IMPACT ANALYSIS OF NATURAL AND SOCIO-ECONOMIC FACTORS IN CORAL COAST AREA USING REMOTE SENSING AND GIS

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The coastal ecosystem is of vital importance to Fiji because of their dependence on marine resources for basic livelihood. These marine resources have been rapidly deteriorating due to elevated nutrient level and sediment discharge. This study focuses on intense and sustained environmental pressures from a range of driving forces in the Coral Coast area of Viti Levu Island, Fiji. The main objectives are to assess the change in coral cover using Landsat ETM$^+$ data, simulate the transport of runoff and sediment in the Coral Coast area using SWAT (Soil and Water Assessment Tool) model and measure the expected anthropogenic pressure generated from different socio-economic activities. The change detection analysis from 1999 to 2003 shows that coral cover reduced by 26 % while algae and sargassum cover increased by 119% and 53 % respectively. The massive growth of algae and sargassum is due to nutrient discharge from coastal villages, as expected anthropogenic pressure increased from 3.66 to 3.85 during 1999-2003 within 3km distance from the coast.

Key Words : *Coral reefs, Coral Coast, Remote sensing, SWAT, Anthropogenic pressure*

1. INTRODUCTION

Coral reefs and their associated habitats are important resources throughout the Fiji Islands. Fiji's economy depends on these marine resources as reefs sustain the second largest aquarium export industry in the world (Green et al., 2001) and tourism became the largest gross foreign exchange earner. In 1999, tourism contributed approximately 16 % of GDP and 22% of foreign exchange.

These coastal zones are currently experiencing intense and sustained environmental pressures from a range of driving forces (Turner et al., 1996). The main stressors affecting the coastal ecosystem are sediments and nutrients from terrestrial ecosystem, which occurs through river transport and via drainage basin network. This need the assessment of driving forces to provide an understanding of socio-economic changes on ecosystem. In the Coral Coast of Viti Levu Island, Fiji, coral reefs have been rapidly deteriorating because of population growth, coastal development, influx of tourism, coral and live rock harvesting, agriculture, deforestation and other factors (Hinrichsen, 1997). The nitrate and phosphate level exceeded thresholds considered harmful to coral reef ecosystems in the Coral Coast area (Mosley and Aalbersberg, 2003) as most of the socio-economic activities are located on the coast, this requires monitoring of coral reef status in the Coral Coast for better management of these important marine resources.

Monitoring and management of tropical benthic habitats require accurate and timely information on the composition and condition of the habitat. In the most common approaches for the monitoring of coral reef environments, field sampling requires large numbers of transects data to monitor the extent of the reef environment, which can be costly and labour intensive. Remote sensing technology is an ideal monitoring tool as it can cover the complete spatial extent of a management area and be collected on a repeated basis (Green et al., 2000). Instead of this it can identify a number of environmental variables associated with habitat that are potential indicators of marine resources distribution and abundance such as coral reefs, algae and seagrass. The objectives of this study are i) to assess the change in coral cover, prepared using Landsat ETM+ data ii) modeling of run-off and sediment discharge from adjoining catchments areas of the Coral Coast area and iii) to find out the influence of land based pollution on fringing coral reef by measuring expected anthropogenic pressure generated from different socio-economic activities with respect to distance and location.

2. METHODOLOGY

(1) Study Site

The Fiji group is situated in the South West Pacific Ocean between latitudes 15-22°S and longitudes 174-178°W. The Coral Coast region is found in the Nadroga Navosa Province on the southern coast of Viti Levu (Figure 1) and stretches from Natadola bay in the west to Namatakula village in the East. Fringing reef extends along the Coral Coast for approximately 63 kilometres and up to 1000 metres offshore. The continuity of the reef is broken by channels cut through the reef due to fresh water influx from rivers and streams and sediment deposition. Tides are semi-diurnal with neap tides having a mean range of 1.6 m and spring tides 1.7 m (Sanchez 1999).Temperature is relatively consistent due to the ocean ranging from a low of 18°C during the coolest months (January and February) to a high of 32°C during the warmest months (July-August). Rainfall is highly variable and mainly orographic often falling in heavy, brief local showers. The predominant winds are the trade winds from the east to southeast, which are generally light to moderate in strength.

(2) Image acquisition and preprocessing

In present study Landsat ETM+ data (4th October, 1999 & 5th March, 2003) with spatial resolution of 30 m. has been used for investigating coral reef habitats. The image was system corrected using UTM Zone 60 and WGS 84 as the projection and reference ellipsoid, respectively. The images are corrected for the atmospheric effects using the Fast Line-of-Site Atmospheric Analysis of spectral Hypercubes (FLAASH) module of ENVI software. A manually digitized land and deep water mask, was applied to enable image processing with focus on the shallow water of Coral Coast area. Then water column correction was performed using depth-invariant index proposed by Lyzenga (1981) to enhance bottom type information.

(3) Image Classification

The images were classified on the basis of spectral characteristics of benthic cover using relationship between band and Landsat ETM$^+$ data digital number (DN). The data has been classified using visual interpretation method with combination of supervised classification to improve the quality of classified output. For supervised classification the signatures were selected for each of the benthic

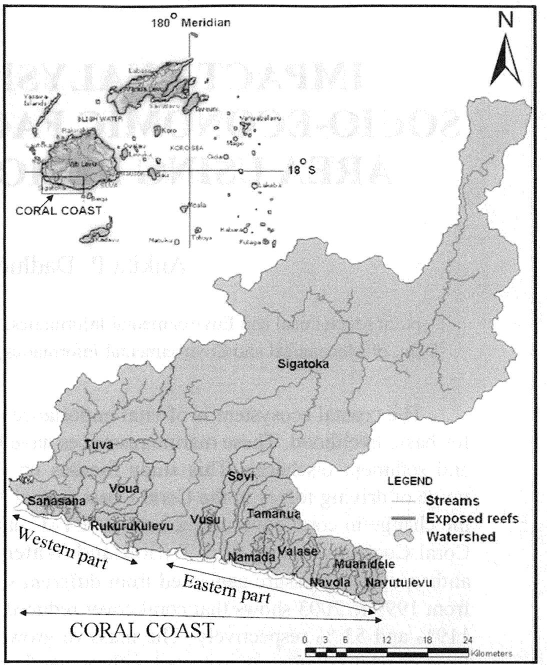

Fig.1 Study location with 16 watersheds along the Coral Coast

Cover (coral, algae, sargassum, rubble, pavement and cay sand) to classify the image using maximum likelihood classifier. A few wrongly classified image features were reassigned manually to the correct classes based on the local knowledge, pixel location and association.

(4) Runoff and sediment yield simulation

The Soil and Water Assessment Tool (SWAT 2005), a physically based continuous time model (Arnold et al., 1998) is used to simulate the transport of runoff and sediment into Coral Coast adjoining watershed areas. SWAT is linked with raster-based geographical information system (GIS) to facilitate the input of the spatial data such as land use, soil map and digital elevation model (DEM). The model is based on the water balance equation:

$$SW_t = SW_{t-1} + \sum_{i=1}^{t} (R_i - Q_i - ET_i - P_i - QR_i) \quad (1)$$

Where, SW is the soil water content; i is the time t (days) for the simulation period; R, Q, ET, P and QR are daily precipitation, runoff, evapo-transpiration, percolation and return flow, respectively. The quality of the calculations performed using SWAT is greatly influenced by the detail of the maps used. Therefore, 25 m resolution DEM is created using topographic maps, from which 16 watersheds (Figure 1) have been delineated adjoining the Coral

Coast area, as well as some topographic attributes (area, slope, slope length) and characteristics of their channel network including length, width and mean slope gradient. The soil map was generated from soil data acquired from Land Resource Planning Division, Fiji. The land use map for the year 1999 is derived from Landsat TM^{+} data and classified into nine landuse classes: high dense vegetation, low dense vegetation, agriculture, built-up, inland waterbody, open land, sugarcane, forest plantation and mangrove forest. For the period 1993-2007, daily values for precipitation, temperature and wind speed, average monthly solar radiation and relative humidity are acquired from Fiji Meteorological service. Daily stream flow data for the major watershed (Sigatoka) is acquired from Department of Energy, Fiji for year 1993-1998.

(5) Expected anthropogenic pressure

To investigate the effect of nutrients on coral cover, different indicators of human activities have been used to measure the expected anthropogenic pressure in Coral Coast area. This requires the rating to criteria deemed relevant to determine expected anthropogenic pressure (Reopanichkul et al., 2009).The weights for each of the criteria are assigned according to their quantity of discharge and distance from the coastline. An ordinal scale is created for each criterion to reflect relative importance to the level of impact (Table 1). The expected level of anthropogenic pressure is calculated by the formula:

$$P = \sum \left(C^{1-n} * W^{1-n} \right) / \sum W^{1-n} \qquad (2)$$

Where, P is expected anthropogenic pressure, C is criteria for rating 1 to n, W is weight for criteria 1 to n. To quantify the impact of human induced

Table1. Weighting and ratings used to determine expected anthropogenic pressure

Criterion	Criterion Weight					Expected anthropogenic pressure rating
	Based on discharge	Based on distance from coastline				
		0-3km	3-6km	6-9km	>9km	
1.Village discharge	9	7	5	3	2	1 to 4 1= low discharge to the sea, 4= high discharge to the sea
2.Livestock discharge						
(i) Beef farms	7	7	5	3	2	
(ii) Dairy farms	6	7	5	3	2	
(iii)Piggeries	5	7	5	3	2	
3.Hotel discharge	4	7	5	3	2	
4. Agriculture discharge	2	7	5	3	2	

activities on the coral community, the buffer zones are created from the coastline, and on the basis of intensity of impact, the rates are allocated to each of the criteria.

3. RESULTS AND DISCUSSION

(1) Coral cover change

The data revealed considerable changes in coral cover of the Coral Coast area from 1999 to 2003 period (Figure 2). On the Coral Coast high levels of algae, dominated by sargassum are found in the inner reef flat area at many locations especially near hotels and coastal villages. The increased nutrient inputs from septic tank and sewage discharges (IAS 2004) have led to a 'phase shift' to algal dominated reefs (McCook 1999) in the Coral Coast area. The change detection analysis of both the images (Table 2) show that coral cover reduced by 26% while algae and sargassum cover increased by 119% and 53% respectively during study period. The overall

Table 2 Coral cover change matrix

Classes	Area (Ha.) in 1999	Area (Ha.) in 2003	% change
Pavement with algae	547.83	530.36	-3.18
Algae	149.04	326.43	119.02
Sargassum	327.15	501.75	53.37
Rubble	521.91	491.98	-5.73
Coral	889.47	656.91	-26.14
Cay sand	713.34	641.1	-10.12

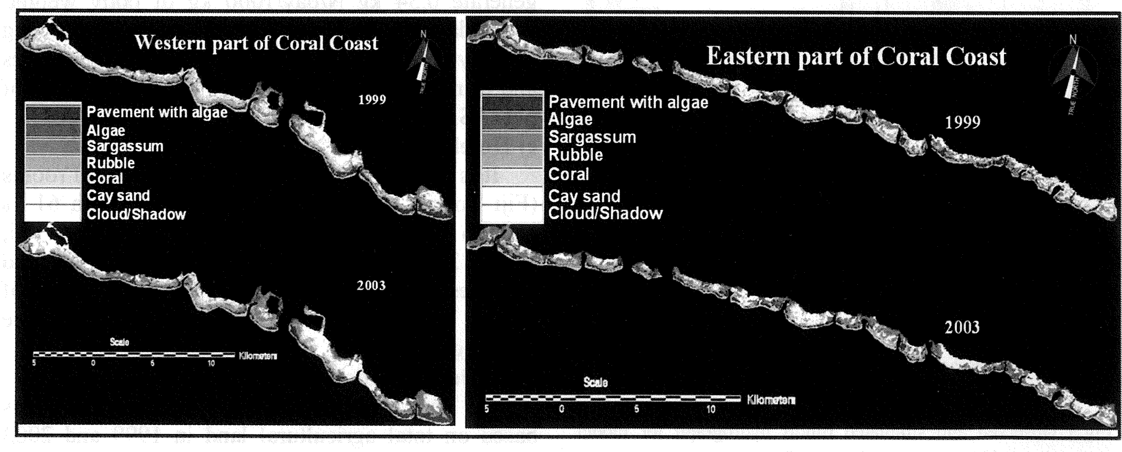

Fig. 2 Coral cover change in Coral Coast area using Landsat ETM^{+} data

accuracy of the classified data is 89.8% and 90% for 1999 and 2003 respectively checked using satellite data with ERDAS module and also with the results of the marine assessment report (Rowlands et al. 2005) for the Coral Coast area. For considering the seasonal variations of algae growth, long term field monitoring was done in study area. Results showed that higher rainfall generated correspondingly peaks of chlorophyll-a concentration in Coral Coast area.

(2) Runoff and Sediment yield Analysis

The daily observed values of surface runoff acquired for Sigatoka watershed for the year 1996 were used for calibration and daily observation data for 1997 to 1998 have been used to validate the model. The time series of the observed and simulated daily runoff for the calibration and validation period were compared graphically (Figure 3). It was observed that the time to the peaks of the simulated runoff hydrograph matched well with its observed values throughout the period. A high value of the coefficient of determination r^2 of 0.94 indicates a close relationship between the observed and simulated runoff. This calibrated model was used to predict the runoff and sediment yield for the remaining 15 watersheds. The maximum sediment yield is observed (Table 3) from Sigatoka watershed (area 1475.749 km^2). The runoff and sediment yield was higher in 1999 due to high precipitation (3141 mm), while reduced in 2003 as precipitation was 1285 mm.

(3) Expected Anthropogenic Pressure

For coastal ecosystem the impact of terrestrial runoff and sewage pollution are the important issues for the nations endowed with coral reefs (Bryant,

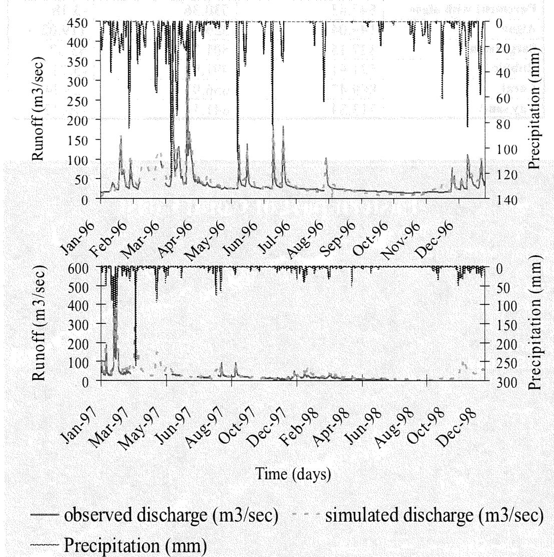

Fig.3 Observed and simulated runoff hydrograph for model calibration (1996) and validation (1997-98)

Table 3 Simulated Runoff and sediment discharge

Watershed	Area (km^2)	Runoff (m3/sec)				Sediment Yield (t/ha)	
		1999		2003		1999	2003
		max	min	max	min		
Sigatoka	1475.749	780	8.05	618	4.04	454.14	52.54
Tuva	231.516	599	2.23	217	1.05	217.08	14.32
Tamanua	72.321	288	1.02	73.7	0.98	306.14	10.68
Voua	70.719	276	0.9	68.2	0.86	310.27	12.31
Sovi	68.483	268	0.89	68.7	0.84	224.19	10.66
Muanidele	25.771	103	0.54	26.4	0.42	300.51	14.68
Valase	21.80	575	2.02	22.3	0.96	253.7	12.10
Rukurukulevu	16.796	36.7	0.42	8.93	0.38	303.47	10.90
Namatakula	14.876	59.8	0.67	15.3	0.55	346.32	10.58
Sanasana	14.664	3.64	0.23	1.8	0.13	203.56	11.17
Vusu	13.231	53	0.62	13.4	0.48	149.48	10.48
Nawaqadamu	12.677	51	0.97	13	0.44	238.47	10.44
Navutulevu	12.373	49.4	0.95	12.5	0.60	302.92	10.70
Navola	11.481	17.1	0.43	4.36	0.39	249.76	10.44
Vatukulelima	9.303	37.4	0.42	9.54	0.31	241.09	13.04
Namada	6.685	26.8	0.83	6.82	0.80	187.96	10.41

1998; Spalding et al., 2001). The effects of these pollution sources differ between locations, distance from point sources and input load. For this purpose nutrient discharge from different sources (villages, livestock farms, hotels/resorts, and agricultural lands) has been quantified.

a) Village discharge

It is calculated on the basis of village population in 1999 and 2003 (projected on the basis of 1996 census data with 0.7 % annual growth) and nitrogen discharge from the human waste. Human wastewater contains approximately 4 kg N/person/year (Gold and Sims, 2001). Maximum weight is given to the village discharge due to 70 % of the nitrogen loading from household wastewater in the village reaches coastal water (Tanner and Gold, 2004).

b) Livestock discharge

The nutrient discharge from piggeries, beef farm and dairy farms is calculated on the basis of average number of farms and average population for each village in Nadroga/Navosa province. The beef cattle generate 0.34 kg N/day/1000 kg of body weight, while dairy cattle generate 0.45 kg N/day/1000 kg of body weight (ASAE, 1993), pigs generate faeces and urine containing 9.5 kg N /year/50 kg mass of pig (ASAE, 2000).

c) Hotel discharge

It is calculated on the basis of 1147 hotel rooms (Fiji Tourist development Plan, 1996), with 61 % and 56 % occupancy (Bureau of Statistics, Fiji, 2010); 2.4 and 2 room density for year 1999 and 2003 respectively. The standard nitrogen loading of 4 kg N/person/year is used to calculate the discharge.

d) Agriculture discharge

The discharge from agricultural area is based on total agricultural land in 1999 and 2003 derived from Landsat ETM+ data and fertilizer

Table 4 Expected anthropogenic pressure

Distance	Anthropogenic pressure (1999)						Total	P
	Villages	Beef farms	Dairy farms	Piggeries	Hotels	Agriculture area		
0-3km	239.4	186.2	157.5	122.5	84	56	845.6	3.66
3-6km	135	128.3	110	84.1	40	40	537.5	3.25
6-9km	54	72.87	63	49.5	0	21	260.37	1.97
>9km	18	47.97	40.28	32.3	0	8	146.62	1.11
Distance	**Anthropogenic pressure (2003)**						**Total**	**P**
	Villages	Beef farms	Dairy farms	Piggeries	Hotels	Agriculture area		
0-3km	252	196	159.6	129.5	112	42	891.1	3.85
3-6km	180	129.8	111.3	86.25	60	30	597.4	3.6
6-9km	81	73.5	63.9	51	0	12	281.4	2.1
>9km	54	48.3	41.4	33.3	0	8	185	1.4

consumption, which is reduced (FAO, 2009) from 51 kg/ha (1999) to 12.9 kg/ha (2003). Results of quantification of nutrient discharge shows maximum input from coastal villages, which rely on onsite wastewater disposal in comparison to other activities and most affected area is within 3km from the coast. The expected anthropogenic pressure (Table 4) increased from 3.66 to 3.85 during 1999-2003 from the villages within 3 km distance from the coast.

4. CONCLUSION

The massive growth of Sargassum macroalgae is deteriorating the health of the fringing reefs in the Coral Coast. The benthic cover change analysis from 1999 to 2003 using Landsat ETM$^+$ data shows that proliferation of algae and sargassum may threaten the future of the tourism industry, and livelihoods of the local communities living along the Coral Coast. The freshwater and sediment discharge input from sixteen watersheds adjoining the Coral Coast is also quantified using SWAT. Calibration and validation results indicate that the SWAT model simulations compare closely with measurements and produce a set of model parameters within physically realistic ranges and acceptable approximations of runoff and sediment yield. The runoff and sediment discharge is maximum from the Sigatoka watershed but the effect of other small watersheds can not be ignored as soil loss is high especially during high rainfall event. In order to quantify the major sources of nutrient input to the Coral Coast, different indicators of human activities have been used to measure the expected anthropogenic pressure. The coastal villages were found to be the dominant source of nutrient discharge followed by livestock farms and hotels. This requires an integrated approach for coastal management to improve and sustain the status of water quality through effective sewage treatment as well as improved agricultural practices. Accordingly, plans are necessary to continue Coral Coast as major tourist destination.

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