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Original Article

Seasonal Water Quality Changes in Reservoirs in Different Climatic Regions of Sri Lanka

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The current study investigates the patterns of the changes of the physicochemical characteristics in 58 relatively shallow, eutrophic reservoirs of Sri Lanka during the wet (rainy) and dry seasons. These reservoirs range in values of specific conductance from 17 to over, 920 µS/cm during the dry season and 16 to over, 630 µS/cm during the wet season and can also be described as slightly alkaline, eutrophic systems. The reservoirs examined are located in four climatic regions [Arid, Dry, Galoya Basin (dry zone), Intermediate, and Highland Wet zones] of Sri Lanka that vary according to, for example, patterns of precipitation, evaporation and seasonality. Results of the study clearly indicate that the specific conductance and related variables reflect the patterns in precipitation and evapoconcentration. The highest specific conductance values are found in the Arid and Dry Zones (average concentrations of 586 and 274 µS cm^{-1}) during the dry season, and are sequentially lower in the Intermediate and Highland Wet zones. Interestingly, reservoirs in the Gal-Oya basin (Dry Zone) also record low specific conductance with the average values 81 and 58 µS cm^{-1} during both dry and wet seasons. The average dissolved oxygen was higher during the dry season in all the regions except in Highland Wet Zone. The concentration and gradient of important nutrients (e.g. ammonia-N, total phosphorus and dissolved phosphorus) show marked variation during wet and dry seasons having higher values especially during the wet season. Pearson correlation analysis shows that a concentration of total phosphorus is strongly related to chlorophyll *a* confirming the phosphorus is the limiting factor for algal growth within the study reservoirs

Key Words : tropical reservoirs, water quality, seasonal variation, eutrophication

1. Introduction

Island of Sri Lanka covers a total land area of (65,000 km^2) with a population of ~21 million people. From the ~1,370 million m^3 of total annual precipitation only ~31% is discharged to the sea by 103 rivers[1)]. However, precipitation is not equally distributed throughout the country; some areas are consistently wet, whereas others show marked seasonality and arid conditions[2)]. The Wet Zone covers only 17,000 km^2, whereas the Intermediate and Dry zones cover 48,000 km^2. The Wet Zone receives a mean annual rainfall (MARF) of more than 2 m, mainly from the southwest and convectional inter-monsoons. Thus, during the period of southwest monsoon the Wet Zone receives more rainfall marking a wet period. However in this region also, a short period of the year remains dry. Usually, precipitation is much greater than the estimated evaporation rate of 1.5 m per year in the Wet Zone[3)]. In contrast, precipitation is highly seasonal in the Intermediate and Dry zones, and evaporation greatly exceeds precipitation. In these regions, precipitation occurs mainly between October and March from the northeast monsoon which delivers a MARF of between 1.5 and 2 m to the Intermediate Zone, and 1 to 1.5m to the Dry Zone[3)]. However, evapotranspiration in the Dry Zone has been estimated to be as high as 2.1 m/year[3)]. Due to the seasonal nature of precipitation, and the fact that evaporation exceeds precipitation over ~75% of the country, remain dry for a greater part of the year.

As the topography of the Dry Zone is well suited for agriculture, especially for rice cultivation, reservoirs have been constructed since ancient time mainly for irrigational purposes[4)]. In addition, to meet country's energy demand large scale hydroelectric power generating reservoirs have also been constructed in the Wet Zone during the recent history as well. As a result more than ~4% of the total land area of the country is covered with reservoirs[5)]. Therefore at least over 2000 years many reservoirs have been used to store water for agricultural, domestic and recreational purposes[6)] and most recently to generate hydroelectricity. Many of these reservoirs are thought to be in danger from eutrophication and pollution due to increase human activities[4),7),8)]. In addition changes of precipitation which mark dry and wet periods especially within the

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Dry and Intermediate zones create significant variations in water quantity and quality of these reservoirs. These seasonal variations of physicochemical characteristics of water has induced changes of the biological characteristics creating lot of environmental and social problems including supply of potable water.

To promote a better understanding of Sri Lankan reservoirs, limnological studies have been encouraged, especially during the past few decades[4),9)]. However, to date the majority of research has been undertaken to understand the taxonomy and biodiversity of the fauna and flora[10),11)], in addition to a few studies designed to assess the impact of developmental programs, such as dam construction, river diversion and introduction of exotic fish[12),13),14)]. Studies leading to the general understanding of the limnology and especially seasonal variation of water quality of these multipurpose reservoirs in Sri Lanka are rare, as are assessments of the ecological characteristics of aquatic organisms.

In this paper we explore the seasonal variation of important physical and chemical limnological variables of 58 reservoirs which vary in age from few decades to hundreds of years. These reservoirs are known to experience variety of stresses from anthropogenic sources and also natural variability. Specifically, we will: (i) provide an overview of the diversity of chemical and physical characteristics of shallow, small to medium-sized reservoirs during wet and dry season from a larger part of Sri Lanka; (ii) determine if the chemical and physical characteristics of the reservoirs sampled, vary between the two seasons studied and also between the selected four different climatic regions of the country.

1.1 *Study sites*

Fifty-eight reservoirs, varying in age from a few decades to hundreds of years since the last restoration of their impoundment, were sampled from four climatic regions. These reservoirs, which cover many areas of the country, were deliberately chosen from a variety of urban, rural and agricultural regions in order to maximize the diversity of limnological conditions. These sites range in elevation above mean sea level from 5m to over 2000 m and include reservoirs in: the Arid Zone (MARF < 1 m), the Dry Zone (MARF = 1 to1.5 m), the Intermediate Zone (MARF = 1.5 to 2 m), and the Highland Wet Zone (MARF > 2.5 m). Not surprisingly, the catchments of the reservoirs sampled include a diversity of vegetation types including: dry evergreen, moist deciduous, moist semi-evergreen, submontane evergreen, and montane temperate vegetation[15)].

The geology underlying the study sites is of Precambrian age and is represented by three approximately equally-sized complexes that run in a north- east (NE) to south-west (SW) direction. The westernmost Wanni Complex (WC) consists of migmatites, granitic gneisses, charnockitic gneisses, minor metasediments and gratitoids[16)], whereas the central Highland Complex (HC) consists of interbanded ortho- and paragneisses. The easternmost Vijayan Complex (VC) consists of migmatites, granitic gneisses, charnockitic gneisses, minor metasediments and granitoids[16)]. The geology of the Dry Zone consists of sites on all of the complexes, whereas the Intermediate Zone occurs on both the WC and HC. The Highland Zone found on the HC, whereas the northern and southern Arid Zones are found on the WC and VC, respectively.

2. Materials and Methods

2.1 *Collection of environmental data*

Collection of water samples for the analysis of physico-chemical variables from the study reservoirs was undertaken between February 2010 to February 2012 at three months interval to cover wet and dry seasons from all the selected climatic regions. The most of the sampling and field measurements were done during the morning and /or early evening hours to avoid winds. Water samples from a depth of ~ 0.5 m were obtained from near the center or close to the center of each reservoir for laboratory analyses of nutrients, dissolved oxygen, sulphate, chlorophyll *a* and alkalinity. Sample collection, preservation and analysis were followed the APHA (American Public Health Association) standard methods for examination of water and wastewater (18th edition). The samples were stored in a cooler and transported to the Institute of Fundamental Studies (IFS) Kandy, within 48 hrs of obtaining the samples. Laboratory analysis of dissolved oxygen was carried out using Winkler method and species of important nutrients (nitrate-N, nitrite-N, ammonia-N, total phosphorus and dissolved phosphorus) were measured using UV-Visible spectrophotometer.

Onsite measurements of temperature, salinity, conductivity were done at 0.5-m below the surface water level at the same sampling site where the water samples were taken using hand held field instrument (Thermo Orion©- Model 105). Field measurements of pH were also obtained using Orion® Model 230A portable pH meter, using a two-point calibration, which encompassed the measured value. Turbidity measurements were also done from the sampling location using portable EUTECH© - TN-100 turbidity meter.

2.2 *Data analysis*

The environmental variables measured in the 58 reservoirs consisted of two physical variables (surface temperature and turbidity), and 10 chemical variables (conductivity, dissolved oxygen, salinity, pH, sulphate, nitrate-N, nitrite-N, ammonia-N, total phosphorus and dissolved phosphorus) and a biological variable (chlorophyll *a*). For all statistical analyses, the distributions of all environmental variables were visually assessed and if necessary, outliers were removed. Two-tailed t-tests were used to detect significant differences in limnological variables between dry and wet seasons and also climatic regions. These tests were done on the chemical characteristics between all five regions. The correlations between the environmental variables was assessed using Pearson correlation coefficients with Bonferroni-adjusted probabilities, computed using the computer program SYSTAT®.

Table 1: Average values of Environmental data of study reservoirs in selected regions during wet and dry seasons

		Dry Zone	Gal-Oya (Dry Zone)	Intermediate Zone	Arid Zone	Highland Wet Zone
Temp. (°C)	Dry season	30.48	33.25	29.95	30.48	19.80
	Wet season	29.25	31.06	29.21	28.48	25.00
Turbidity (NTU)	Dry season	16.95	12.99	5.90	13.31	16.21
	Wet season	8.76	21.17	9.51	10.68	7.82
pH	Dry season	8.23	7.93	7.89	8.63	8.16
	Wet season	7.71	7.50	7.70	8.11	7.10
Cond. (µS/cm)	Dry season	274.26	81.13	184.36	586.63	51.00
	Wet season	262.15	58.25	184.18	486.38	51.33
Alk.total (mg/l)	Dry season	131.65	95.73	101.12	198.85	22.78
	Wet season	118.13	37.30	103.57	200.45	32.14
Nitrite (µg/l)	Dry season	26.68	15.69	33.59	17.93	21.87
	Wet season	33.85	45.22	37.99	26.94	19.53
Nitrate (mg/l)	Dry season	0.08	0.02	0.14	0.09	0.03
	Wet season	0.10	0.19	0.15	0.08	0.44
Ammonia (µg/l)	Dry season	62.78	31.30	54.63	60.31	167.44
	Wet season	85.28	108.61	34.31	78.80	44.67
TP(µg/l)	Dry season	55.21	66.78	38.39	41.78	89.52
	Wet season	60.90	64.99	42.57	41.49	39.15
DP (µg/l)	Dry season	7.90	6.12	3.95	6.84	11.73
	Wet season	18.26	33.56	16.65	8.81	6.22
Sulphate (mg/l)	Dry season	3.46	1.65	1.94	8.35	1.73
	Wet season	4.88	3.13	2.24	9.03	1.51
Do (mg/l)	Dry season	7.17	6.24	7.42	6.93	6.48
	Wet season	6.22	6.22	6.97	6.91	7.46
Chlo-a (mg/l)	Dry season	30.33	29.77	11.95	14.48	57.67
	Wet season	19.71	34.84	17.33	12.62	25.46

3. Results and Discussion

3.1 *Results*

The reservoirs sampled show variation in their limnological measurements and the average physical and chemical characteristics of the study reservoirs during wet and dry seasons are summarized in Table 1. The temperature range of the surface waters varied from ~ 19.6 to 36. 8°C, whereas the average values varied from 33.25 to 19.8°C (Table 1).

The average surface-water temperature was 19.8°C in the Highland Wet Zone (HWZ), which was significantly different from the other zones, where the average temperatures varied between ~33 to 29°C (Table 1). Values of dissolved oxygen in the surface waters of the study reservoirs were closer to saturation or less especially during the wet season. Further chemical characteristics of the reservoirs can be broadly categorized as eutrophic, freshwater (salinity always < 0.5 g l^{-1}) and alkaline (well buffered) except in the reservoirs of HWZ. Values of conductivity were quite low and the average ranged from ~51 – 587µS cm^{-1} during the dry season and ~51 - 486µS cm^{-1} during the wet season. However results of the t-test show that conductivity of only Gal-oya basin (cascade) reservoirs are significantly different in wet and dry seasons (Table 2).

Table 2 :Results of two-tailed t-test. * indicates variables significantly different between two given seasons. Abbreviations: AR = Arid Zone; DR = Dry Zone; GOB(DR) = Gal-oya basin in eastern Dry Zone; IT = Intermediate Zone; HWZ = Highland Wet Zone; TP= phosphorus; DP= dissolved phosphorus.

VARIABLE	DR	GOB (DR)	IT	AR	HWZ
Temperature	*	*		*	*
Conductivity		*			
Turbidity	*				
TP					
DP	*	*	*		
Chl. *a*					
Nitrite					
Nitrate		*			
Ammonia		*	*		
DO	*				
pH	**			*	
SO_4		*			
Alkalinity	*				

Further, average values of conductivity of reservoirs in the HWZ were low and significantly different from the reservoirs in the other regions (Table 2). The pH of the study reservoirs ranged from 7 to 8.98 and the average values ranged from 7.89 to 8.63 (Table 1). The highest average pH was recorded in the Arid Zone (pH = 8.63). However significant differences of pH during wet and dry seasons were only detected within the Arid Zone and the Dry Zone reservoirs (Table 2). Measurements of nutrients indicate that during the study period reservoirs were in the range of eutrophic condition in both seasons. Although no significant difference of TP was observed during wet and dry seasons throughout the study reservoirs, DP values were significantly different in both seasons in DZ, DOB and IT. The highest average DP values were recorded from the GOB during the wet season and lowest average DP values were recorded from the IT during the dry season (Table 1). Similarly, the average values of the species of nitrogen, such as ammonia-N (NH_3), nitrate-N (NO_3) and nitrite-N (NO_2^-) were high during the wet season except in the HWZ where average NH_3 was high during dry season. However results of the two tailed t-test indicated that NH_3 was significantly different in dry and wet seasons in the GOB and IT (Table 2). Further, values of NO_3 significantly different between wet and dry seasons within the reservoirs of GOB only. Results of the Pearson correlation analysis show that there is higher correlation exists between more variables during the dry season than the wet season (Tables 3a &3b). Average values of chlorophyll *a* (Chl. *a*), range from ~12 mg l^{-1} – 58 mg l^{-1} and the highest value recorded from the HWZ during the dry season. However, there was no significant difference of Chl. *a* between two seasons in any of the regions studied (Table 2). Turbidity measurements ranged from 2 - 46 NTU and were significantly different in two seasons only in the DZ. Pearson correlation indicates that the Turbidity is positively and significantly correlated to TP and Chl. *a*. Further, values of chlorophyll *a* were significantly correlated to TP in both seasons but the correlation is higher during the dry season than the wet season. Sulphate (SO_4^-) values were high during the wet season, however only in GOB show a significant variation during wet and dry seasons.

3.2 *Discussion*

Thousands of reservoirs constructed throughout Sri Lanka are estimated to cover ~4% of the total land area[5], play an important role in the development of Sri Lanka by supporting activities such as agricultural production, domestic water supply, inland freshwater fisheries, and hydroelectric power generation. It is apparent that the water quality of many of these reservoirs has started to deteriorate due to both natural changes of the environment and anthropogenic activities including agricultural development and urbanization. Among the natural changes, patterns of rainfall could affect the quality of water creating seasonal changes of water quality that could ultimately cause serious environmental and social problems[7),13)].

Our survey of 58 reservoirs from throughout Sri Lanka characterizes these reservoirs with respect to their unique physical and chemical characteristics during wet and dry seasons. According to Wetzel (2001) the three main processes that govern the ionic composition and concentration of surface waters include: the balance between the evaporation and precipitation, atmospheric fallout, and the influence of the geology. Our study suggests that the reservoirs in Sri Lanka are largely influenced by the nature of the precipitation and the resulting concentration of ions by evaporation. The Arid Zone and Dry Zone together have the highest evapotranspiration rates, and thus records the highest conductivity values especially during the dry season (Table 1). Although evapo-concentration appears to account for the main trends between climatic regions, other factors appear to influence the reservoirs which located in the eastern part of the Dry Zone of Sri Lanka. For example GOB reservoirs record relatively low values of conductivity which may be attributed to high flushing rate of the systems as well as geological influence.

According to the results of Pearson correlation analysis, concentration of SO_4^- is positively and significantly correlated with the conductivity in both seasons (Tables 3a & 3b) which is different from the findings of Yatigammana (2004) that records low concentration of SO_4^- in Sri Lankan systems. Additionally concentrations of measured nutrients (TP, DP, NO_2^-, NO_3 & NH_3) and associated variables (turbidity and chlorophyll *a*) were high and above the ranges found in other studies from Sri Lanka[8), 14)] and other tropical regions[18)]. Although the concentrations of nutrients in the reservoirs do not vary between the climatic regions, NO_3 & NH_3 and DP vary during wet and dry seasons especially in DZ, GOB and IT regions (Table 2). For example DP is high during wet season in all the regions except in HWZ and this could be due to the high surface runoff followed by the intense rainfall of the country. This situation could be due to year around rainfall of HWZ making it difficult to identify a marked variation of seasons and also the catchments of the reservoirs in the region are subjected to intense agricultural practices.

Table 3a: Pearson correlation matrix on transformed environmental variables with Bonferroni adjusted probabilities for 13 environmental variables in the 58 reservoirs during Dry season. * Indicates significant correlation at $P < 0.05$.

	Temp.	**Turb.**	**pH**	**Cond.**	**Alk.**	**NO_2^-**	**NO_3**	**NH_3**	**TP**	**DP**	**SO_4**	**Do**	**Chl. *a***
Temp.	1												
Turb.	0.05	1											
pH	0.08	0.22	1										
Cond.	0.07	0.15	**0.46***	1									
Alk.	0.15	0.05	0.24	**0.63***	1								
NO_2^-	-0.11	0.29	-0.22	0.07	-0.01	1							
NO_3	0.02	-0.15	-0.08	0.15	0.03	0.3	1						
NH_3	**0.63***	0.26	-0.03	-0.03	-0.15	0.17	-0.12	1					
TP	-0.02	**0.64***	0.4	0.12	-0.01	0.02	-0.2	0.15	1				
DP	-0.22	0.34	0.41	0.27	0.02	0.08	-0.12	0.14	0.39	1			
SO_4	0.07	0.29	0.39	**0.68***	**0.48***	-0.06	0.12	0.02	0.4	0.3	1		
Do	0.11	0.24	0.13	0.22	0.05	0.21	0.28	-0.1	0.24	0.1	0.14	1	
Chl. *a*	-0.11	**0.59***	0.42	0.02	-0.08	0.03	-0.2	0.17	**0.83***	0.4	0.23	0.2	1

Table 3b: Pearson correlation matrix on transformed environmental variables with Bonferroni adjusted probabilities for 13 environmental variables in the 58 reservoirs during Wet season. * Indicates significant correlation at $P < 0.05$.

	Temp.	**Turb.**	**pH**	**Cond.**	**Alk.**	**NO_2^-**	**NO_3**	**NH_3**	**TP**	**DP**	**SO_4**	**Do**	**Chl. *a***
Temp.	1												
Turb.	0.36	1											
pH	0.14	0.16	1										
Cond.	-0.05	0.02	**0.46***	1									
Alk.	-0.12	-0.15	0.44	**0.84***	1								
NO_2^-	0.16	0.23	-0.01	-0.12	-0.06	1							
NO_3	-0.11	0.19	0.3	-0.19	-0.29	0.11	1						
NH_3	0.11	0.23	-0.07	0.09	-0.03	0.02	-0.01	1					
TP	0.22	0.3	0.14	0.15	-0.1	-0.01	0.07	0.29	1				
DP	0.35	0.31	-0.07	-0.15	-0.15	0.34	0.07	0.16	0.16	1			
SO_4	0.04	0.15	0.22	**0.54***	**0.53***	0.05	-0.07	0.16	0.14	0.1	1		
Do	-0.01	0.01	0.12	-0.06	0.01	-0.14	0.23	-0.2	-0.24	-0	-0.1	1	
Chl. *a*	0.19	0.45	0.26	-0.05	-0.22	-0.24	0.21	0.17	**0.570***	0.2	-0.1	-0	1

However, Pearson correlation indicates that TP, turbidity and Chl. *a* positively and significantly correlated which is not been encountered by previous studies in Sri Lanka[8),12)] but a very common phenomenon in natural lakes[19)]. Therefore, the conditions could be related to reservoir aging, high water retention time coupled with low flushing rate which ultimately could be related to recent climate change scenarios of the world. In addition according to Yatigammana (2004) many of our reservoirs were P limited which is also questionable with today's situation where TP exhibit a positive robust relationship with primary production and turbidity.

Further, elevated levels of dissolved oxygen (DO) were also observed in Dry, Intermediate and Arid Zone reservoirs during the dry season, a condition which is common among the eutrophied lakes[8)]. However HWZ reservoirs show high values during the wet season may be related to time of sampling at higher photosynthesis take place and the effect of mixing due to the changes of temperature and atmospheric circulation. The values of Chl. *a* of the study reservoirs also indicates a relationship with the patterns of precipitation, where many reservoirs recorded high values of Chl. *a*. during the wet season, when nutrients are not limited. Pearson correlation analyses also show that a concentration of total phosphorus is strongly related to chl.*a.* and turbidity during both seasons indicating that the reservoirs are moving toward the year around eutrophic conditions and phosphorus is appear to be the cause.

Finally it is widely accepted that tropical reservoirs are structurally and functionally different from natural lakes, especially those from temperate regions[19),20),] However the positive relationship observed between nutrients and chl.*a.* evident that the reservoirs in Sri Lanka are been gradually absorbing to natural landscape of Sri Lanka.

4. Conclusion

Accordingly, seasonal climatic changes appear to affect the limnological conditions in the reservoirs in different climatic regions of Sri Lanka. Among the chemical variables, conductivity and pH show high values during the dry season in many reservoirs, while nutrients and primary production do not show such a pattern.

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