Project no. **032103**

Project acronym

BOMOSA

Project title

Integrating BOMOSA cage fish farming system in reservoirs, ponds and temporary water bodies in Eastern Africa

Instrument: **Specific Target Project**

Thematic Priority: **INCO-DEV**

Deliverable 4.1: Synthesis of baseline environmental data from existing BOMOSA plots

Due date of deliverable: March 2007
Actual submission date: March 2007

Start date of project: 01. October 2006
Duration: 36 Months

Organisation name of lead contractor for this deliverable: Ethiopian Institute of Agricultural Research

Revision [draft 2]

Project co-funded by the European Commission within the Sixth Framework Programme (2006-2009)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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1 INTRODUCTION

1.1 General introduction (overview)

The aim of this task was to analyse existing data and to collect additional data and information from the three existing BOMOSA plots, which were established in Kenya for feasibility study in 2003. Such information is necessary for setting the design for the environmental monitoring program of the new BOMOSA plots (see objectives WP 4 in Annex I).

The results from the preliminary study give an overview of different water quality parameters from March to August 2003. The region where the plots are located has three distinct annual seasons; a dry warm season from January to March, a wet warm season from April to May, and a dry cold season from June to August. Since the dry warm season was not captured in the preliminary study, an additional data was collected in February 2007. The additional data excluded one site, the Kavovi dam, because previous results had shown that the water quality was unsuitable for cage fish farming. The data and information provide a reasonable indication of the annual and short term (diurnal, nocturnal and diel) variations of the water quality parameters. The present information will form a baseline for the design of the environmental monitoring programme of the new BOMOSA plots.

The present report has been split into two main sections:

The first section provides synthesized information from the existing data of the previous feasibility studies (see description of WP 4 in the Annex I) and includes data from the three sites.

The second section provides information, which was synthesized from the additional data collected in February 2007. This section contains information from only two sites after deleting Kavovi dam from the list of BOMOSA plots.

1.2 Introduction

Cage culture is one of the fish rearing systems that exploit existing water resources and is well established in many countries (McGhie et al., 2000; Troell et al., 1997; Pawar et al. 2001; Papatryphon, 2004; Karakassis et al. 2000). The success of cage culture has been enhanced by a thorough understanding of water quality dynamics and other hydrological features of the ecosystems. Available information on water quality for cage culture has mainly been derived from large water bodies, which have relatively stable water quality parameters. Unfortunately, such information may not be directly applicable to small reservoirs, which have highly unstable water quality parameters that are also characterised by marked variations, both on seasonal and daily basis. Under such environmental conditions, fish may be subjected to severe environmental stress with respect to low DO and adverse levels of ammonia. Rapid changes in water quality parameters occurring within short periods will also be stressful to fish and adversely effect fish growth (Bocci, 1999). Therefore, the dynamics of water quality in small water bodies/reservoirs should be understood for rational exploitation of the water bodies through cage fish farming.

The recent developments of cage culture in Kenya involve integration of fish cages in to fish ponds (Liti et al. 2005). However, cages are now being tried on a trial basis in small man-made reservoirs. Interest has been focused on small water bodies because of their abundance and wind distribution in arid and semi-arid lands (Asal) of Kenya, where the majority of the dams are utilized as watering points for domestic animals as well as irrigation. However, these water bodies do not support a viable fishery. This paper reports on the findings of a study, which was carried out to generate information to assist in developing criteria for site selection, and a monitoring environmental programme for the new plots of the BOMOSA project.

2 MATERIALS AND METHODS

The first study was conducted in three reservoirs, namely, Ngeki, Ngei and Kavovi located at 5250 ft above sea level. The largest reservoir, Ngeki, is located between 37o10´ and 37o15´ E, 1o30´ and 1o35´ S and has a surface area of 2 ha and an average depth of 2 m. Ngei and Kavovi, which lie to the North West of Ngeki have surface areas of 0.75 and 1.0 ha, and are relatively deep with average depths of 5 and 4 m, respectively.

Ngeki is rain-fed through a seasonal stream and has an outlet, which flows only during flood rains. The basin is V-shaped a broad sloping brim. Ngei is conically shaped, and is fed by a small seasonal stream, although there seem to be underground influx of freshwater. The dam has no feasible outlet, is relative deep to its surface area, and sheltered from strong winds. Kavovi is fed through a small stream and the dam is quite unique because more than the half of its area is covered by macrophytes, mainly Phragmites, Communis and Nymphaea.

The study was carried out between March and August (2005) and covered the long rain season, which occurs from March to May, and the cold dry season between June and August. A total rainfall of 368.3 mm was received during the study period and air temperatures ranged from 25.0-28.2°C while monthly evaporation reached 113 to 146.0 mm. The June-August cold season received a total rainfall of only 2 mm. During the cold period maximum air temperatures ranged from 22.0-22.7°C and minimum temperatures from 8 to14°C. Monthly evaporation ranged from 85 to 104 mm.

Samples for water quality analyses were collected bi-weekly using a column sampler (total length 1.12 m) developed by Boyd & Tucker (1992). In Ngei and Kavovi one sampling site for each dam was located in the open water at the central part of each reservoir, whereas in Ngeki, samples were taken from fish cages and the open water which are 10 m away from the cage pier (plate 1). Temperature and specific conductivity were measured with HI 9060 and HI 8733 meters (Hanna Instruments, U.S.A), while dissolved oxygen and pH were measured with DO-5509 and pH-201 (Lutron metres, Taiwan).

Water samples were filtered through Whatman glass filter papers and analysed for total alkalinity, total hardness, dry mass and ash, inorganic nutrients (nitrite-nitrogen, ammonium-nitrogen, nitrate-nitrogen, soluble reactive phosphorus, and total phosphorus). Chlorophyll-a was measured spectrophotometrically using Spectronic 21/ Milton Roy. Water quality analyses were done according to procedures adopted from American Health Association standard methods (APHA, 1995). Algae in fresh and fixed samples were examined microscopically.

Data were analysed by SPSS 12.0.1 statistical programme. One-way analysis of variance (Anova) was used for testing the significant differences of parameters within and among reservoirs and between cages and open water. A probability level of P=0.05 was used to declare significance.

3 RESULTS AND DISCUSSION

Temperature and dissolved oxygen profiles for the three reservoirs are shown in Figure 1 to Figure 3, respectively. The water temperature ranged between 27-17°C and the water in the reservoirs was characterized by strong daily thermal gradients between March and May, which were interrupted either by rainfall or night cooling. The daily thermal gradients eventually became weaker and gradually ascended towards the surface between June and August leading to frequent daily mixing. Based on thermal structure, two phases were identifiable in Ngeki reservoir. The first phase was represented by relatively higher temperatures and daily thermal stratification and occurred between March and May. The second phase was a period of low water temperature with complete daily mixing from June to July. Generally stratification was more pronounced in Ngei than in the other reservoirs. The cool period with temperature range of 17-20 °C is close to 16°C, the range in which *O. niloticus* ceases feeding. Based on this result, it is more efficient to reduce feeding or to design a grow out operation to exclude the June-August cold period.

Table 1: Mean temperature and dissolved oxygen in Ngeki, Ngei and Kavovi reservoirs (Mean ± SE)

	Reservoir		
Parameter	**Ngeki**	**Ngei**	**Kavovi**
Temperature (°C)			
Max (wet season)	27.4 ± 0.5^{a}	27.3 ± 0.8^{a}	25.2 ± 0.7^{a}
Min (wet season)	23.7± 0.6^{b}	20.9 ± 0.3^{a}	22.5 ± 0.7^{ab}
Max (cold season)	19.6 ± 0.5^{a}	18.8 ± 0.4^{a}	18.5 ± 0.4^{a}
Min (cold season)	19.0 ± 0.6^{a}	17.6 ± 0.5^{a}	18.0 ± 0.6^{a}
DO (mg L^{-1})			
Mean	7.6 ± 1.1^{b}	5.4 ± 0.5^{b}	3.9 ± 0.5^{a}
Min (wet season)	6.2 ± 1.1^{b}	0.3 ± 0.1^{a}	1.7 ± 0.8^{a}
Min (dry season)	3.4 ± 0.7^{b}	1.0 ± 0.4^{a}	0.9 ± 0.4^{a}

SE = standard error of the mean physico-chemical characteristics of the reservoirs

Mean dissolved oxygen levels are presented in Table 1, while the isopleths for the reservoirs are shown in Figure 1 b. The mean DO in all the reservoirs ranged between 7.6-3.9mg/L. In Ngeki, DO content was higher than in the other reservoirs and stratification was more pronounced in the wet season (March-May) and there was a close link between the DO distribution patterns and the thermal gradients. However, as with temperature, the DO stratification was completely destroyed during the cool season (June-August). In Ngeki, an unusual DO distribution, which depicted a positive heterograde type curve, was observed. This type of distribution is characteristic of basins which allow cool oxygenated water from the shallow regions of a basin to flow and accumulate in the deeper parts of the basin. In such cases, fish cages are, if located above the points of accumulation, sand-witched between two water strata, rich in DO. Thus, there is likelihood of redistribution of DO within the cages between the two water strata as a result of fish movements thus creating a suitable environment for fish growth.

In Ngei, a different scenario in DO distribution was observed (**Fehler! Verweisquelle konnte nicht gefunden werden.** b). A higher DO content was only confined to layers above 0.5 m, while low DO occurred at greater depths. This type of DO distribution pattern may limit the depth at which cages may be installed. However, this limitation may be overcome by extending the horizontal dimensions of the cages, while maintaining low cage depths although this approach may lead to feed wastage as the time and space of accessing food by fish is reduced.

Kavovi, on the other hand, was characterized by relatively low DO content throughout the study period (Figure 3 b). The reservoir has its surface area covered by macrophytes, which results in heavy load of organic matter to the system from decaying macrophytes and also as a result of active secretion from living macrophytes (Wetzel 1983). The distribution of DO in fish cages and open water illustrated in Figure 4 b indicate that presence of fish in cages did not markedly influence the DO distribution which may be attributed to the nature of mixing regime in Ngeki reservoir.

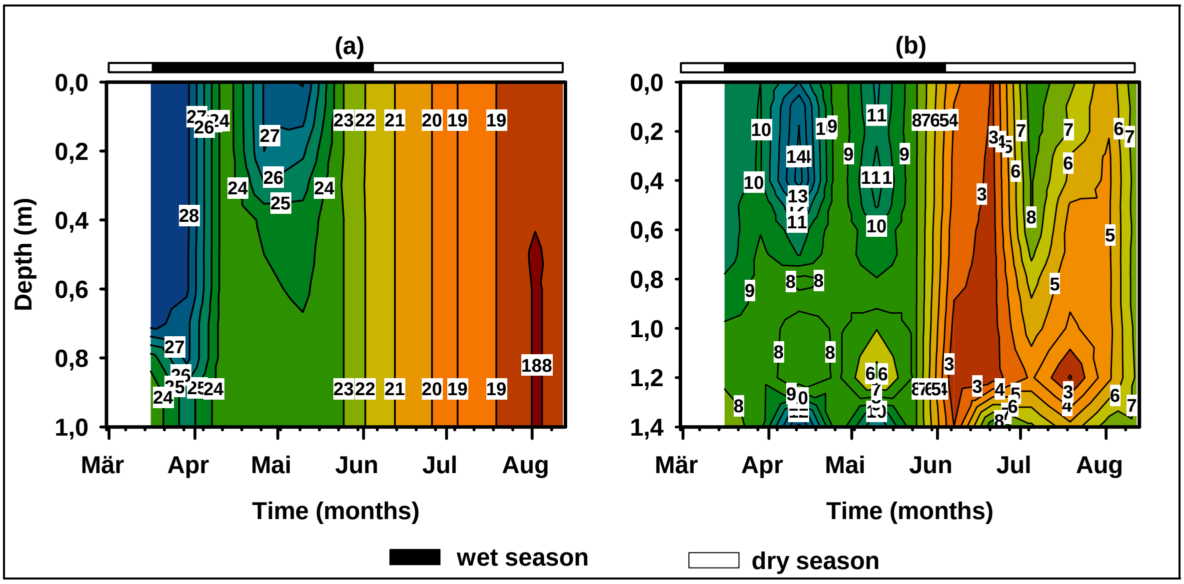

Figure 1: Depth-time representation of **(a) Temperature (^{o}C)** and **(b) Oxygen (mg L^{-1})** isopleths for Ngeki reservoir during the study period (March – August, 2005)

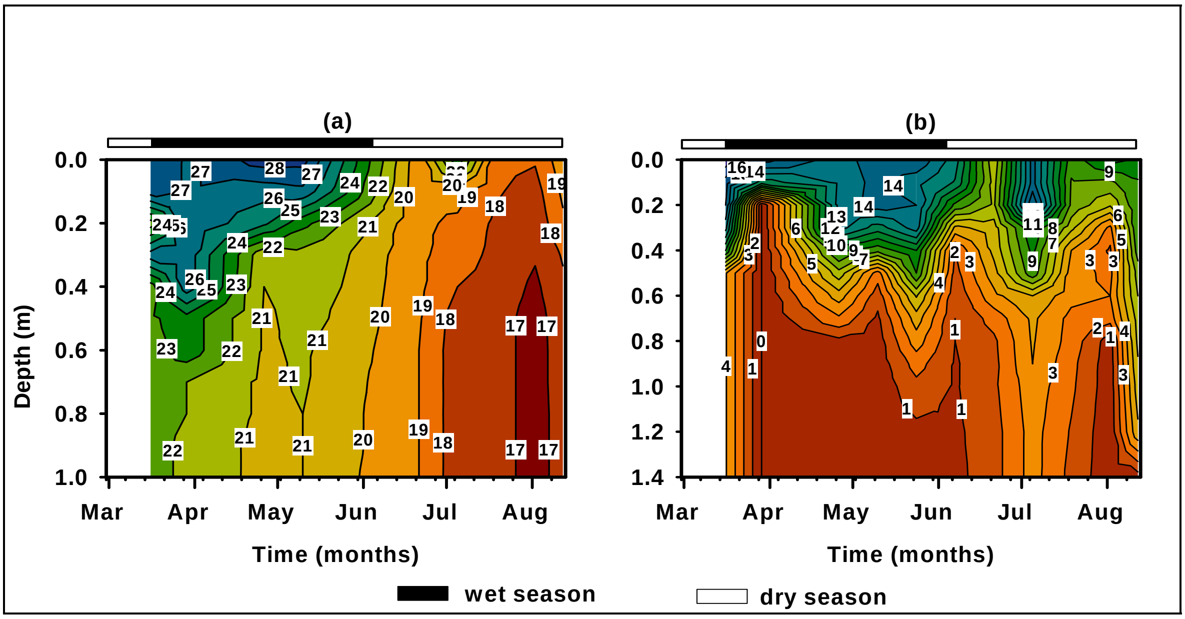

Figure 2: Depth-time representation of **(a) Temperature (^{o}C)** and **(b) Oxygen (mg L^{-1})** isopleths for Ngei reservoir during the study period (March – August, 2005)

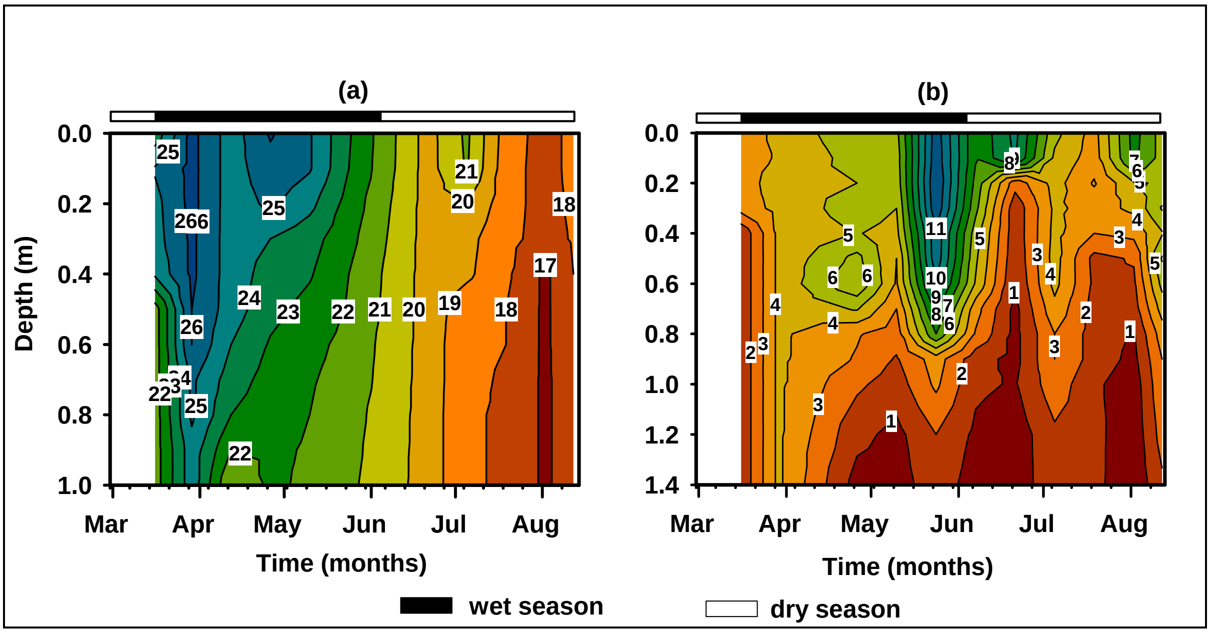

Figure 3: Depth-time representation of **(a) Temperature (^{o}C)** and **(b) Oxygen (mg L^{-1})** isopleths for Kavovi reservoir during the study period (March – August, 2005)

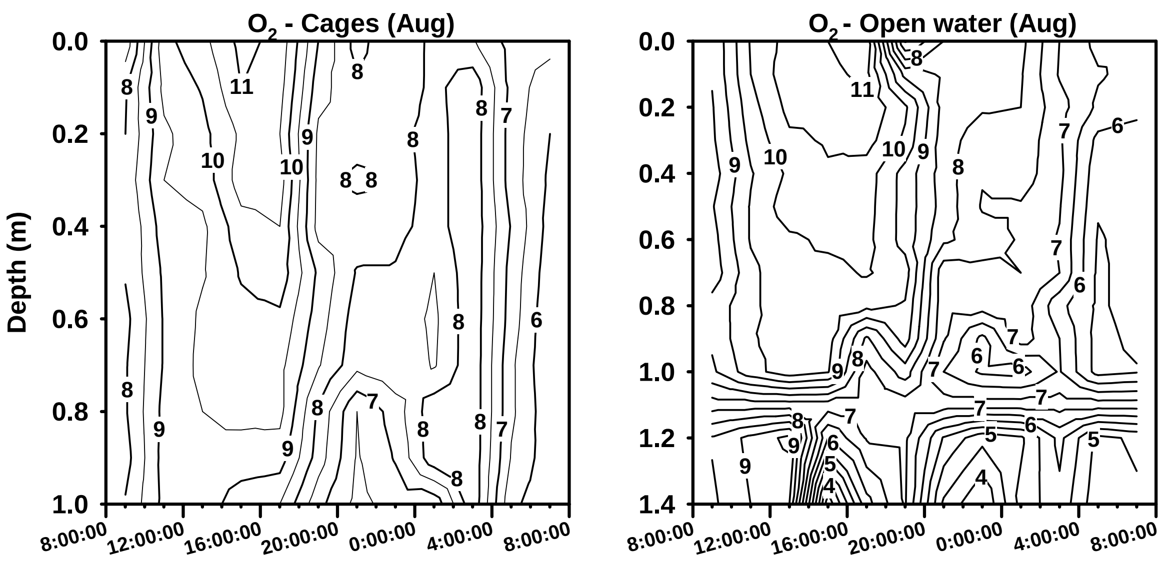

Figure 4: Depth-time representation of dissolved **Oxygen (mg L^{-1})** isopleths in cages **(a)** and open-water **(b)** in Ngeki reservoir during the study period (March – August, 2005)

Other water quality variables are shown in Table 2. Some variables differed significantly among and within reservoirs, while others were similar. Total alkanity (TA) in Kavovi was more than double that in the other two reservoirs. TA and total hardness (TH) were similar in Ngeki while TA was higher than TH in Ngei and Kavovi reservoirs. Both parameters have levels higher than 20mg CaCO3/L, which is the lower limit for fish production. The similarity between TA and TH in Ngeki suggested that carbonates systems were closely associated with Ca/Mg while the higher TA than TH in Ngei and Kavovi reservoirs suggested that the carbonate system was also associated with other than the alkaline earth metals. Kavovi had extremely high levels of ammonia suggesting a probable association of the carbonate system with the ammonium ion. Presence of high levels of ammonia is likely to stress fish, especially at high pH levels when a higher proportion of the total ammonia is in gaseous form. In all the reservoirs, the proportion dissolved phosphorus was very low.

Table 2: Data on some water quality variables and nutrients in the reservoirs (Mean ± SE)

Variable	**Reservoirs**		
	Ngeki	**Ngei**	**Kavovi**
Total alkalinity (mg Ca CO_3 L^{-1})	62.5 ± 4.41^a	50.0 ± 4.5^a	128.9 ± 7.6^b
Total hardness (mg Ca CO_3 L^{-1})	61.3 ± 3.1^b	22.6 ± 1.6^a	67.8 ± 4.1^b
SRP (µg L^{-1})	19.1 ± 7.4^b	29.3 ± 9.7^b	12.06 ± 5.8^a
TP (µg L^{-1})	181.2 ± 17.2^b	376.9 ± 35.0^c	104.3 ± 10.9^a
NH_4-N (µg L^{-1})	42.9 ± 10.4^a	56.7 ± 6.4^a	297.3 ± 65.1^b
NO_3-N (µg L^{-1})	83.9 ± 4.5^b	96.8 ± 7.3^b	48.9 ± 3.0^a
NO_2-N (µg L^{-1})	3.3 ± 1.1^a	13.1 ± 2.9^b	3.8 ± 1.3^a
Chlorophyll- *a* (µg L^{-1})	156.0 ± 12.1^a	348.2 ± 27.5^b	105.6 ± 20.4^a

Organic content (mg L^{-1})	48.1 ± 2.7^{b}	96.3 ± 8.7^{c}	23.3 ± 1.9^{a}
Specific Conductivity (μS cm^{-1})	812.9 ± 12.3^{c}	125.8 ± 5.9^{a}	552.0 ± 29.8^{b}
pH	8.4 ± 0.4^{b}	7.9 ± 0.3^{a}	7.2 ± 0.1^{a}
Secchi depth (m)	0.25 ± 0.01^{b}	0.11 ± 0.004^{a}	0.54 ± 0.04^{c}

SE = standard error of the mean physico-chemical characteristics of the reservoirs

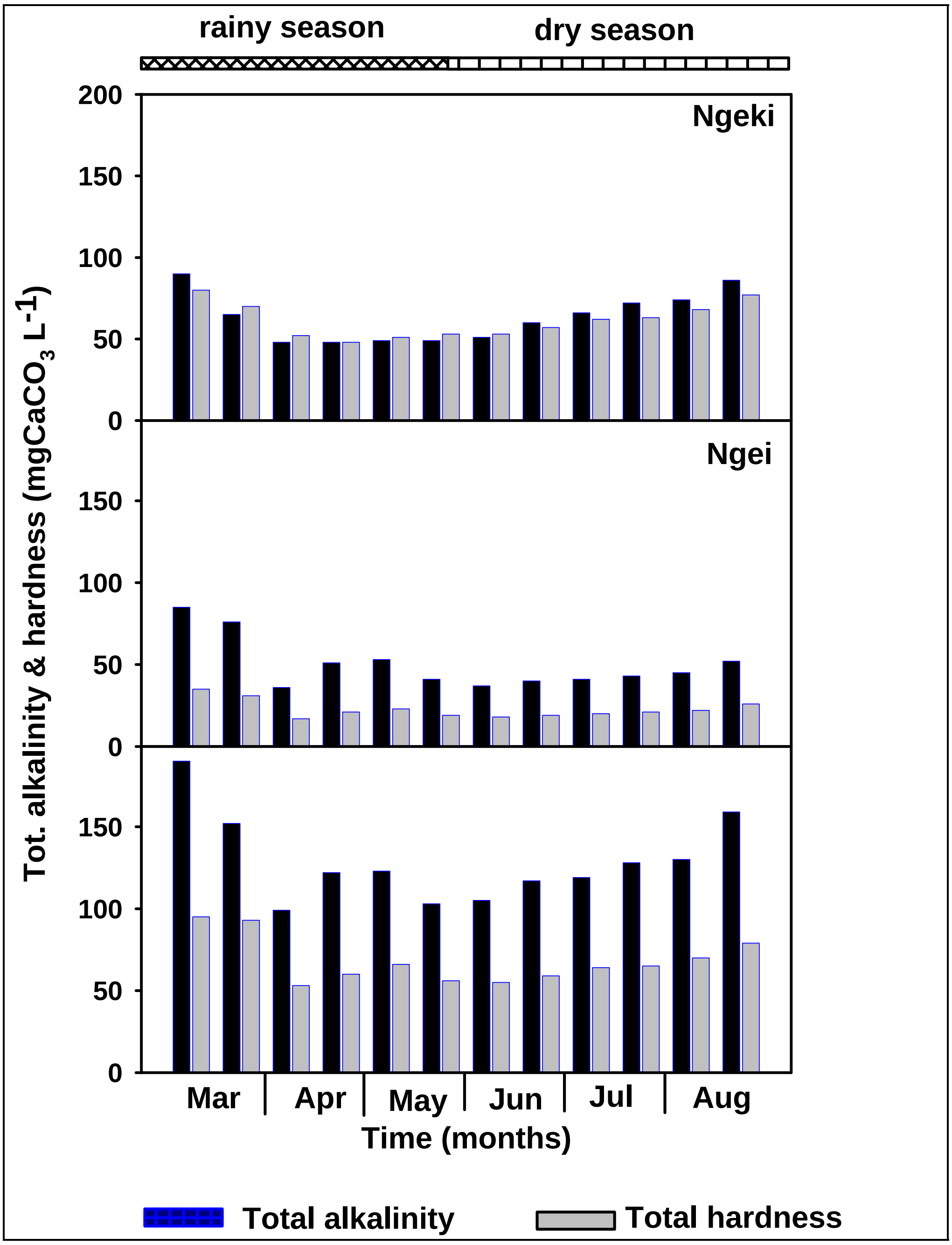

Figure 5: Total alkalinity and hardness variations in Ngeki, Ngei and Kavovi during the sampling period (March – August, 2005)

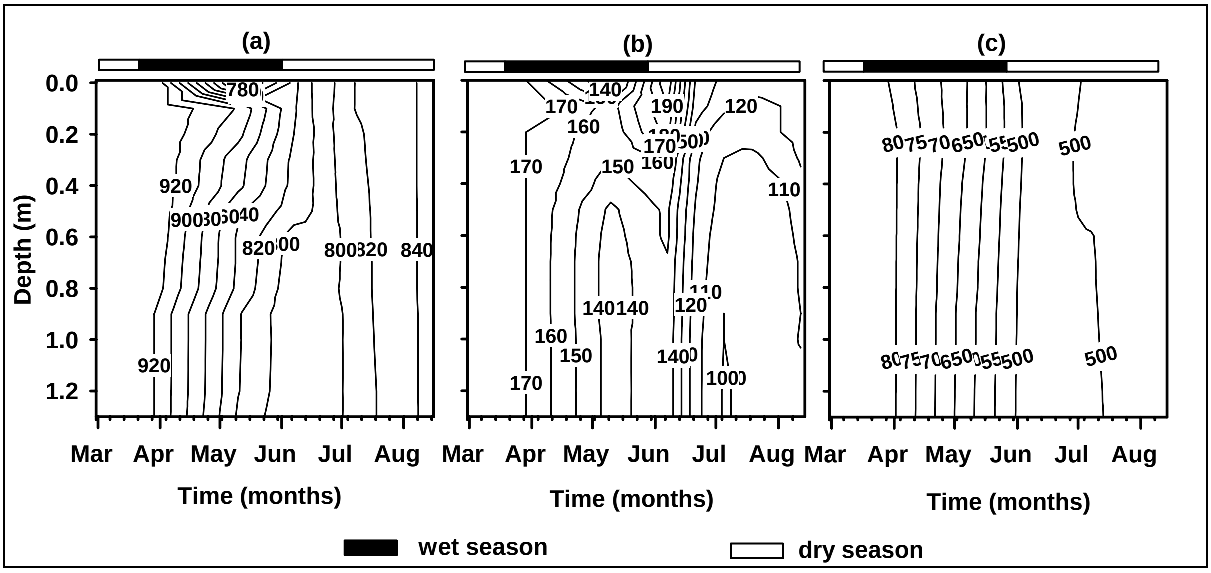

Figure 6: Specific conductivity isopleths for Ngeki (a), Ngei (b) and Kavovi (c) during the sampling period (March – August, 2005)

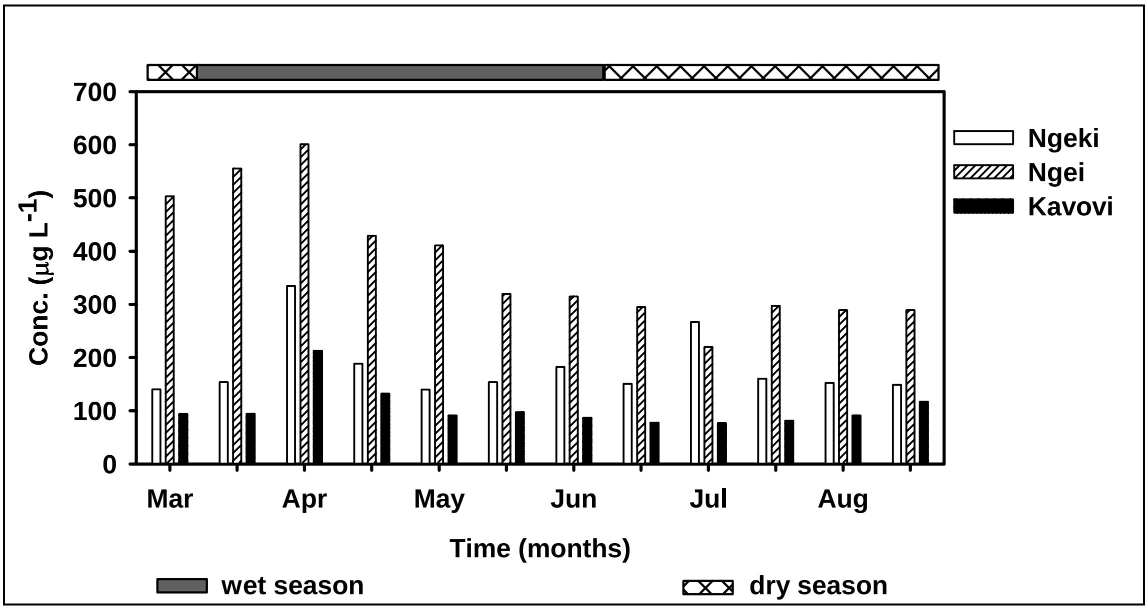

Figure 7: Temporal trends of TP concentrations in Ngeki, Ngei and Kavovi reservoirs during the study period (March – August, 2005)

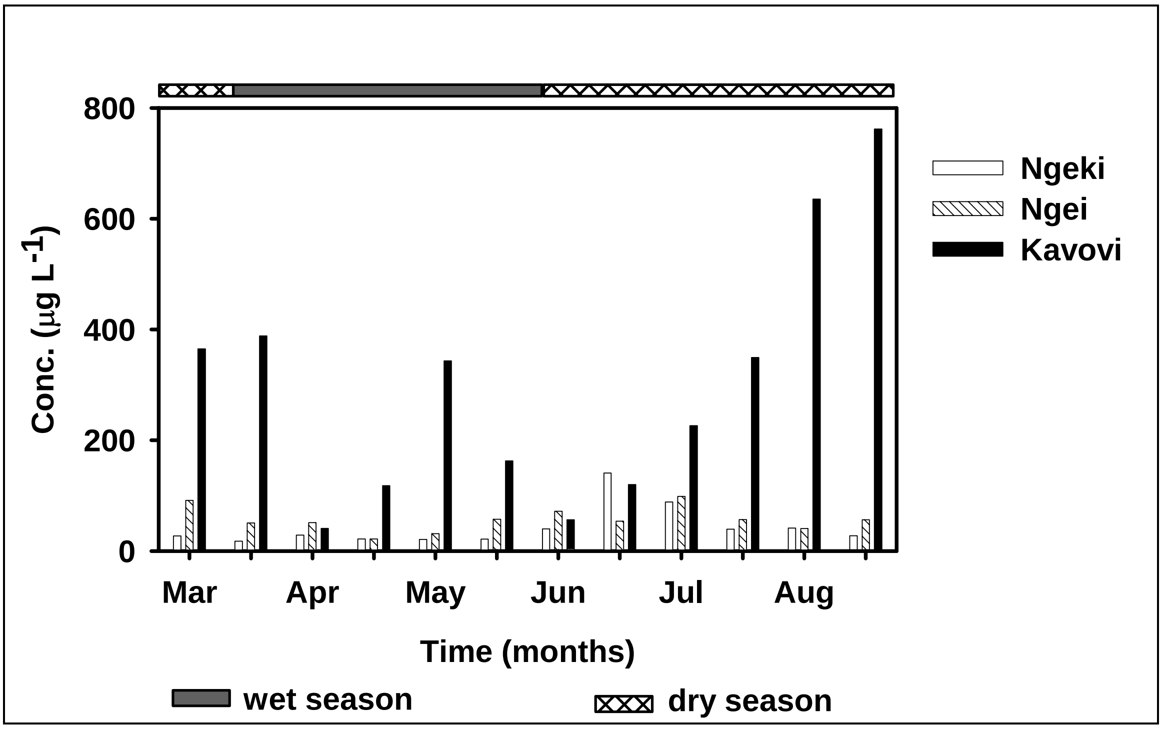

Figure 8: NH_4-N concentration variations in Ngeki, Ngei and Kavovi reservoirs during the study period (March – August, 2005)

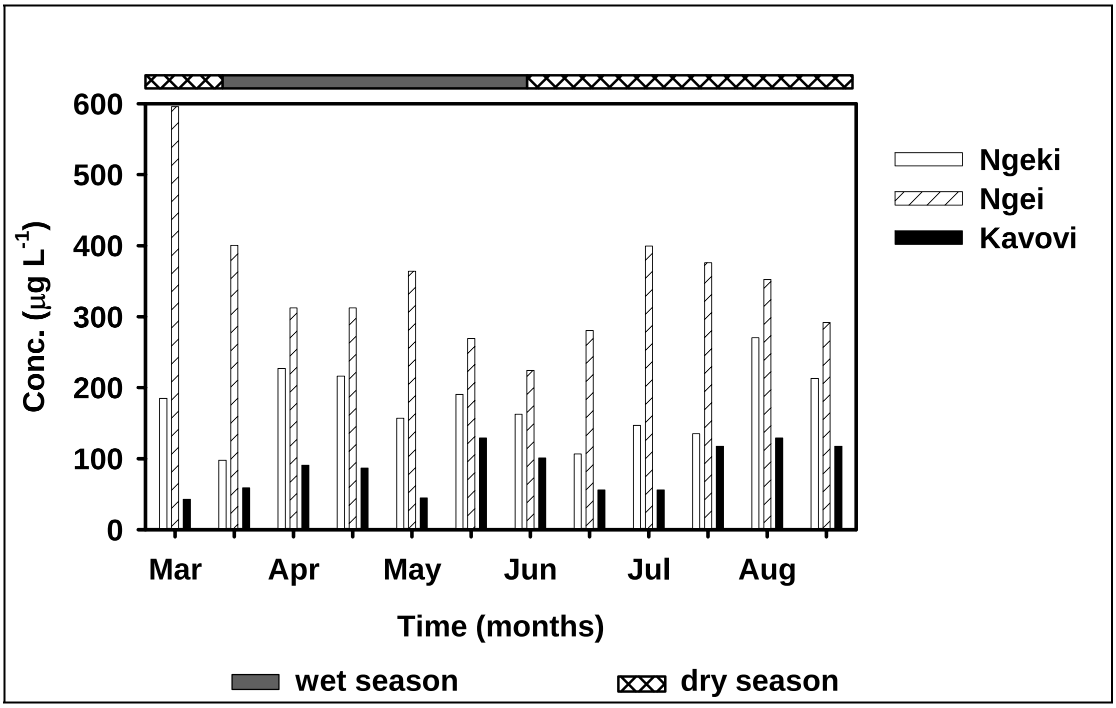

Figure 9: Chlorophyll-*a* variations in Ngeki, Ngei and Kavovi reservoirs during the study period (March – August, 2005)

Significant differences ($P<0.05$) were observed in specific conductivity among all the three reservoirs. However, Ngei had the lowest specific conductivity, which may be attributed to influx of more dilute underground water.

Figure 7 shows seasonal variation in TP for Ngeki, Ngei and Kavovi respectively. The values demonstrated a clear temporal trend with maxima values in April for all the reservoirs and concentrations dropping gradually to low values in the dry season. However, the seasonal trend was not observed in the distribution of inorganic nitrogen (Figure 8) in all the reservoirs. During the rainy season there was inorganic and organic load input in all the reservoirs from the catchment. Thus, the elevated levels of TP were probably a result of this input. A mini-survey, which was conducted during the study period indicated that fertilisers such as diammonium phosphate (DAP) were commonly used in the agricultural farms during the planting season. The exceptionally high TP levels in Ngei were probably a result of internal loading. This phenomenon was probably more pronounced because the reservoir has no outlet, leading to exceptional accumulation of nutrients. Mineralization of organic matter has marked ecological influence in shallow waters because of the greater ratio of sediment to water surface ratio and the lower opportunities for vertical transport (Talling & Lemoalle, 1998). The anoxic condition, which was noted earlier, may signal a high rate of mineralization occurring in the dam leading to generation of higher nutrient levels. Another reason could have been the low turnover rates, which are usually expected in such a phosphorus-rich water body. On the other hand, Kavovi had low TP and SRP levels which were probably caused by nutrient stripping by the floating and emergent macrophytes. The dense emergent macrophytes utilise the dissolved nutrients thereby reducing nutrient concentrations for a given loading.

Exceptionally high levels of NH_4-N were observed in Kavovi (Figure 8). The high levels of NH_4-N in Kavovi might be attributed to the presence of hydrophytes, which actively secrete organic matter. The organic material is degraded by bacteria releasing ammonium. This view is supported by the preponderance of Euglenophytes in the reservoir, which commonly occur in waters rich in dissolved organic matter. However, levels of ammonia were high due to lowered photosynthesis as a result of high overcast.

All reservoirs with exception of Ngeki exhibited high levels in chlorophyll-*a* levels (Figure 9). There was no significant difference ($p > 0.05$) in the chlorophyll-*a* levels between the cages and open water in Ngeki reservoir. Chlorophyll-*a* level appear to be influenced by the nutrient levels in all the reservoirs. Phytoplankton biomass is usually an indicator of nutrient availability (Talling & Lemoalle, 1998) and the response of algae populations is highly dependent on the variations in nutrient concentrations (Reynolds, 1984). The fluctuations observed were markedly influenced by the weather conditions and on days with high solar radiation, chlorophyll-*a* levels increased due to enhanced primary production whereas on cloudy days the levels were low.

The algal composition in all the reservoirs consisted mainly of five groups which included Chlorophyta, Cyanobacteria, Euglenophyta, Bacillariophyceae and Dinophyta. Cyanonobacteria were more abundant during the rainy season while Bacillariophyceae were dominating in the dry season. Euglenophytes occurred more abundant in Kavovi dam, probably due to high organic matter load. Chlorophyta such as *Pediastrum sp*., *Scenedesmus sp*., and *Botryococcus sp.* were high at the beginning of the rainy season when nutrient levels were highest. However, with the onset of thermal gradients that prevailed during the rainy season colonial Cyanobacteria like *Microcystis sp*. and the large uni-cellular Dinoflagellate *Peridinium sp.* competed against the Chlorophyta. The dominance was probably occasioned by some morphological and behavioural adaptations such as the density ‘reduction’ (mucilaginous colonies) and motility (flagellates). Also controlled buoyancy might have enabled prolonged residence times in the euphotic zone.

The *K*-strategists were not a common feature in Kavovi probably due to the low nutrient levels compared to the other reservoirs. The dominance of Euglenophytes in Kavovi might be attributed to the high transparency of the water column as indicated by the high Secchi transparency and organic matter. Euglenoids such as *Trachelomonas sp*. have been found more frequently in the hypolimnia of transparent lakes (Reynolds, 1984).

The additional sampling was conducted in the month of February 2007 to represent the dry warm season, which was not covered during the first phase of sampling. This set of data completes information on the annual cycle characteristics of the water quality variables in Machakos region. The data indicate a characteristic similar to the April-May period, which demonstrate distinct diurnal thermal and DO gradients that are destroyed during nocturnal cooling. Since the months of September, October, January and February have similar characteristics of being hot and dry and have similar conditions with the period September-October. Therefore the information of February is representative of a hot and dry period and implies an additional growing period (September-October) in the year. The months of November, December are warm and wet and have similar characteristics to April and May and may be considered suitable for fish growth. On the basis of the present results, the grow out phase may be limited to the period between September-May, while the cold season June-August may be used as preparative phase.

Table 3: Water quality parameters in Ngei and Ngeki for February 2007

PARAMETER	**SITE**	**NGEI**	**NGEKI**
Dissolved oxygen	Maximum	5.1	9.1
	Minimum	0.1	0.3
Temperature	Maximum	29.2	28.5
	Minimum	19.8	21.7
	Average	21.0 ± 0.60	23.5 ± 0.14
Conductivity	Maximum	210	880
	Minimum	60	780
	Average	76.1± 9.2	809±2.3
pH	Maximum	7.20	8.92
	Minimum	6.26	6.78
	Average	6.16 ± 0.15	7.76 ± 0.10

SE = standard error of the mean physico-chemical characteristics of the reservoirs

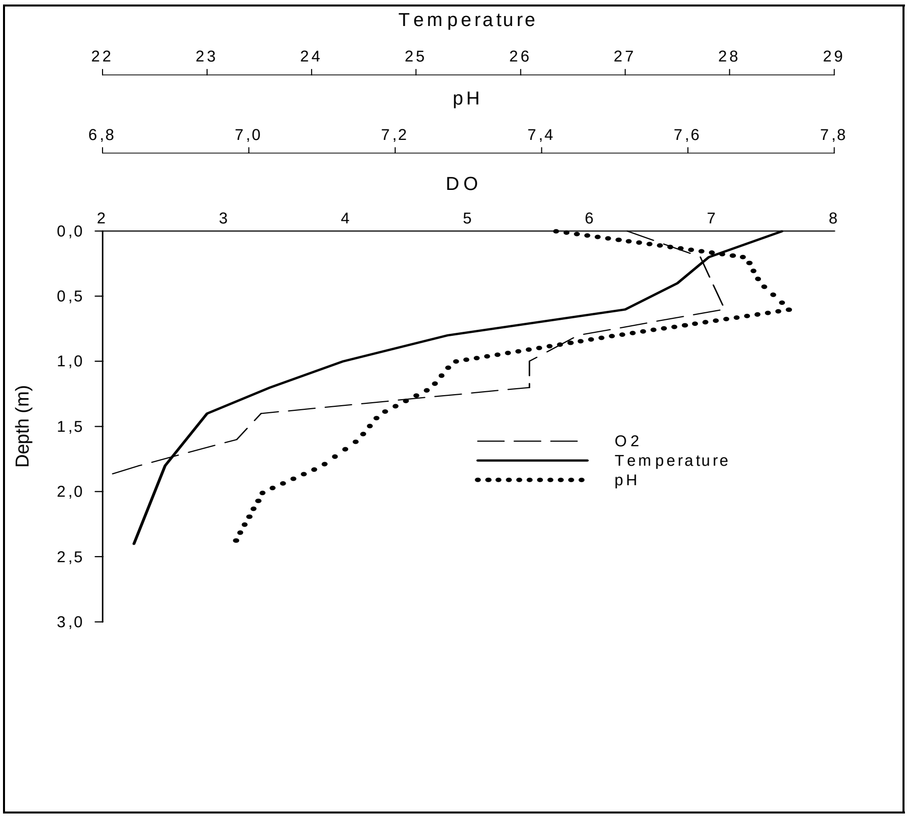

Figure 10: Some water quality profiles for Ngeki Dam, February 2007

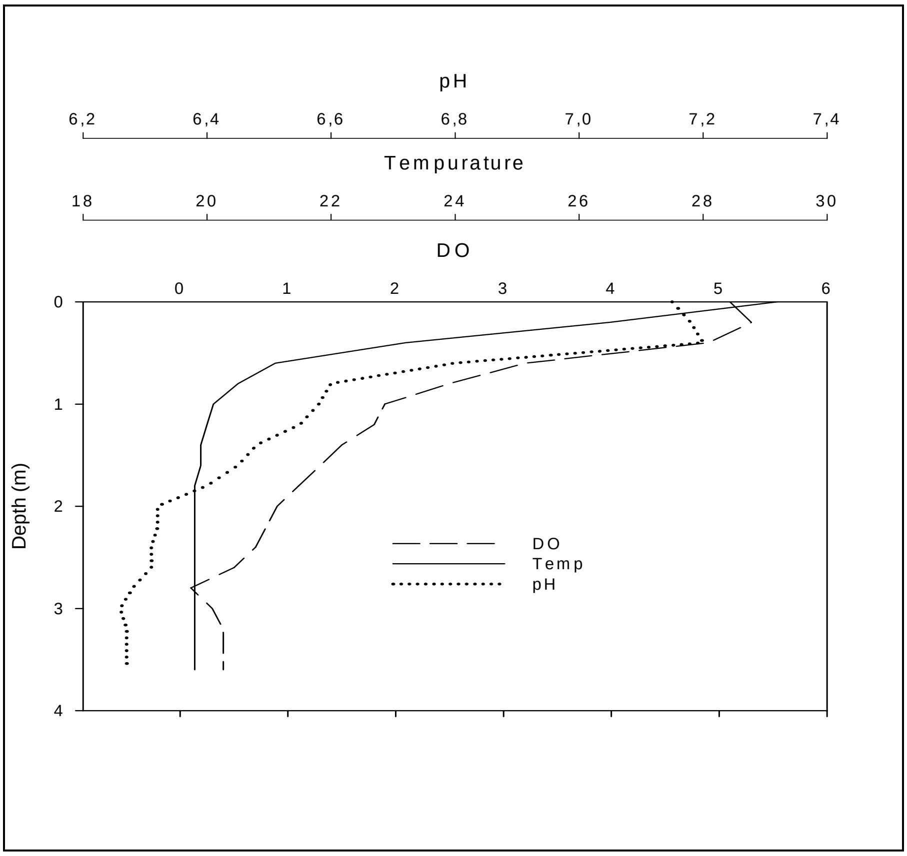

Figure 11: Some water quality profiles for Ngei Dam, February 2007

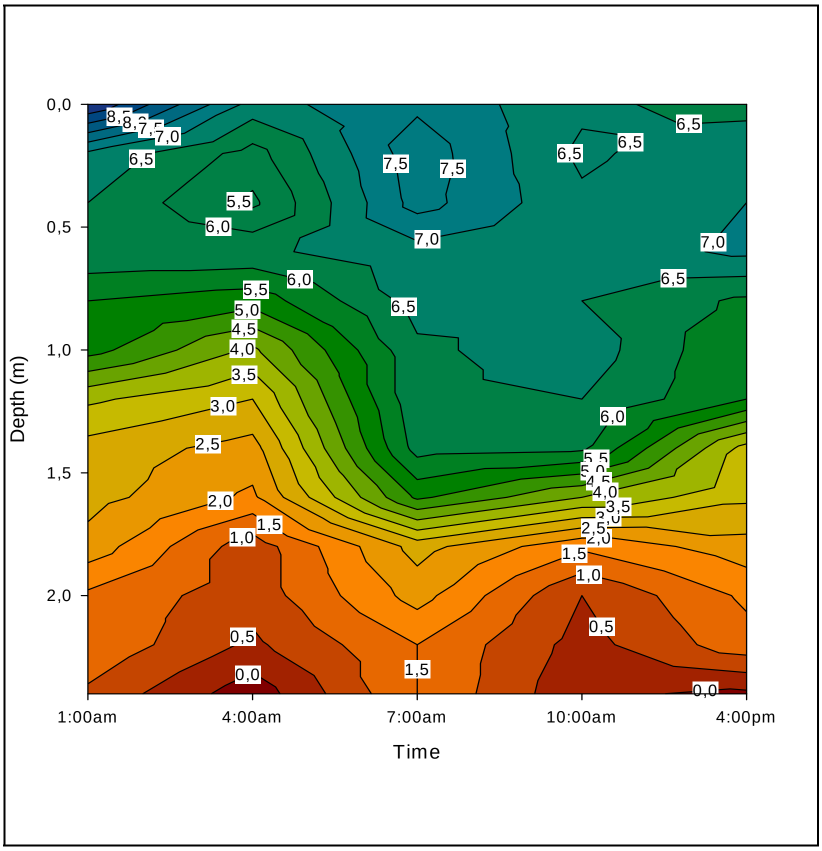

Figure 12: Depth-diel DO profiles for Ngeki Dam, February 2007

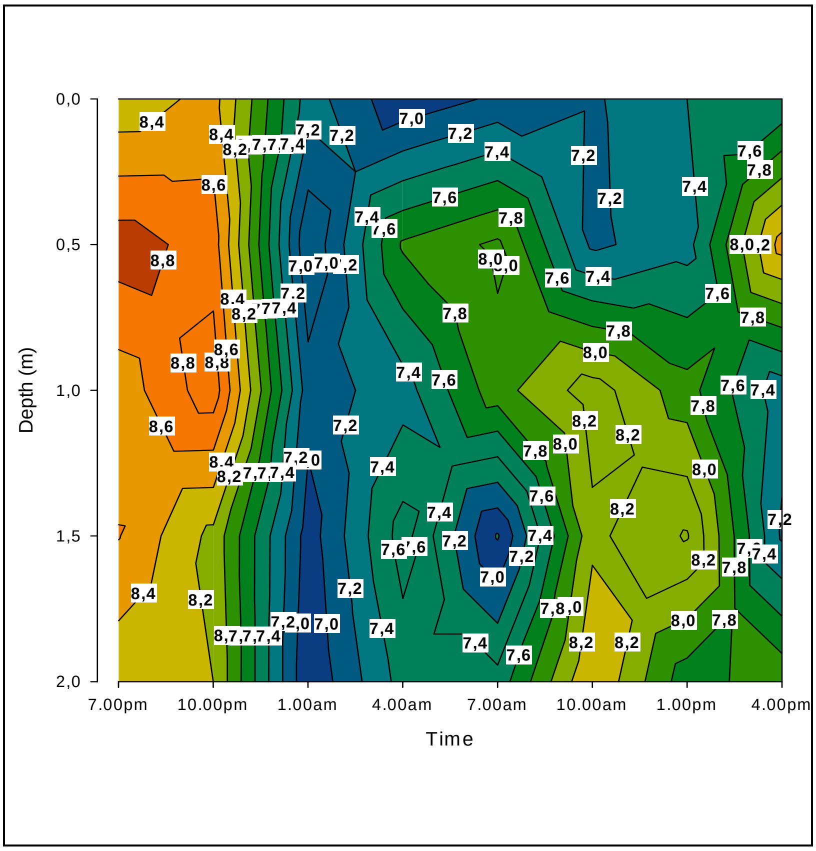

Figure 13: Depth-diel pH isoplot for Ngeki Dam, February 2007

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5 LIST OF FIGURES AND TABLES