second survey. There was a slight decrease in volume noticed for the third survey analysis showing a sign of little erosion. The only increases in sediment volume for that cell occurred along transect ML9 after the second survey. However, a decrease in volume is noticed for the third survey plot which means that some erosion has taken place in that area during the heavy rainfall period.

The sediment volume analysis for the Var Brulé cell confirmed the accretion characteristics when the second survey was carried out. This is clearly expressed by the rise in sediment volume in the figure above. Furthermore, the general erosive trend as laid down in the profile plot analysis for the third survey is also confirmed in the sediment volume analysis as noticed by the decrease in sediment volume.

The Graviers cell also confirms the erosive trend after the second and third survey respectively; the decrease in sediment volume being a clear sign of it.

Plot (d) above also confirmed the stability of the Petit Graviers beach strip when the second survey was carried out noticed by an almost same sediment volume for survey 1 and 2. Survey 3 analysis showed a rise in the sediment volume which confirms an accretion along that part of the beach. This accretion may be explained by sand movement from in front of the stream's mouth which got 'stuck' in that area during the rainwater runoff.

7 Hydrodynamics analysis within the SEMPA

In order to undertake a proper hydrodynamic analysis around the SEMPA, an in-depth bathymetric survey has been carried out for mounting the SEMPA's bathymetry. The output was thus used for further hydrodynamic analysis whereby the effect of wind and tidal forcing over the morphological change along the sandy beaches within SEMPA were carried out. The open source Delft3D-FLOW software was used for the study.

7.1 Bathymetry build-up

A depth eco-sounder connected to a battery for power supply was mounted on a pirogue. The Latter driven by a skilful skipper was driven along transects from shore to reef and back at varied distance of approximately 100 to 150 meters.

Figures below illustrate the equipment mounting together with transects taken by the pirogue.

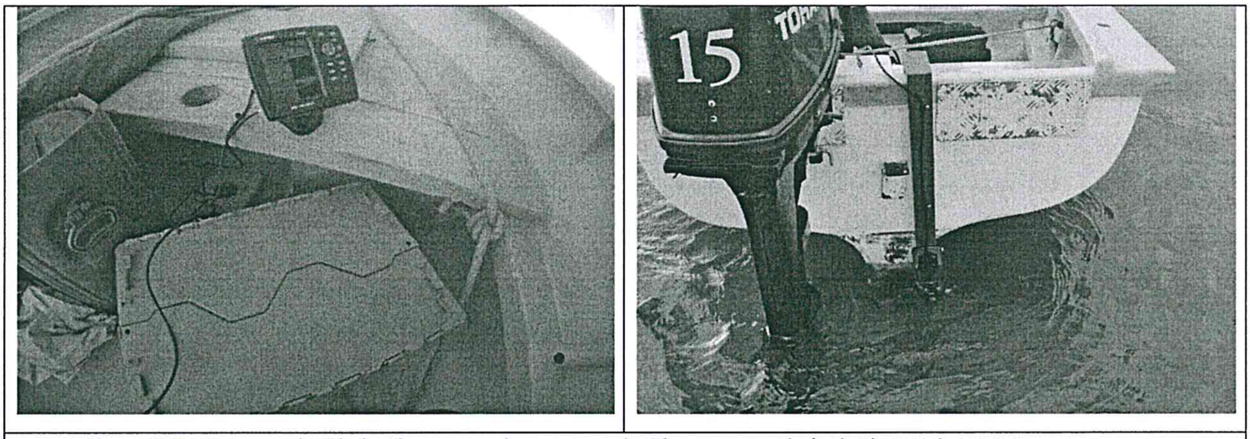


Figure 7: Boat mounted with depth eco-sounder connected with power supply for bathymetric survey

Figure 8: Yellow lines showing transects followed by pirogue during bathymetric survey

The water depth along each transect has been recorded and saved. All data collected has been used for construction of the bathymetry of the SEMPA lagoon.

7.2 Adjusting recorded water depth

Once all the data were obtained, it was necessary to correct the recorded depth in order to reduce errors. The first step was to consider the transducer anchorage under the water and to add it to the depth. However, the used boat being a flat bottom Fibre-glass one had its bottom floating just on the water level making the transducer to be just at the water level itself.

Furthermore several tests were performed where a rod was nailed into the sea floor and the boat made to pass to and through close to it in order to record the drop in water level. No apparent drop was noticed in the water level at the corresponding boat sailing speed.

Finally, another important factor was to consider the water level change itself in order to bring all the recorded depth to the same datum. For that purpose, the tidal level was extracted via the open source from the Intergovernmental Ocean Commission website (www.ioc-sealevelmonitoring.org) and was subtracted from the recorded depths. When that was done, all the data were then available related to Mean Sea Level (MSL).

7.2.1 The bathymetry layout

Using the submenus in QUICKIN menu, the bathymetry was plotted. Same has then been converted to an adapted format (KML) so that it can be viewed in Google earth as shown below.

Figure 9: Bathymetry layout used as input to hydrodynamic model

7.3 Hydrodynamic analysis using tidal and wind forcing

After that the bathymetry data was available, focus was made on the hydrodynamic model. The main reason for setting up the hydrodynamic model was to better understand the hydrodynamic forces that create variation along the sandy beaches profiles. The dominant factors that usually affects a beach morphology are tidal forces, wave climate and sediment sizes. In this study, sediment sizes have not been considered. The open source Delft3D software has been used to make the analysis.

The Delft3D-FLOW model forms the core of the Delft3D model software. A complete description is given in (Lesser, *et al.*, 2004). It solves the unsteady shallow-water equations consisting of the continuity equation, the horizontal momentum equations, and the transport equation under the shallow water and Boussinesq assumptions thus replicating water motion due to tidal and meteorological forcing. The FLOW module can also simulate wave effects, such as enhanced bed shear stresses and radiation stresses by coupling with stationary runs of a wave driver, that can either be SWAN (Booij, *et al.*, 1999) or XBeach (Roelvink, *et al.*, 2010). The process flowchart of the Delft3D-FLOW including waves is summarized below.

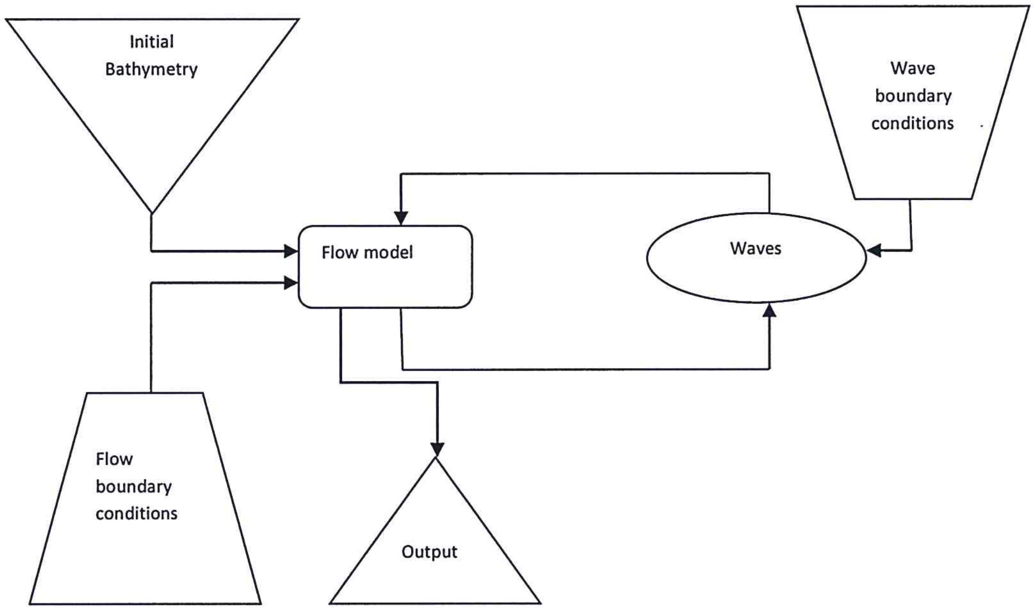


Figure 10: Hydrodynamic flow chart model

A grid lying about 11 km in the longshore direction and around 13 km in the crosshore direction were constructed with the help of the RGFGRID menu of the Delft3D-Flow model. As seen in the picture below, it was made finer along the coastline and within the SEMPA lagoon (the upper parts) which are the areas of interest.

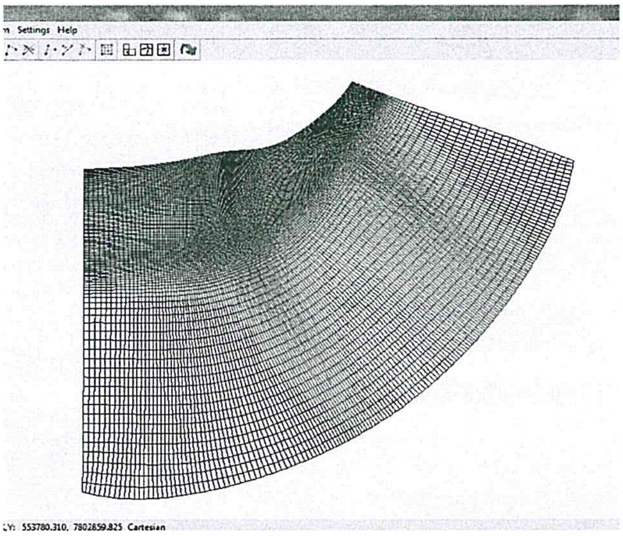


Figure 11: Computational grid of the hydrodynamic model

The highly orthogonal grid has a resolution of as high as around 25 m along the coastal parts and up to 50 m in the lagoon especially in front of the sandy beaches, along the coral reefs and also where the channel connects the lagoon to the outer sea. The resolution in the open sea has been made lower ranging from around 100 m up to around 300 m. The whole domain contains 176 grids in the M-direction and 105 grids in N-direction.

The bathymetry for the model has been built based on collected data from the bathymetric field survey. An important point to note is about the limitation of the depth to 30m in the open sea at far distance from the reef flats. This was done in order to avoid any discrepancy in the output results.

A uniform wind condition was applied to the domain based on data downloaded from the Wind-Guru website (www.windguru.cz). A wind speed of 10 m/s for a uniform direction of 135^{O} (South East direction) were therefore attributed which represents the average of the actual data.

Wave data were also downloaded from the Wind-Guru website (www.windguru.cz) whereby the records were uploaded into the *params* and *waveconxb* files which provide the input parameters for coupling between Delft3D-FLOW and XBeach regarding the wave processes.

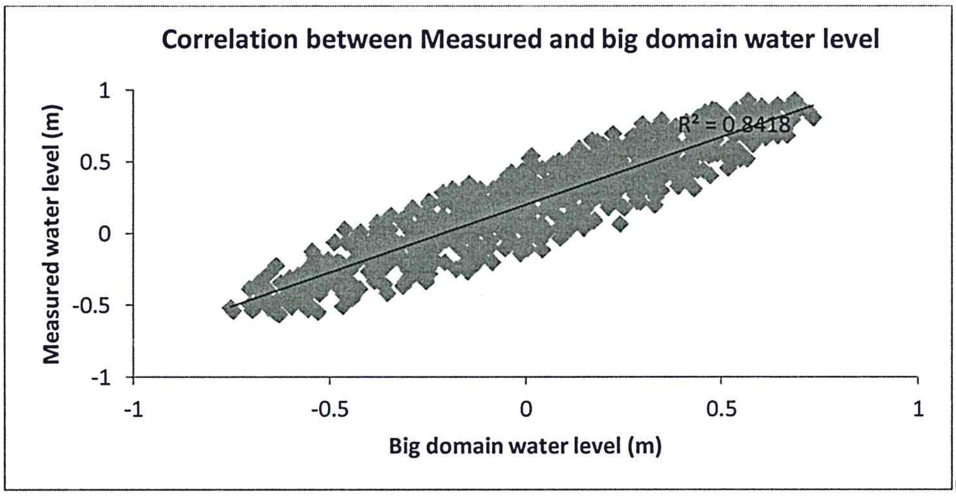
In the model, the offshore boundary was set as open boundary with water level as boundary condition. Astronomical forcing was also attributed to this boundary. Furthermore, the right and left boundaries were also set as open, but here Neumann boundary condition was attributed to each of them with a time series forcing. This was the most appropriate conditions that helped to fine-tune the model.

The model was run from 15th July 2015 for duration of one month. A computational time step = 0.02 minute equivalent to 1.2 seconds was also set.

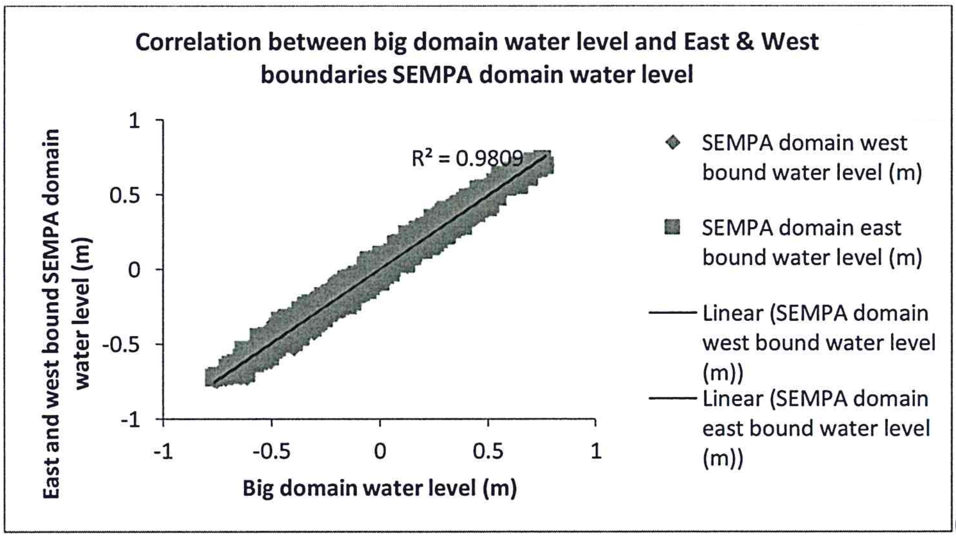
7.4 Model fine-tuning and Calibration

No in situ data was available for calibration of the hydrodynamic model within the SEMPA boundary. However, tidal level data was obtained from a tidal gauge located in the Northern part of the island within the harbor. Water level data was therefore extracted from a bigger domain model built over that part of the ocean. Same was correlated with available data within the harbor. Further to this, the "big domain" water level was used to correlate with the modelled water level within the SEMPA. The big domain was built using open source data available from the Gebco (www.gebco.net) where a five kilometers resolution grid was built over the South Western part of the Indian Ocean whereby Rodrigues Island was positioned almost in the middle. The bathymetry was also extracted from Gebco and the computational time was set to 60 seconds.

The correlation for (a) the big domain water level and the measured water level and (b) the big domain water level and the modelled water level within the SEMPA are reproduced below.



(a)



(b)

Figure 12: Graphs showing water level correlation for (a) the big domain and the measured one; and (b) the big domain and the modeled one within the SEMPA

In graph (a), the best line fit gives an R-square value of 0.8418 which is high. This denotes a high correlation.

Considering graph (b), a higher R- squared value (= 0.9809) was obtained meaning high correlation also.

The water level for the corrected deep sea water to 30 m was further compared to the water level obtained from the bathymetry build from Gebco (with depth of up to 2 km at certain part of the domain) and bathymetric survey. The result showed a 100 % correlation as indicated on the graph below.

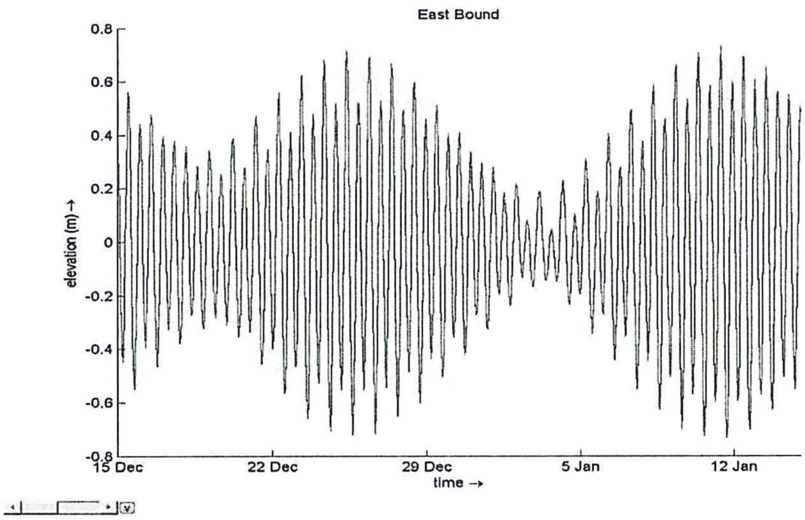


Figure 13: Graph showing water level correlation for corrected deep sea water depth to 30 m against bathymetry build from and Gebco via Delft Dashboard both including the part of bathymetric survey foe in-lagoon

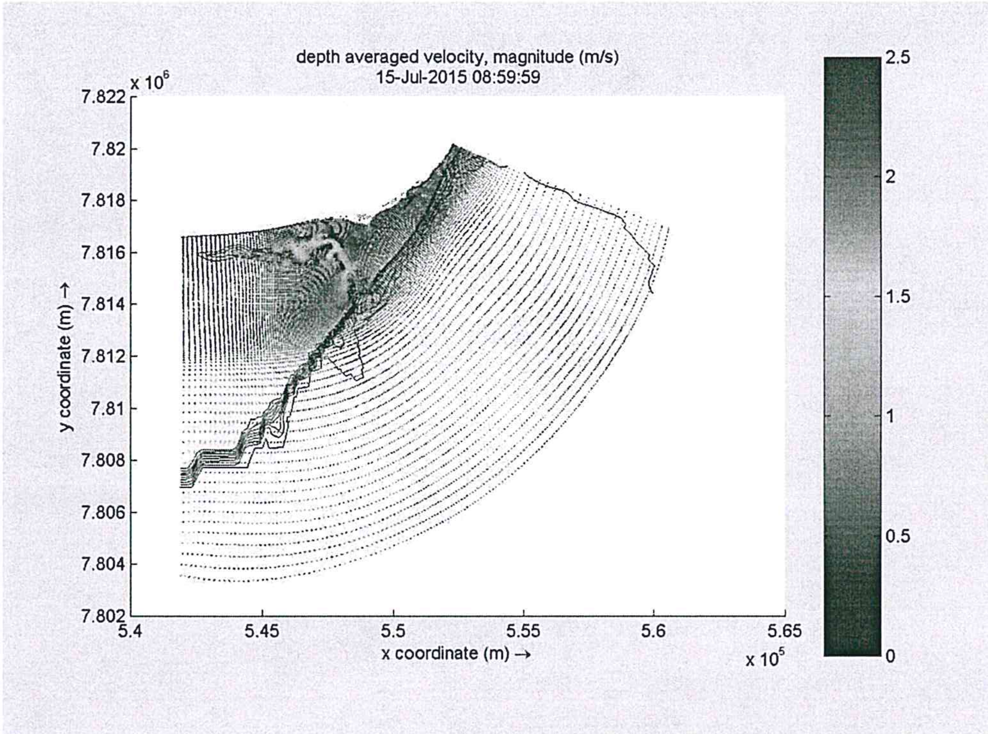
7.5 Model Simulation and analysis

The model output enabled to have an insight about the current pattern that exists within the SEMPA denoted by colored arrows. The direction of the arrows denote the water current direction while the color pattern denotes the velocity variation whereby blue color shows a smaller velocity and red color higher velocities. Having noted that during flooding and ebbing time created more water movement In and out of the lagoon and thus over the reef system, the analysis are focused during those two periods with more attention on specific areas such as around the channel, on the reef crest and along the sandy beach. In view of identifying more pronounced water circulation, the analysis took into consideration the spring tide.

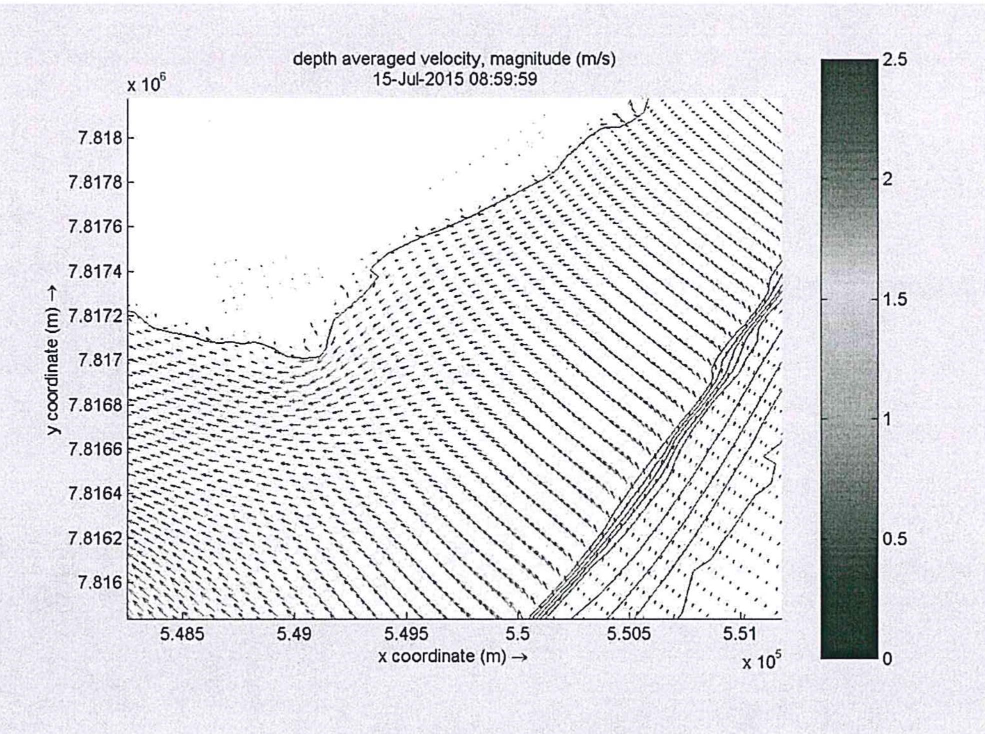
The areas of interest for the analysis are being shown on the picture below.

Figure 14: SEMPA domain indicating the areas to be focused on during analysis

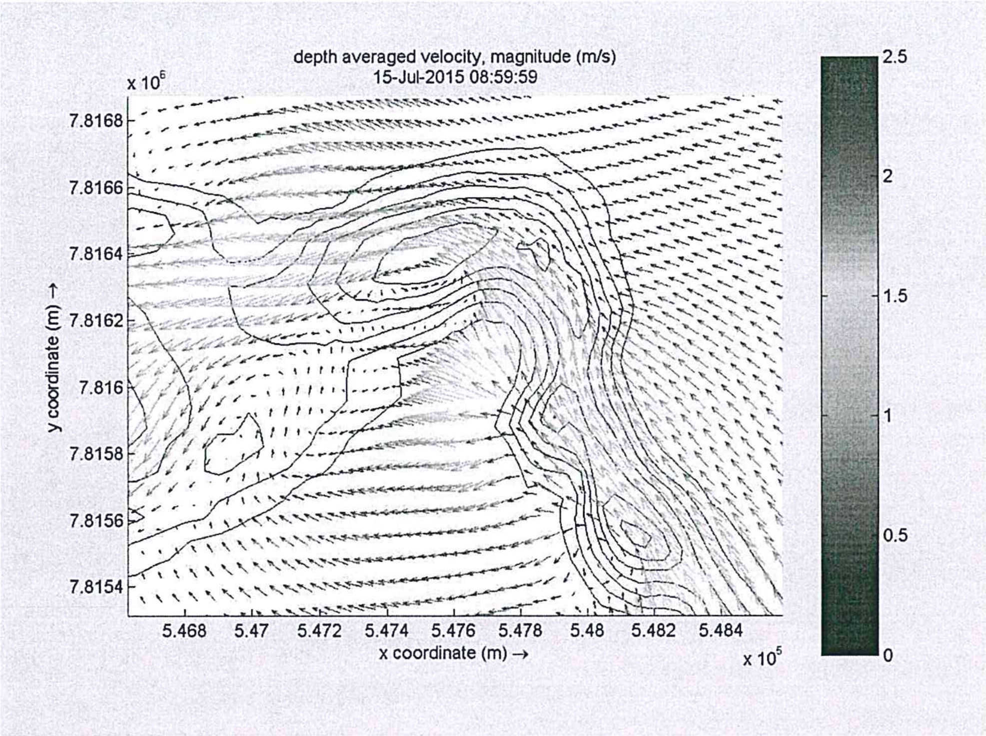
The model output for the flooding period dated 15th July 2015 at around 09 am is being reproduced in the set of figures below:



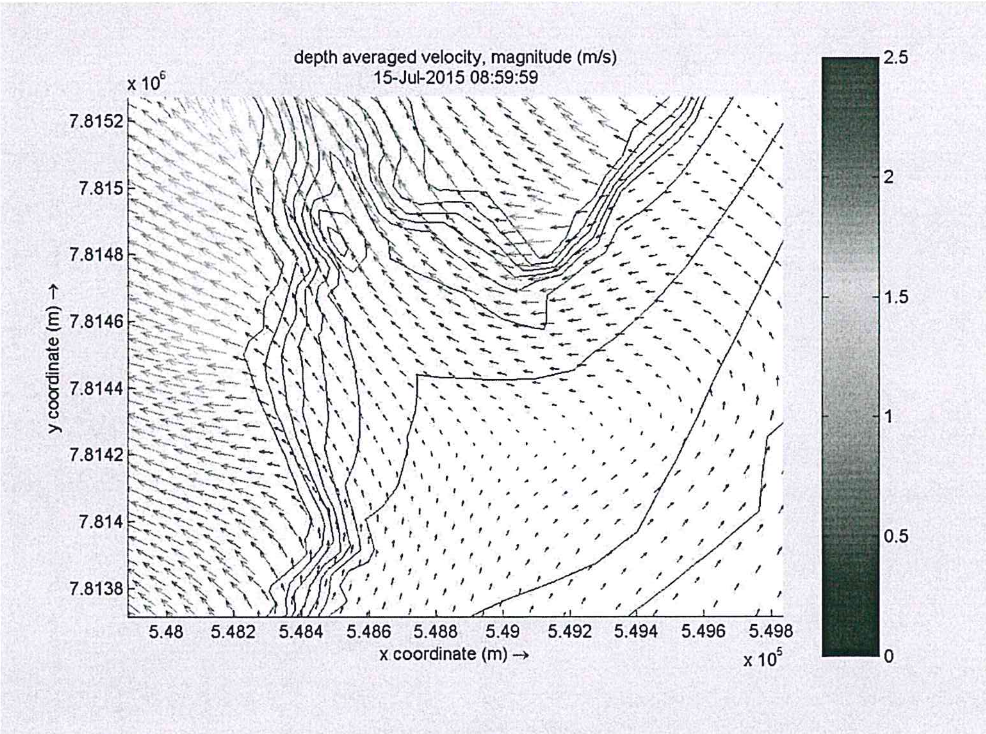
(a)



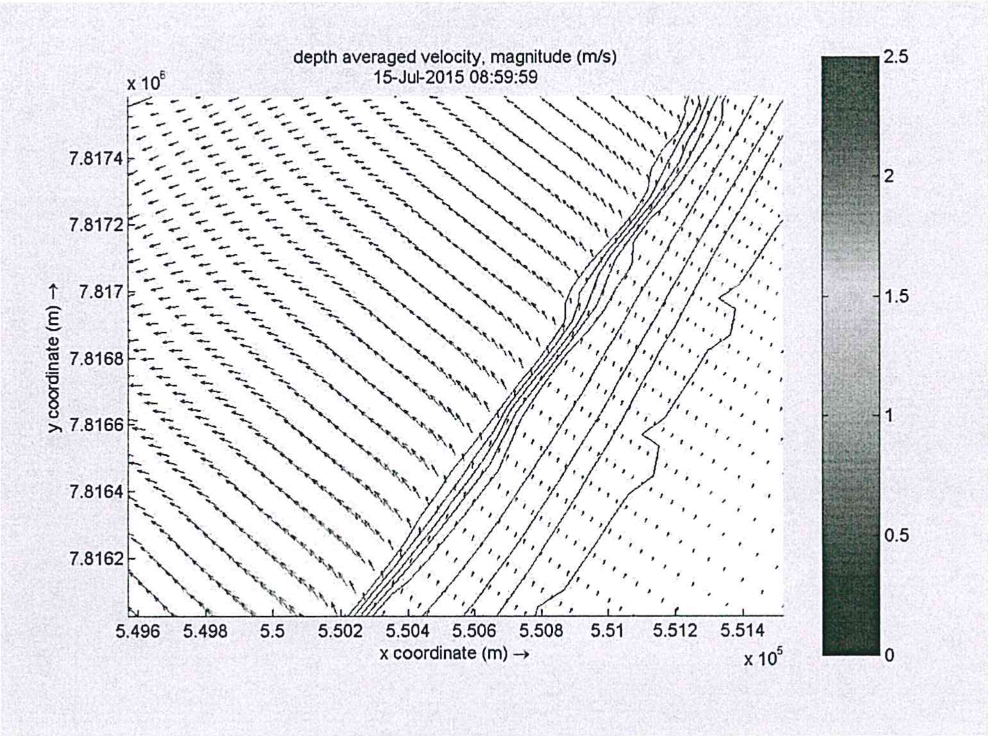
(b)


depth averaged velocity, magnitude (m/s)
15-Jul-2015 08:59:59
x 10^6
7.8168
7.8166
7.8164
7.8162
7.816
7.8158
7.8156
7.8154
y coordinate (m) →
5.468
5.47
5.472
5.474
5.476
5.478
5.48
5.482
5.484
x coordinate (m) →
x 10^5
2.5
2
1.5
1
0.5
0

(c)


depth averaged velocity, magnitude (m/s)
15-Jul-2015 08:59:59
x 10^6
7.8152
7.815
7.8148
7.8146
7.8144
7.8142
7.814
7.8138
y coordinate (m) →
5.48
5.482
5.484
5.486
5.488
5.49
5.492
5.494
5.496
5.498
x coordinate (m) →
x 10^5
2.5
2
1.5
1
0.5
0

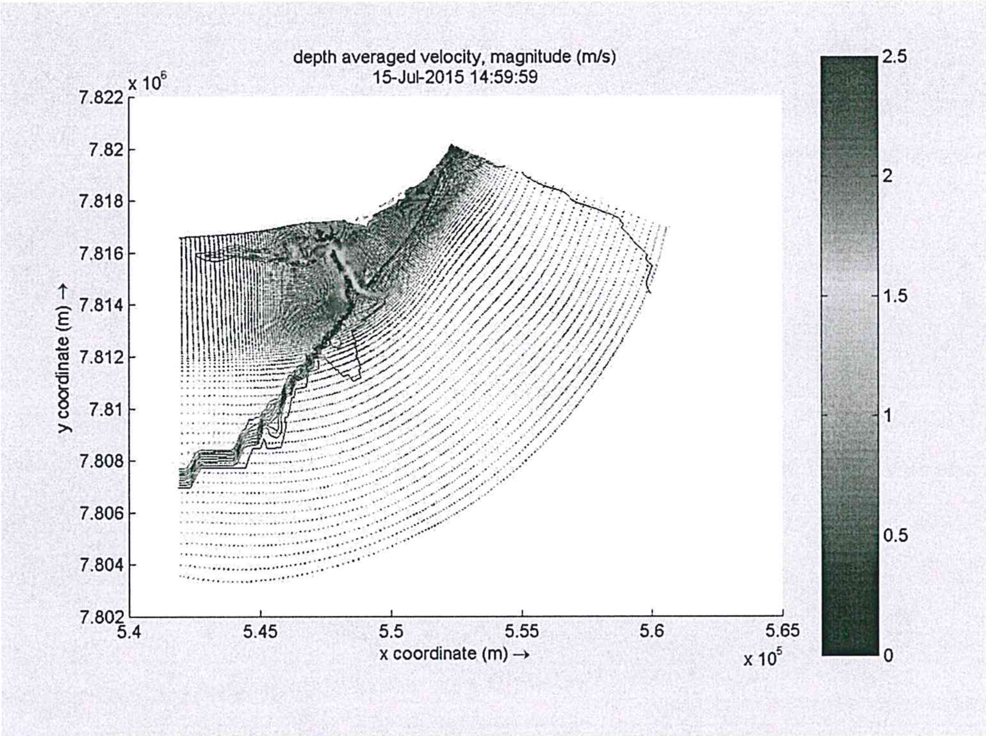
(d)



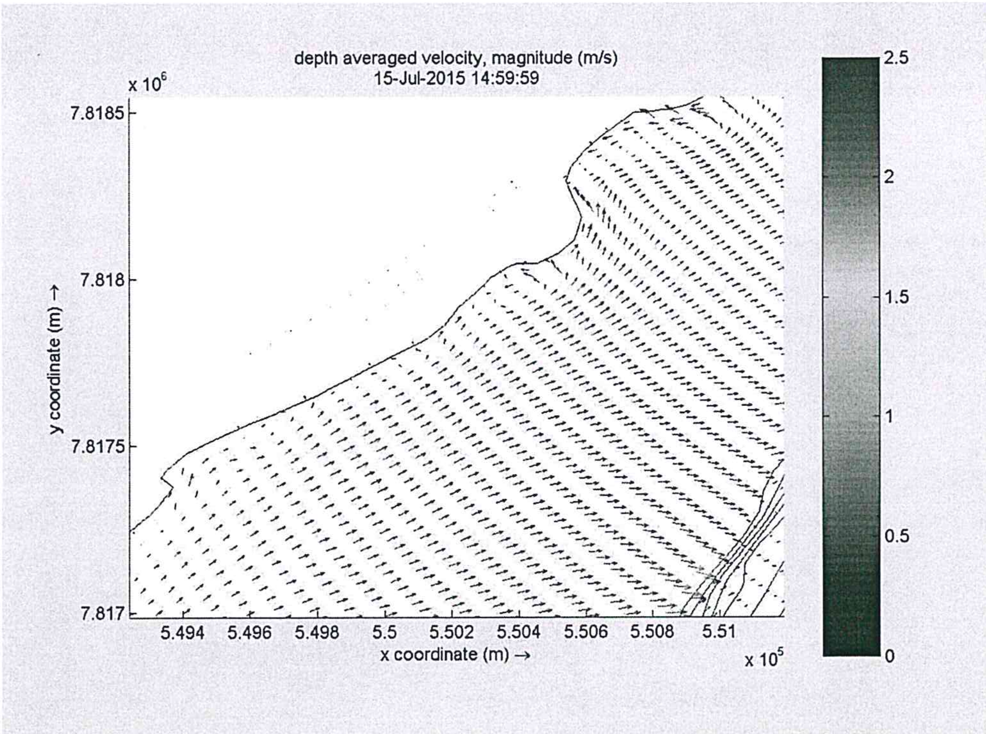
(e)

Figure 15: Model output showing current pattern and directions for (a) the whole domain; (b) along the sandy beaches; (c) in the Grande Passe channel; (d) at the entrance of the Grande Passe Channel; and (e) on the reef edge; during the flooding phase of the tide

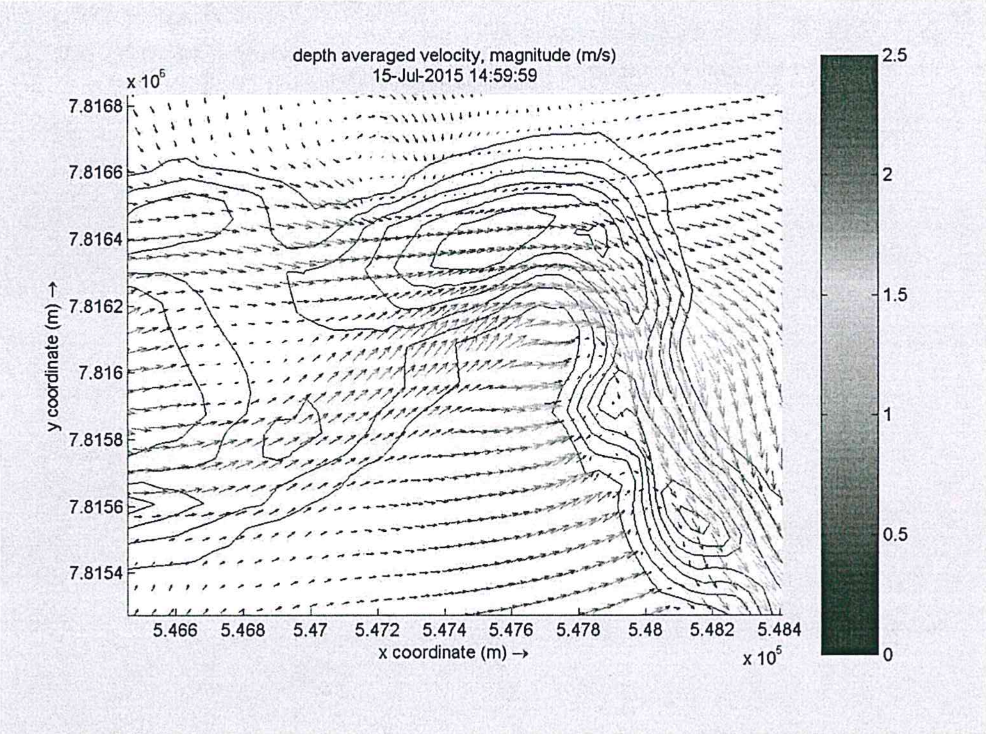
The next step has been to compare with the ebbing phase of the tide and to focus on the areas mentioned on the domain earlier. The layouts are shown below:



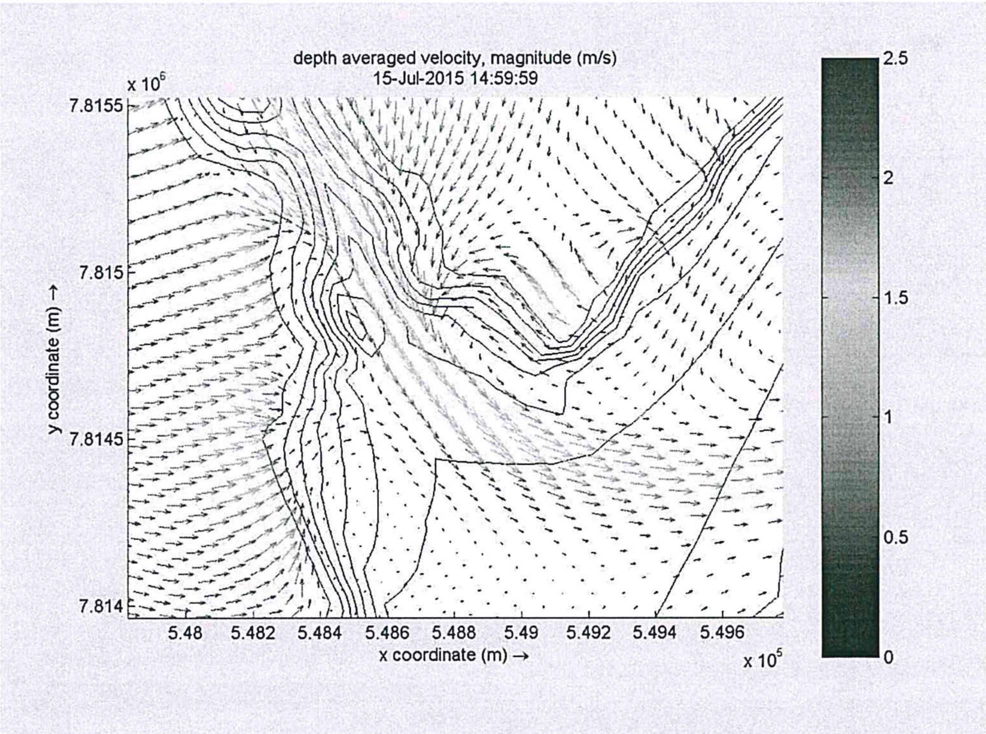
(a)



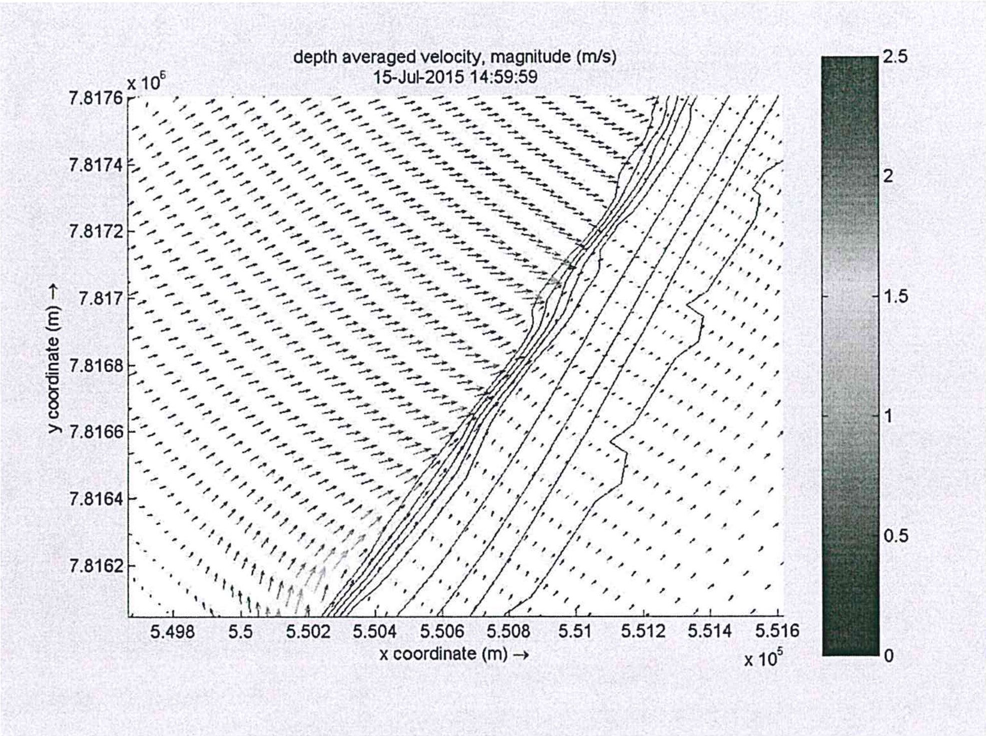
(b)


depth averaged velocity, magnitude (m/s)
15-Jul-2015 14:59:59
x 10^6
7.8168
7.8166
7.8164
7.8162
7.816
7.8158
7.8156
7.8154
y coordinate (m) →
5.466
5.468
5.47
5.472
5.474
5.476
5.478
5.48
5.482
5.484
x coordinate (m) →
x 10^5
2.5
2
1.5
1
0.5
0

(c)


depth averaged velocity, magnitude (m/s)
15-Jul-2015 14:59:59
x 10^6
7.8155
7.815
7.8145
7.814
y coordinate (m) →
5.48
5.482
5.484
5.486
5.488
5.49
5.492
5.494
5.496
x coordinate (m) →
x 10^5
2.5
2
1.5
1
0.5
0

(d)



(e)

Figure 16: Model output showing current pattern and directions for (a) the whole domain; (b) along the sandy beaches; (c) in the Grande Passe channel; (d) at the entrance of the Grande Passe Channel; and (e) on the reef edge; during the ebbing phase of the tide.

7.5.1 Results interpretation

The darker color pattern on the figure showing complete domain with the flooding phase of the tide denotes the area with higher water velocity thus higher current pattern. Same is located along and around the channel and the reef edge. This may be explained by the induced current occurring due to water movement into the lagoon during the flooding phase. Focusing onto the Mourouk to Graviers sandy beaches, it can be seen that the general flow pattern lies along the shore from a general eastern to western direction. While zooming on the channel and its entrance, it can clearly be understood that water is flowing into the lagoon through the channel due to comparatively high velocities occurring in that area. The velocity direction along the reef edge confirms that some water is coming into the lagoon through that path.

The complete domain showing the ebbing phase of the tide also denotes higher velocities along the deep channel and over the reef crest illustrated by the darker colored pattern in those areas. However the velocity directions show a general water movement out of the lagoon. The zooming images over the channel, its entrance and over the reef crest confirms this water movement out of the lagoon which is logical for lowering tide.

The above two analysis have been observed visually during the field data collection campaign and also correlates with interviews made with fishermen in the area about the usual current pattern.

8 Conclusion

This present piece of research work has enable t have a better insight about the water flow pattern within the SEMPA thus to better understand the existing hydrodynamics. The field data collection campaign has enable to obtain input the various analysis made. Beach profile measurement has allowed to do some beach profile and sediment budget analysis. The morphodynamics analysis has enable to better understand the sand movement pattern along the sandy coastline.

Furthermore, the water flow in and out of the SEMPA has been studied and the results obtained correlate much with observations made onsite and with fishermen feedback. The hydrodynamic flow model have helped to better understand the current flow pattern with tidal, wind and wave dominant forcing. A longshore transport mechanism (from east to west) seems to be highly dominating the beach morphology.

9 Recommendations and future works

The present work can further be deepen by doing further intensive in situ data collection about the wave and current pattern. Same data will enable to better calibrate the model whereby it can be used for future prediction especially as related to different sea level rise scenarios. The possible impact of extreme weather condition especially impact of storms on the coastline can be analyzed.

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I certify to the best of my knowledge (1) the statement herein (excluding scientific hypotheses and scientific opinion) are true and complete, and (2) the text and graphics in this report as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or of individuals working under their supervision. I understand that willfully making a false statement or concealing a material fact in this report or any other communication submitted to MRC is a criminal offense.

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