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Stratification in Karnataka Reservoirs

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Stratification studies unveil some of the ongoing limnological processes related to fish production. In the present paper, an attempt is made to study the thermal and chemical stratifications in eleven reservoirs under Cauvery, Krishna and Sharavathy river systems in Karnataka. Harangi, Manchanbele and Bhadra reservoirs showed thermoclinity with clear demarcation of epi- and metalimnion. Oxygen profile was orthograde in Ghataprabha, Malaprabha, Narayanpur and Bhadra and clinograde in Harangi, Manchanbele, Nugu, Vani Vilas Sagar and Linganamakki. The strength of oxycline in water column especially during pre-monsoon influences the success of gillnetting operations, as the fish confines to the epilimnetic zone as observed in Manchanbele.

Key words: Stratification, productivity, reservoirs, Karnataka

Though the freshwater resources are impressive, Karnataka lags behind in inland fish production (about 1.3×10^5 t in 1999-2000) (Chandrasekhariah, 2001) as the yield potential of these water bodies have not been fully tapped due to lack of understanding of ecological principles and trophic dynamics. Limnological implication of stratification is a subject of much discussion as it exerts influence not only in the reservoir but also affects the stream flowing below the dam. Barring the works on Tungabhadra (David *et al.,* 1969), VV Sagar (Ray, 1969) and Markonahalli (Ramakrishniah *et al.,* 1998), very little scientific information has been documented in respect of Karnataka reservoirs. The present study has been undertaken to focus on stratification and its impact on limnological processes in some selected reservoirs of Karnataka.

Materials and Methods

Eleven reservoirs, viz., Hemavathy, Harangi, Kabini, Nugu and Manchanbele under Cauvery river system, Vani Vilas Sagar (VV Sagar), Bhadra, Narayanpur, Ghataprabha and Malaprabha under Krishna river system and Linganamakki from the west flowing Sharavathy river sytem have been selected for limnological studies. Among the Cauvery basin reservoirs (CB reservoirs) except Manchanbele (on river Arkavathy) others are on the tributaries originating in Western Ghats. In case of Krishna basin reservoirs (KB reservoirs), Bhadra (on the river Bhadra), and VVSagar (on river Vedavathy) belong to Tungabhadra drainage; Ghataprabha and Malaprabha are on the tributaries, while Narayanpur is on the main stream of river Krishna (Fig. 1).

The study involved seasonal *in situ* measurement and analyses of physico-chemical parameters of water depth-wise, following standard methods (APHA, 1992). The sampling of each reservoir was made in pre-monsoon (April-May), monsoon (August-September) and post-monsoon (November-December) seasons during 1995-97 confining to the deepest lentic sector. Water samples from different depths were collected using a Vandorn sampler. Temperature and dissolved oxygen (DO) were recorded using Oxymeter (WTW, Gemany) coupled with probe and cables. Bottom sediments were analysed following standard methods (Jackson, 1973).

Results and Discussion

Salient morphometric and hydrographic features of these reservoirs are given in Table 1. CB reservoirs are at lower latitudes

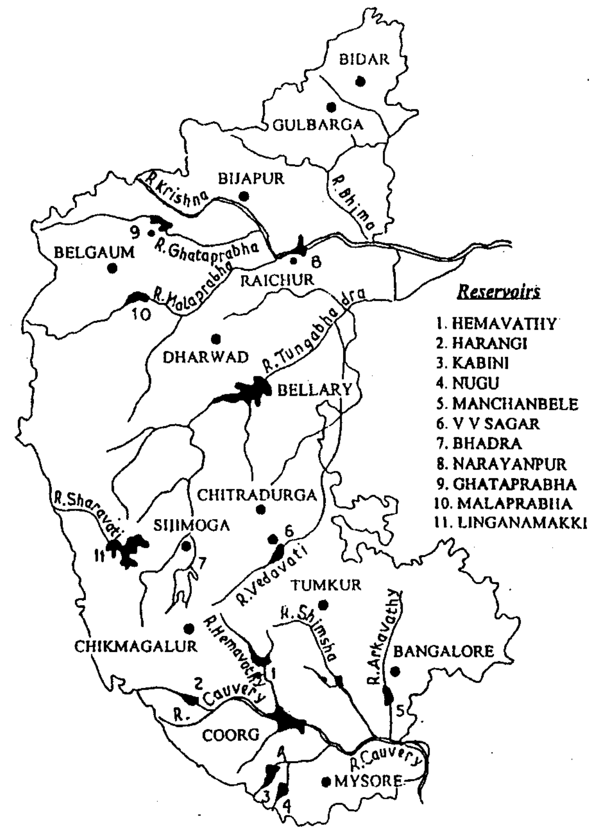

Fig. 1. Map of Karnataka showing the location of reservoirs

(11°58' & 12°52' N) and higher elevations (755.9 to 890.6 m asl) compared to KB reservoirs, which are at relatively higher latitudes (13° 42′ & 16°15' N) and lower elevations (492.2 to 633.8 m asl). Linganamakki is the largest (water spread: 31,728 ha) and Manchanbele, the smallest one with an area of 329 ha. VV Sagar, the oldest one, was formed in 1901, while Manchanbele is a new impoundment filled in 1991. The ratio of catchment to reservoir area (C/A) at FRL, an index of allochthonous load into the reservoir, is very high in Manchanbele (435) and lowest in Linganmakki. The mean depth, a basic productivity factor, is highest in Bhadra (21.1m) and lowest in Malaprabha (7.9 m). The flushing rate (annual inflow / storage capacity) is very high in Narayanpur (21.4) and very low in VV Sagar (0.17). In general, CB reservoirs have higher flushing rate than others. High C/A with moderate flushing rate have a greater bearing on productivity.

Table 1. Location, morphometry and hydrology of Karnataka reservoirs

	Cauvery basin					Krishna basin					Sharavathy
Reservoir	Hemavathy	Harangi	Kabini	Nugu	M.bele	VV Sagar	Bhadra	N.pur	G.prabha	M.prabha	L.makki
River	Hemavathy	Harangi	Kabini	Nugu	Arkavathy	Vedavathy	Bhadra	Krishna	G.prabha	M.prabha	Sharavathy
Latitude (N)	12°40'	12°29'	11°58'	11°58'	12°52'	13°51'	13°42'	16°10'	16°15'	15°45'	14°10'
Elevation (m asl)	890.6	871.4	755.9	762.0	736.1	621.0	619.7	492.2	662.9	633.8	555
Year of construction	1979	1984	1974	1958	1991	1901	1963	1982	1977	1974	1964
Catchment (C) (km^2)	2800	419	2142	984	1590	5374	1968	47850	1412	2176	1992
Reservoir area (A) (ha)	8502	1909	6060	1398	329	8759	11250	13200	6837	13578	31728
C/A ratio	33	22	35	70	435	61	17	362	21	16	6
Capacity ($\times 10^6$ m^3)	1050.6	240.7	552.7	154.1	31.4	840.7	2023	1066	1443	1068	4435
Max. depth (m)	40.2	47.2	-	-	24.4	41.4	54.9	22.3	53.4	40.2	52
Mean depth (m)	12.4	12.6	9.1	11	9.5	8.6	18.0	8.1	21.1	7.9	13.6
Total inflow ($\times 10^6$ m^3)	3646	1113	-	283	36.6	145	2324	22824	2147	-	5867

All the reservoirs are situated in high rainfall (100-200 cm) zone of Western Ghats with dense green forest cover. Manchanbele and VV Sagar lie in the rain shadow region of Western Ghats. Barring Manchanbele, VV Sagar and Narayanpur, most of the reservoirs have uninterrupted extensive catchment. The rainfall decreases from west to east. Temperature fluctuates between 16 and 34°C. Maximum precipitation occurs during May to October, with peak in June-July. Red and lateritic soils predominate in the catchment. Hemavathy and Bhadra originate from Chikmagalur district, the catchment of which is mostly hilly with forest cover including cultivated land. Clay-loam to sandy-clay-loam is the soil texture. River Vedavathi arises in Bababudangiri hills having 62-84 cm rainfall. Land is under rain-fed cultivation in association with moderate dense forest cover. Narayanpur catchment comprises hills and undulating plains with predominance of black soil, while annual precipitation ranges from 68-80 cm. Ghataprabha rises in the hills of Sahyadri having 44-285 cm precipitation with predominance of red-gravely soil covered by forest, grass and cultivated land, while catchment of Malaprabha is situated in the transitional precipitation belt (153-470 cm) of the leeward side of Western Ghats, major portion of which is under cultivation.

Basin texture remained predominantly sandy in most of the reservoirs. In CB reservoirs, soil reaction was acidic with pH in the range 4.9 (Harangi) to 5.8 (Hemavathy)(Tanle 2). It was acidic (pH 5.3) in Linganamakki also, while in KB reservoirs, it was slightly acidic in Bhadra and Ghataprabha, neutral in Narayanpur and Malaprabha and alkaline in VV Sagar (pH 8.1).Fairly rich organic carbon content was noticed in almost all the reservoirs ranging from 0.7 (Narayanpur) to 2.7% (Harangi). It was more than 1.5% in all the reservoirs except Narayanpur and Malaprabha, which is considered to be optimal for fish production. Decomposition rate of bottom organic matter was low due to acidic nature of soil, especially in all the CB reservoirs and Ghataprabha and Bhadra under KB reservoirs, getting reflected in high C/N ratio of their sediment (Das & Rao, 1999). High C/N ratio in VV Sagar also was due to macrophytic load.

Water temperature varied from 24.3 (Ghataprabha) to 27.9°C (Linganamakki) in the overall range of 22.2 to 32.0°C with narrow seasonal fluctuations (3-7°C) due to low latitude (11°58' to 16°15' N). Turbidity was very low in most of the reservoirs. Secchi depth ranged from 0.9 (Nugu) to 3.2 m (Bhadra). In monsoon, it was lowest in Ghataprabha (0.1m) and highest in Bhadra (2.0 m). Water reaction was neutral to alkaline. During summer, water pH reached beyond 8.0 in Narayanpur, Nugu and Malaprabha (Table 2). Surface waters were well oxygenated with dissolved oxygen (DO) around 7.0 $mg.l^{-1}$ but showed variation in oxygen content with depth. On most occasions, free CO_2 was noticed in surface waters in the range from 1 to 6 $mg.l^{-1}$. CB reservoirs had lower values of total alkalinity (26-48 $mg.l^{-1}$), barring Manchanbele (144 $mg.l^{-1}$) compared to KB reservoirs; it was lowest in Bhadra (31 $mg.l^{-1}$) and highest in VV Sager (207 $mg.l^{-1}$). Total alakalinity was lowest in Linganamakki (20 $mg.l^{-1}$) amongst all the reservoirs investigated. Among CB reservoirs, specific conductance was lowest in Kabini and highest in Manchanbele. VV Sagar recorded the highest value (647 $mS.cm^{-1}$) and Linganamakki had lowest value (57 $mS.cm^{-1}$).

Stratification in reservoirs is a subject of much discussion because it exerts influence not only in the reservoir itself but also affects the stream flowing below the dam. The importance of stratification studies and their limnological significance have been systematically discussed by Sreenivasan (1971) and Natarajan (1977 & 1979).

Physical stratification precedes chemical stratification. In tropical Indian reservoirs, thermal stratification may not be stable and

Table 2. Chemical characteristics of soil and water of Karnataka reservoirs (average & range)

	Sediment				Water					
	pH	Org C (%)	Total N (%)	C/N ratio	Temp. (°C)	Trans. (m)	DO ($mg.1^{-1}$)	pH	TA ($mg.1^{-1}$)	Sp. cond. ($mS.cm^{-1}$)
Hemavathy	5.8 5.6-6.0	1.8 1.5-2.0	0.07 0.05-0.08	28 22.1-37.8	24.8 22.5-27.5	1.6 0.5-2.2	7.6 7.0-7.6	7.7 7.3-8.3	48 29-78	147 100-200
Harangi	4.9 4.8-5.0	2.7 2.3-2.9	0.1 0.09-0.12	26 23.8-29.0	25.3 22.4-28.5	1.7 1.5-1.9	7.6 7.3-7.8	7.4 7.1-8.0	35 16-68	97 90-100
Kabini	5.0 4.9-5.2	1.9 1.3-2.4	0.07 0.06-0.08	25 21.3-29.6	27.5 24.6-32.0	1.6 1.0-2.0	6.9 6.6-7.2	7.5 7.0-7.8	25 20-36	90 60-110
Nugu	5.5 5.0-6.3	1.7 1.5-1.9	0.09 0.07-0.10	20 15.9-23.2	27.4 25.2-30.0	0.9 0.4-1.2	7.3 7.0-7.8	8.1 7.5-8.8	40 28-48	120 100-140
Manchanbele	6.5 6.4-6.5	1.8 1.1-2.4	0.09 0.06-0.12	22 17.0-30.1	27.3 26.0-29.5	0.9 0.7-1.0	7.3 7.1-7.6	8.5 8.3-8.7	144 138-148	403 390-420
Narayanpur	7.2 6.9-75	0.7 0.6-0.8	0.05 0.04-0.07	14 11.4-15.0	25.8 23.2-27.8	1.1 1.0-1.2	7.6 7.5-7.7	8.3 7.8-8.8	154 148-160	457 440-480
Ghataprabha	5.8 5.6-6.3	2.0 1.3-2.5	0.07 0.05-0.08	30 26.0-35.0	24.3 22.2-27.5	1.5 0.1-3.3	6.9 6.6-7.2	8.2 7.8-8.5	32 24-40	100 70-150
Malaprabha	6.5 6.4-6.7	0.9 0.8-1.2	0.08 0.06-0.09	12 10.0-13.3	25.0 22.5-27.6	1.3 1.0-1.5	7.2 6.8-7.7	8.4 8.1-8.7	79 56-92	203 120-270
Bhadra	5.5 5.3-5.6	2.2 2.0-2.4	0.08 0.07-0.09	28 25.0-31.0	26.9 25.2-28.3	3.2 2.0-4.0	7.8 7.2-8.4	7.5 7.3-7.7	31 18-48	117 100-130
VV Sagar	8.1 8.1-8.2	1.9 1.8-2.0	0.09 0.07-0.10	22 19.2-25.3	26.2 25.0-26.8	1.2 1.0-1.5	6.7 6.4-7.0	8.2 7.9-8.4	207 200-210	647 550-730
Linganamakki	5.3 4.6-6.1	2.0 1.1-3.4	0.07 0.06-0.09	27 17.1-34.4	27.9 26.1-30.0	1.5 0.4-2.3	6.9 6.5-7.3	7.1 6.7-7.6	21 14-28	57 40-80

prolonged and degree of thermoclinity is less when compared to temperate reservoirs. Prolonged and stable thermal stratification with stable chemical stratification is more effective for biological productivity. Wide seasonal fluctuation in air temperature is the predisposing factor in the thermal characteristics of the north Indian reservoirs. Fluctuation in air and water temperatures throughout the year is of narrow order in peninsular Indian reservoirs preventing the formation of stable thermal stratification. In

Table 3. Difference in surface and bottom values of some water parameters of reservoirs

Reservoirs	Sampling depth (m)	Temperature (°C)	DO ($mg.1^{-1}$)	Alkalinity ($mg.1^{-1}$)	pH
Hemavathy	12.5	0.75	3.6	28.0	0.7
Harangi	12.5	4.75	7.7	8.0	1.3
Kabini	10.0	4.0	2.5	4.0	0.8
Nugu	12.5	3.0	7.1	6.0	1.5
Manchanbele	8.0	4.5	7.4	3.0	1.5
Narayanpur	10.0	0.6	1.2	16.0	–
Ghataprabha	14.0	0.9	1.4	8.0	0.6
Malaprabha	13.0	0.6	1.0	4.0	0.2
Bhadra	25.0	4.0	1.7	16.0	1.5
VV Sagar	12.5	1.8	6.6	20.0	0.4
Linganamakki	10.0	0.8	4.7	4.0	0.6

Karnataka, water temperature never falls below 20°C and temperature remains comparatively higher in contrast to northern reservoirs.

Limnological importance of thermal stratification is manifold as the water above (epilimnion) and below thermocline (metalimnion & hypolimnion) do not mix up resulting in locking up of nutrients at the bottom. High bottom temperature prevailing in deep tropical reservoirs facilitates rapid decomposition of organic matter and in turn accelerates the processes of nutrient release. Thermal stratification results in reduced heat budget thus causing more evaporation and heat loss at the surface. Owing to the separation of stratified cold bottom layer from the trophogenic zone, algal and atmospheric aeration do not occur resulting in depletion of O_2 with the onset of chemical stratification.

Unlike temperate lakes, thermal stratification is not well defined in peninsular Indian reservoirs of lower latitudes (Sreenivasan, 1989). Same is true in Karnataka reservoirs, also. In deep reservoir like Bhadra, the difference between surface and bottom (25 m) temperature was only 4°C (Table 3) during summer. Only in Harangi and Manchanbele, strong ther-

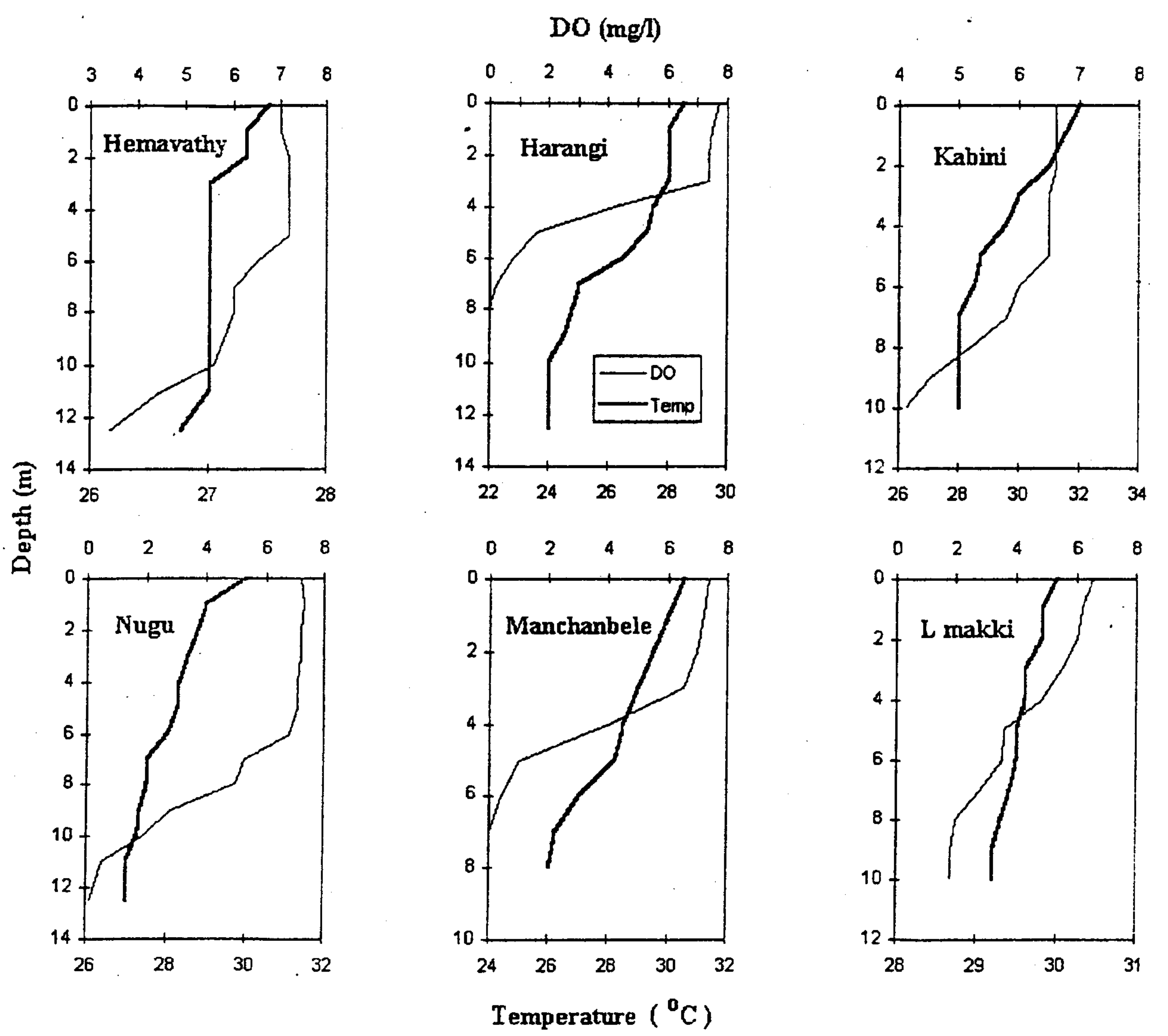

Fig. 2a Stratification in Karnataka reservoirs in summer

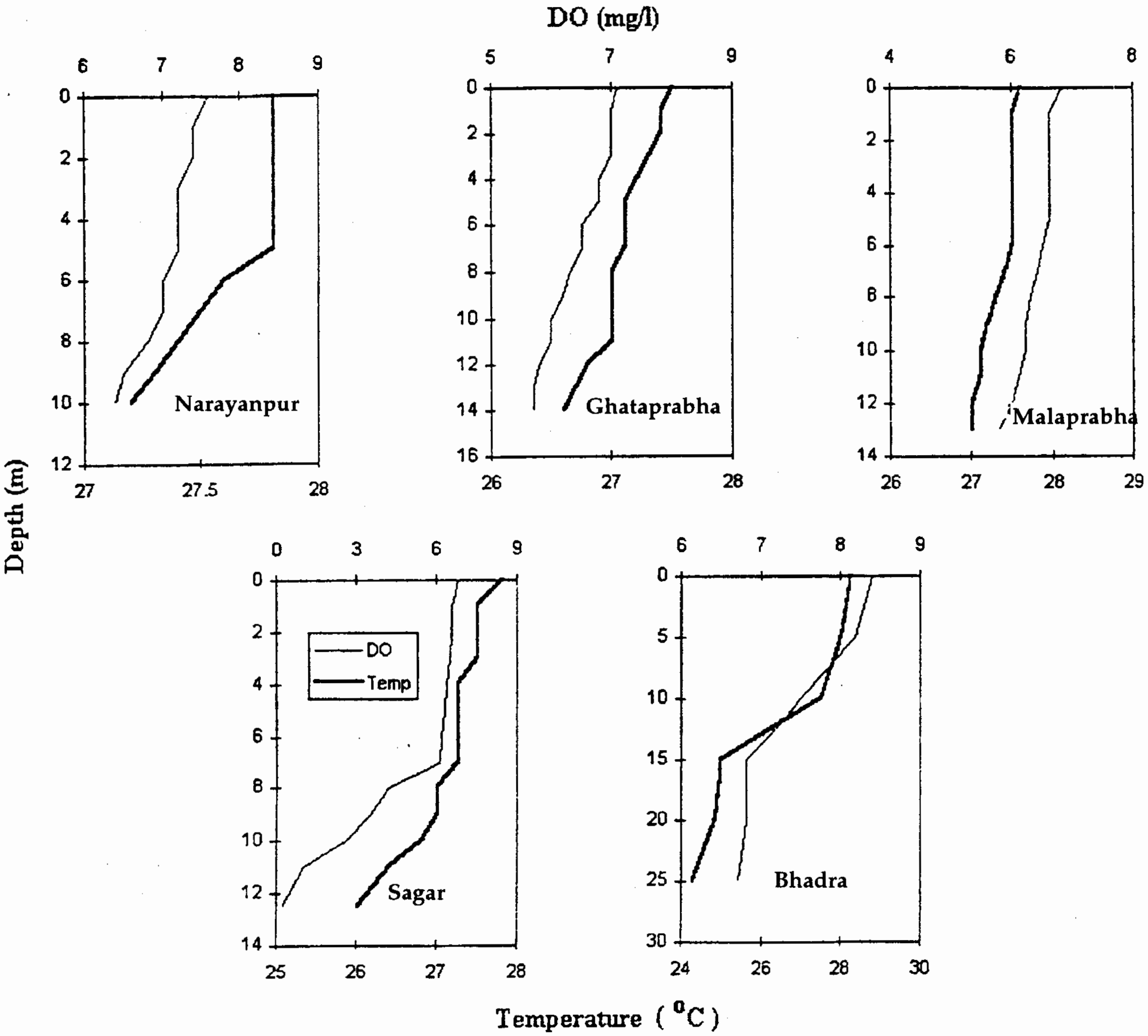

Fig. 2b Stratification in Karnataka reservoirs in summer

mocline with a clear demarcation of epilimnion and hypolimnion was noted in summer (Fig. 2). In Harangi, thermocline was noted between 4 and 9 m depth and in Manchanbele, it was between 3 and 7 m depth. In Manchanbele, stable thermal stratification was observed during April, May and October 1999 and March 2000 with a fall of bottom temperature (15 m depth) from surface by 5.4, 4.5, 5.5 and 4.0°C, respectively. Very little change in temperature was noted in the water column in other reservoirs and homothermal conditions prevailed during monsoon and post-monsoon months. Kabini and Nugu also had shown some thermal stratification with lesser stability. Even in Nelligudda, a small reservoir near Bangalore (area 80 ha), stable thermal stratification was reported during summer where difference in surface to bottom temperature was 4.0°C at 4 m depth (Rao, 1999). Thermal stratification with a fall in metalimnion temperature of less than 1°C has been observed in many tropical lakes (Lewis, 1973; Taylor & Gebre-Mariam, 1989). The same was true in case of some reservoirs in the upper peninsular India comprising South Bihar, Madhya Pradesh and Gujarat, which undergo transient phases of thermal stratification during summer.

Depth profile studies made in some north Indian reservoirs indicate presence of thermal stratification during summer with three distinct phases like epilimnion extending up to 6 m in Getalsud reservoir in Bihar (mean depth 4.52 m; area 3400 ha at FRL), thermocline at metalimnion (between 7 and 12m) and hypolimnion below 12 m (Pal, 1979). The temperature drop in the themocline region was 25.3°C at 7 m to 20.8°C at 11 m. Similar trend of thermal stratification has also been observed in other north Indian reservoirs like Konar (Sardar, 1977) wherein metalimnion between 3 to 9 m depth (0.7-1.1°C.m^{-1}) was observed. In Rihand, well defined metalimnion between 4 to 13 m with a fall of temperature between surface and bottom at 10, 8.5 and 9.5°C in May 1975, 1976 and 1977, respectively, has been reported (Desai & Singh, 1979). Very strong and well defined thermocline was observed in Govindsagar reservoir (Sarkar *et al.*, 1977) wherein warm top layer remained a separate thermal regime and the inflowing Beas water that joined the reservoir at the lotic sector did not get mixed up and retained its cool character at the bottom.

Thermal stratification results in chemical stratification and mostly occurs in premonsoon and post-monsoon months. The strength of oxycline is a clear indication of richness of bottom deposits representing a dependable index of reservoir productivity. Strong oxycline was noticed in Manchanbele and Harangi with anoxic conditions at hypolimnion. Near anoxic condition at the bottom was also experienced in Nugu, VV Sagar and Linganamakki. Sharp decline in DO was reported 5 m below from the surface in Manchanbele and Harangi, 7 m in Linganamakki and 9 m in Nugu and VV Sagar. Oxycline was weak in Hemavathy, Kabini, Narayanpur, Ghataprabha, Malaprabha and Bhadra (Table 3). Thus, oxygen profile was orthograde in Ghataprabha, Malaprabha, Narayanpur and Bhadra while it was clinograde in Manchanbele, Harangi, Nugu, VVSagar and Linganamakki. Narayanpur, Kabini and Hemavathi were relatively shallow with sprawling lentic sector being subjected to strong wind and wave actions during premonsoon months. It probably explains the orthograde oxycline in spite of these reservoirs being productive.

A decreasing trend in alkalinity with clinograde distribution in pre-monsoon was well marked in KB reservoirs like VV Sagar, Narayanpur, Bhadra and Ghataprabha. In CB reservoirs, barring Hemavathy where decrease in alkalinity from surface to bottom was 28.0 mg.l^{-1}, the declining trend in total alkalinity was not sharp (Table 3). This is due to the fact that on account of presence of free CO_2 from surface to bottom year round, no carbonate deposit remains at the bottom and thus during stratification further increase in free CO_2 at the bottom could not increase the bicarbonate and specific conductivity. Except Harangi and Bhadra, other reservoirs showed a declining trend in specific conductance from surface to bottom.

Apart from indicating the trophic status of the reservoir, the oxygen regime also aids in fishing operations, as fish prefer well-oxygenated waters. Thus, a knowledge of vertical distribution of oxygen helps operators to lay gill nets at appropriate depths which is true in Manchanbele reservoir where bigger sized (>1.2 kg) tilapia (*Oreochromis mossambicus)* is caught in summer (April-May) by the surface gill nets as two-third of the water column remains anoxic below epilimnion after March every year.

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