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Catchment Characteristics and Water Quality of Three Reservoirs (Victoria, Minneriya and Udawalawe) in Sri Lanka

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Abstract

The structure, ecosystem processes and dynamics of Victoria, Minneriya and Udawalawe reservoirs in Sri Lanka, were studied over a period of two years (1998-2000) under the FISHSTRAT programme. As a component of the overall study, catchment characteristics and subsequent water quality of the three Sri Lankan reservoirs were examined. Catchment characteristics (viz., geochemistry, altitude, climate and weather, vegetation and soil, and the land use pattern) are the major determinants of the overall characteristics of the three reservoirs. Accordingly, water temperature, pH and electrical conductivity, important physical characteristics of Victoria showed marked differences from Minneriya and Udawalawe.

The annual surface temperature ranged between 25.5°C and 30.0°C in Victoria and it was 27.0°C - 29.5°C and 27.0°C - 31.5 °C in Udawalawe and Minneriya reservoirs respectively. The open water was alkaline throughout 1999 in the two dry zone reservoirs, Minneriya and Udawalawe while it changed from more or less neutral to alkaline in Victoria. The maximum suspended solids transported by the Udawalawe inflow was 4 times than that of the Mahaweli trunk stream and 6.6 times of the inflow of the Minneriya reservoir. There is a similarity with slight exceptions in relative proportions of major cations and anions in open water and respective inflows mainly calcium, magnesium and sodium ions is balanced by bicarbonate and chloride.

Introduction

FISHSTRAT, the European Union funded INCO-DC programme analyzed structure, ecosystem processes and dynamics of Victoria, Minneriya and Udawalawe reservoirs in Sri Lanka, Ubolratana reservoir in Thailand and Lake Taal in the Philippines over a period of two years (1998-2000). The primary objective of the FISHSTRAT programme was to derive a management tool for capture fishery and aquaculture practices based on ecosystem structure processes and dynamics, fisheries potential and socio-economics of riparian community. The fundamental aspects of limnology of these water bodies were studied in detail along with the ecology of the ichthyofauna and fisheries potential as a resource base and socio-economics of fishers living in the periphery with a view to propose sound management strategies for sustainable resource use.

The first workshop on limnology under the scope of FISHSTRAT activities was held in Bangkok, Thailand in February 2000 to compile and analyze the already available data on limnology of five water bodies with a view to fill potential gaps. The available data on limnology of five water bodies with a view to fill potential gaps. The workshop was concluded with an agreement to publish basic information on descriptive limnology of respective water bodies in local journals, and conference proceedings. Therefore, the objective of this paper is to describe the catchment characteristics and subsequent water quality of three Sri Lankan reservoirs studied under the FISHSTRAT programmeme, as a prerequisite to characterize ecosystem structure, processes and dynamics.

Materials and Methods

Study sites

Three reservoirs namely Minneriya, an irrigation tank of ancient category, Udawalawe, a recently build irrigation cum hydropower reservoirs and Victoria, a modern hydropower reservoir were studied under the FISHSTRAT programme. Minneriya and Victoria reservoirs fall hydrologically within the Mahaweli River basin while the Udawalawe reservoir is fed by the Walawe River which drains the southern escarpment of the central highland (Fig. 1).

Minneriya Reservoir: Minneriya reservoir is a lowland shallow irrigation tank located in the North Central dry zone (6° 02' N ; 80° 53'E) at 96m above mean sea level (Table 1). The reservoir was built by King Maha Sen in the third century (276 - 303 A.D.) and it was further repaired and augmented by King Parakrama Bahu (1153 - 1186 A.D). Therefore, the Minneriya reservoir is considered as an ancient irrigation tank but it was abandoned after shifting the ancient Sinhalese kingdom from Polonnaruwa to Yapahuwa. The reservoir was restored in 1902 under the British regime and subsequently improved and enlarged in 1953. However, the construction of cascading reservoirs (e.g., Giritale, Minneriya, Kaudulla and Kantale) with a feeder canal diverted from the Amban Ganga, a major tributary of the Mahaweli river is considered as one of the greatest engineering achievements of dry zone tank civilizations of ancient Sri Lankans.

The Minneriya tank was fed by its own catchment and the water from the Amban Ganga diverted via the Elahera anicut channeled through the 30 km long Elahera-Minneriya Yoda Ela feeder canal (Fig. 2a). In the mid seventies, the main stream of the Mahaweli River was partially diverted at Polgolla (Kandy) and chandelled northward through a link tunnel (6.5 km) to Sudu Ganga, a major tributary of the Amban Ganga with the implementation of the first phase of the Mahaweli Development Programme. The Minneriya tank then received an additional amount of water from the Mahaweli River conveyed through Bowetenna storage tank since 1978 resulting in a significant change in the hydraulic balance of the reservoir.

The primary objective of the reservoir is to provide water for rice paddy in the command area (8690 ha) during two major cultivation seasons (*Maha*, October - March; *Yala*, April - September). At present, the reservoir fills up to its full supply level (268 MCM) during the second inter-monsoon (October - January) inundating an area of 25.5 km^2 and the water level recedes to its lowest towards the end of the dry season (July - August). The reservoir is more lacustrine in nature and became an important resource of the commercial fishery following the introduction of African cichlids in the early 1950s. Today, the Minneriya reservoir together with its surrounding environs and infrastructure development has become an important socio-economic center in the North Central dry zone.

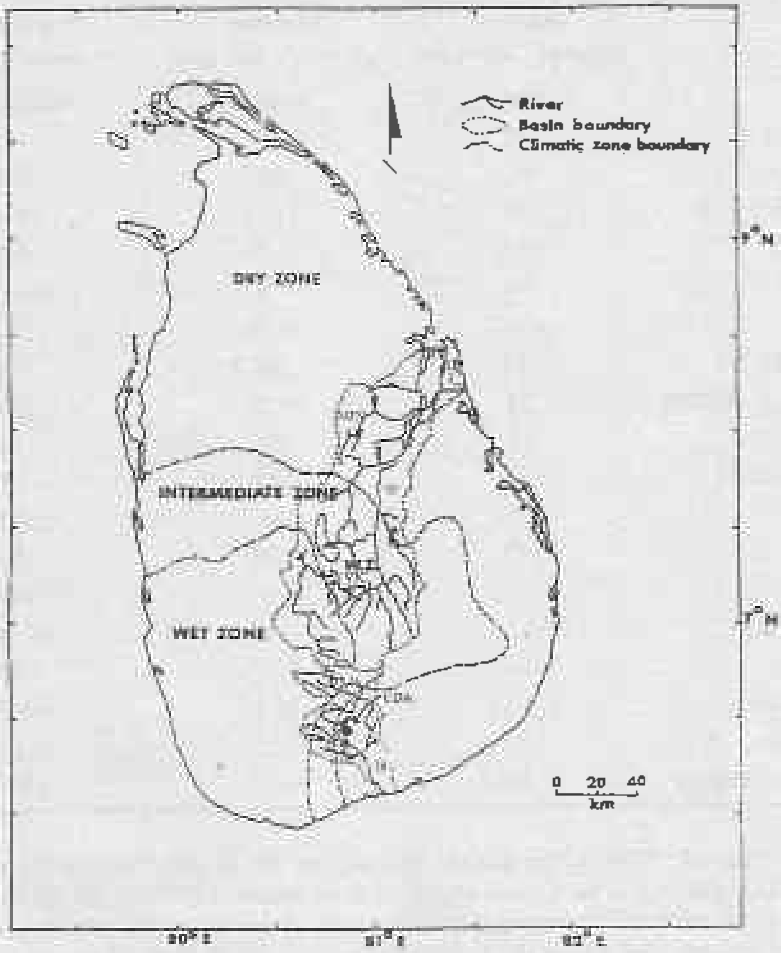

Figure 1 Map of Sri Lanka showing three FISHTRAT reservoirs in there respective river basins

Udawalawe: Udawalawe, the third largest reservoir (6° 23' N ; 80° 50'E) in Sri Lanka (34 km^2) was built in 1962 for irrigation cum hydropower generation, by damming the trunk stream of the Walawe River in the southern dry zone at 80 m above mean sea level (Fig. 1). The reservoir is located within the Udawalawe National Park about 40 km north of the southern coast. The Udawalawe reservoir provides irrigation water for 29,447 ha in the downstream command area and generates 6 MW of hydroelectricity. This multi fringe reservoir (Fig. 2b) has inflow and outflow in the north-south direction and the presence of dead trees sunk in the reservoir, the remnant of of the jungle is a prominent feature at low water level. In addition to irrigation and the generation of hydropower, the reservoir has a proven potential of fish production.

Table 1. Morphological and hydrological characteristics of three FISHSTRAT reservoirs (D.Depth: A.Area: V.Volume: SL.Shoreline: F.Fetch: Sp.Specific)

Parameter	Minneriya	Udawalawe	Victoria
Type	Irrigation	Irrigation	Hydropower
Location	8° 02' N : 80° 53' E	6° 27' N : 80° 50' E	7° 13' N : 80° 47' E
Basin	Mahaweli	Walawe	Mahaweli
Age (years)	97	33	14
Altitude (m)	96	80	438
Catchment (km^2)	249	1164	1891
Area (km^2)	25.5	34.08	22.7
D_{mean} (m)	5.8	7.9	30.5
D_{max} (m)	11.6	39.52	98
Volume (MCM)	135	268	783
Dead storage (MCM)	3.2	26.26	34
Shoreline (km)	55	53	115
SL development	3.05	2.05	6.789
Fetch (km)	8.99	10.7	8.57
A:F (km)	2.83	3.19	2.59
V:F (km^2)	15.02	25.05	91.36
Yield (MCM)	60.71	15.81	17.80
Sp. Yield	0.31	1.37	0.94
Issue (MCM)	177.32	425.11	768.44
Yield : Issue	1.34	3.72	2.32
Flushing rate (years)	0.766	0.631	1.018

Victoria: Victoria, the deepest (98 m) and the largest reservoir by volume (783 MCM) is located in the Central Highland of the country (7° 13' N: 80° 47' E) at 438 m above mean sea level. Damming the trunk stream of the Mahaweli River by a double curvature concrete arch dam at the Victoria Falls where the Hulu River merges with the Mahaweli River formed the Victoria reservoir. The reservoir which morphologically shows the shape of W can be divided into two distinct segments called Mahaweli and Hulu sectors (Fig. 2c). In addition to the Hulu River, Galmal Oya, a left bank tributary of the Hulu River in the Hulu Sector and Maha Oya and a few other lesser tributaries in the Mahaweli Sector also feed the Victoria reservoir. The catchment area of the reservoir is 1891 km^2. The Victoria is essentially a hydropower reservoir with a capacity of 210 MW. In addition of generation hydropower, fishing is a major activity throughout the year.

Catchment characteristics

Although located in the Highland Series which is a distinct geological feature of Sri Lanka, the three FISHSTRAT reservoirs represent different catchment characteristics with respect to climate, geomorphology, geochemistry, hydrology, pedology and land use The terrain of the Minneriya catchment is undulating with scattered rock-knob plains and eroded land with erosional remnants The upper

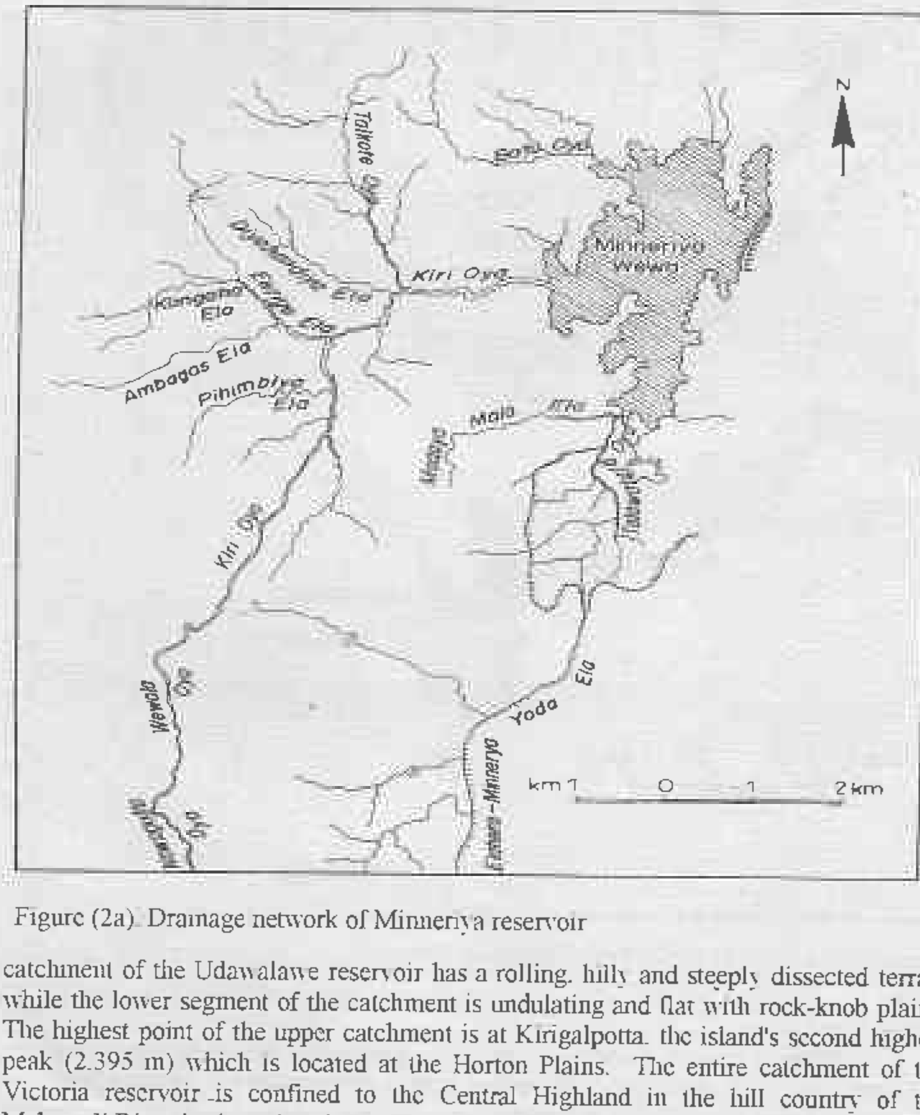

Figure (2a). Drainage network of Minneriya reservoir

catchment of the Udawalawe reservoir has a rolling, hilly and steeply dissected terrain while the lower segment of the catchment is undulating and flat with rock-knob plains. The highest point of the upper catchment is at Kirigalpotta, the island's second highest peak (2.395 m) which is located at the Horton Plains. The entire catchment of the Victoria reservoir is confined to the Central Highland in the hill country of the Mahaweli River basin and to the southwestern slope of the Knuckles Range. Therefore, a major part of the Victoria watershed is mountainous. In addition, the terrain of the catchment is hilly and steeply dissected and rolling The elevation of the catchment ranges from 416 m to 3000 m above mean sea level.

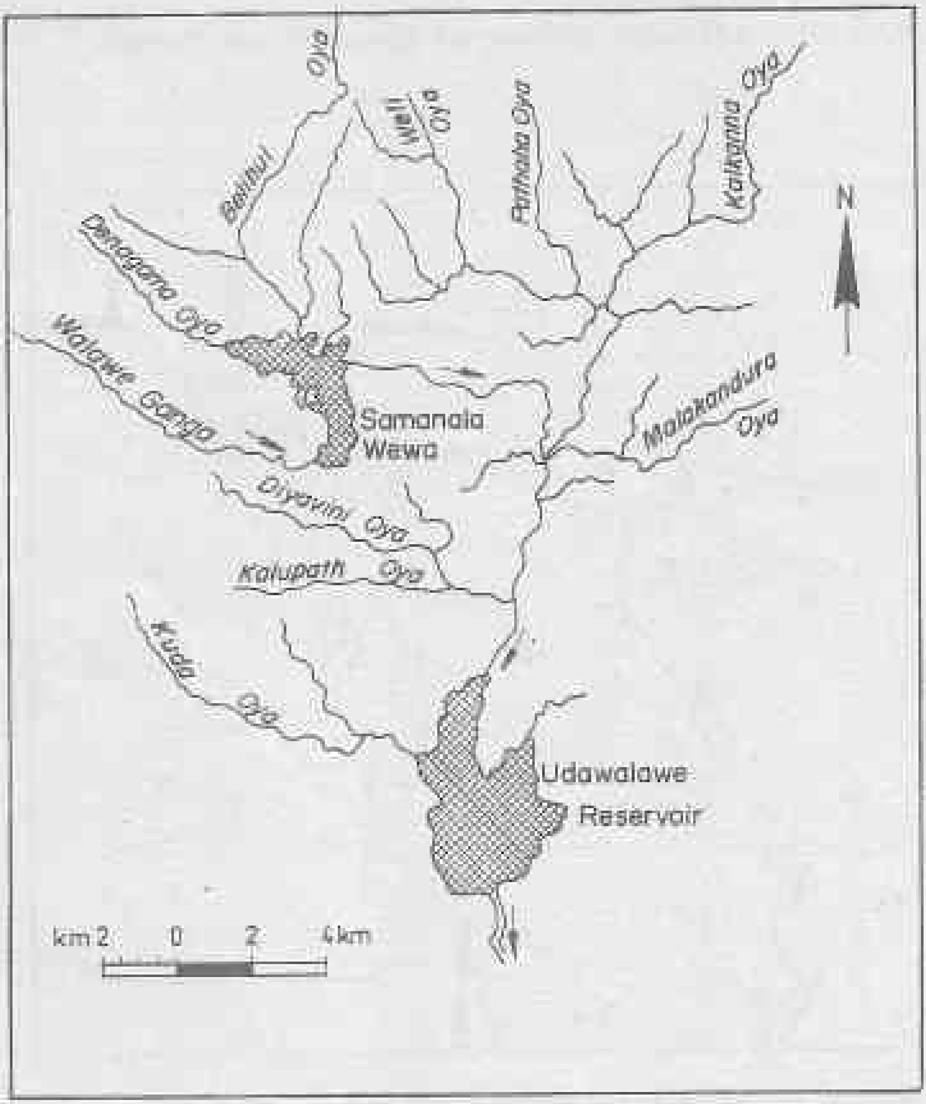

Figure (2b). Drainage network of Udawalawe reservoir

Geology and Soils

The three reservoirs and their respective catchments are mainly located in the Highland Series (Charnokite to sedimentary series) of Precambrian origin with a few exceptions. These Precambrian geological forms consist predominantly of sedimentary succession of a variety of rocks inter-blended invariably with charnokites (Cooray 1984). Meta-sedimentory rocks are now being a succession of well-blended calc and cordite gneisses, quartz-schists, granitiferrous and quartz feldspar granites, crystalline limestone and dolomite and garnet-sillimanite-graphite-schists under metamorphic condition. Quartzites are perhaps the most predominant members in the catchments, which have attained their greatest development in the Central Highland, and in the region of Minneriya and Polonnaruwa. The eastern segments of the Udawalawe and Minneriya catchments belong to the Vijayan Series and are also of Precambrian origin. but mainly comprise of rocks of biotite and biotic horn-blend gneisses.

When rocks are not exposed. alluvial and erosional deposits of Holocene. Pleistocene and other formations (Panabokke 1996) largely cover the terrain of the catchments of the three reservoirs. The undulating terrain of Minneriya and Udawalawe catchments are covered with reddish-brown earth and low humic gley soils. Alluvial soils of variable origin and textures are found in the flat terrain of the Udawalawe catchment along the river and stream as narrow strips. The rolling, hilly and deeply dissected terrain of the Udawalwe catchment consists of reddish brown earth, immature brown loam and red-yellow podzolic soils. However. reddish brown latzolic and immature brown loam soils are found in hilly and steeply dissected terrain of the Victoria catchment. The mountainous terrain of the Victoria catchment consists of red-yellow podzolic soils and immature rigasols

Drainage networks

The watershed of the Minneriya reservoir is drained largely by Kiri Oya a seasonal brook and two seasonal tributaries named Batu Oya and Talawature Ela (Fig 2a). The Kiri Oya originates as Nawagolla Oya in Huragala hills at 490 m above mean sea level about 20 km south of the reservoir. Several lesser seasonal brooks and canals namely Talkote Oya. Eerige Ela and Pihimbiya Ela merge with the Kiri Oya on its right bank. The Minneriya tank has been formed initially by damming the Kiri Oya. Subsequently the Elahera-Minneriya Yoda Ela, a feeder canal has been channeled to Minneriya tank via Talwatura Oya on its left bank. At present Minneriya reservoir also receives Mahaweli water diverted at Polgolla via Sudu Ganga.

A vast area of the upper catchment of the Udawalwe reservoir is drained by the Weli Oya. Belihul Oya and Walawe Ganga while the lower catchment is drained by Diyavini Oya. Kuda Oya and Malakandura Oya (Fig. 2b). Weli Oya which originates from the west of Haputale and Ohiya Group merge with Pathaba Oya and then with Kalkanna Oya. which originates from the east of the Haputale-Koslanda and Haldumulla areas respectively. Belihul Oya originates in the Horton Plains and merges with Kirikeli Oya and Denagama Oya on its left bank and merges with the Walawe Ganga on its right bank. The Walawe Ganga rises from the southern boundary of the peak wilderness. The Weli Oya merges with the Walawe Ganga at Uggalkaltota, forming the Walawe River proper. At present. the Belihul Oya, Denagama Oya and Walawe Ganga feed the Samanala Wewa reservoir. the youngest hydropower reservoir in Sri Lanka and its outflow merges with the Weli Oya. The Walawe River proper then receives water from Malakandura Oya on its left bank immediately downstream of Uggalkaltota and Diyavini Oya on its Right Bank at 5 km downstream of the above confluence. In addition. Kuda Oya a left bank tributary of the Walawe River in the lower catchment. which drains the Weligepola area, feed the Udawalawe reservoir separately since the construction of the reservoir (Fig. 2b).

The entire catchment of the Victoria reservoir is confined to hill country and drained by the Mahaweli River in the Central Mahaweli Valley and Hulu River in the Knuckles. The uppermost tributary. Hatton Oya. the second major tributary of the Mahaweli River in the hill country drains the western slope of the Hatton Plateau. The Hatton Oya merges with the Kotmale Oya (presently the outflow of the Kotmale Reservoir) at Pallegama. a few kilometers downstream from the Nawalapitiya township-giving rise to the Mahaweli River proper. The Hatton Oya and associated major and lesser streams and brooks together drain mainly semi-urbanized and cultivated landscape. This area receives heavy rainfall having its maximum during the southwest monsoon.

The trunk stream of the Mahaweli River also receives water from tributaries such as Atabage Oya and Nilambe Oya on the right bank and Nanu Oya and Pinga Oya on the left bank. The Hulu Ganga, a major left bank tributary, which drains the southwestern

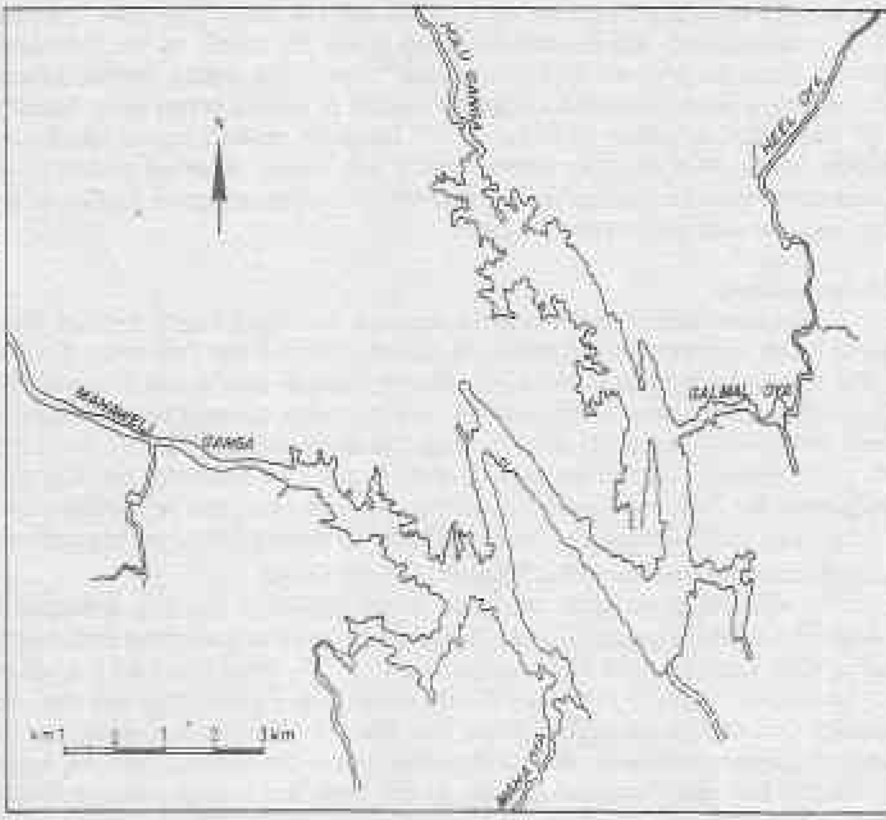

Figure (2c) Map of the Victoria reservoir which shows Mahaweli & Hulu sectors

slope of the Knuckles Range, feeds the Victoria reservoir separately after the construction of the dam immediately downstream of the confluence of the Mahaweli and Hulu Rivers. The Hulu Ganga also drains a large area having a heavy rainfall during the second inter-monsoon and southwest and northeast monsoons. Galmal Oya, a left banks tributary of the Hulu River and Maha Oya a right bank tributary of the Mahaweli River also empty into the Victoria reservoir separately (Fig. 2c).

Land use

Major land use types in the Minneriya catchment are dry zone secondary forest (47.1%) and scrub (31.5%). The land use for paddy cultivation (3.3%) and home gardens (3.4%) is more or less twofold compared to chena cultivation, which is 1.8 % of the total area of the catchment. The predominant land use types in the Udawalwe catchment are montane forest (24.8%) and scrub (13.3%). The area used for chena cultivation (24.4%) is more or less similar to that of the area covered by the montane forest. Tea plantations and paddy fields cover 7.4% and 4.7% of the catchment area respectively. However, home gardens cover 9.223 ha (9.1%) of the catchment. Other plantations (6.4 %) are also a prominent feature of the Udawalawe catchment land use (Table 2). The predominant land use feature of the Victoria catchment, which is the largest among the three reservoirs, is home garden (28.6%). In addition, tea plantations cover 24 % of the catchment and only 20.4% are left as natural forest. The grasslands (9.8%) and paddy fields (8.1%) are also prominent land use features of the Victoria catchment.

Table 2. Land use types (ha) of the three FISHSTRAT reservoirs (Victoria, Minneriya and Udawalawe)

Type	Minneriya	%	Udawalawe	%	Victoria	%
01. Forest	11.492	47.4	28.335	24.8	27.260	20.4
02. Scrub	7633	31.5	15.161	13.3	-	
03. Chena	433	1.8	28.189	24.7	-	
04. Tea	-		8.434	7.4	32.084	24
05. Rubber	-		501	0.4	-	
06. Coconut	-		845	0.7	-	
07. Paddy	800	3.3	5410	4.7	10.784	8.1
08. Grassland	49	0.2	3172	2.8	13.110	9.8
09. Home gardens	822	3.4	9.223	9.1	38.183	28.6
10. Other Plantation	371	1.5	7.335	6.4	-	
11. Annual crops	-		-		4.209	3.1
12. Bare lands	20	0.1	1.281	1.1	4.411	3.3
13. Water bodies	2.636	10.8	6.056	5.3	3.653	2.7
Total	**24,259**		**114,169**		**133,637**	

Water analysis

Water samples were collected bimonthly for a period of two years from August 1998 to July 2000 from the center and the inflow and outflow of Minneriya and Udawalawe reservoir. In the case of the Victoria reservoir water samples were collected from the Mahaweli (VIC_M) and Hulu (VIC_H) sectors and their respective inflows. The outflow of the Victoria reservoir was not sampled due to security reasons. Basic physico-chemical characteristics such as temperature, pH, conductivity and alkalinity were determined *in situ*. Samples were also processed in the field to determine major cations (Na, K, Ca and Mg) and anions such as Cl^- and SO_4^{-2} and SiO_2 in the laboratory. Temperature (glass mercury thermometer), electrical conductivity (TOC conductivity meter, model CM-IK), pH (Expandable Ion Analyzer - Orion Research EA 920) and total alkalinity (acidimetric titration) were determined *in situ*. The water samples filtered through GF/C filter papers were processed to determine chloride (argentometric titration with $AgNO_3$) and sulfate (turbiditimetric method). The dissolved oxygen content was determined using a modified Winkler Technique (HYDRO-BIOS Kiel Dosimat 715 digital titrator). The suspended solid content was measured gravimetrically after filtering water through pre-weighed micro fiber membrane filter papers diameter (0.45μ). Filtered water samples were acidified with conc. HNO_3 acid and used to determine the concentrations of calcium, magnesium, sodium and potassium ions using an Atomic Absorption Spectrometer coupled with a graphite furnace (GBC 933 AA). The concentration of silica was determined spectrophotometrically (UV Shimadzu Model 1610) after forming heteropoly molybdosilicic acid blue complex (APHA 1989).

Results

Table 3 shows the annual ranges (1999) of physico-chemical characteristics of open water and respective inflows of three FISHSTRAT reservoirs. Minimum surface temperature (25.5°C) was recorded in Victoria (VIC_M) and it was 26.1°C in the Hulu sector (VIC_H) and 27.8°C and 27.0°C in Udawalawe and Minneriya reservoirs respectively. The highest surface water temperature (31.5°C) was recorded in the Minneriya reservoir and it was 29.0°C and 30.0°C in VIC_H and VIC_M respectively. The highest surface temperature recorded in Udawalawe was 29.5°C. Accordingly, the range interval of temperature (4.5°C) was found in both Minneriya and VIC_M and it was 2.9°C in VIC_M and 1.7°C in Udawalawe. In the case of water temperature of inflows VIC_H had the lowest temperature (23.5°C) while the lowest temperature in VIC_M, Minneriya and Udawalawe inflows were 24.0°C, 25.4°C, and 26.1°C respectively (Table 3). The inflow of the Minneriya reservoir had the highest range interval in temperature (4. 6°C) while it was 3.1°C, 2.6°C and 3.0°C for Udawalawe, VIC_H and VIC_M were respectively.

The open water was alkaline throughout the year 1999 in two dry zone reservoirs, Minneriya (7.32 - 8.35) and Udawalawe (7.33 - 8.58) while it changed from more or less neutral to alkaline in VIC_H (7.09 - 7.89) and in VIC_M (7.10 - 7.89). A more or less similar trend was found for inflow waters but the inflow of the VIC_H reached the pH of 6.70 indicating slightly acidic conditions under storm condition. Bicarbonate alkalinity was relatively low in both VIC_H (34 - 46 mg l^{-1}) and VIC_M (34,- 52 mg l^{-1}) and it was 64 - 89 mg l^{-1} in Udawalawe and 50 - 132 mg l^{-1} in Minneriya. Although the trend was more or less similar in the case of inflow water, the values were extremely low in VIV_H (19 - 36 mg l^{-1}) and VIC_M (10 - 46 mg l^{-1}). The range interval of bicarbonate was highest in Minneriya (196 mg l^{-1}) and it was 105 mg l^{-1} in Udawalawe. The level of electrical conductivity of open and inflow waters of the three reservoirs was more or less similar to that of bicarbonate alkalinity (Table 3). However, the electrical conductivity ranged from 98 - 213 μS in Minneriya and the ranges were 103 - 134 μS, 66 - 81 μS and 69 - 93 μS in Udawalawe, VIC_H and VIC_M respectively.

Dissolved oxygen in Minneriya ranged from 6.84 mg l^{-1} to - 8.11 mg l^{-1} and it was 7.11 - 8.02 mg l^{-1} in Udawalawe (Table 3). VIC_H and VIC_M had dissolved oxygen ranging from 5.89 mg l^{-1} to 8.02 mg l^{-1} and 6.31 mg l^{-1} to 8.14 mg l^{-1} respectively. The dissolved oxygen content in inflow waters was ranged in a similar pattern without marked variations. Suspended solid contents in open water and in inflows of the three water bodies showed marked variations (Table 3). In Minneriya reservoir the range was 1.0 - 54.7 mg l^{-1} while in Udawalawe it ranged between 2 - 23 mg l^{-1}. Both sectors of the Victoria had more or less similar contents of suspended solids (VIC_H = 0.6 - 12 mg l^{-1} and VIC_M = 1.0 - 12 mg l^{-1}). Similarly, the inflow of the Minneriya reservoir

Table 3. Ranges of physico-chemical parameters of three FISHSTRAT reservoirs (MIN. Minneriya; UDA. Udawalawe; VIC_H, Victoria Hulu Ganga sector; VIC_M, Victoria Mahaweli sector)

Parameter	MIN	UDA	VIC_H	VIC_M
Temp. (°C)	27.0 - 31.5	27.8 - 29.5	26.1 - 29.0	25.5 - 30.0
Inflow	26.9 - 31.0	26.1 - 30.1	23.5 - 26.1	24.0 - 27.0
pH	7.32 - 8.35	7.33 - 8.58	7.09 - 7.89	7.1 - 7.89
Inflow	7.33 - 8.35	7.24 - 7.98	7.03 - 8.37	6.7 - 7.67
Alkalinity (mg l^{-1})	56 - 132	61 - 89	33 - 46	34 - 52
Inflow	34 - 230	51 - 156	19 - 36	10 - 46
EC (μS)	98 - 213	102 - 134	66 - 81	69 - 93
Inflow	74 - 333	74 - 223	29 - 60	36 - 78
TDS mg l^{-1}	81 - 188	83 - 128	48 - 69	47 - 79
Inflow	51 - 290	69 - 195	25 - 57	21 - 70
Secchi Depth (cm)	45 - 280	50 - 205	135 - 280	95 - 270
Diss. O_2 (mg l^{-1})	6.84 - 8.11	7.11 - 8.02	6.98 - 8.78	6.31 - 8.14
Inflow	6.82 - 8.23	7.32 - 8.74	7.89 - 8.75	7.32 - 8.21
Sus. Solids (mg l^{-1})	01 - 55	2.0 - 23	0.6 - 12	01 - 12
Inflow	01 - 77	04 - 504	01 - 11	07 - 126
Chloride (mg l^{-1})	4.80 - 14.8	2.10 - 5.00	4.40 - 6.38	4.00 - 6.38
Inflow	6.03 - 12.8	1.70 - 4.96	2.00 - 5.67	3.00 - 6.03
Sulphate (mg l^{-1})	1.27 - 8.44	2.01 - 5.55	0.48 - 1.03	0.66 - 2.30
Inflow	1.43 - 6.13	1.80 - 6.92	0.44 - 1.62	0.98 - 8.77
Silica (mg l^{-1})	1.03 - 2.23	0.23 - 1.66	0.46 - 0.73	0.55 - 1.02
Inflow	1.19 - 4.08	0.25 - 1.96	0.84 - 1.32	0.66 - 1.04
Sodium (mg l^{-1})	4.78 - 8.13	4.16 - 6.38	3.14 - 4.44	3.10 - 5.19
Inflow	1.11 - 8.95	3.00 - 10.6	3.03 - 4.33	2.49 - 5.02
Potassium (mg l^{-1})	1.65 - 2.94	1.81 - 2.83	0.91 - 1.7	1.2 - 2.095
Inflow	0.96 - 2.37	1.24 - 2.74	0.53 - 1.47	0.95 - 2.24
Calcium (mg l^{-1})	9.12 - 14.9	8.04 - 14.5	3.07 - 6.30	3.77 - 8.15
Inflow	4.85 - 21.97	7.09 - 15.7	2.04 - 5.7	2.33 - 5.71
Magnesium (mg l^{-1})	3.57 - 7.3	3.5 - 4.93	1.87 - 3.01	1.87 - 3.4
Inflow	2.63 - 8.27	2.99 - 4.92	1.44 - 2.57	1.20 - 2.98
TDS (mg l^{-1})	81 - 188	83 - 128	48 - 69	47 - 74
Inflow	51 - 290	69 - 195	28 - 57	21 - 71

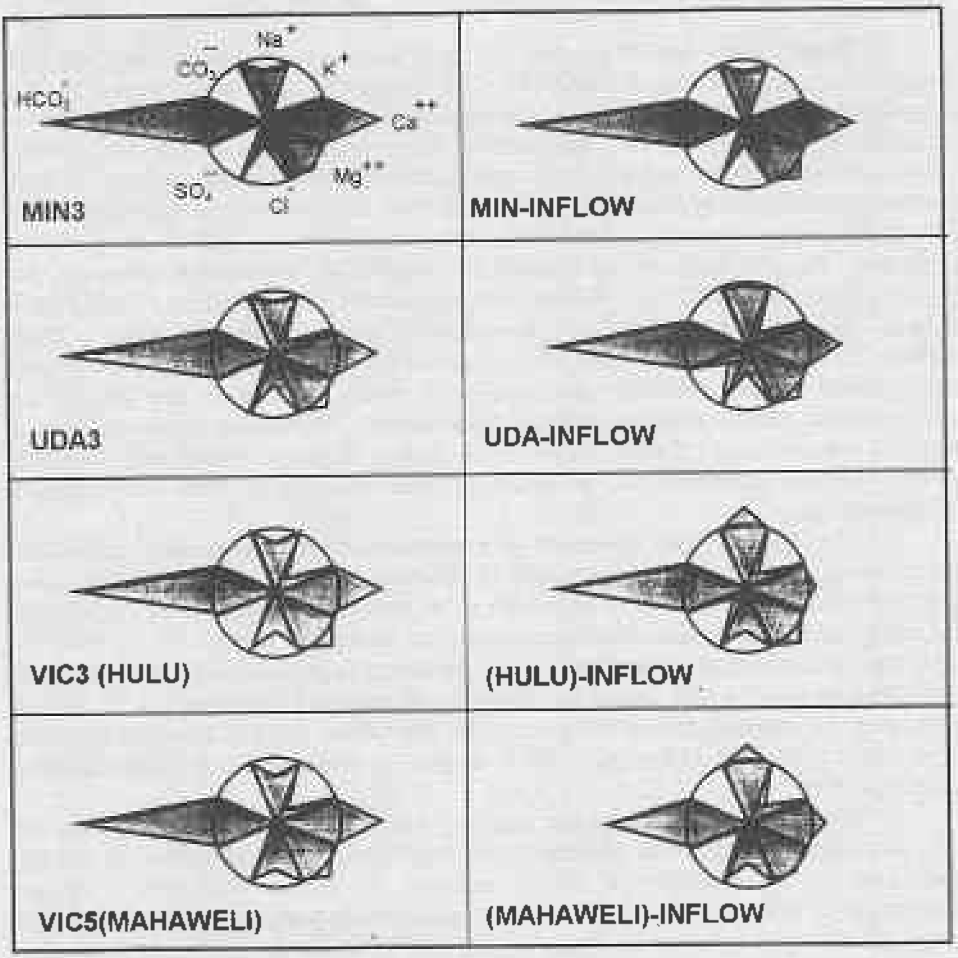

Figure 3. Maucha's ionic field diagrams

Discussion

Limnologically reservoirs in Sri Lanka differ fundamentally in their basin and catchment morphology, depth, flow-through-regime and nutrient status and underwater light regime, consequently their biological productivity (Duncan *et al.* 1993). The V-shaped mountain basins of the upland reservoirs (e.g. Victoria) have small areas of littoral zone and a greatly reduced extent of bottom sediment compared to those of shallow irrigation reservoirs located in the lowland dry zone (e.g., Minneriya and Udawalawe). Duncan *et al.* (1993) came to this conclusion based on the results of an extensive limnological study conducted in Parakrama Samudra, an ancient manmade lake in the north central dry zone (Schiemer 1983) and other related limnological studies in Sri Lanka (Silva & Davies 1986, 1987, Piyasiri 1991). However no study has compared the limnology of two distinct types of Sri Lankan reservoirs simultaneously before the implementation of the FISHSTRAT programme in 1998. Therefore the results of the FISHSTRAT programme will be extremely important to explain the limnological characteristics and in turn the fisheries potential of Sri Lankan manmade water bodies.

Slightly low water temperature and pH of the two major inflows emptying into Victoria compared to two lowland dry zone reservoirs may be attributed to the geographical location and pedology of the respective catchments. Red-yellow podzolic soils and soft laterite of the catchment of Victoria is acidic (Panabokke 1996). Landscape morphology, land use forms and weathering processes taking place in both terrestrial and aquatic systems also play an important role with respect to surface water pH in the tropics (Talling & Lemoalle 1998, Silva 1998). Further, in eutrophic reservoirs, the pH increases as a result of bicarbonate assimilation processes by phytoplankton. The occurrence of hard rocks with a narrow over burden in the highland (Cooray 1984) results in rainwater discharges as springs after percolating a short distance in steep slopes. The low concentration of total dissolved salts and subsequently the low electrical conductivity of inflow of Victoria and Udawalawe reservoirs also may be attributed to limited weathering. Weathering limitation of steep slopes is succeeded by transport limitation on shallow slopes with thick soils (Stallard 1985). This is in agreement with the results of three FISHSTRAT reservoirs examined during this study.

The Walawe River transports an enormous amount of suspended solids into the reservoir. However, the magnitude of sediment transport into reservoirs is not reflected either by the amount of suspended solid content and Sechchi disk visibility in the open water due to sedimentation taking place along the stream flow within the reservoir. In the case of Udawalawe a major portion of suspended matter is transported via Kalkanna Oya, which drains the Haldulmulla area and is subjected to regular landslides. In addition, road development activities taking place in Beragala-Haputale area has also resulted in loading a large amount of sediments to Pathaha Oya and Kalkanna Oya.

A wide range of Sechchi disk visibility and the lowest values recorded during low water level especially in Minneriya and Udawalawe is an indication of mixing behaviour and re-suspension of bottom sediment in shallow reservoirs. The re-suspension of bottom sediment is extremely high during peak monsoons when wind velocity may reach even up to 5 m s^{-1}. This may result in the development of high waves of about 1-m in Minneriya and Udawalawe. These two reservoirs also have a relatively high wind travel distance or fetch compared to Victoria. The development of wind induced waves are relatively low in Victoria which has a steep basin surrounded by a hilly landscape. Therefore, the open water column of Victoria shows permanent stratification. Piyasiri (1991) classified Victoria as an oligomictic water body with a sharp thermocline established below 20 m depth. The daily density changes in the upper 15 - 20 m strata may result in relocation of phytoplankton even during calm days without disturbing the thermocline (Schiemer persn. Comm.). The vertical distribution patterns of dissolved oxygen of the three reservoirs will be discussed elsewhere.

Generally accepted phenomenon is that surface water in the tropics are rich in Na^{+} and Cl^{-} compared to Ca^{++} and HCO_3^{-} since calcareous formations like limestone are not well representative over much of the tropics and the principle source of Na^{+} and Cl^{-} is sea spray (Gibbs 1970, Meybeck 1985, Meybeck *et al.* 1989, Talling and Lemoalle 1998). In contrast, Ca^{++} and Mg^{++} dominance over Na^{+} and K^{+} in Sri Lankan surface water has been shown during several instances (Gunatilaka & Senaratne 1981, Gunawardena and Adikari 1981, Dissanayake & Weerasooriya 1986, Silva 1998, 1999). A sodium-potassium type of water is generally prevalent in the wet zone of Sri Lanka, while calcium types are more common in the dry zone (Dissanayake & Weerasooriya 1986). In Sri Lanka almost all the land where tea grows is slightly acidic and continuously intensive application of nitrogenous fertilizers tend to increase the acidity resulting in mobilization of Ca^{2+} and Mg^{2+} in the soils (Ponnamperuma 1987). The source of bicarbonate may be either lithogenic or atmospheric fall-out but the concentrations are strongly related to Ca^{++} concentrations, which reflect the weathering of limestone and dolomite. Salt detached in wind driven oceanic spray and borne in rain contributes to major ions especially Na^+, Cl^- and Mg^{++} in fairly high concentration that are likely to decline sharply towards the hinterland (Gaudet & Melack 1981, Stallard & Edmond 1981, Lewis *et al.* 1987, Wood & Talling 1988). A relatively high concentrations of Na^+ and Cl^- were found in a headwaters of Sri Lanka with the onset of the southwest monsoon (May-September) which drives oceanic winds towards the mainland (Silva 1998). Further, rain water in Sri Lanka also contains a fair amount of Na^+ and Cl^- (Silva and Manuweera in press). Burning vegetation in the tropics is also a major contributor of salt into surface waters (Lewis 1981, Lewis & Weibezahn 1981, Crutzen & Anchrea 1990, Bootsma *et al.* 1996). Burning of scrub jungles for the preparation of land for *chena* cultivation is a common practice in Sri Lanka. Of the three reservoirs understudied, Udawalawe catchment has the highest percentage of *chena*.

The sources of sulfate to surface waters include rocks, fertilizer, atmospheric precipitation and dry deposition. A tremendous amount of sulfate containing nitrogenous fertilizers are being regularly applied to tea plantations in Sri Lanka but their behavior in terrestrial and aquatic ecosystems is unknown. The rock minerals are the primary source of silica but the concentration changes in inflow and open water of three reservoirs as a result of variable catchment characteristics and bio-assimilation within the reservoirs respectively. The mineral products of weathering and so the export of salts are also influenced by climate and especially the mean annual water run-off (Dunne 1987). The situation may be different in tropical reservoirs with different water retention time where both cation and anion undergo complex bio assimilation and mineralization processes under different physico-chemical characteristics. Decrease in major ions in open water can be attributed to several factors. Sedimentation could happen partly by biological assimilation such as $CaCO_3$ deposition by molluscs, K incorporation by macrophytes and Si incorporation by diatoms (Carmouze 1983, Carmouze *et al.* 1978). Non-biological transfer to sediments occurs on a large scale by transformations of sediment minerals favoured by an alkaline medium rich in soluble silicate.

The concentrations and relative abundance of major ions and silica in surface water is not unique throughout the tropics. It is essentially a site specific phenomenon governed primarily by landscape geology, climate and weather. A greater part of the Brazilian Amazon produced waters are very poor in lithogenic dissolved salts. Difference in the Amazon systems: acidic black water with low ionic content and white water with high ionic content are reflected in geochemistry of sub-watersheds (Sioli 1984, Stallard & Edmund 1983, 1987). A similarity of Sri Lankan stream waters to the Brazilian Amazon has been discussed by Weninger (1972) emphasizing poor dissolved salt content in mountain streams. Talling (1976) also reported a strong chemical divergence in two main sectors of Upper Nile with cationic calcium dominant in the Blue Nile and Na^+ dominance in the White Nile. A study by Lesack, (1993) on solute export from a small forested sub watershed off the middle Amazon demonstrated chemical divergence between several transport pathways.

Conclusions

Catchment characteristics (viz., geochemistry, altitude, climate and weather, vegetation and soil, and the land use pattern) are the major determinants of the overall physico-chemical characteristics of three FISHSTRAT reservoirs in Sri Lanka). Accordingly water temperature, pH and electrical conductivity, important physical characteristics of Victoria showed marked differences from Minneriya and Udawalawe, which can be attributed to its geographical location and pedology.

With respect to cations, Ca^{2+} was the richest while Na^{+} and Mg^{2+} were more or less similar in concentration in all three water bodies. But Potassium had the lowest concentration. In contrast, Na^{+} was dominant in the inflows of VIC_H and VIC_M which is not unusual (Silva, 1998). Although bicarbonate ion concentrations were relatively higher, reservoir water was also rich in chloride when compared to sulphate. Na^{+}:K^{+} ratio was high in Victoria while Ca^{2+}:HCO_3^{-} was higher in both Minneriya and Udawalawe. It is apparent that silica concentration has been reduced within the reservoirs, mainly in Minneriya and Udawalawe.

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