STUDY AREA
Goa is the smallest state of the Indian union lying along the West Coast. It is located between latitudes 15°48'33"N and 14°53'54"N longitudes 74°20'13"E and 73°40'33"E situated at 1,022 m above sea level. The three lakes chosen for the present limnological studies are Pilar lake (PL), Carambolim lake (CL) and Santa Monica lake (SML). These are located close to one another in Tiswadi Taluka of Corlim district in north Goa, 12-16 kms away from the capital city Panaji. Of these, PL is located at 73°54'N and 15°27'E. CL at 73°55'N and 15°30'E and SML at 73°57'N and 15°31'E. A distance of 3 km separates PL and CL while SML lies 1 km away from Carambolim lake (Map: 0.1).

PL, the smallest of three lakes is a natural water body spread over an area of 3.34 ha (Fig: 0.1). It is flanked by a road on its north and east. On its southern and western sides Pilar village is situated in the immediate neighborhood. On the northeast corner of the lake the village road joins another main road passing through Carambolim and Neura village connecting the two highways NH 17 and NH 4A (Map: 0.2). Towards the northwest corner of the lake, lies the village crematorium (Fig: 0.2). A small agricultural plot (area=100*20m) in its north encroaching into the lake is used for growing vegetables during summer exposure. The lake water is used mainly by the villagers for various purposes like washing of clothes, cattle, vehicles and irrigation of agricultural plots located in the immediate vicinity. The lake also serves as a dumping ground for post cremation remnants like ash and bones. During summer, the exposed and completely dry eastern edge is used as an amusement park/recreation ground by children and village folk.

CL is a unique man-made minor irrigation tank. It is the largest of all the three lakes under study spread over an area of 70 ha. of which central 40 ha. is chiefly water laden and surrounded by grassland (Fig: 0.3). As shown in map 0.3
the top southern embankment serves as the approach road linking Carambolim village with neighboring Pilar. The railway route on the western edge of the lake cuts an area of about 1 ha while an agricultural plot of about 150 * 30 m² area encroaches into the lake along the eastern edge (Fig: 0.4). The lake besides serving the purpose of minor irrigation is largely used as a dumping ground for waste, for making religious offerings, bathing the cattle and also as sanitation ground.

SML is a permanent man-made wetland situated inside the industrial premises of Novartis India Ltd (Map: 0.4). On the southern edge of the lake lies the NH 4A and the Cumbarjua canal on its north. The lake, spread over an area of 8.85 ha. gets divided into two unequal parts a larger A in the east and a smaller B in the west, by an approach road to the industry, running in northsouth direction and linking the NH4A. Lake A (Fig: 0.5) with the surface area of 7.34 ha. and lake B (Fig: 0.6) with a surface area of 1.50 ha. are connected to each other trough two culverts beneath the approach road.

Water Regime

Contour maps indicating the bathymetric profile of the lakebeds PL, CL and SML are presented in Map 0.5, 0.6 and 0.7 respectively. While seasonal variations in the volume of water in the lakes through different seasons are presented in table: 0.1 and its monthly variations are presented in Graph: 0.1.

At PL, the bed being bow shaped, retains most of its water in the central region. Monsoonal precipitation and surface run off are the only sources of water to the lake. Maximum depth of the lake was up to 1.70 m in the eastern end. Maximum volume of water in the lake was recorded during August being upto 10,30,61.28 m³ while it was minimum during June being 230,457.64 m³. The
The lake was full during mid monsoon and post-monsoon. The water column which receded continuously through winter and summer reached the lowest ebb during late summer/early monsoon.

The lake bed at CL is more or less uniformly flat except for the deeper region more towards the southern end of the lake in the vicinity of sluice gates (Fig: 0.7), where in the depth was 2.75 m. The major source of water to this lake is surface run-off directed towards it through culverts situated beneath the railway tracks on the western edge. The sluice gates in the southern region are manually operated. The sluice gates are closed by mid July or early August thereby flooding the lake upto 20,34,211.12 m³ by end of August. The regular water flow irrigates the Rabi crop of paddy in the lower reaches grown during winter period (Fig: 0.8 and 0.9). The maximum volume of water attained by end of August remains within higher limit till post monsoon and starts depleting precipitously through winter and reaches the lowest limit by late summer. Unlike PL, at CL, the volume of water during summer/early monsoon is minimum, only in the form of a zigzag watercourse running diagonally across the lake. Harvesting of the naturally grown fish in the lake is initiated during depletion of the water column due to irrigational use, which culminate with the drawdown of the lake water by late summer. This provides the additional revenue to the village commune called 'Communidade'.

The topography of SML is not very uniform as it has a number of small islands and mud embankments/bunds that get exposed by late summer retaining pools of water in deeper depressions of the lake. Like other two water bodies, the source of water for SML is also precipitation/surface run-off. Metallic sluice gates adopted in eastern dam regulate the volume of the water (Fig: 0.10), if it is unusually in excess during monsoon. At the top of the sluice gates series of
outlets take care of routine overflow during the season. Water flow in SML is strictly unidirectional, through narrow outlet opening into the Cumbarjua canal. To control the excessive loss of water by surface evaporation from the lake, the management regularly practices addition of Cythyl alcohol especially during summer. For this purpose a chain of P.V.C barrels containing the chemical are placed on a thermocol base serving as a float spread across the lake (Fig: 0.11) from which the chemical seeps at slow pace forming a thin film on the surface of water.

During the year 1996 maximum depth of the lake was 2.50 m. following desiltation in the lake carried out during summer season of second year the depth further increased by a meter. The volume of the water is maximum during monsoon, which starts reducing from post monsoon onwards reaching lower limit by winter and summer.

Weather

Like any subtropical region, in Goa also, seasons are strongly influenced by heavy rainfall due to southwest monsoon predominantly during June to September. Therefore generally the seasons are thus categorised in relation to monsoon as pre-monsoon, monsoon and post-monsoon. However, in the present study, as the emphasis was on bird fauna, sizeable population of which was constituted by winter visitors, the post monsoon period was differentiated into post monsoon and winter for the sake of convenience. The pre-monsoon season is the warmest period of the year and experiences occasional showers towards the end of May. The annual atmospheric temperature for the state shows two peaks one in October, when the warmest conditions exist and second peak is during May, the hottest month of the year. On an average the
summer temperature fluctuates between 24.00° C to 32.00° C. The southwest monsoon extending from June to September receives most of its rainfall with an average of 3000 m. The average relative humidity may range upto 80%. And average wind speed varied upto about 13 Km/Hr blowing westerly during monsoons, easterly during summer and north easterly during winter. The post-monsoon period extending from October to November show temperature range between 21.00° C to 32.20° C. Seasonal variations in climatological parameters during the present study as obtained from the Indian Meteorological Department, Goa Observatory Panaji, Goa is provided in table: 0.2 along with its monthly variations in Graph: 0.2.

Temperature:

Maximum atmospheric temperature during the present investigation varied between 29.00° C in July to 34.00° C in May. During the year 1997 it was highest during summer followed by that of post-monsoon, winter and was lowest during monsoon. During the year 1998 it was highest during post-monsoon followed by that of summer and winter and was lowest during monsoon. Minimum atmospheric temperature varied between 18.90° C to 27.90° C.

Sunshine Hours:

Total mean sunshine hours varied from 4.40 hours in June to 7.78 hours in March. Maximum sunshine hours were during summer followed by winter post-monsoon and were lowest during monsoon.

Rainfall:

Rainfall during study period varied from 000.10 mm in March 1997 to 1210.50 mm in July 1997. The monsoonal precipitation very often extends in to post-monsoon period some time encroaching in to early winter. During the year
1996 the rainfall went up to October while during the year 1997 it continued up to December.

Relative Humidity:

Mean humidity during the study ranged from 71.00 % in May 1997 to 92.00 % in August in 1997. It was highest during monsoon and lowest during summer.

Wind Speed:

Mean wind speed during study period varied from 1.00 Km/Hr in February in 1997 to 15.09 Km/Hr in July 1997. Like humidity the wind speed was maximum during monsoon but minimum during post monsoon.

Vegetation

The northern embankment of PL supported thick vegetation mainly of *Anacardium occidentale*, *Mangifera indica* and *Cocus nucifera* followed by few shrubs of *Calotropis* and *Zizyphus*. The vegetation was flanked by a narrow strip of grazing area. The lake harboured extensively the hydrophytes like *Portulaca oleracea*, *Nymphaea stellata*, *Nelumbo sp.* *Utricularia aurea*, *Hydrilla verticillata* and *Trapa natans*. The eastern edge of the lake being rocky and barren the Department of forest has planted *Peltophorum ferrugineum* and *Polyalthia sp.* along this edge, under afforestation program.

Carambolim lake along with its grazing marsh land is surrounded by lush green growth of vegetation. It is enclosed by embankment on all the four sides. The north-east embankment supports rich plantation of *Cocus nucifera*, *Tectona grandis*, *Anacardium occidentale*, *Mangifera indica* and *Artocarpus integrifolia*. On the western edge of the lake the forest department has planted thick stand of *Acacia auriculiformes*. A mat of luxuriant grass surrounding *Nymphaea* bed covers
the marshland. The quantum of aquatic vegetation varies depending on the degree of flooding of the lake. The lake when flooded supports diverse macrophytic vegetation such as *Nymphaea stellata*, *Nymphoides cristata*, *N. indica*, *Utricularia aurea*, *Hydrilla verticillata*, and *Oryza rufipogon*. During summer the lake gradually turns into a dry grassland with seasonal die-out of rooted and submerged macrophytes. The surrounding lateritic soil supports several variety of grasses namely *Dactyloctenium aegyptium*, *Eleuine indica*, *Echinochloa colonum*, *Panicum psilopodium*, *Sacciolepis interrupta*, *Cyperus* sp. and herbs like, *Alternanthra tenela*, *Emilia sonchifolia*, *Asteraceae* sp., *Sesbania* sp. etc.

In SML, the sector A supports relatively less dense vegetation. Northern end supports Coconut plantation and eastern edge is with wild trees like *Tamarindus*, *Tremma orientalis*, *Ficus racemosa*, *Bougainvillaea spectabilis* and *Mangifera indica*. The southern bank is skirted with patches of *Polygonum glabrum* in the littoral zone and *Acacia auriculiformes* all along the road. The western edge running along the main approach road is also lined by plantation of *Polyalthia longifolia*.

Lake B in its the south-west region is mainly surrounded by dense forest represented by tall wild and cultivated trees such as of *Tectona grandis*, *Bridelia spinosa*, *B. stipularis*, *Boerhavia diffusa*, *Bombax ceiba*, *Zizyphus* sp, *Peltophorum ferrugineum*, *Ficus racemosa*, *Alstonia grandis*, *Dalbergia sympthatica* along with climbers namely *Ipomea quamoclit*, *I. Maxima I. Obscura*, *Merrimia vitifolia*, *Mucuna* sp, *Trichosanthus cucumeria* etc. The lake is mainly encompassed with a belt of *Polygonum glabrum* on all sides. The eastern bank along the approach road also supports wild herbs and grasses like *Cynotis cristata*, *Cyperus* and *Wedilia trilobata* besides a avenue trees of *Polyalthia longifolia* plantation.
Table 0.1

Seasonal variations in Volume of Lake water in $m^3$ at Pilar, Carambolim and Santa Monica Lakes from March 1996 to May 1998

<table>
<thead>
<tr>
<th>YEAR / SEASONS</th>
<th>PILAR LAKE</th>
<th>CARAMBOLIM LAKE</th>
<th>SANTA MONICA LAKE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996 SUMMER</td>
<td>57010.95 ± 32954.30 (52416.42, 63232.00)</td>
<td>437001.09 ± 252601.78 (20172.06, 919360.81)</td>
<td>33886.66 ± 19587.67 (11050.00, 57460.00)</td>
</tr>
<tr>
<td>1996 MONSOON</td>
<td>88550.99 ± 44275.50 (49616.00, 102843.81)</td>
<td>1416421.57 ± 708210.79 (5228.02, 1945766.72)</td>
<td>177463.00 ± 88731.50 (44200.00, 221884.00)</td>
</tr>
<tr>
<td>1996 POST-MONSOON</td>
<td>102503.26 ± 72697.34 (102503.26)</td>
<td>1945766.72 ± 1379976.39 (1945766.72)</td>
<td>168623.00 ± 119590.80 (146302.00, 190944.00)</td>
</tr>
<tr>
<td>1996 WINTER</td>
<td>87907.50 ± 50813.58 (77732.55, 98348.92)</td>
<td>1738309.50 ± 1004803.17 (1621114.53, 1857899.54)</td>
<td>53629.33 ± 30999.61 (110058.00, 33150.00)</td>
</tr>
<tr>
<td>1997 SUMMER</td>
<td>58242.61 ± 33666.25 (54415.00, 70341.11)</td>
<td>371529.52 ± 214756.95 (34593.60, 890621.08)</td>
<td>57312.66 ± 33128.71 (5304.00, 65858.00)</td>
</tr>
<tr>
<td>1997 MONSOON</td>
<td>81596.97 ± 40798.48 (31616.00, 103061.28)</td>
<td>1509502.31 ± 454751.15 (5256.75, 2034211.12)</td>
<td>262769.00 ± 131384.50 (130832.00, 306748.00)</td>
</tr>
<tr>
<td>1997 POST-MONSON</td>
<td>102705.13 ± 72840.51 (102705.13)</td>
<td>2034211.12 ± 1442702.92 (2034211.12)</td>
<td>234260.00 ± 166141.80 (216580.00, 251940.00)</td>
</tr>
<tr>
<td>1997 WINTER</td>
<td>87443.99 ± 50545.66 (70142.33, 102705.13)</td>
<td>1826301.81 ± 1055665.80 (1611245.33, 2034211.12)</td>
<td>133189.33 ± 76988.05 (94588.00, 171054.00)</td>
</tr>
<tr>
<td>1998 SUMMER</td>
<td>55104.01 ± 31852.02 (40836.02, 65456.14)</td>
<td>870186.90 ± 502998.21 (9546.50, 1536853.21)</td>
<td>47588.66 ± 27507.90 (26962.00, 69836.00)</td>
</tr>
</tbody>
</table>
Weather changes in Goa from March 1996 to May 1998

<table>
<thead>
<tr>
<th>Year / Seasons</th>
<th>Mean Maximum atmospheric temperature (°C)</th>
<th>Mean Minimum atmospheric temperature (°C)</th>
<th>Mean Sunshine (Hrs)</th>
<th>Actual Rainfall (mm)</th>
<th>Mean Relative Humidity (%)</th>
<th>Mean Wind Speed (km/Hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996 SUMMER</td>
<td>Mean ± S.E (max, min) 33.00 ± 0.17 (32.7,33.33)</td>
<td>Mean ± S.E (max, min) 25.20 ± 0.58 (24.20,26.20)</td>
<td>9.53 ± 0.25 (8.78,9.78)</td>
<td>0.43 ± 0.22 (0.00,0.70)</td>
<td>78.00 ± 2.52 (75.00,83.00)</td>
<td>10.00 ± 0.58 (9.00,11.00)</td>
</tr>
<tr>
<td>1996 MONSOON</td>
<td>Mean ± S.E (max, min) 29.85 ± 0.53 (29.00,31.20)</td>
<td>Mean ± S.E (max, min) 32.83 ± 0.29 (24.30,25.50)</td>
<td>4.53 ± 0.83 (2.61,5.93)</td>
<td>661.32 ± 249.73 (131.90,1131.80)</td>
<td>89.50 ± 1.50 (85.00,91.00)</td>
<td>11.00 ± 1.41 (7.00,13.00)</td>
</tr>
<tr>
<td>1996 POST-MONSOON</td>
<td>Mean ± S.E (max, min) 31.80 ± 0.10 (30.70,32.90)</td>
<td>Mean ± S.E (max, min) 19.90 ± 0.58 (18.90,20.90)</td>
<td>9.30 ± 0.29 (9.90,9.45)</td>
<td>4.00 ± 2.21 (4.40,7.60)</td>
<td>78.66 ± 1.20 (78.00,81.00)</td>
<td>8.10 ± 2.69 (8.00,8.30)</td>
</tr>
<tr>
<td>1997 SUMMER</td>
<td>Mean ± S.E (max, min) 33.13 ± 0.47 (32.40,34.00)</td>
<td>Mean ± S.E (max, min) 24.60 ± 0.69 (23.70,26.00)</td>
<td>9.53 ± 0.47 (9.23,9.66)</td>
<td>0.03 ± 0.03 (0.00,0.10)</td>
<td>75.66 ± 4.18 (71.00,84.00)</td>
<td>9.47 ± 0.65 (8.25,10.45)</td>
</tr>
<tr>
<td>1997 MONSOON</td>
<td>Mean ± S.E (max, min) 30.17 ± 0.63 (28.90,31.30)</td>
<td>Mean ± S.E (max, min) 24.62 ± 0.17 (24.20,25.00)</td>
<td>4.71 ± 1.08 (2.78,7.31)</td>
<td>794.92 ± 256.37 (57.60,1210.50)</td>
<td>89.00 ± 1.29 (86.00,92.00)</td>
<td>12.15 ± 1.63 (7.63,15.09)</td>
</tr>
<tr>
<td>1997 POST-MONSOON</td>
<td>Mean ± S.E (max, min) 33.35 ± 0.35 (33.00,33.70)</td>
<td>Mean ± S.E (max, min) 24.50 ± 0.15 (24.40,24.70)</td>
<td>8.19 ± 0.43 (7.77,8.62)</td>
<td>54.70 ± 3.41 (51.30,58.10)</td>
<td>85.00 ± 0.00 (83.00,84.00)</td>
<td>8.00 ± 0.00 (8.00)</td>
</tr>
<tr>
<td>1998 WINTER</td>
<td>Mean ± S.E (max, min) 32.16 ± 0.20 (22.70,32.50)</td>
<td>Mean ± S.E (max, min) 21.60 ± 0.59 (20.70,22.70)</td>
<td>9.39 ± 0.44 (8.66,10.18)</td>
<td>23.36 ± 23.39 (0.00,70.10)</td>
<td>83.12 ± 1.16 (81.00,85.00)</td>
<td>8.41 ± 0.30 (8.00,9.00)</td>
</tr>
<tr>
<td>1998 SUMMER</td>
<td>Mean ± S.E (max, min) 33.45 ± 0.20 (22.70,32.50)</td>
<td>Mean ± S.E (max, min) 25.63 ± 1.46 (22.90,27.90)</td>
<td>9.21 ± 0.17 (8.93,9.54)</td>
<td>22.80 ± 22.83 (0.00,68.40)</td>
<td>79.66 ± 2.67 (77.00,85.00)</td>
<td>8.60 ± 0.50 (7.80,9.53)</td>
</tr>
</tbody>
</table>
Graph 0.1: Monthly variations in the volume of lake water at PL, CL and SML from January 1996 to June 1998.

Graph 0.2: Fluctuations in the climatological parameters at monthly intervals from January, 1996 to June, 1998.
Map 0.1: The outline map of Tiswadi taluka of Goa indicating the location of Three lakes, Pilar (PL), Carambolim (CL) and Santa Monica Lake (SML) in relation to the Konkan railway track and the two major rivers of the state.
Map 0.4: Site map of SML along with the location of Santa Monica Plant within industrial premises of Novartis India Ltd. The location of National Highway 4 A and bank of Cumbarjua canal linking the 2 major rivers of the state, Mandovi and Zuari can be seen.
Map 0.7

- Telephone Pole
- Island
Fig 0.1 : The birds eye view of PL in completely flooded state with the 3 sampling stations (P1 to P3) indicated.

Fig 0.2 : Village crematorium by the edge of PL, which is supposed to be one of the major sources of excessive PO₄ getting in to the lake in the form of post-cremation remnants washed down through monsoon torrents.
Fig 0.3: The view of CL in the flooded state from southeastern side. The railway station and the embankment serving as the base for railway track can be seen in the background. Two (C1 to C2) of the 5 sampling stations lying on the western and northeastern side are indicated.

Fig 0.4: Eastern bank of the CL. Reclamation and encroachment in the form of vegetable garden in the foreground and the approach road linking Carambolim and Pilar villages in the background can be seen. Three (C3 to C5) of the 5 sampling stations lying on southern, southeastern and northeastern sides of the lake are also indicated.
**Fig 0.5**: The view of the larger eastern sector, A of SML with 3 (S1 to S3) of the total 5 sampling stations indicated. In the foreground rich stand of *Polygonum glabrum* can be seen.

**Fig 0.6**: The view of the smaller western sector, B of SML with the 3 (S4 to S6) sampling stations indicated. In the foreground the rich stand of *Polygonum glabrum* can be seen.
Fig 0.7: The only sluice gate at CL on its southeastern side, which is used for regulating the water supply for irrigating the paddy fields and also for final draw down of water during late summer.

Fig 0.8: The main canal supplying the water from the CL to the paddy fields in the lower reaches of the lake.
Fig 0.9: The paddy saplings raised for *rabi* crop and the fields being readied for transplantation, in the lower reaches of CL, being irrigated by the water from the lake.

Fig 0.10: The dam in the northeast of SML reinforced with steel sheets. The series of outlets on its upper portion meant for outflow of excess water likely to flow in to the lake during monsoon can also be seen.
Fig 0.11: Chain of P.V.C. barrels containing cythyl alcohol kept afloat to provide a thin film facilitating prevention of excessive loss of water through surface evaporation at SML.