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RESEARCH ARTICLE

Distribution of diatom assemblages in the surface sediments in Sri Lankan reservoirs located in the main climatic regions and potential of using them as environmental predictors

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Abstract

Diatom assemblages preserved in surface sediment are widely used for the bio-assessment of reservoirs and the present study is carried out to evaluate the distribution of diatom assemblages in reservoirs and potential of using diatom communities as indicators along with physical and chemical measurements from the reservoirs. Non-urban, shallow, small-scale reservoirs which span among three major climatic zones (Wet, Dry and Intermediate zones) were selected for the study. The present study reveals that most of the study reservoirs belong to the eutrophic category. From all the study reservoirs a total of 76 diatom taxa belonging to 46 genera were identified. Of these, the highest diversity was recorded from the Dry Zone. *Aulacoseira granulata* was the most dominant taxa whereas *Achnanthidium*, *Pinnularia*, *Cymbella*, *Frustulia*, *Synedra*, *Eunotia*, *Nitzschia*, *Navicula*, *Cyclotella*, *Stauroneis* and *Gomphonema* were also recorded at high abundane and widely distributed. The study reveals *A. granulata*, *Achnanthidium*, *Nitzschia*, *Cyclotella* and *Diatoma* inhabit in organically polluted eutrophic waters while *Synedra acus*, *Synedra ulna* and *Amphora ovalis* are the prime indicators of cultural eutrophication. Canonical correspondence analysis identified phosphate, dissolved oxygen, nitrite, conductivity and total dissolved solids as the most important measured environmental variables that could account for the distribution of diatom assemblages. However, the results of the present study reveal that the species distribution may depend on integration of a series of environmental variables and unmeasured environmental variables are also important in structuring diatom assemblages.

Keywords Acidification · Conductivity · Environmental indicators · Eutrophication · Pollution · Relative abundance · Water quality

Introduction

As the human population continues to rise continuously, the environment we live-in is subjected to constant changes. Aquatic ecosystem and its ecology have been the major concern during last century owing to rapid urbanization, strengthening of agriculture and anthropogenic changes with impacts on the physical, chemical and biological shifts (Alakananda et al. 2010). These changes in any aquatic ecosystem will directly affect the species uniqueness and ecological characteristics of biotic community composition with loss of biotic integrity (Alakananda et al. 2010). In this regard freshwater systems associated with human communities are recognized as more vulnerable to pollution and other changes (Smol et al. 1986). The significance of understanding the water quality has led to conduct more limnological studies by the government, especially during the past 2 decades in Sri Lanka (Yatigammana and Cumming 2016). However, few studies have been carried out to assess whether the aquatic communities could be used to understand the water quality changes in Sri Lankan systems (e.g. Yatigammana 2012; Yatigammana and Cumming 2017). Since long-term monitoring data are not widely available in Sri Lankan systems, indirect measurements would be the only viable option. Amongst all the biotic community, diatoms provide a representative group of indicative species as a whole changes in response to changes in environmental conditions.

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Among several biological indicators, diatoms play a major role as biological indicators in environmental assessments as diatoms are abundant, diverse, and well preserved (Leventer and Dunbar 1996). Diatoms (Bacillariophyceae) are unicellular microscopic algae characterized by siliceous cell walls which preserved in sediments contain paleoenvironmental information (Stoermer and Smol 1999). Their ecological diversity is reflected by their occurrence in almost all aquatic and most wet terrestrial habitats. Each habitat has its own chemical and physical environment and is represented by its own characteristic diatom flora. As diatoms respond quickly to environmental changes and reflect both physical and chemical characteristics of the overlying water masses, they are particularly useful for paleoecological reconstructions (Cooper 1999; Jiang et al. 2001). Therefore, knowledge on the distribution, composition and diversity of diatom assemblages provide reliable records of environmental changes such as lake eutrophication, acidification, salinisation and land use change. Usually, reservoirs are structurally and functionally different from natural lakes. Less availability of taxonomic data of diatoms and the lack of knowledge of the preservation of diatoms in reservoirs in Sri Lanka are the main reasons for the lack of applications of diatoms as environmental indicators. Therefore, it is essential to have a better understanding on the taxonomy of diatoms and their potential of preservation in reservoir environments. In addition, the most of the studies on diatom as indicators are based on temperate, subarctic and arctic regions while few studies are on mountain natural lakes. Therefore, the tropical diatoms and the applications of using them for environmental predictions will definitely help to fill gaps in the knowledge about environmental indicators. Thus, the present study aims to understand whether reservoir diatoms could be used as environmental indicators to assess environmental changes in Sri Lanka through multivariate statistical approaches.

Materials and methods

Study sites

The present work is based on thirty (30) reservoirs selected from the main climatic regions of Sri Lanka including twenty (20) reservoirs from Dry Zone (~ 1500 mm Mean Annual Rainfall), five (05) reservoirs from Intermediate Zone (~ 2000 mm Mean Annual Rainfall) and five (05) reservoirs from Wet Zone (> 2000 mm Mean Annual Rainfall) (Fig. 1). The most of the studied reservoirs can be described limnologically as non-urban, shallow, small scale freshwater systems ranged from minimum average surface area of 0.20 km^2 to the maximum average surface area of 10 km^2.

Collection of physico—chemical data of water samples

Physical and chemical parameters were measured in the water column using both field instruments and laboratory analysis. Water samples were obtained at a depth of 0.3 m below the water surface of each reservoir. Temperature (Mercury thermometer), turbidity (Secchi disk), conductivity (HI 99300 EC/TDS meter), pH (HI 9125 pH/ORP meter), Total Dissolved solids (TDS) (HI 99300 EC/TDS meter) and Dissolved Oxygen (DO) (HI 9146 Dissolved Oxygen meter) were measured onsite while major anions (Nitrite, Nitrate, Sulphate, Fluoride, and Phosphate) were measured using UV/Vis Spectrophotometer (HACH DR/2400).

Sampling of sediments, preparation and identification of diatom

Surface sediment (5 cm) samples were collected from the deepest basin of each reservoir using a gravity corer (Hydrobios/6.5 cm in diameter). The collected sediment samples were stored at 4 °C until analysis. Each sediment sample was divided into three sub samples and was processed using standard acid digestion technique outlined by Wilson et al. (1996). A sub-sample of wet sediment (about 0.2 g) was boiled in a 50:50 mixture of HNO_3: H_2SO_4 to digest the organic material, and then rinsed several times to remove the acid residue. An aliquot of the resulting sediment slurry was resuspended in distilled water, evaporated onto cover slips, and mounted onto slides using Naphrax" mounting medium (R.I. = 1.74). Diatom frustules on each slide were analyzed following counting procedures detailed in Kingston (1986). Every diatom frustules within a field of view was identified and counted along transects marked across the cover slip using a compound light microscope equipped with phase contrast optics (OLYMPUS CX31). Replicate counting was carried out in each sample for the accuracy of results. Results were expressed as relative abundances (%) for each diatom species/genus using the following equation.

$$\text{Relative abundance}(\%) = \frac{(\text{Number of diatom frustules of a particular species/genus} \times 100)}{\text{Total number of diatom frustules}}$$

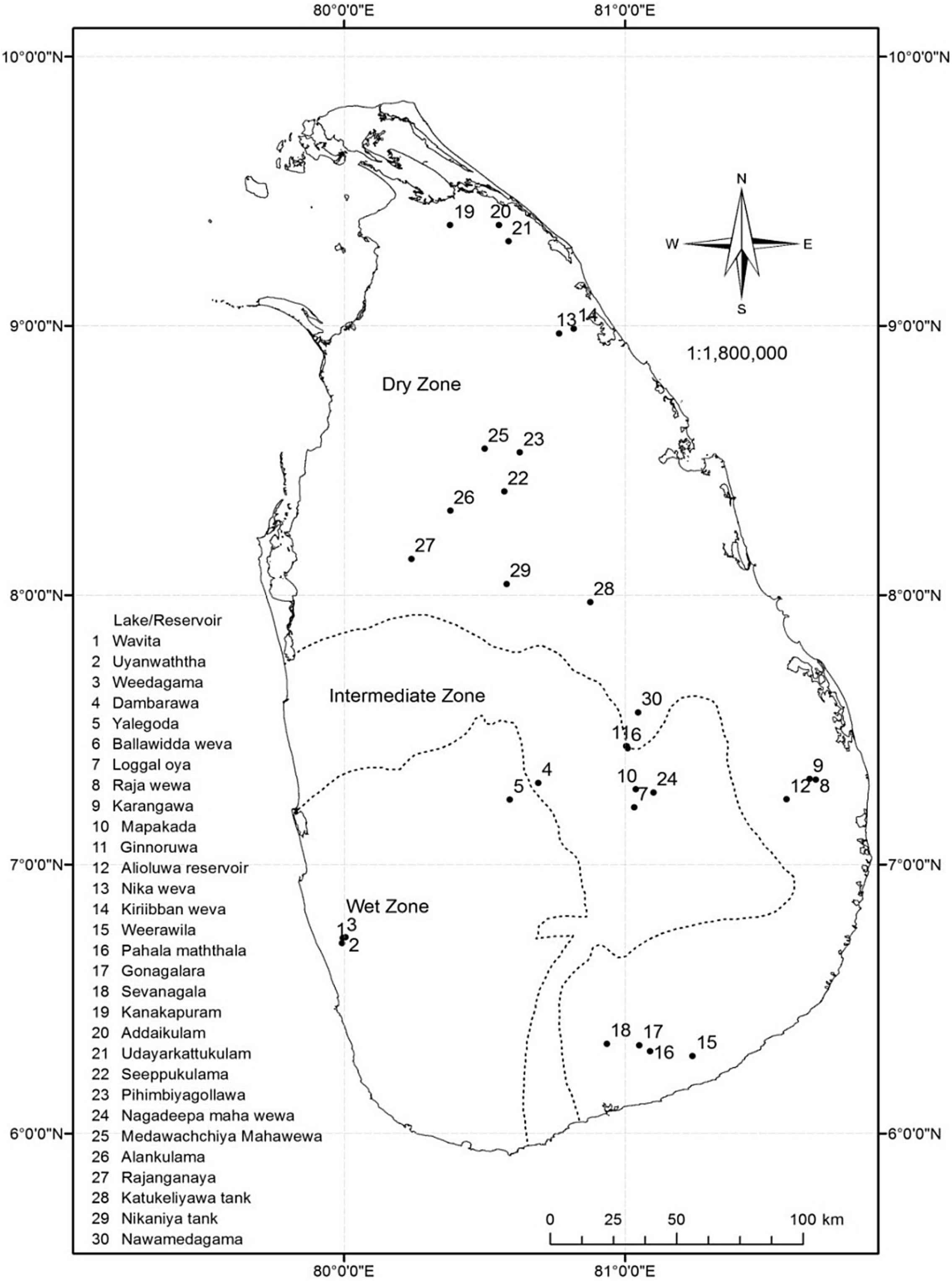

Fig. 1 Locations of the 30 study reservoirs in Sri Lanka

Identification of diatom frustules was carried by using standard identification guides prepared by Abeywickrama (1979), Fernando (1990), Patrick and Reimer (1966) and Taylor et al. (2007) and to possible taxonomic levels. In addition photo micrographs of diatoms available in international data bases were also used for further clarification of the identification.

Statistical analysis

The relationship between measured environmental variables (Temperature, pH, Total Dissolved Solids, Conductivity, Secchi depth, Nitrite, Nitrate, Fluoride and phosphate) and biological data were assessed using multivariate statistical techniques. Canonical Correspondence Analysis (CCA) was used to understand the environmental variable(s) that could best explain the distribution of diatom assemblages in study sites using the statistical software, Canoco for windows (*v*.5). For CCA, seventy six species with more than 1% of relative abundance in at least two sites were selected as the best criteria suggested by terBraak and Smilauer (1998) for the analysis. Cluster analysis was carried out to determine the similar sites based on species composition and environmental conditions using the PRIMER 5 statistical software package (Clarke and Warwick 1994). Correlations among the environmental variables were assessed using Pearson correlation coefficients using Minitab (v.14).

Results

Diversification of diatom assemblages in study reservoirs

Altogether thirty (30) surface sediment samples obtained from thirty (30) reservoirs in three (03) major climatic regions including five (05) reservoirs from Wet Zone, five (05) reservoirs from Intermediate Zone and twenty (20) reservoirs from Dry Zone were considered in this study. Most of the examined samples contained sufficiently well preserved diatom taxa. Collectively, seventy six (76) species belonging to twenty nine (29) genera were identified. The distribution pattern of the assemblages varied significantly among the studied sampling sites. The highest diversity was recorded from the Dry Zone which was sixty three (63) species belong to twenty seven (27) genera whereas similar diversity was detected from both Wet Zone and Intermediate Zone counting of forty six (46) species belong to twenty (20) genera. Out of all species, the most dominant species was *Aulacoseira granulata* in all three zones which having average relative abundance greater than 40% (> 40%) in each zone. However, none of *Aulacoseira granulata* cells could be detected in Seeppukulama reservoir (Medawachchiya area) and Medawachchiya reservoir in the Dry Zone while very low relative abundance (< 10%) were observed in Nikaniya reservoir (Kekirawa) and Rajanganaya reservoir in the same climatic zone. As an alternative, *Nitzschia* taxon (*Nitzschia palea* and *Nitzschia clausii)* and *Cocconeis* taxa occurred in Seeppukulama and Medawachchiya reservoirs with the values of greater than 55% and 65%, respectively (> 65%). In the same way, the most abundant species in Nikaniya and Rajanganaya reservoirs is *Synedra ulna* (> 35%) though it has a very low population of *Aulacoseira* taxon. However, the most common taxa in the studied reservoirs in three major climatic zones were *Achnanthidium*, *Pinnularia*, *Cymbella*, *Frustulia*, *Synedra*, *Eunotia*, *Nitzschia*, *Navicula*, *Cyclotella*, *Stauroneis* and *Gomphonema. Rhopholodia*, *Suriella*, *Amphora*, *Epithemia* and *Diatoma* taxa were detected only in Dry Zone reservoirs especially, in Nawamedagama reservoir the second most dominant taxa was *Diatoma* (> 33%).

Table 1 Range and mean values of environmental characteristics of 30 study reservoirs located in main climatic regions of Sri Lanka. *WZ* wet zone, *IZ* intermediate zone, *DZ* dry zone

	Minimum			Maximum			Mean		
	WZ	IZ	DZ	WZ	IZ	DZ	WZ	IZ	DZ
Tem/°C	22.50	25.50	24.40	32.00	36.70	33.10	28.50	31.50	30.20
pH	6.97	7.33	7.05	7.81	9.21	9.00	7.26	8.09	8.05
DO/ppm	3.45	3.36	2.04	6.40	7.37	7.60	5.53	5.92	5.10
TDS/ppm	21.80	40.00	40.00	337.00	1152.00	344.00	100.72	244.37	195.21
Cond/µScm^1	44.90	90.00	90.00	621.00	2560.00	626.00	195.41	537.95	401.74
Secchi/m	0.190	0.100	0.100	1.500	0.600	0.800	0.734	0.333	0.437
NO_2^-/ppm	0.03	0.01	0.00	0.04	0.03	0.03	0.03	0.01	0.01
NO_3^-/ppm	0.90	0.70	0.60	57.00	70.00	75.00	12.86	12.90	5.87
F^-/ppm	0.01	0.03	0.01	0.38	0.77	1.15	0.15	0.33	0.49
SO_4^{2-}/ppm	7.00	2.00	6.00	52.00	19.00	84.00	18.20	13.83	30.63
PO_4^{3-}/ppm	0.01	0.06	0.05	0.60	1.26	1.35	0.23	0.33	0.41

Variation of physical and chemical characteristics of study reservoirs

The studied reservoirs were selected from three major climatic zones (Wet, Intermediate and Dry Zones) in Sri Lanka ranged from minimum average surface area of 0.20 km^2 to the maximum average surface area of 10 km^2. The range and average values of physical and chemical characteristics of the study reservoirs in different climatic regions are summarized in Table 1. Average temperature ranged from 28.50 °C in the Wet Zone, 31.50 °C in the Intermediate Zone and 30.20 °C in the Dry Zone. Average pH values indicate a slightly alkaline condition to some extant in all studied reservoirs with the values of 7.26 in the Wet Zone, 8.09 in the Intermediate Zone and 8.05 in the Dry Zone (Table 1). Similarly, the average dissolved oxygen concentration in the surface waters of the reservoirs were relatively low, ranging between 2.04 ppm and 7.60 ppm. Conductivity values varied greatly among the different climatic regions within the range of 44.90–2560 µScm^{-1} and with the mean values of 195.41 µScm^{-1}, 537.95 µScm^{-1}and 401.74 µScm^{-1} in Wet, Intermediate and Dry Zones, respectively (Table 1). Water transparency is approached by Secchi depth and the average Secchi depth in these study reservoirs is driven between 0.3 to 0.7 m. However, the major nutrients measured in the study reservoirs in all climatic regions show that they belong to eutrophic category as average phosphate-phosphorous levels were greater than the standard level of 0.1 ppm (Table 1). In the same way, average nitrate–N (NO_3^-–N) concentrations were also exceeded the acceptable level of 10 ppm (> 10 ppm in both Wet and Intermediate Zones) except Dry Zone (5.87 ppm). However, despite the above nutrients, average nitrite–N (NO_2^-–N) concentrations in every zones were up to the standard (< 1 ppm). As a final point, when in view of both fluoride and sulphate concentrations were also accordance with the standards.

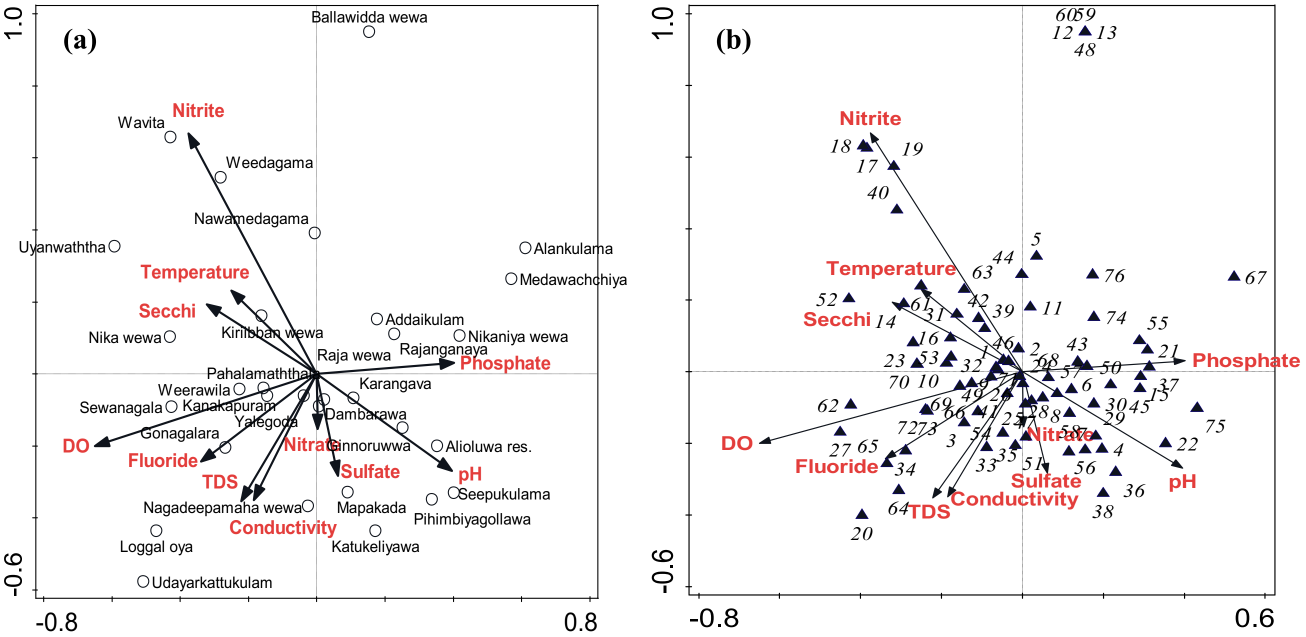

Fig. 2 Canonical correspondence analysis (CCA) of sites (**a**), species (**b**). Solid arrows represent forward selected environmental variables (*DO* dissolved oxygen, *TDS* total dissolved solids). 1. *Aulacoseira granulata*, 2. *Achnanthidium minutissimum*, 3. *Pinnularia viridis*, 4. *Pinnularia subcapita*, 5. *Pinnularia major*, 6. *Pinnularia biceps*, 7. *Pinnularia nobilis*, 8. *Pinnularia borealis*, 9. *Cymbella ventricosa*, 10. *Frustulia rhomboids*, 11. *Frustulia saxonica*, 12. *Frustulia capitata* 13. *Frustulia sp*., 14. *Frustulia crassinervia*, 15. *Eunotia minor*, 16. *Eunotia monodon*, 17. *Eunotia pseudosudetica* 18. *Eunotia rhomboidea,* 19. *Eunotia bidentula*, 20. *Eunotia robusta*, 21. *Eunotia pectinalis*, 22. *Eunotia bidens*, 23. *Synedra amphicephala*, 24. *Synedra ulna*, 25. *Synedra acus*, 26. *Nitzschia sigma*, 27. *Nitzschia sigmatella*, 28. *Nitzschia palea*, 29. *Nitzschia clausii*, 30. *Nitzschia amphioxys*, 31. *Nitzschia scalaris*, 32. *Navicula radiosa*, 33. *Navicula capitatoradiata*, 34. *Navicula liber*, 35. *Navicula anglica*, 36. *Navicula cryptocephala*, 37. *Navicula gregaria*, 38. *Navicula bacillum,* 39. *Cyclotella sp*., 40. *Grammatophora angulo*, 41. *Grammatophora arcuat*, 42. *Fragilaria crotonensis,* 43. *Fragilaria virescens*, 44. *Fragilaria harrisonii*, 45. *Fragilaria tenera*, 46. *Stauroneis anceps*, 47. *Stauroneis phoenicenteron*, 48. *Gomphoneis* sp., 49. *Gomphonema parvulum*, 50. *Gomphonema lanceolatum*, 51. *Gomphonema olivaceum*, 52. *Tabellaria sp*., 53. *Caloneis amphisbaena*, 54. *Caloneis silicula*, 55. *Achnanthes exigua*, 56. *Neidium productum,* 57. *Neidium affine*, 58. *Neidium hitchcockii*, 59. *Acanthus sp*., 60. *Craticula cuspidata*, 61. *Neidium affine,* 62. *Neidium floridanum*, 63. *Neidium iridis*, 64. *Gyrosigma fasciola*, 65. *Gyrosigma acuminatum*, 66. *Cocconeis pediculus*, 67. *Cocconeis sp*., 68. *Diploneis oculata,* 69. *Eunotogramma leave*, 70. *Amphora ovalis*, 71. *Amphora coffeaeformis*, 72. *Rhopalodia ventrocosa*, 73. *Rhopalodia gibba*, 74. *surirella tenera*, 75. *Epithemia sp*., 76. *Diatoma sp.*

Relationship between environmental characteristics and diatom distribution

Canonical Correspondence Analysis (CCA) relates the composition and distribution of diatom assemblages with environmental variables. In CCA ordination diagram where the points represent the species and sites while vectors (arrows) represent the environmental variables (ter Braak 1986). The relative length of each vector indicates the degree of importance of each environmental factor (strength of correlation) to determine diversity and community composition of the species in different sites. The angle of the environmental variable to the particular axis denotes the correlation of each environmental variable. According to the resulted CCA ordination diagram, it is apparent that the majority of measured environmental factors are important in the determination of diatom composition in different sites (Fig. 2). However, phosphate is the most important environmental factor in determining the distribution of diatom assemblages as it is very closely associated with the 1st axis which is the most important environmental gradient in explaining species distribution. In addition, DO is also important when explaining species distribution as the length and position of the particular vector is associated with the 1st axis (Fig. 2). Further elaborating the ordination plot, it is clear that nitrite, conductivity, TDS and nitrate are also important in explaining species variation since it is closely associated with the 2nd axis which is the second most important environmental gradient (Fig. 2). Pearson correlation analysis was carried out to clarify further the strength and direction of the linear relationship between two continuous environmental variables. Even if CCA ordination revealed that Phosphate and DO are the determining environmental factors in explaining species composition in different sites (Fig. 2), according to the Pearson correlation analysis, it is indicated that there is no significant positive relationship between particular variables (Table 2). However, a significant positive correlation ('P' < 0.05) could be detected between conductivity and TDS and also both conductivity and TDS with the nitrate concentration convincing the importance of the particular variables in the determination of the diatom distribution among different sites (Table 2). Also, it is apparent that though a positive relationship was observed between nitrite concentration with conductivity, TDS and nitrate concentration (Table 2), the association between those variables was not significant ('P' > 0.05) despite of importance of nitrite as an environmental factor in explaining species variation according to the resulted CCA ordination plot (Fig. 2).

Table 2 Pearson correlation matrix including Pearson correlation coefficient (R) for 11 environmental variables in the 30 reservoirs. * Indicates significant correlation at 0.05 significance level

	Tem (°C)	PH	DO (ppm)	TDS (ppm)	Cond (µScm^{-1})	Secchi (m)	NO_2^- (ppm)	NO_3^- (ppm)	F$^-$Egypt (ppm)	SO_4^2 (ppm)	PO_4^{3-} (ppm)
Tem/°C	1										
pH	−0.01	1									
DO/ppm	0.17	0.06	1								
TDS/ppm	−0.14	0.05	−0.15	1							
Cond/µScm^1	−0.13	0.04	−0.16	0.99*	1						
Secchi/m	0.12	−0.14	0.05	−0.09	−0.08	1					
NO_2^-/ppm	−0.12	−0.33	0.06	0.01	0.02	0.28	1				
NO_3^-/ppm	−0.53	−0.18	−0.27	0.66*	0.66*	−0.24	0.21	1			
F$^-$/ppm	0.14	0.47	0.22	0.16	0.12	−0.01	−0.25	−0.27	1		
SO_4^{2-}/ppm	−0.03	0.01	−0.28	0.13	0.09	−0.12	−0.44	−0.11	0.27	1	
PO_4^{3-}/ppm	−0.55	0.32	−0.29	0.05	0.06	−0.13	−0.12	0.36	0.12	0.18	1

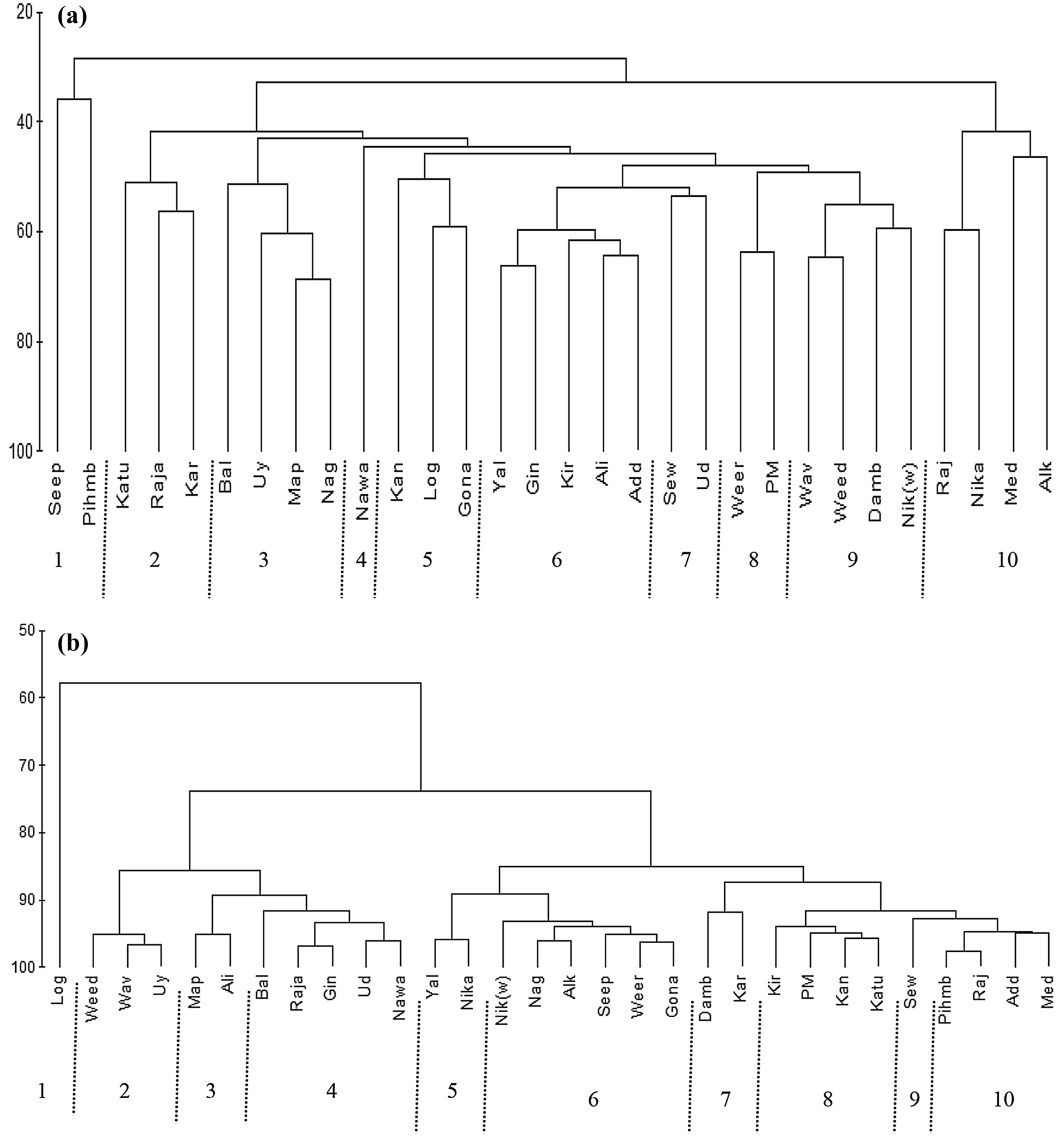

Fig. 3 Cluster analysis of samples based on relative abundance of the diatom taxa (**a**) and environmental variables (**b**) 0.1–10 represents the cluster number. *Wav*, Wavita; *Uy*, Uyanwaththa; *Weed*, Weedagama; *Damb*, Dambarawa; *Yal*, Yalegoda; *Bal*, Ballawidda; *Log*, Loggaloya; *Raja*, Raja wewa; *Kar*, Karangava; *Map*, Mapakada; *Gin*, Ginnoruwa; *Ali*, Alioluwa; *Nik(w)*, Nika wewa-welioya; *Kir*, Kiriibban wewa; *Weer*, Weerawila; *PM*, Pahalamaththala; *Gona*, Gonagalara; *Sew*, Sewanagala; *Kan*, Kanakapuram, *Add*, Addaikulam, *Ud*, Udayarkattukulam; *Seep*, Seeppukulama; *Pihmb*, Pihimbiyagollawa; *Nag*, Nagadeepa maha wewa; *Med*, Medawachchiya; *Alk*, Alankulama; *Raj*, Rajanganaya; *Katu*, Katukeliyawa; *Nika*, Nikaniya; *Nawa*, Nawamedagama

Cluster analysis

One of the main multivariate exploratory technique used in this analysis was cluster analysis by BRAY–CURTIS Similarity analysis. This seeks to identify natural grouping or clustering in a collection of subjects. Those which are very similar were regarded as being the same group or cluster while those which were dissimilar are regarded as being different clusters. At this point, seventy six (76) most common diatom taxa led to recognition of ten (10) clusters based on species composition which further implies that those study sites clustered together were similar in species composition (Fig. 3a). Similarly, ten (10) clusters were resulted based on the measured environmental variables showing that study reservoirs clustered together are having similar environmental characteristics (Fig. 3b).

Discussion

This study was based on the distribution of diatom assemblages in surface sediments of Sri Lankan reservoirs in major climatic regions (Wet, Dry and Intermediate Zones). The abundance and distribution of the diatom taxa can be interpreted as a sedimentary record of the occurrence and it is one of the powerful tools for the monitoring of the water quality since they exhibit the cumulative effects of the present and past conditions. The most dominant taxon encountered in this study was *Aulacoseira granulata* which prefers shallow nature of the reservoirs (Gomez et al. 1995). It forms resting stages preserved in lake sediments for several years and it has an ability to fix carbon within 1–8 h of exposure to moderate light (Smol 2002). Mostly, *A. granulata* is a widespread centric diatom in reservoirs mainly in carbonate-rich, moderately eutrophic waters (Mesotrophic and eutrophic waters) (Kilham and Kilham 1975; Margalef 1983). Therefore, our finding is in an agreement with this fact as the most of the study reservoirs belong to the eutrophic category (Table 1). For this reason, *A. granulata* can be further used as a water pollution indicator. Moreover, according to the findings of Talling and Rzóska (1967), *A. granulata* occurs in well mixed moderately alkaline waters ($pH > 7.0$). The average pH in the present study was also skewed towards the alkaline side of the pH spectrum (Table 1) convincing *A. granulata* would be an indicator of elevated pH in reservoirs. High pH in these systems may be mainly due to agriculture induced nutrient enrichment since majority of study reservoirs are associated with paddy fields. Apart from this particular taxon, *Achnanthidium minutissimum*, *Pinnularia* spp., *Cymbella ventricosa*, *Frustulia* spp., *S. ulna*, *Eunotia* spp., *Nitzschia* spp., *Navicula* sp., *Cyclotella* sp., *Stauroneis anceps* and *Gomphonema* spp. were detected in this study. *Gomphonema* spp. and *Achnanthidium minutissimum* are known to indicate organic pollution (Fabri and Leclercq 1984). Thus, the occurrence of *Achnanthidium minutissimum* at high abundances shows the organic pollution of the reservoirs which can be related to agricultural runoff and contamination with domestic sewage. In addition, *Achnanthidium* sp. has a wide range of ecological preference of occurring in oligotrophic waters with tolerance to mesotrophic conditions (Alakananda et al. 2010). Since the ecology of *Achnanthidium* sp. is not properly understood, further studies to assess the ecology on this particular genus aids in comprehending. Taxa, such as *Eunotia*, *Frustulia* (*Frustulia rhomboids*, *Frustulia saxonica*), *Navicula*, and *Stauroneis* have a preference to humic waters with high dissolved organic carbon according to the literature (Davis et al. 1985; Anderson et al. 1986; Kingston and Birks 1990). Here, the dissolved carbon was not considered as a major environmental variable, but presence of particular taxa could be considered as an indication of high dissolved organic carbon in the reservoirs. Moreover, the study reservoirs were associated with the diatom species such as *Nitzschia* spp., especially *Nitzschia palea*. Overall relative abundance of the genus *Nitzschia* was greater than 45% in study reservoirs located in intermediate zone which is significant compared to other two climatic regions. *Nitzschia* taxon is one of the ordinary pollution tolerant taxon (Krammer and Lange-Bertalot 1986-1991; Lange-Bertalot 1979; Van Dam et al. 1994) and also this particular taxon is representative of water with elevated electrolyte concentrations (Krammer and Lange-Bertalot 1986-1991). Therefore, the representation of this taxon in study reservoirs is in accordance with this finding as average conductivity values in study reservoirs, especially in intermediate zone reservoirs were greater than that of standard value of $500\ \mu Scm^{-1}$ (Table 1). Thus, substantial existence of *Nitzschia* could be an indication of pollution and elevated electrolyte concentration in intermediate zone reservoirs compared to other two climatic regions. Similarly, *Cyclotella*, a pollution tolerant taxon was also abundant in study reservoirs in this study indicating water quality as eutrophic. This particular species is well documented in inhabiting moderate to highly polluted lakes (Facca and Sfriso 2007) persuading that study reservoirs were comparatively polluted. Interestingly, *Rhopholodia gibba*, *Suriella*, *Amphora ovalis*, *Epithemia* and *Diatoma* taxa were specific to dry zone reservoirs where having excessive amounts of phosphate (Mean $PO_4^{3-} = 0.41$ ppm). In accordance with Ruhland et al. (2003), *Suriella* is frequent in eutrophic waters. *Suriella* taxon, therefore, can be suggested as environmental indicator to detect eutrophication of reservoirs. Similar to this, *Amphora ovalis* is also a prime indicator of cultural eutrophication (Maishale and Ulavi 2015). As a result, the occurrence of both species is an indication of cultural eutrophication in dry zone reservoirs, which may be due to high levels of disturbances created by human since most of the study reservoirs in dry zone was closely associated with the human settlement. Similar to other two zones, the dry zone reservoirs were also characterized by the alkaline waters (Mean pH = 8.05, Table 1). *Epithemia* is one of the epiphytic, alkaline taxon and is commonly associated with *Rhopholodia gibba* (Zalat and Vildary 2005). Hence, the presence of both taxa is a clue of elevated levels of pH in the waters. *Diatoma* is an another taxon found in nutrient-rich environments with organic pollution (Fabri and Leclercq 1984). Dry zone reservoirs are encountered with elevated levels of NO_3^-–N and PO_4^{3-}, especially in Nawamedagama reservoir, NO_3^-–N and PO_4^{3-} levels are 3.4 ppm and 0.17 ppm, respectively, which were exceeded the natural levels convincing availability of extra loads of nutrients. Further, the second most dominant taxon of this particular reservoir was *Diatoma*. Thus, considering both facts it can be concluded as this reservoir contains extra loads of nutrients causing organic pollution which may be from domestic sewage or agricultural runoff since the reservoir is located within human settlement and agricultural lands. For that reason, *Diatoma* can be considered as a prime indicator of nutrient rich, organically polluted environments and which is in agreement with Fabri and Leclercq 1984. Although, *A. granulata* was the most dominant species in all over the study reservoirs in three major zones, there was an exception in Medawachchiya reservoir where the most dominant taxon was *Cocconeis* sp. *Cocconeis* is also a widely distributed diatom taxon found in almost all freshwaters with alkaline pH which seems to be tolerant to moderate eutrophication (mostly oligotrophic) with elevated conductivity (Beres et al. 2014) values. This fact would be further rationalized by coming across the physical and chemical characteristics of particular reservoir (pH = 8.34, $PO_4^{3-} = 0.05$ ppm and Conductivity = 378 μScm^{-1}) implying this particular reservoir is undergoing moderate eutrophication with increased levels of pH and conductivity. In the same way, Seeppukulama reservoir near Medawachchiya area is dominated by the *Nitzschia* spp. (*Nitzschia palea* and *Nitzschia clausii*) with relative abundance of over 50%. According to the literature, this particular species reaches the maximum abundance with increasing of total nitrogen and total phosphorous of their environment (Beres et al. 2014). Seeppukulama reservoir is having NO_3^-–N and PO_4^{3-} values of 3.0 ppm and 0.06 ppm, respectively. The condition imply a slightly elevated level of NO_3^-–N than the natural level (1.0 ppm) nevertheless less than the maximum acceptable level of PO_4^{3-} (0.1 ppm) to avoid accelerated eutrophication. Therefore, the occurrence of *Nitzschia* spp. at high dominance partially concurs with the findings of Beres et al. (2014). *Synedra ulna* was the most abundant species in Rajanganaya and Nikaniya reservoirs located in the dry zone and both *S. ulna* and *S. acus* are the prime indicators of anthropogenic eutrophication (Maishale and Ulavi 2015). Both reservoirs showed NO_3^-–N levels greater than the standard level which was an extreme condition in Nikaniya reservoir rather than Rajanganaya reservoir by showing 75 ppm of NO_3^-–N. Likewise, when reflecting to PO_4^{3-} values in both reservoirs, it showed the elevated amounts with the values of 1.08 ppm and 1.35 ppm in Rajanganaya and Nikaniya reservoirs, respectively, causing for accelerated eutrophication and consequent problems in reservoirs. Thus, our findings were in an agreement with the findings of Maishale and Ulavi (2015) convincing that both reservoirs are under threat of eutrophication due to anthropogenic activities and *S. ulna* can be considered as an excellent indicator of cultural eutrophication.

The CCA ordination suggests that the distribution of diatom taxa in the reservoir sediments is influenced by the environmental parameters such as PO_4^{3-}, DO, conductivity, TDS and NO_3^-(Fig. 2). However, according to the Pearson correlation analysis, PO_4^{3-} was not positively correlated with DO though those two factors were the key environmental gradient when explaining species distribution. But, significant positive correlations were resulted among conductivity, TDS and NO_3^- concentration. Moreover, according to some literature (Rusydi 2017), the relationship between TDS and electrical conductivity is not always linear and the situation highly depends on water salinity and material contents that come from nature and from human activities such as agriculture which were not considered in the present study as the major environmental factors. However, when compared with the findings of Kouman et al. (2001), it was disclosed that NO_3^-–N concentration can be evaluated straightforwardly from the values of electrical conductivity irrespective of soil type which concurred with our findings. Also, cluster analysis indicates the clusters gathered in similar conditions based on the relative abundance of the diatom species measured environmental variables. But at this point, the CCA ordination diagram is not exactly tallying with the dendograms resulted from cluster analysis. The reason for this is the abundance and distribution of species may depend on not only the environmental variables which have considered in the present study, but also it may depend on the combined effects of environmental factors which were not taken into account in the present study. However, unlike in temperate countries, a very few studies have been carried out in tropical countries like Sri Lanka of using diatoms as environmental indicators and their related environmental conditions. Therefore, through this study, an attempt was taken to provide an understanding on importance and potential of using diatom as environmental indicators in developing models to predict temporal and spatial environmental changes and later can be developed to reconstruct past environmental changes in paleolimnology.

Conclusions

Most of the Sri Lankan reservoirs appear to have a risk of eutrophication and other consequence problems and the situation is more prominent in Dry and Intermediate Zones than Wet zone. These changes can be detected easily by using diatom assemblages preserved in surface sediments as environmental indicators. Diatom distribution is mainly associated with the factors such as phosphate amount, dissolved oxygen (DO), nitrite amount, conductivity and total dissolved solids (TDS) in this study. However, other environmental variables which were not considered here are also important when explaining species distribution.

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