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Original Article

Development and application of wetland zooplankton index to assess the degree of eutrophication in Sri Lankan reservoirs

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Abstract: Wetland Zooplankton Index (WZI) was developed for the low country intermediate zone of Sri Lanka using 20 reservoirs located between latitudes 7°20'22.081"N - 7°48'33.558"N and longitudes 80°1'44.55"E - 80°9'51.509"E. WZI ranged from 1.56 in Anukkane reservoir which is located in a low flat terrain in the midst of agricultural lands to 3.69 in Tampana reservoir which is located in a hilly area with a watershed mainly covered with forests. WZI showed a significant negative correlation with the Nitrate-N content (r = -0.797) and cumulative content of Nitrate-N and total phosphorus (r = -0.795) indicating that it can be used as an indicator of the degree of eutrophication of inland reservoirs in the low country intermediate zone of Sri Lanka.

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Introduction

Sri Lanka is a country that has a culture entangled with ancient irrigation systems with many cascading reservoirs and canals. Due to these man-made reservoirs, Sri Lanka has a very high density of inland wetlands, which is about 4 ha for every km^2 of land. About 12000 of these man-made wetlands are located in the dry zone and the intermediate zone of Sri Lanka (Jayasena et al., 2011). These play a significant role in economy by providing water for irrigation, livestock, fisheries, aquaculture and generation of hydropower. In addition, these water bodies supply drinking water as well as for domestic purposes (Imbulana et al., 2006).

Eutrophic conditions have been reported in many reservoirs in Sri Lanka mainly due to uncontrolled and excessive use of agrochemicals (Imbulana et al., 2006). Major types of fertilizer used for agricultural activities in Sri Lanka are sulphate of ammonia, urea, rock phosphate, Muriate of potash, triple super phosphate and mixed fertilizers (Mubarak, 2000).

Due to high costs of the chemical tests and the chemical waste generated by these methods, several alternatives are being used today to assess the water quality (Barra et al., 2012). These include the use of indicator organisms (Gannon and Stemberger, 1978; El-Shabrawy and Khalifa, 2002; Füreder and Reynold, 2004; Yantsis, 2009) and water quality indices (Chow-Fraser, 2006; Seilheimer et al., 2009). Wetland Zooplankton Index (WZI) is one of such indices (Lougheed and Chow-Fraser, 2002).

Although some studies on the relationship between the abundance of some zooplankton species and water quality have been carried out (Kamaladasa and Jayatunga, 2007; Gammanpila, 2010), development and use of a WZI to indicate water quality of inland water bodies is a novel approach in Sri Lanka. Developing a WZI to find out whether it can be used to assess the eutrophic conditions of the reservoirs is highly appropriate in the present-day context as Sri Lanka is reported to have a high fertilizer consumption of 101.5 kg ha^{-1} (Mubarak, 2000).

Therefore, the objective of the present study was to develop a WZI and to find out whether it can be used

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Table 1. Location and the surface area of the reservoirs studied.

Reservoir number	Name of the Reservoir	Location	Surface Area (ha)
1	Adukkane	80°08'14.233"E 7°31'28.100"N	2.9
2	Anukkane	80°07'14.380"E 7°30'43.170"N	9.1
3	Bathalagoda	80°26'50.246"E 7°31'59.222"N	255.2
4	Bodhimulla	80°05'51.912"E 7°31'35.360"N	3.9
5	Dewahuwa	80°32'26.782"E 7°48'33.558"N	756.3
6	Galewela	80°34'34.283"E 7°45'41.707"N	5.9
7	Galpihilla	80°09'30.015"E 7°20'52.894"N	1.0
8	Gaiyawa	80° 01'44.55"E 7°28'46.210"N	16.2
9	Kanogama	80°09'51.509"E 7°32'35.510"N	22.4
10	Karangamuwa	80°10'21.512"E 7°32'50.654"N	8.9
11	Kimbulwana	80°28'19.837"E 7°39'50.338"N	237.9
12	Kurunegala	80°21'43.271"E 7°29'36.949"N	48.0
13	Makandura	79°59'38.603"E 7°20'22.081"N	36.0
14	Metiyagane	80°10'59.642"E 7°23'37.450"N	5.2
15	Munamaldeniya	80°03'51.940"E 7°32'57.392"N	17.4
16	Polpitiya	80°11'90.675"E 7°31'40.407"N	11.2
17	Saragama	80°20'10.126"E 7°30'37.575"N	20.1
18	Tampana	80°24'25.140"E 7°26'55.036"N	1.5
19	Umangawa	80°10'50.130"E 7°32'01.440"N	3.0
20	Wendaru	80°22'30.099"E 7°27'55.695"N	92.0

to assess the degree of eutrophication in the reservoirs in the low country (Elevation: <300 m msl) intermediate zone (Annual rainfall: 1,750-2,500 mm) of Sri Lanka.

Materials and Methods

This study was carried out in 20 reservoirs located in the low country intermediate zone of Sri Lanka between latitudes 7°20'22.081"N-7°48'33.558"N and longitudes 80°1'44.55"E-80°9'51.509"E (Table 1). The surface area of the reservoirs varied from 1 ha to 756.3 ha (Table 1).

The low country intermediate zone was selected for this study as this area is a heavy agricultural area with paddy fields and coconut plantations. In addition, this area has a very high density of inland reservoirs. The reservoirs used in the present study except for two, namely Tampana and Kurunegala reservoirs provide water for irrigation purposes. Tampana and Kurunegala reservoirs are used to provide water for the households in the urban and suburban areas of Kurunegala town.

Zooplankton of these reservoirs were sampled from June to October 2013 using "Patalas-Schindler" Plankton sampler of 10-L capacity. Sampling was carried out at least 5 m away from the aquatic vegetation and at least 3 m away from the shore as recommended by Lougheed and Chow-Fraser (2002). Samples were immediately preserved using 5% formalin based on Dhargalkar and Verlecar (2004). Zooplankton were identified under the optical microscope using the taxonomic keys provided by Fernando (1990). The abundance of each species was determined by sub-sampling using a Sedgewick rafter.

At the time of sampling, water samples were also collected in dark plastic-bottles for the determination of nitrate-N and total phosphorus levels. The water samples were immediately preserved at the site by adding 0.5 ml of concentrated sulphuric acid and the nitrate and total phosphorus contents were determined using APHA (1998).

On each sampling occasion, three samples were taken from each site. When the reservoirs were <20 ha in surface area, samples were taken from three sites, and when the reservoirs were 20-50 ha in surface area, samples were taken from five sites. The number of sample sites in each of the Kimbulwana (278 ha) and Bathalagoda (255 ha) reservoirs were eight. From Wendaru (92 ha) and Dewahuwa 756 ha)

Table 2. Summary of the allocation of U values for different zooplankton species.

Cluster/clusters of reservoirs where a particular zooplankton species is present	U value assigned
1	5
1 and 2	4
1 and 3	3
2	3
1, 2 and 3	3
2 and 3	2
3	1

(Cluster 1- Comparatively low nitrate-N and total pPhosphorus level; Cluster 2 - Intermidiate nitrate-N and total phosphorus level; Cluster 3 – Comparatively high nitrate-N and total phosphorus level).

reservoirs, samples were taken from six and ten sites, respectively. Sampling sites were selected to cover the entire water body.

WZI for each reservoir was calculated using the following equation of Lougheed and Chow-Fraser (2002).

$$\mathrm{WZI} = \frac{\sum_{i=1}^{n} Y_i T_i U_i}{\sum_{i=1}^{n} Y_i T_i}$$

Where, Yi =Abundance of species i, Ti = Tolerance value (1-3) of species i, Ui = Optimum value (1-5) of species i and n = number of zooplankton species in the reservoir.

The values for WZI ranged from 1.0, indicative of low water quality (high eutrophication) to 5.0, indicative of high quality (low eutrophication) (Lougheed and Chow-Fraser, 2002). Tolerance values (T) indicate tolerance or the niche breadth of a species. Species that have a narrow range of distribution were given a low tolerance score as recommended by Lougheed and Chow-Fraser (2002). In the present study, if a species was present in less than 33% of the studied reservoirs, i.e., ≤ 7 reservoirs, a T value of 1 was assigned. For the species that were found in 8-13 reservoirs, i.e., 33-67% of the studied reservoirs, T value of 2 was assigned and for the species that were found in more than 13 reservoirs, i.e., in more than 67% of the studied reservoirs, the assigned T value was 3.

To assign U values, three clusters of reservoirs were identified based on nitrate-N and total phosphorus contents. Clustering was done based on Bray Curtis similarity using Primer 5.0 software package. Reservoirs with comparatively low nitrate-N and total phosphorus contents were grouped in cluster 1 and reservoirs with comparatively high nitrate-N and total phosphorus contents were grouped in cluster 3. The reservoirs with comparatively intermediate nitrate-N and total phosphorus levels were grouped in cluster 2. The assigning of U values for different zooplankton species is summarized in Table 2.

The product-moment correlation coefficients of WZI with the nitrate-N level, total phosphorus level and cumulative values of nitrate-N and total phosphorus were calculated. When the correlation coefficients were significantly different from zero, linear regression algorithms were developed taking WZI as the independent variable.

Results

Table 3 gives the mean ± standard error of the mean (SEM) and the range of the nitrate-N and total phosphorus values of the reservoirs studied. The highest nitrate-N content was recorded at Anukkane Reservoir (5.624 ± 0.072 mg L^{-1}) while the lowest nitrate-N content was recorded at Adukkane Reservoir (1.186 ± 0.013 mg L^{-1}). Total phosphorous levels varied from 0.003 ± 0.002 mg L^{-1} recorded in Bodhimulla Reservoir to 0.529 ± 0.036 mg L^{-1} recorded in Karangamuwa Reservoir

The separation of reservoirs into clusters based on

Table 3. Mean ± SEM values of nitrate-N levels and total phosphorus levels of the reservoirs studied. Ranges are given within brackets.

	Reservoir	Nitrate - N (mg L^{-1})	Total Phosphorus (mg L^{-1})
1	Adukkane	1.186 ± 0.013 (1.199-1.173)	0.046 ± 0.004 (0.05-0.042)
2	Anukkane	5.624 ± 0.072 (5.696-5.552)	0.086 ± 0.008 (0.094-0.078)
3	Bathalagoda	2.403 ± 0.370 (2.773-2.033)	0.075 ± 0.007 (0.082-0.068)
4	Bodhimulla	3.886 ± 0.215 (4.101-3.671)	0.003 ± 0.002 (0.005-0.001)
5	Dewahuwa	3.416 ±0.227 (3.643-3.189)	0.060 ± 0.012 (0.072-0.048)
6	Galewela	4.936 ± 0.038 (4.974-4.898)	0.190 ± 0.022 (0.212-0.168)
7	Galpihilla	2.548 ± 0.076 (2.472-2.624)	0.042 ± 0.008 (0.05-0.034)
8	Gaiyawa	3.923 ± 0.133 (4.056-3.79)	0.104 ± 0.01 (0.114-0.094)
9	Kanogama	2.626 ± 0.100 (2.726-2.526)	0.071 ± 0.009 (0.080-0.062)
10	Karangamuwa	3.452 ± 0.442 (3.894-3.01)	0.529 ± 0.036 (0.565-0.493)
11	Kimbulwana	4.213 ± 0.256 (4.469-3.957)	0.147 ± 0.006 (0.153-0.141)
12	Kurunegala	2.620 ± 0.344 (2.964-2.276)	0.164 ± 0.018 (0.182-0.146)
13	Makandura	1.570 ± 0.390 (1.96-1.180)	0.065 ± 0.011 (0.076-0.054)
14	Metiyagane	4.574 ± 0.345 (4.919-4.229)	0.065 ± 0.009 (0.056-0.074)
15	Munamaldeniya	4.213 ± 0.094 (4.307-4.119)	0.068 ± 0.007 (0.075-0.061)
16	Polpitiya	2.294 ± 0.687 (2.981-1.607)	0.309 ± 0.019 (0.328-0.290)
17	Saragama	3.344 ± 0.108 (3.452-3.236)	0.038 ± 0.008 (0.046-0.030
18	Tampana	1.932 ± 0.074 (2.006-1.858)	0.046 ± 0.006 (0.052-0.040)
19	Umangawa	2.765 ± 0.193 (2.958-2.572)	0.057 ± 0.004 (0.061-0.053)
20	Wendaru	2.294 ± 0.241(2.535-2.053)	0.030 ± 0.005 (0.035-0.025)

the nitrate-N and total phosphorus contents is shown in Figure 1. Three clusters of reservoirs were identified at 61% similarity level. The reservoirs with relatively low nitrate-N and total phosphorus levels positioned in cluster 1. Only three reservoirs were grouped in this cluster. Reservoirs with relatively moderate levels of nitrate-N and total phosphorus were grouped in cluster 2. There were 7 reservoirs in this cluster. In cluster 3, reservoirs with relatively high levels of nitrate and total phosphorus were included. There were 10 reservoirs in this cluster (Fig. 1).

A total of 31 species of rotifers, 3 species of copepods and 9 species of cladocerans were identified in the samples (Table 4). The optimum values (U) assigned to different zooplankton species are also given in Table 4.

Two species of rotifers namely *Brachionus donneri* and *Testudinella elliptica* were found only in the reservoirs of cluster 1. Therefore, a U value of 5 was assigned to them. One species of copepods, 3 species of cladocerans and 7 species of rotifers were found only in the reservoirs of cluster 3 and a U value of 1 was assigned to them. Two species of cladocerans and 12 species of rotifers were found only in the reservoirs of cluster 2 and 3 and were assigned a U value of 2. No zooplankton species was found in the reservoirs of both clusters of 1 and 2. Hence, a U value of 4 was not assigned to any species. Balance 16 species were in the reservoirs categorized either under cluster 2 or both in cluster 1 and 3 or in all three clusters and therefore, they were assigned a U value of 3 (Table 4).

The Tolerance value (T) assigned to each zooplankton species are also given in Table 4. Only 1 species namely *Diacyclops nanus* was present in more than 66.6% of the reservoirs studied. Therefore, a T value of 3 was assigned to this species. T value of 2 was assigned only to 4 species namely *Diaptomus nadus*, *Filinia terminalis*, *Hexarthra mira* and *Trichocerca cylindrica*. All other species were found in less than 33.33% of reservoirs studied and therefore those species were assigned a T value of 1.

Table 4. Optimum values (U) and tolerance values (T) assigned for the zooplankton species recorded in the present study.

Species	Cluster present	U value	No. of reservoirs present	T value
Copepoda				
Acanthocyclops vernalis	3	1	2	1
Diacyclops nanus	1, 2 and 3	3	15	3
Diaptomus nadus	1, 2 and 3	3	10	2
Cladocera				
Alona monocantha	3	1	1	1
Chrydorus eurynotus	2 and 3	2	2	1
Chydorus parvus	1, 2 and 3	3	4	1
Diaphanosoma brachyurum	2, 3	2	3	1
Diaphanosoma singhalense	2	3	1	1
Karualona karua	3	1	1	1
Leptodora kindti	2	3	1	1
Moinodaphnia macleayi	3	1	1	1
Pseudosida szalayi	2	3	1	1
Rotifera				
Asplanchna priodonta	3	1	1	1
Brachionus angularis	2	3	1	1
Brachionus budapestinensis	2 and 3	2	2	1
Brachionus caudatus	1, 2 and 3	3	6	1
Brachionus donneri	1	5	1	1
Brachionus falcatus	2 and 3	2	3	1
Brachionus forficula	2 and 3	2	5	1
Brachionus patulus	2 and 3	2	3	1
Brachionus rubens	2 and 3	2	2	1
Brachionus urceus	3	1	2	1
Coelopus tenuior	1 and 3	3	2	1
Eothinia elongata	2 and 3	2	3	1
Euchlanis dilatata	2 and 3	2	5	1
Filinia terminalis	2 and 3	2	8	2
Hexarthra mira	2 and 3	2	8	2
Kellicottia longispina	3	1	1	1
Keratella earlinae	1 and 3	3	2	1
Keratella lenzi	2	3	1	1
Keratella quadrata	3	1	1	1
Lecane curvicornis	2 and 3	2	4	1
Monostyla bulla	1, 2 and 3	3	6	1
Polyarthra dolichoptera	3	1	1	1
Polyarthra vulgaris	2 and 3	2	6	1
Rattulus tigris	3	1	1	1
Rotaria citrine	2	3	1	1
Testudinella elliptica	1	5	1	1
Testudinella patina	1 and 3	3	2	1
Trichocerca cylindrica	1, 2 and 3	3	10	2
Trichocerca dixon-nuttalli	2	3	1	1
Trichocerca similis	3	1	1	1
Trichotria pocillum	2 and 3	2	2	1

The values for WZI calculated for the 20 study sites are given in Table 5. The highest WZI was obtained for Tampana (3.69) while the lowest WZI was obtained for Anukkane (1.56). WZI showed a significant negative correlation with nitrate-N content ($r = -0.797$; $P = 0.00$) while they were not significantly correlated with the total phosphorus content ($r = 0.11$; $P = 0.64$). Nevertheless, WZI

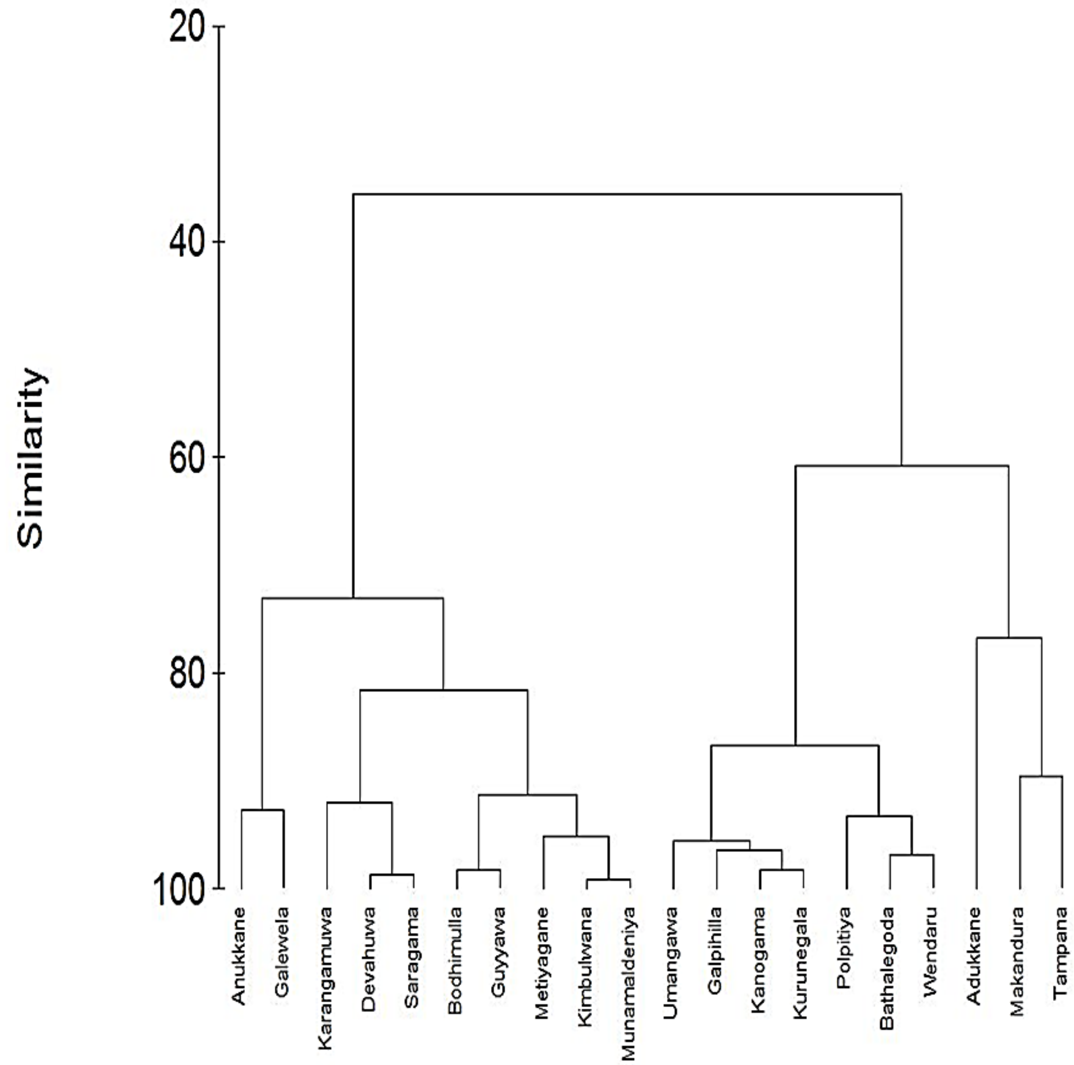

Figure 1. Clusters of reservoirs based on nitrate-N and total phosphorus levels [Cluster1- Comparatively low nitrate-N and Total phosphorus levels; Cluster 2- moderate nitrate-N and total phosphorus levels; Cluster 3- Comparatively high nitrate-N and total phosphorus levels].

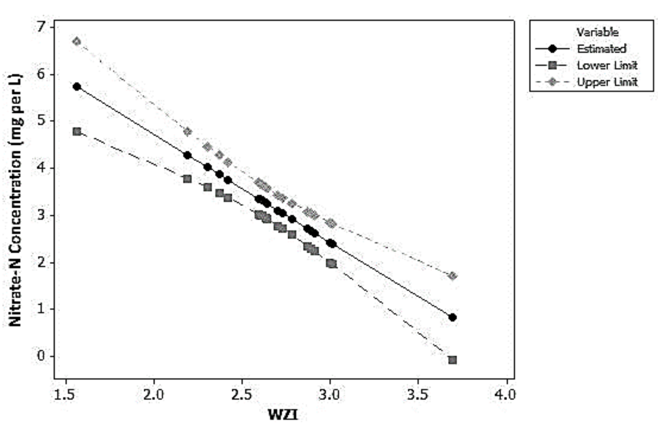

Figure 2. Simple linear regression algorithm between WZI and nitrate-N levels of the reservoirs studied with 95% confidence band.

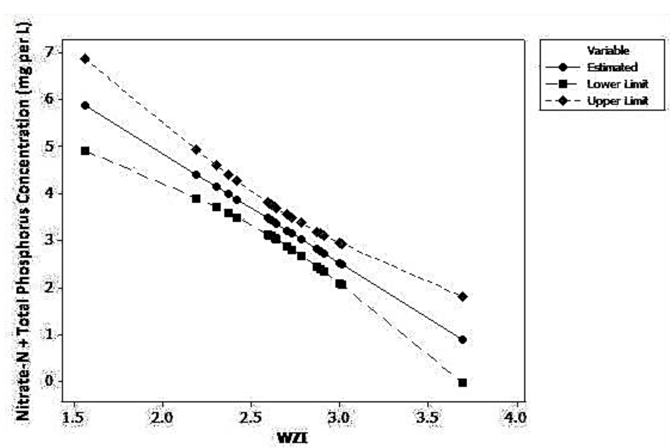

Figure 3. Simple linear regression algorithm between WZI and cumulative levels of nitrate-N and total phosphorus of the reservoirs studied with 95% confidence band.

showed a significant negative correlation with the cumulative content of nitrate-N and total phosphorus

Table 5. The values for WZI of the reservoirs studied.zooplankton species.

Name of the Reservoir	WZI
Adukkane Wewa	3.07
Anukkane Wewa	1.94
Bathalegoda Reservoir	3.30
Bodhimulla Wewa	3.13
Dewahuwa Reservoir	3.00
Galewela Wewa	2.99
Galphilla Wewa	3.11
Gaiyala Wewa	2.97
Kanogama Wewa	3.38
Karangamuwa Wewa	3.25
Kimbulwana Wewa	3.13
Kurunagala Wewa	3.77
Makandura Wewa	3.45
Metiyagane Wewa	3.39
Munamaldeniya Wewa	3.02
Polpitiya Wewa	3.00
Saragama Wewa	3.52
Thampana Reservoir	4.33
Umangawa Wewa	3.12
Wedaru Wewa	3.06

contents (r = -0.795; P = 0.00).

Because of the significant correlation of WZI with nitrate-N and cumulative value of nitrate-N and total phosphorus, the linear regression algorithms were developed using WZI as the independent variable and these are as follows (P = 0.00).

Nitrate-N (in mg L^{-1}) = 9.35 – 2.31 WZI (R^2 = 66.4)

Nitrate-N + Total Phosphorus (in mg L^{-1}) = 9.55 – 2.34 WZI (R^2 = 66.1)

The 95% confidence band for these two algorithms are given in Figures 2 and 3, respectively.

Discussion

Zooplankton respond rapidly to the changes in environmental conditions (Schindler, 1987). However, they have been hardly used in Sri Lanka to study the environmental conditions of aquatic habitats (Kamaladasa and Jayatunge, 2007; Gammanpila, 2010). Although some individual species of zooplankton are used as indicator organisms of water quality (Slȧdeĉek, 1983; Perbiche-Neves et al., 2013), studies on the use of zooplankton communities as a whole to indicate water quality are sparse (Lougheed and Chow-Fraser 2002, Yantsis 2009).

All the reservoirs used in this study are located in a cascading system (Jayasena et al., 2011) and except for Tampana and Kurunegala reservoirs, the land-use in their watersheds contain many paddy field and coconut lands. Hence, storm water from these agricultural fields and excess water for wet paddy cultivation lands ultimately flow into these reservoirs. The watershed of Tampana and Kurunegala reservoirs are mostly covered with forests and urban residential areas, respectively.

Sri Lanka is among the highest fertilizer users in South Asian region (Mubarak, 2000). In addition, the Kurunegala District where most of these reservoirs are located is accounting for the highest extent of agricultural production (DCS, 2013). According to World Bank statistics, fertilizer consumption in Sri Lanka was measured as 257.93 kg ha^{-1} of arable land in 2009. The most used fertilizers are nitrogenous, potash and phosphate fertilizers, including ground rock phosphate (Trading Economics, 2013). Farmers use fertilizer excessively in fields due to lack of knowledge. Large amounts of nutrients especially nitrate and phosphates are added to these inland water bodies due to agricultural runoff resulting in high nitrate-N and total phophorus levels. According to the nitrate-N and total phosphorous levels, all the reservoirs used in the present study are eutrophic (Nürnberg, 1996). Many negative environmental and social impacts have been reported in some Sri Lankan reservoirs due to eutrophication (Wijesundara et al., 2012; Ariyawansa et al., 2012; Azmy et al., 2012). Hence, it is important to assess the degree of eutrophication in inland fresh water bodies in order to take suitable mitigation measures to reduce further eutrophication and improve the water quality.

The WZI recorded in the present study are within the range recorded by Lougheed and Chow-Freser (2002) for Laurentian Great Lakes basin although the water bodies are under contrasting ecological extremes. The U values for different zooplankton species were assigned in the present study using a simple method of clustering the reservoirs based on the nitrate-N and total phosphorus levels where as

Lougheed and Chow-Fraser (2002) used partial canonical correspondence analysis.

WZI closer to 1 indicates high degree of eutrophication while the values closer to 5 indicate least degree of eutrophication. The highest WZI value was recorded for Tampana reservoir (3.69) which indicates least eutrophication. This reservoir has a comparatively low nitrate-N level of 1.932 mg L^{-1} and total phosphorus level of 0.046 mg L^{-1}. The watershed of this water body, which is located in high elevation contains many forest areas and therefore does not receive agricultural runoff.

The lowest WZI (1.56) was recorded for Anukkane which is located in a flat terrain surrounded by agricultural lands. The highest nitrate value was recorded in this reservoir. This low WZI indicates high degree of eutrophication probably due to addition of large amount of nutrients from the agricultural fields in the watershed.

The algorithms developed in the present study may be used to estimate the nitrate-N level and cumulative level of nitrate-N and total phosphorus in the inland reservoirs in this region of the country using the WZI. The U values and T values developed for each zooplankton species in the present study can be used in the estimation of WZI.

The algorithms developed in the present study may not be applicable in the other regions due to differences in zooplankton diversity. Hence area specific algorithms have to be developed for other regions of the country.

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چکیده فارسی

توسعه و کاربرد شاخص زئوپلانکتون تالاب برای ارزیابی درجه یوتریفیکاسیون در منابع آبی سریلانکا

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چکیده:
شاخص زئوپلانکتون تالاب (Wetland Zooplankton Index=WZI) برای ناحیه سرزمینی میانی سریلانکا با استفاده از ۲۰ منبع آبی که در طول جغرافیایی 7°20'22.081"N - 7°48'33.558"N و عرض جغرافیایی 80°1'44.55"E - 80°9'51.509"E واقع شده بودند، توسعه داده شد. براساس نتایج، مقادیر WZI از ۱/۵۶ برای منبع آبی Anukkane ، که در یک منطقه کم ارتفاع در میانه زمین‌های کشاورزی واقع شده است تا ۳/۶۹ برای منبع آبی Tampana که در ناحیه تپه‌ای با حوضه‌ای با پوشش جنگلی واقع شده است، متغیر بود. نتایج WZI یک همبستگی منفی را با محتوای نیترات (r = -۰/۷۹۷) و محتوای تجمعی نیترات و فسفر کل (r = -۰/۷۹۵) نشان داد که بیانگر این موضوع می‌باشد که WZI می‌تواند به‌عنوان شاخص درجه یوتریفیکاسیون برای ارزیابی منابع آبهای داخلی در ناحیه سرزمینی میانی سریلانکا مورد استفاده قرار بگیرد.

کلمات کلیدی: شاخص زئوپلانکتون تالاب، یوتریفیکاسیون ، نیترات، فسفر.