WATER PROPERTIES IN THE SUVA LAGOON, FIJI

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The salinity, temperature and turbidity in the lagoon are some important parameters for water quality which are continuously changing with the seasons and need to be studied because they are efficient indicators of variations in the lagoon and can transform the marine ecosystem. Results obtained showed that the salinity near the head of Laucala Bay during the wet-warm season was below 24.8 psu and was 33.7 psu during the dry-cool season. The temperature range for the Suva Lagoon during the wet-warm season was between 28.0–30.5 °C and between 24.5–25.5 °C during the dry-cool season. The turbidity in the lagoon was always above 3.0 FTU near the river mouths. The model salinity distribution compared well with the observed distribution from field data after the model was validated for salinity distribution.

1. Introduction

Fiji is an island group located in the Pacific Ocean lying between latitudes 15°S−22°S and longitudes 177°W−175°E (Fig. 1). One of the two main islands, Viti Levu, hosts the capital city of Suva, which is home to nearly a quarter of the population of Fiji thereby placing a lot of anthropogenic pressure on its lagoon.

Figure 1. Map of Fiji Islands.

1.1. *Climate of Fiji*

Fiji enjoys a tropical climate without great extremes of heat or cold. The country experiences a distinct wet and dry season, controlled largely by north and south movements of the Inter Tropical Convergence Zone (ITCZ), the main rainfall producing system for the region. During all seasons, the predominant winds over Fiji are the southeast trade winds. Rainfall is highly variable from region to region and is mainly influenced by the island topography and the prevailing southeast trade winds. Temperatures throughout Fiji are fairly uniform. In the lee of the mountains on the larger islands, however, the day-time temperatures are often 1 – 2 °C above those on the windward side.

1.2. *Physical Geography and Bathymetry of the Suva Lagoon*

The city of Suva is perched on a hilly peninsula between Laucala Bay and Suva Harbour, which together comprise the Suva Lagoon in the southeast corner of Viti Levu. The Suva Harbour lays on the west of the lagoon and to the east lays Laucala Bay, as shown in Fig. 2.

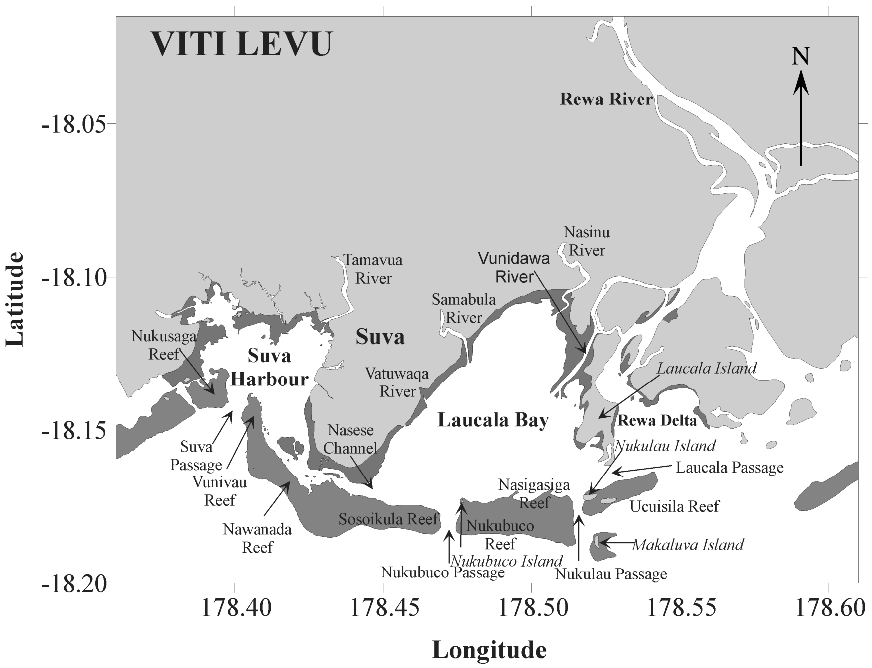


Figure 2. Map of the Suva Lagoon.

The average water depth in Laucala Bay is 9 m deepening to more than 40 m in the Nukubuco and Nukulau Passages. Laucala Bay is connected to Suva Harbour by the narrow Nasese Channel that is 5–10 m deep. Suva Harbour has an average depth of 15 m with depths of 80–100 m in the Suva Passage [1].

The Rewa River is the longest river and the largest fluvial system in Fiji. Its drainage basin covers one-third of the island of Viti Levu and originates in Tomanivi (Mount Victoria), the highest peak in Fiji (maximum height above sea-level is 1323 m), and flows southeast for 145 km before splitting up two-thirds on its way downstream into several tributaries. One of these tributaries is the Vunidawa River, which is the major source of variations in salinity, temperature and turbidity in the Suva Lagoon. It is therefore important to study the freshwater runoff in order to understand the water properties in the lagoon.

1.3. *Hydrodynamic Circulation*

The first application of a hydrodynamic model to the Suva Lagoon was done by Kumar [2]. He used a 2D model (built by the Institut de Recherche pour le Développement – IRD in Noumea) to define the water circulation due to the M_2 tidal constituent (without river runoff or wind). Rao [3] built up on the work done by Kumar [2] by using the application of a 3D hydrodynamic model (also built by IRD) to determine the water circulation in the Suva Lagoon by considering the effects of river runoff, wind stress, bathymetry, bottom friction and the M_2, S_2, K_1 and O_1 tidal constituents. This project will further build up on the work of Rao [3] by applying a modified MARS3D model to the Suva Lagoon to simulate the salinity distribution due to different river discharges.

2. Methodology

2.1. *Wind Data*

The wind data was monitored at the School of Marine Studies (SMS) at the University of the South Pacific under technical assistance of IRD. The wind speed and direction were recorded at regular intervals of 10 minutes at a height of 10 m above mean sea level.

2.2. *River Runoff and Rainfall Data*

The Rewa River is fed by several rivers before it reaches the Suva Lagoon. These rivers include the Waidina, Wainimala, Wainibuka and Waimanu Rivers (located further north of Suva therefore not shown in Fig. 2), which introduce a significant amount of freshwater into the Rewa River [4]. Although direct measurements of river discharge at the Rewa River mouth is not available, the discharge from the Rewa River can be determined by adding up the individual runoffs from these rivers. However, due to the lack of continuous discharge data of these contributing rivers into the Rewa River, the Rewa River discharge during the sampling time was determined by plotting a relationship between available discharge data between years 2000 and 2005 (from the Fiji Hydrology Department) and rainfall data for the same period (from the Fiji Meteorological Service).

2.3. *Water Properties Data*

The water properties in the Suva Lagoon were determined by collecting *in situ* data using a CTD probe, fitted with an additional sensor to measure turbidity. Several cruises were taken in 2006 during the wet-warm and dry-cool seasons, but a data set each from the wet-warm season (*Cruise 1*) and the dry-cool season (*Cruise 5*) will be discussed in this paper.

2.4. *Model Validation and Implementation*

An improved version of the MARS3D model [5] is applied to the Suva Lagoon in this study. This model is able to simulate the salinity distribution in the lagoon due to different tidal and wind forcings and river runoffs. The model solves the governing equations using the hydrostatic and Boussinesq approximations. Boundary conditions are imposed at the sea-surface, sea-bottom and along the coastline. The Alternating Direction Implicit (ADI) method is used for time discretization and the finite difference method is used for space discretization. A modified Arakawa C-grid is used in the study.

Model validation was carried out by comparing the profiles of salinity from the model output with field data. Once validated, the model was used to simulate the salinity distribution in the lagoon under different river discharges.

3. Results and Discussion

3.1. *Field Data*

3.1.1. *Wind regime*

During the dry-cool season (May–October), the southeast trade winds are dominant blowing with great regularity over the lagoon. The mean monthly wind speed during the dry-cool season is between 4.4–5.6 m s^{-1} and between 3.3–4.5

m s^{-1} during the wet-warm season (November–April). Figure 3 shows the magnitude and direction of the wind during the dry and wet seasons.

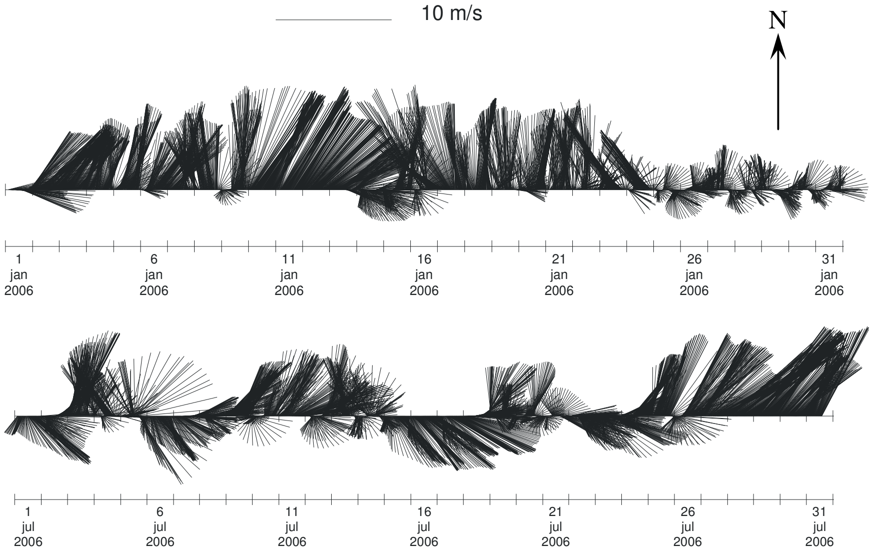


Figure 3. Two hourly wind stick plots showing magnitude and direction of wind during the wet-warm season (above) and dry-cool season (below) for the Suva Lagoon.

3.1.2. *River discharge*

A relationship between river discharge and rainfall was used to determine the river discharge during the sampling period as data was unavailable for that period. The mean monthly runoff of the Rewa River shows a linear relationship with the total monthly rainfall at Suva with a correlation coefficient of 0.87 [3]. Equation (1) shows the relationship between river discharge and rainfall.

$$R_d = 0.4393 R_f + 31.722 \qquad (1)$$

where R_d is the Rewa River discharge in m^3 s^{-1} and R_f is the total monthly rainfall at Suva in mm. Using Eq. (1), it was found that the river discharge during *Cruise 1*, the wet-warm season, was ~200 m^3 s^{-1} and ~80 m^3 s^{-1} during *Cruise 5*, the dry-cool season.

3.1.3. *Field salinity*

The salinity in the Suva Lagoon is largely controlled by the freshwater input from the Vunidawa River. During the wet-warm season, there is high rainfall resulting in high freshwater discharge therefore salinity in the lagoon is expected to be low. The low discharge during the dry-cool season due to low rainfall is expected to affect the lagoon salinity to a lesser extent. The salinity variations in the lagoon were analyzed for the wet-warm and dry-cool seasons and are plotted in Fig. 4.

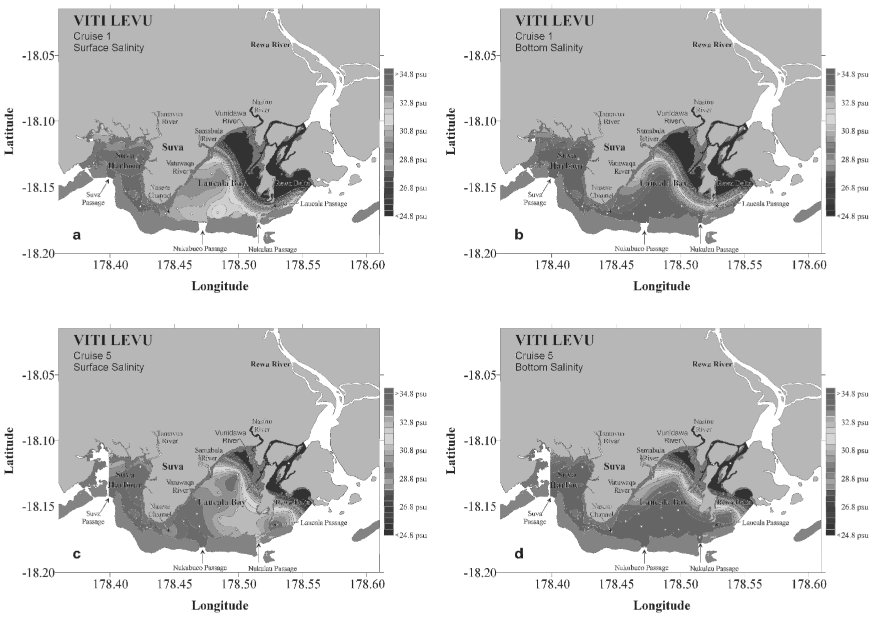


Figure 4. Horizontal salinity variations on the surface (left column) and bottom (right column) in the Suva Lagoon during the (a&b) wet-warm and (c&d) dry-cool seasons.

The low salinity water near the head of Laucala Bay during *Cruise 1* is due to the high freshwater discharge from the Vunidawa River entering Laucala Bay. The shallow waters at the head of the bay kept the surface and bottom salinity below 24.8 psu as can be seen in Fig. 4(a&b). A path of low salinity water on the surface near the head of the bay was observed to be forming along the shallow Laucala Bay coast. The path is more evident in the bottom layer as seen in Fig. 4b and indicates that freshwater discharged from the Vunidawa River enters the bay and begins to flow seaward along the coast. The surface salinity in the bay was between 31.2–33.3 psu and the bottom salinity ranged from 32.4–34.9 psu indicating freshwater mixing on the surface layer and an influx of seawater through the Nukubuco and Nukulau Passages in the bottom layer. The Suva Harbour seems to be isolated from the effects of the freshwater discharge from the Vunidawa River.

Due to the low freshwater discharge from the Vunidawa River during *Cruise 5*, the salinity in Laucala Bay was generally found to be higher than during *Cruise 1*. The surface salinity in Laucala Bay ranged from 33.7 psu near the head of the bay to 34.5 psu at the Nukubuco Passage. The high salinity water entering through the Nukubuco Passage at the surface can be seen to move towards the Laucala Bay coast and the middle of the bay as seen in Fig. 4(c&d). This highly saline water extends towards the head of Laucala Bay mixing with the freshwater discharged from the Vunidawa River. Although the freshwater discharge is low during the dry-cool season, it still influences the salinity in the bay. Suva Harbour is unaffected by the freshwater discharge from the Vunidawa River.

3.1.4. *Field temperature*

The water temperature in the lagoon is expected to be higher in the wet-warm season than in the dry-cool season. The freshwater input from the Vunidawa River is the major source of temperature variations in the lagoon. The temperature variations in the lagoon were analyzed for the wet-warm and dry-cool seasons and are plotted in Fig. 5.

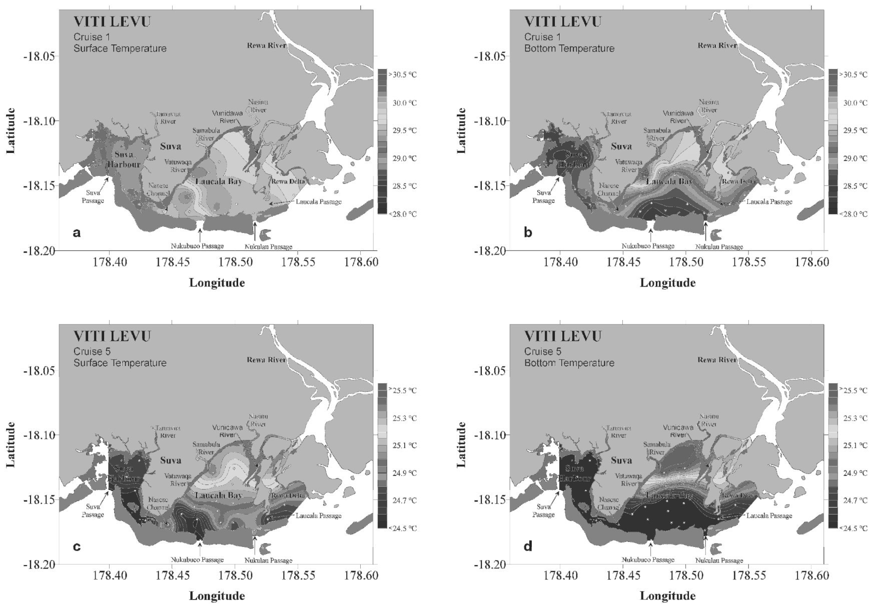


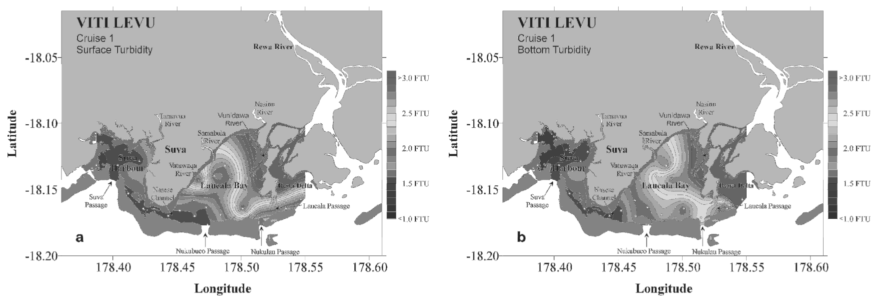
Figure 5. Horizontal temperature variations on the surface (left column) and bottom (right column) in the Suva Lagoon during the (a&b) wet-warm and (c&d) dry-cool seasons.

Figure 5a shows that the surface temperature in Laucala Bay during *Cruise 1* ranges from 30.0°C near the head of the bay to 30.2°C in the middle of the bay and 29.3°C at the Nukubuco Passage. Figure 5b shows that there is an influx of cold seawater from the Nukubuco Passage moving towards the middle of the bay. A path of warm freshwater is observed to be moving along the Laucala Bay coast towards Nasese Channel. The surface and bottom temperatures in Suva Harbour are fairly uniform at around 29.3°C and 28.5°C respectively showing little or no influence of the effects of the discharge of the Vunidawa River.

The surface temperature in Laucala Bay during *Cruise 5* ranged from 24.5°C near the passages to 25.2°C near the head of Laucala Bay as seen in Fig. 5c. Cooler waters entering through the Nukubuco Passage extended to the middle of the bay where it mixed with the warm waters discharged from the Vunidawa River. A path of warm water was observed to be forming along the Laucala Bay coast as can be seen in Fig. 5d. The surface and bottom temperature at Suva Harbour was uniform at 24.7°C and 24.4°C respectively.

3.1.5. *Field turbidity*

The turbidity in the Suva Lagoon is influenced to a large extent by the freshwater input from the Vunidawa River. The turbidity is expected to be high during the wet-warm season when the freshwater discharge is high and low when during the dry-cool season. The turbidity variations in the lagoon were analyzed for the wet-warm and dry-cool seasons and are plotted in Fig. 6.



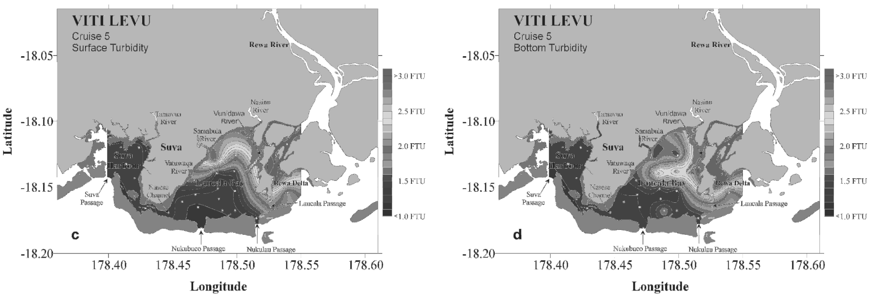


Figure 6. Horizontal turbidity variations on the surface (left column) and bottom (right column) in the Suva Lagoon during the (a&b) wet-warm and (c&d) dry-cool seasons.

Figure 6(a&b) shows that the turbidity in Laucala Bay during *Cruise 1* is high at the Vunidawa River mouth. Surface turbidity is 2.0 FTU while the bottom turbidity is 2.8 FTU. There is higher turbidity at the bottom due to resuspension of bottom sediments in the water column. There are also discharges form smaller rivers like the Vatuwaqa River where the surface turbidity at its river mouth is 2.9 FTU and 2.0 FTU at the bottom. The turbidity found at Suva Harbour is less than 1.8 FTU with maxima near the Tamavua River mouth.

Due to lower freshwater discharge during the dry-cool season, the turbidity in Laucala Bay is less. However, turbid waters (2.9 FTU) were observed on the surface (Fig. 6c) at the mouth of the Samabula River. The bottom turbidity (Fig. 6d) at the Vunidawa River mouth was found to be higher than the surface turbidity. This is due to resuspension at the bottom stirring up the bottom sediments. Lower turbidity in Laucala Bay is due to lower freshwater discharge during the dry season. The Suva Harbour shows uniform turbidity of 1.2 FTU from the surface to a depth of 30 m.

3.2. *Model Verification*

Verification of the model was carried out by comparing the field data with model output. A successful comparison would be achieved if the profiles derived from the model follow the field profiles. To ensure realistic representation, the model used the M_2, S_2, K_1 and O_1 constituents of tide, wind data from the weather station at SMS for the simulation period and a river discharge of 200 m^3 s^{-1}. The model results are taken 120 hours after the introduction of freshwater into the model.

3.2.1. *Salinity profiles from the model results and field data*

Four sites were chosen to represent salinity distribution in the lagoon. These were at Suva Harbour, Nukubuco Passage, Laucala Bay and Rewa Delta. Figure 7 shows the field and model salinity profiles at each site.

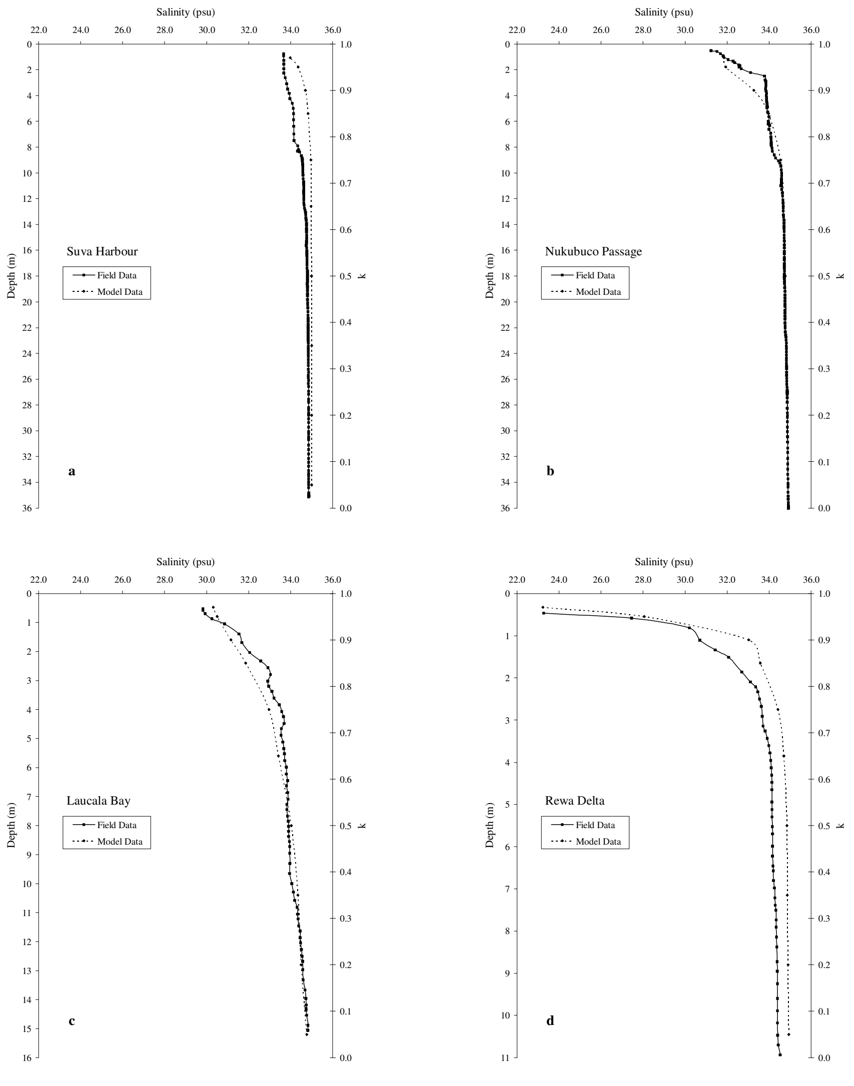


Figure 7. Field and model salinity profiles levels at different locations in the Suva Lagoon (a) Suva Harbour, (b) Nukubuco Passage, (c) Laucala Bay and (d) Rewa Delta.

The model salinity in Suva Harbour (Fig. 7a) shows a slight deviation from the field salinity at the surface. This can be attributed to the estimated discharge of 5 $m^3\ s^{-1}$ from the Tamavua River used in the model. The discharge is probably more and using a higher value for the discharge will decrease the model salinity and generate a more accurate salinity profile. The model salinity at Nukubuco Passage and Laucala Bay (Fig. 7b, c respectively) follow the field salinity with an average deviation of 0.2 psu. The model salinity is generally lower than the field salinity at the surface due to the continuous river discharges used in the model. Instead of using a constant rate of river discharge, more realistic and instantaneous runoffs would increase the model salinity generating more accurate profiles. The salinity profiles show a good comparison between model output and field data in the Rewa Delta (Fig. 7d).

The bottom salinity at the four sites shows better agreement between model results and field data than at the surface. This means that the discharge from the rivers influences the surface salinity more than the bottom salinity. This is similar to Rao's [3] findings. The model and field salinity profiles in Fig. 7 follow each other in a similar manner showing that the model is reasonably capable of representing the salinity distribution in the Suva Lagoon fairly accurately and that the model has been verified for salinity distribution. The model used 10 vertical σ layers to represent the salinity distribution.

3.2.2. *Model salinity distribution in the lagoon*

In order to study the salinity distribution during the wet season, more realistic river discharge is used in the model. In accordance to past records, a river discharge of 400 $m^3\ s^{-1}$ was used in the model. The results are studied after 120 hours from point of introduction of freshwater into the model and are shown in Fig. 8.

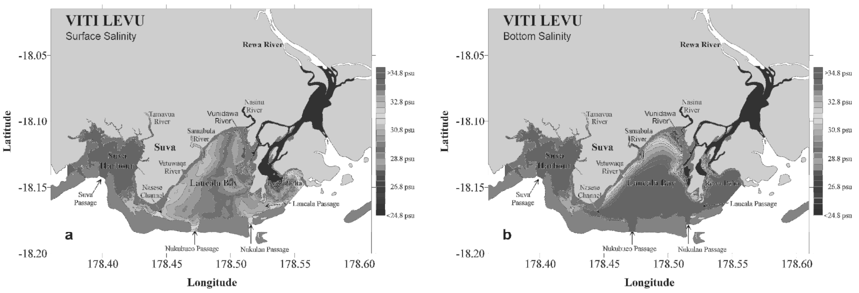


Figure 8. Horizontal salinity variations on the (a) surface and (b) bottom in the Suva Lagoon for a river discharge of 400 $m^3\ s^{-1}$.

The high volume of freshwater rushes into Laucala Bay largely undiluted so the salinity drops at the surface remaining below 24 psu (Fig. 8a). Since the volume of low salinity water is large, the transport of freshwater water and vertical mixing by the wind is enhanced. The wind drags the low salinity surface water into the harbour while in Laucala Bay, vertical mixing by tides transports low salinity water to the bottom making the salinity distribution at the bottom less saline. The bottom salinity along the coast was less than 24 psu (Fig. 8b) due to the small depths along the coast.

4. Conclusions

The southeast trade winds have a mean annual wind speed of about 6 m s^{-1} and are an important component in the distribution of salinity, temperature and turbidity in the lagoon. River runoff is also an important factor which influences the distribution of these parameters. The high discharge from the Vunidawa River during the wet-warm period is seen to affect the lagoon water properties more than during the dry-cool period.

The southeast trade winds tend to push the freshwater discharged from the Vunidawa River towards the head of Laucala Bay resulting in high temperature and turbidity and low salinity waters being accumulated there. The piled-up water flows back along the Laucala Bay coast and towards Nasese Channel. The influx of seawater through the Nukubuco and Nukulau Passages extend up to the middle of the bay beyond which there is mixing with freshwater at depths of less than 3 m.

The validated numerical model was sufficiently able to replicate the field salinity with some modifications needed to get a more precise agreement between model output and field data. These modifications include addition of discharges from the smaller rivers entering the Suva Harbour and Laucala Bay. Model simulations of high river discharge of 400 m^3 s^{-1} on the salinity distribution showed conformity with field data.

Further work is currently being undertaken to validate the model for turbidity distribution and to test the model for different river discharges on the suspended sediment transport in the lagoon. The importance of the sandbank on the salinity and turbidity distribution in the lagoon and the effect of increasing the model resolution are also being studied.

Acknowledgments

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