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The Use of GIS to Visualize Spatial Distribution of Zooplankton in Teluk Bahang Reservoir, Penang, Malaysia

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ABSTRACT

The Teluk Bahang Reservoir is the largest in Penang, Malaysia and supplies drinking water to the inhabitants of the Northwest of Penang Island. A monthly testing of water quality and study of zooplankton species abundance was conducted at four different sampling locations and three different water depths. The water quality parameters measured include water temperature, dissolved oxygen, conductivity, pH, orthophosphate (PO_4-P), ammonium-nitrogen (NH_4-N), nitrite-nitrogen (NO_2-N) and nitrate-nitrogen (NO_3-N). In this study, multiple techniques in ArcMap software, namely, Inverse Distance Weighted (IDW) and Kernel Density, were used to identify the relationship among water quality parameters and species abundance of zooplankton in the sampling stations. In GIS spatial analysis, high abundance areas or hotspot areas of zooplankton were presented in a visual map. The distribution pattern of zooplankton species and the geographic distribution of water quality parameters were clearly identified based on inspection of the map. The data generated from GIS mapping in this study is important for ecological research, particularly on zooplankton distribution in a drinking water reservoir.

Keywords: *Penang, water quality, zooplankton, ArcMap, Inverse Distance Weighted, GIS*

INTRODUCTION

Zooplankton play a crucial role in food webs of aquatic ecosystems. Most zooplankton are filter feeders, serving as primary grazers of algae, bacteria, protozoans, as well as primary food sources for fish larvae and invertebrate predators. Zooplankton are highly sensitive to environmental variation and often exhibit rapid changes to abundance and diversity, in response to the environmental disturbance (*Golmarvi et al. 2018*). Long-term monitoring of zooplankton community structures provides useful information about environmental changes. The detection of anthropogenic impact could be troublesome if information in the background studies and changes in ecological systems are scarce. For example, with long-term monitoring of zooplankton community structures, variations in patterns and species composition related to climatic and water quality changes can be detected (*Wiafe et al. 2008; Scheef et al. 2012*). *Magurran et al.* (*2010*) also reported the importance of long-term datasets in biodiversity studies, in order to reduce the rate of biodiversity loss. Several long-term studies have dealt with marine plankton such as *Volvenko* (*2019*) who mapped the distribution of plankton in East seas and the Pacific Ocean from 1984-2013 while *Balazy et al.* (*2018*) investigated the size structure of plankton in Arctic region from 2010-2016.

Geographic Information System (GIS) tend to be a practical and efficient tool in ecological research, particularly for model prediction on species diversity patterns. Numerous studies documented the use of GIS in mapping species distribution of fauna and flora in the marine ecosystem. For instance, *Bryan and Metaxas* (*2007*) predict suitable habitat for gorgonian corals while *Embling et al.* (*2010*) envisage habitat for harbour porpoise in the west coast of Scotland. Other than that, *Peterson et al.* (*2000*) modelled endemic mammals in Veracruz, Mexico. Data presentation based on GIS, specifically on the zooplankton distribution, is a current novel scenario. The clear view of the metadata with a geospatial component based on a series of maps, provides information on zooplankton species distributed in any spot of the waterbody that has rarely been explored. This data can be displayed geographically, to become suited for data collection and analysis for zooplankton monitoring during the study period. GIS was used in order to determine the occurrence and abundance of zooplankton per month, based on maps, along with the temporal and spatial variations of water quality parameters.

Studies on GIS application on freshwater zooplankton are scarce and have not much been utilized by zooplankton ecologists. Most of the zooplankton studies related to GIS applications were conducted on coastal and marine waters (*Kane and Prezioso 2008; Panti et al. 2015; Putra et al. 2016, Canencia and Ascano 2017*). In Malaysia, analyzing freshwater zooplankton data using GIS has not yet been explored. Thus, this study aimed to produce maps that illustrate the zooplankton abundance and the prevailing environmental conditions using GIS (ArcGIS 10.3).

MATERIALS AND METHODS

Study site

Teluk Bahang Reservoir, constructed in 1999, is located in the Northwest of Penang Island of Malaysia (5º26'22"N and 100º12'49"E). It is the largest reservoir in Penang Island that supplies drinking water to the people in Penang. The maximum water capacity is 19.24 x 109 L, with an average daily run-off of 61.6 x 109 L d-1. The reservoir is fed by small rivers and rainfall in the water catchment areas. It is an earth-filled reservoir, built across the flood plain of Teluk Bahang Basin, and was designed to complement the natural landscape. The surrounding reservoir is a natural tropical forest, which is one of the recreational areas and venues for the dragon boat competition in Penang. An equatorial climate predominates in Penang, characterized by hot and humid weather all year round. Annual precipitation rates are about 2,707 mm with the temperatures range between 29-35 °C during the day. It has two distinct seasons, namely wet seasons (March-April and July-October) and dry seasons (May-June and November-February) (*Nurul-Ruhayu and Yahya 2013*).

Field sampling and laboratory analyses

Zooplankton samples were collected using 30 µm mesh plankton net, while water samples were collected using a Van Dorn water sampler at four independent locations (**Figure 1** and **Table 1**), at three depths (5 m, 10 m, and 15 m), from March 2014 to March 2015. The selection of sampling stations was based on different depth and characteristic. Station 1 is the deepest station and situated at the limnetic zone while Station 2 is shallower than Station 1 and located in the limnetic zone in the middle of the reservoir. Station 3 is shallower than Stations 1 and 2 and situated at the meeting point of two small rivers while Station 4 is the shallowest among the sampling stations and located at one of the small rivers.

Three sampling depths (5 m, 10 m and 15 m) which were in the aphotic zone were chosen in the present study due to the characteristics of light-avoidance by zooplankton (*Martynova and Gordeeva 2010*). Preliminary survey also exhibited a higher abundance of zooplankton in these depths. Taxonomic identification followed *Idris* (*1983*), *Korovchinsky* (*1992*), and *Shiel* (*1995*). The quantitative determination of water temperature, dissolved oxygen (DO), conductivity, and pH, were carried out in-situ using YSI multi-probes (Model 556 MPS). Analyses of orthophosphate (PO_4-P), ammonium-nitrogen (NH_4-N), nitrite-nitrogen (NO_2-N), nitrate-nitrogen (NO_3-N) and chlorophyll a concentration were conducted in the laboratory, following the method of *Adams* (*1991*).

Visualization and mapping

GIS software ArcGIS 10.3 was used to map zooplankton distribution by analysing spatial data collected during field sampling. The spatial analysis tool was used to identify hotspot areas using the Kernel Density technique. Next, the distribution pattern of zooplankton population was created. An Inverse Distance Weighted (IDW) technique using the interpolation function was used to project the correlation between water quality parameters and zooplankton population abundance.

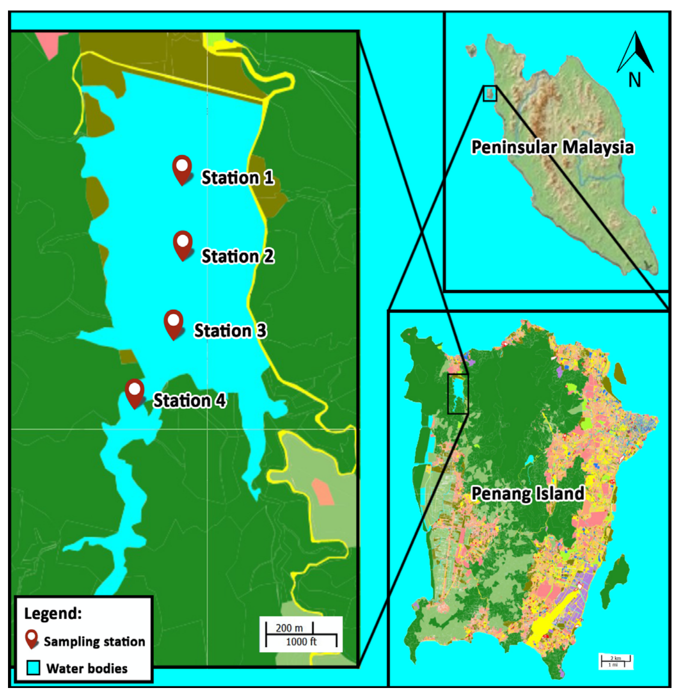

Figure 1. Sites and sampling locations for the study of water quality and zooplankton species abundance in Teluk Bahang Reservoir, Pulau Pinang, Malaysia (Modified from *Pulau Pinang Town and Country Planning Department 2018*).

Table 1. The locations and depths of the sampling stations in the study of water quality and zooplankton species abundance in Teluk Bahang Reservoir, 2014-2015.

Station	Latitude	Longitude	Depth (m)	
			Maximum	Minimum
1	05º26’37.14”N	100º12’42.92”E	38.2	31.2
2	05º26’20.88”N	100º12’48.36”E	37.4	30.4
3	05º26’05.94”N	100º12’50.46”E	31.6	24.6
4	05º25’57.54”N	100º12’44.10”E	10.1	3.1

RESULTS AND DISCUSSIONS

Physicochemical parameters

Geographic Information System (GIS) application is a vital tool in the analyses of aquatic ecosystem studies. This tool provides many functions that enhance practical methods to be more systematic in terms of analysis, as compared to previous conventional methods, such as statistical techniques and numerical modelling. Geographic Information System is a relatively new technology that is suitable in the application of conservation purposes, as the data availability can be shared and updated at any time through the use of database collection. In fact, it is frequently used for monitoring and predicting the trends and hotspots of biotic and abiotic components, in order to aid in effective management and conservation of aquatic systems (*Putra et al. 2016*). GIS provides accurate and comprehensible information in graphic form; thus decision-makers are able to respond urgently in matters related to tropical water management. Ecological information can be linked with the management decisions of tropical waters using GIS (*Mironga 2004*).

Due to the limitations in sampling time and samples processing, only four stations were established for sampling stations. The temperature decreased with depth. The highest mean water temperature was recorded at 5 m depth (29.2 ± 0.3 °C); whereas the lowest mean water temperature was recorded at 15 m depth (27.7 ± 0.1 °C) (**Figure 2**). When comparing among stations, the temperature almost had similar measurements at all sampling stations. Warm and consistent water temperature measurements were obtained throughout the study. According to *Xing et al.* (*2014*), tropical lakes are characterized by weaker seasonal variation in solar radiation than temperate lakes, thus, the warmer water temperatures due to larger solar radiation.

Mean DO demonstrated a similar pattern at Stations 1, 2 and 3 (**Figure 3**). It decreased with depth, subsequently showing hypoxia at the bottom. Station 4 recorded the highest mean DO at 5 m depth (6.27 ± 0.28 mg L^{-1}); whereas Station 2 recorded the lowest mean DO at 15 m depth (0.48 ± 0.25 mg L^{-1}) (**Figure 3**). Overall, DO levels decreased from upper to deeper water columns. As pointed out by *Payne* (*1986*), DO is highest when it is close to the surface water due to the uptake from the atmosphere, and the production of oxygen by phytoplankton during photosynthesis (*Andersen et al. 2017*). Hypoxic condition, which refers to very low oxygen content in water, was observed at 10 m and 15 m depths in the study site. This phenomenon is similar to the Chenderoh Reservoir in Perak, Malaysia (*Meor Hussain et al. 2002*). In addition, below the euphotic zone, the decomposition of dead algae and organic matters contributed to the DO reduction rapidly, resulting in the formation of anoxia area (*Huang et al. 2019*). During the decomposition of organic matters, DO is consumed, which leads to low DO in water (*Chapman 1996*). This is, thus, in agreement with the present study showing evidence for low DO in deeper water layers, probably due to the plants that have been inundated (when the reservoir is built) and have undergone decomposition process.

Mean conductivity increased with depth. Station 1 recorded the highest mean conductivity at 15 m depth (30.68 ± 1.39 µS cm^{-1}); whereas Station 4 recorded the lowest mean conductivity at 5 m depth (24.60 ± 0.40 µS cm^{-1}) (**Figure 4**). *Chapman* (*1996*) points out that the normal conductivity of most freshwater ecosystems ranges from 10 to 1,000 µS cm^{-1}. In this study, mean conductivity recorded was 27.89 ± 0.27 µS cm^{-1}, thus, within the range proposed by *Chapman* (*1996*). *Abida and Harikrishnarai* (2008) pointed out that decomposition and mineralization of organic materials will increase the level of conductivity in the water column. *Bhateria and Jain* (*2016*) came up with a similar idea that the existence of inorganic constituents in run-off together with the

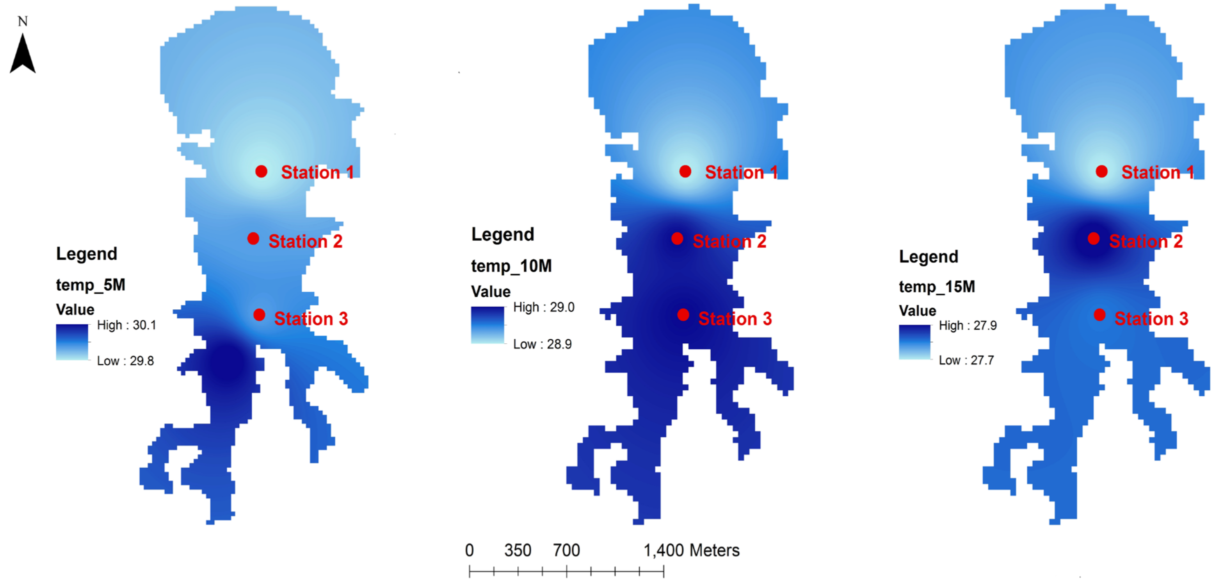

Figure 2. Variations of water temperature (°C) at different stations in the study of water quality and zooplankton species abundance in Teluk Bahang Reservoir, Malaysia, 2014-2015.

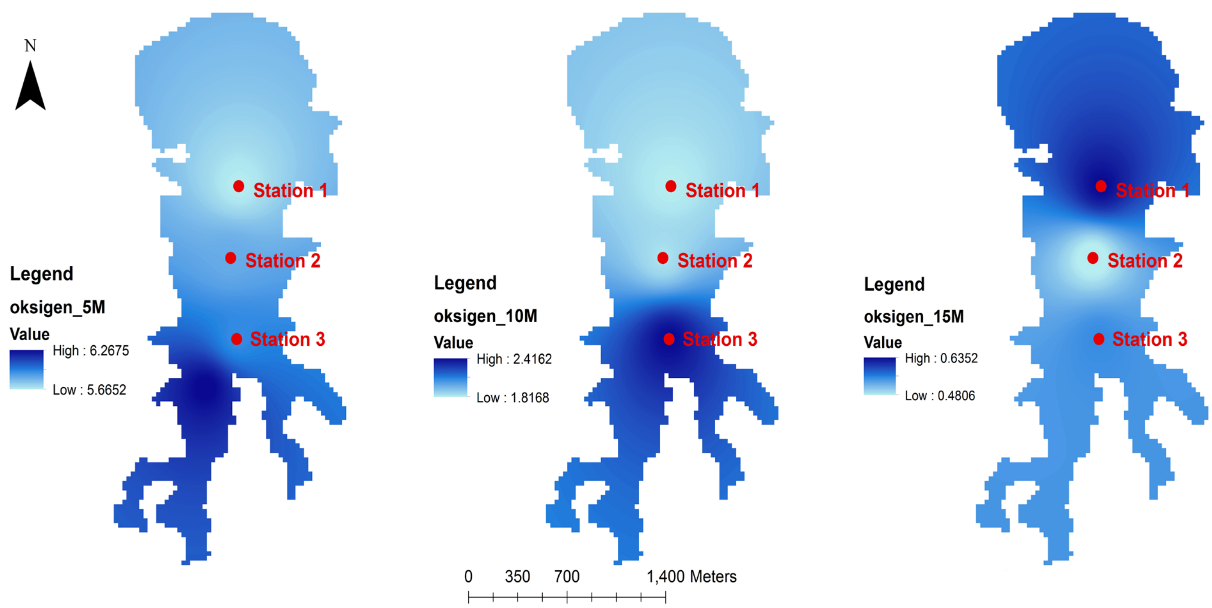

Figure 3. Variations of dissolved oxygen (mg L^{-1}) at different stations in the study of water quality and zooplankton species abundance in Teluk Bahang Reservoir, Malaysia, 2014-2015.

presence of chloride, phosphate, and nitrate from sewage systems would increase the conductivity level. Hence, conductivity is a very useful water quality parameter to determine the effect of run-off and effluent discharges in the aquatic system (*Chapman 1996*).

Mean pH also decreased with depth. Station 4 recorded the highest mean pH at 5 m depth (6.9 ± 0.12); whereas Station 2 recorded the lowest mean pH at 15 m depth (6.03 ± 0.08) (**Figure 5**). This finding is in line with the work by *Ling et al.* (*2017*) on the Bakun Reservoir in Sarawak, Malaysia. Lower pH measurements recorded in the deeper water column might be due to the decomposition process, which produces carbon dioxide (*Krachler et al. 2009; Nydahl et al. 2019*). According to *Chapman* (*1996*), 6.0-8.5 is the pH range of most natural waters. pH is a crucial variable in water quality monitoring of ecosystem health as aquatic organisms have certain ranges of pH tolerance. pH water depends on the nature of the water, which is transported from the catchment area and drainage networks (*Mihu-Pintilie et al. 2014*).

Station 1 recorded the highest mean PO_4-P concentration at 10 m depth (0.038 ± 0.008 mg L^{-1}), whereas Station 3 recorded the lowest mean PO_4-P

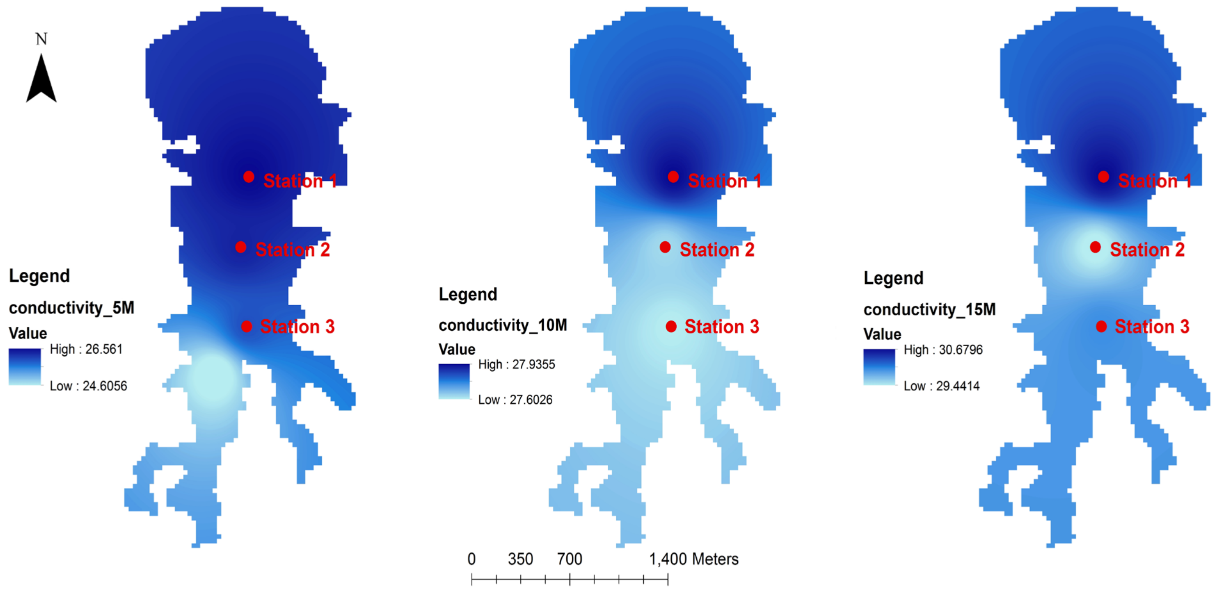

Figure 4. Variations of conductivity (μS cm^{-1}) at different stations in the study of water quality and zooplankton species abundance in Teluk Bahang Reservoir, Malaysia, 2014-2015.

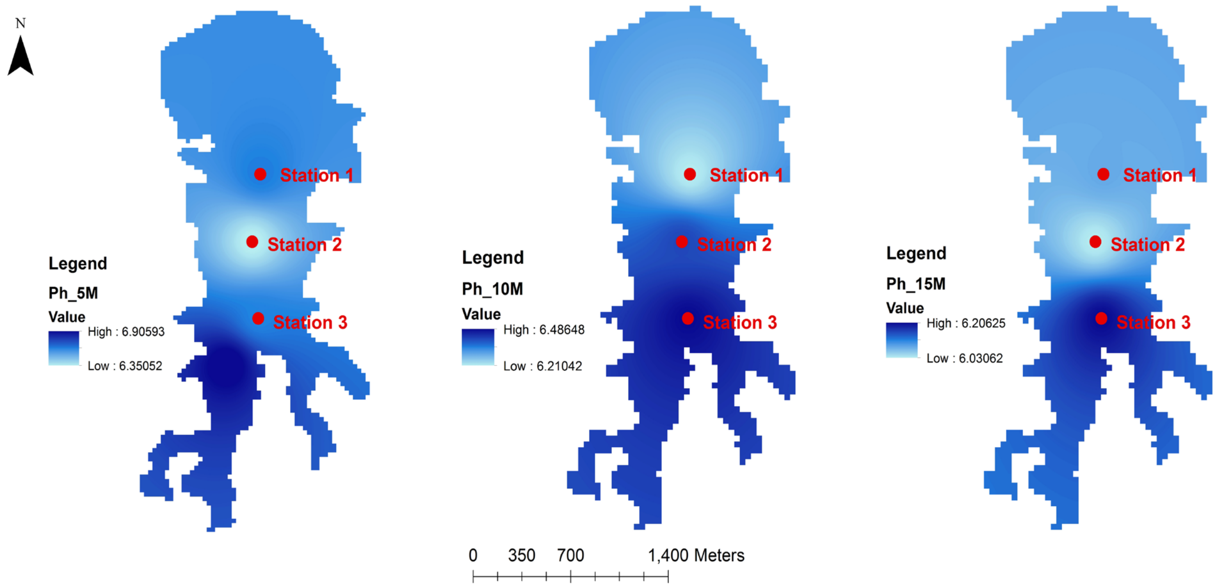

Figure 5. Variations of pH at different stations in the study of water quality and zooplankton species abundance in Teluk Bahang Reservoir, 2014-2015.

concentration at 5 m depth (0.023 ± 0.003 mg L^{-1}) (**Figure 6**). *Oram* (*2005*) verified that the PO_4-P concentrations range from 0.01-0.03 mg L^{-1} is the level in uncontaminated lakes. Therefore, low PO_4-P level indicates that the Teluk Bahang Reservoir is unpolluted. *Quinton et al.* (*2001*) point out that greater rainfall intensities increased the run-off and erosion leading to an increase in phosphorus transport, while *Blick et al.* (*2004*) verified that phosphorus often combines with fine soil particlesand flow along with water as suspended sediments.

Mean NH_4-N concentration increased with depth. Station 2 recorded the highest mean NH_4-N concentration at 15 m depth (0.158 ± 0.029 mg L^{-1}); whereas Station 4 recorded the lowest mean NH_4-N concentration at 5 m depth (0.052 ± 0.012 mg L^{-1}) (**Figure 7**). This is probably derived from the decomposition of submerged trees and terrestrial plants at the bottom of the reservoir contributing to higher nutrients level and organic matter in the deeper depth (*Straskraba et al. 1993*). *Yusoff et al.* (*2011*) stated that NH_4-N is produced from nitrogenous waste excreted by fish and crustaceans in the water column.

Mean NO_3-N showed fluctuations at Stations 1, 2 and 3 (**Figure 8**). Station 2 recorded the highest mean NO_3-N

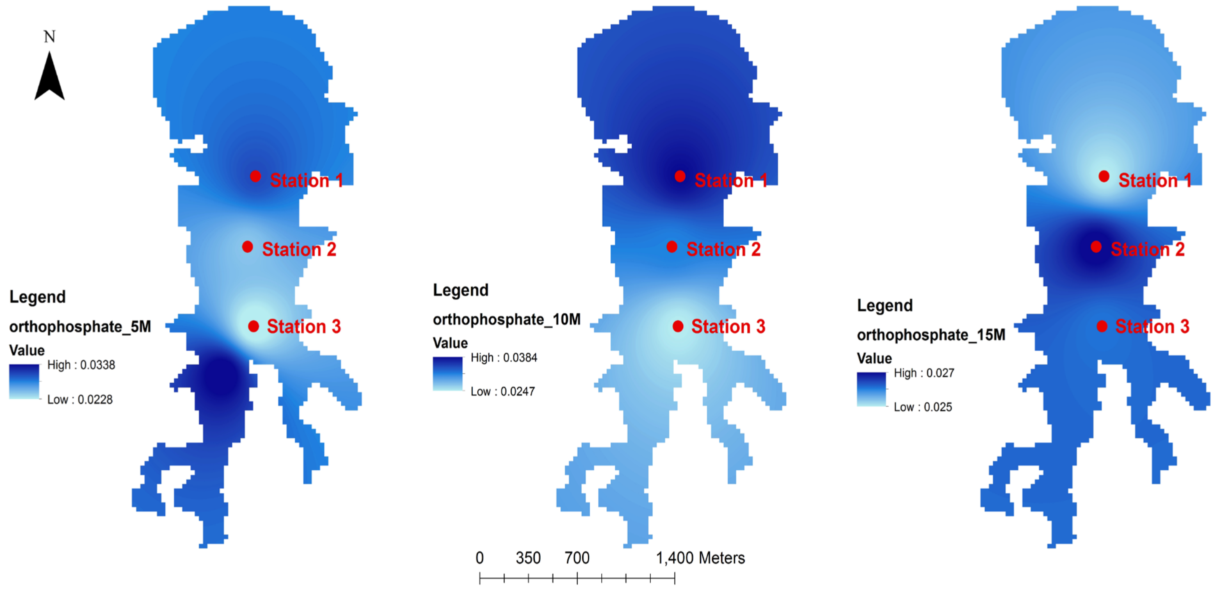

Figure 6. Variations of orthophosphate (mg L^{-1}) at different stations in the study of water quality and zooplankton species abundance in Teluk Bahang Reservoir, 2014-2015.

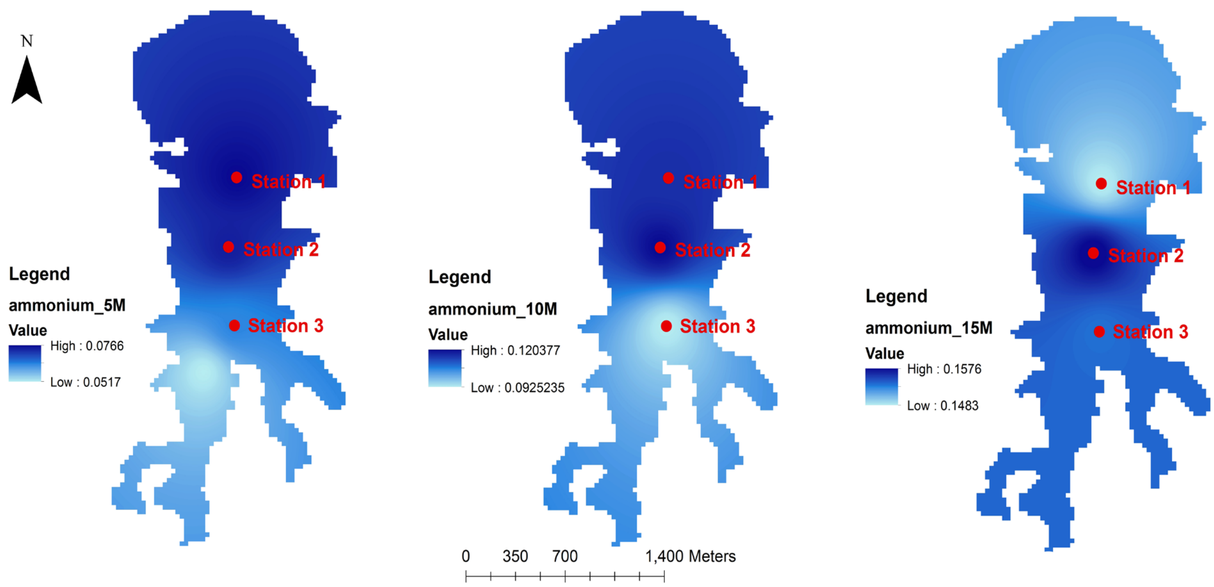

Figure 7. Variations of ammonium-nitrogen (mg L^{-1}) at different stations in the study of water quality and zooplankton species abundance in Teluk Bahang Reservoir, 2014-2015.

at 10 m depth (0.051 ± 0.011 mg L^{-1}); whereas Station 4 recorded the lowest mean NO_3-N (0.028 ± 0.008 mg L^{-1}) at 5 m depth (**Figure 8**). As described in detail by *Quiros* (*2003*), NO_3-N, NH_4-N accumulate in lentic water bodies, such as lakes and reservoirs. When NO_3-N enters the lake from external sources, such as drainage basin, it is transformed in organic matter by autotrophs and bacteria, which then goes to the NH4-N pool through food web transmission (*Quiros 2003*). *Zorcic et al.* (*2015*) provide evidence, suggesting that the changes of NO_3-concentration in the reservoir depend on the changes in the amount and quality of water from its tributaries.

Fluctuations of mean NO_2-N concentration were observed at various depths of all sampling stations (**Figure 9**). Station 3 recorded the highest mean NO_2-N concentration at 15 m depth (0.004 ± 0.001 mg L^{-1}); whereas Station 4 recorded the lowest mean NO_2-N concentration at 5 m depth (0.003 ± 0.001 mg L^{-1}). Variations of NO_2-N and NO_3-N concentrations were obtained in the sampling stations. According to *Wetzel* (*2001*), algal assimilation and denitrification would result in a rapid decline in nitrate. Higher levels of NO_2-N and NO_3-N were observed during the sampling months with higher rainfall, as they can easily dissolve in rainwater and then move into the reservoir.

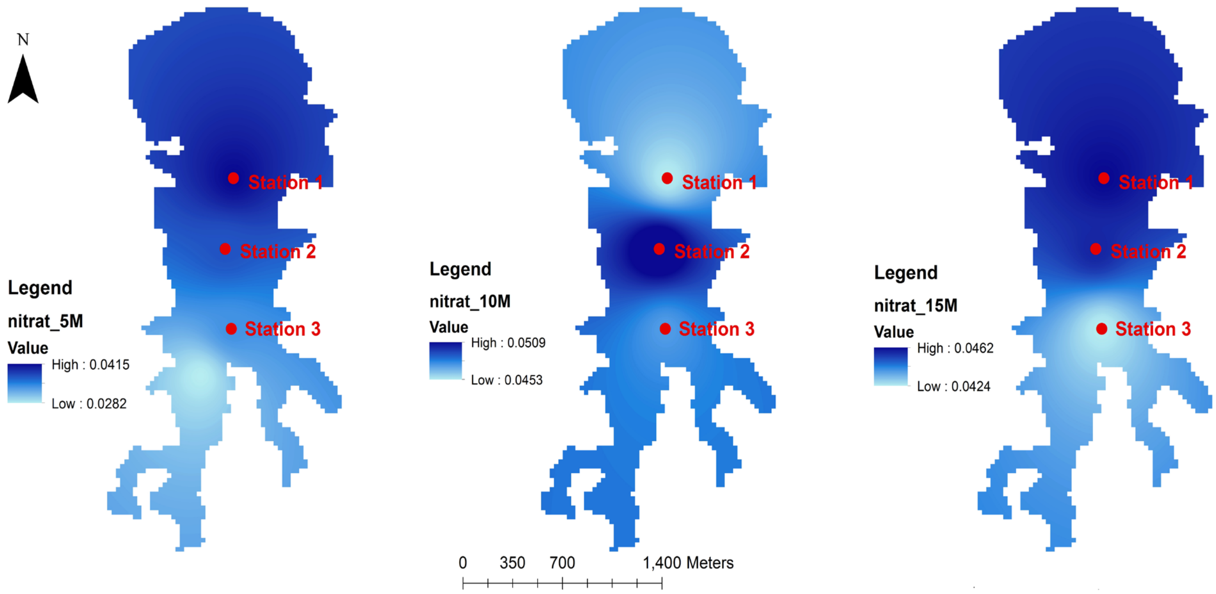

Figure 8. Variations of nitrate-nitrogen (mg L^{-1}) at different stations in the study of water quality and zooplankton species abundance in Teluk Bahang Reservoir, 2014-2015.

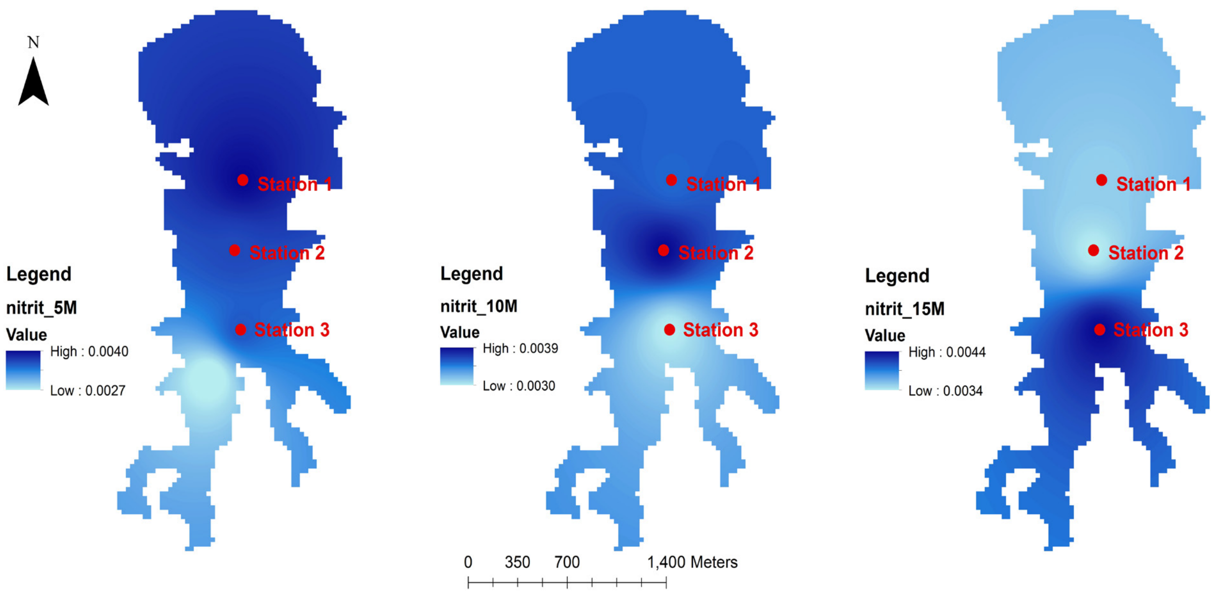

Figure 9. Variations of nitrite-nitrogen (mg L^{-1}) at different stations in the study of water quality and zooplankton species abundance in Teluk Bahang Reservoir, 2014-2015.

Based on the vertical profiles, mean chlorophyll a concentration showed a similar pattern at Stations 1, 2 and 3 (**Figure 10**). Our observations showed that chlorophyll a level decreased with depths at all stations. Station 1 recorded the highest mean chlorophyll a concentration (8.01 ± 0.58 µg L^{-1}) at 5 m depth whereas Station 3 recorded the lowest mean chlorophyll a concentration (1.99 ± 0.51 µg L^{-1}) at 15 m depth (**Figure 10**). This finding is in accord with work by *Narvekar and Kumar* (*2014*), who reported that chlorophyll biomass decreases rapidly with depth. According to *Wen et al.* (*2016*), light was the limiting factor for photosynthesis in the deeper water column and consequently, the algal growth rate was seriously limited. The measure of chlorophyll a concentration provides an estimation on the density of photosynthetic plankton, making it a potential indicator of trophic status in aquatic systems. Hence, it is an important parameter for water quality monitoring and assessment.

Zooplankton

Zooplankton were the most abundant at 5 m, followed by 10 m and 15 m, across all sampling stations during the study (**Figure 11**). The highest mean abundance of zooplankton was observed at 5 m depth of Station 4 (349

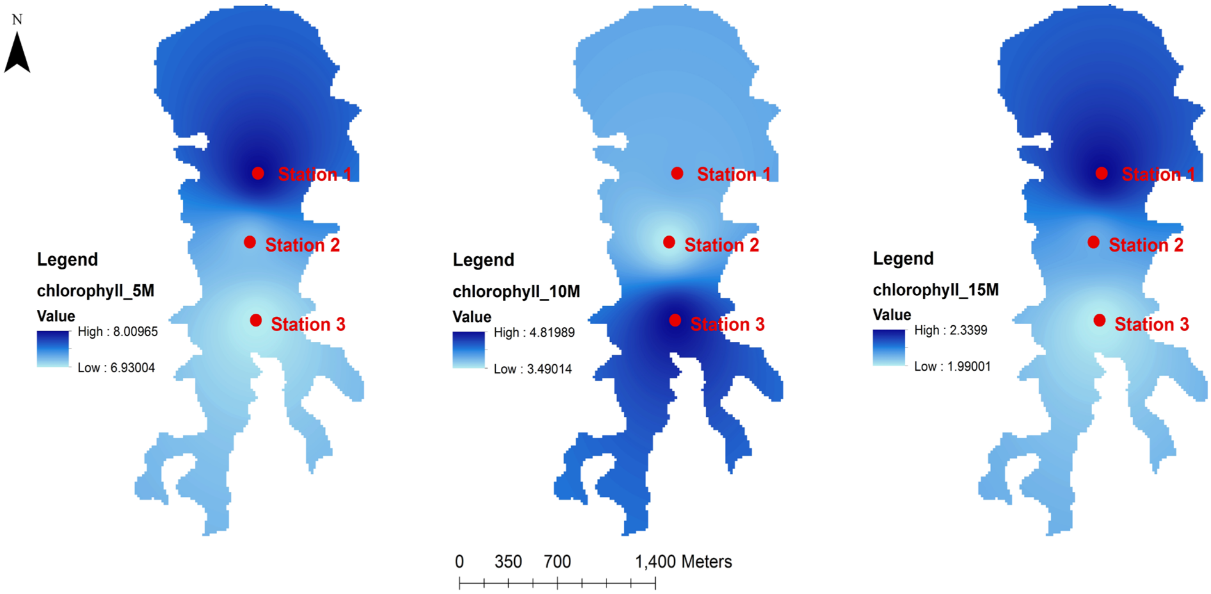

Figure 10. Variations of chlorophyll a (μg L^{-1}) at different stations in the study of water quality and zooplankton species abundance in Teluk Bahang Reservoir, 2014-2015.

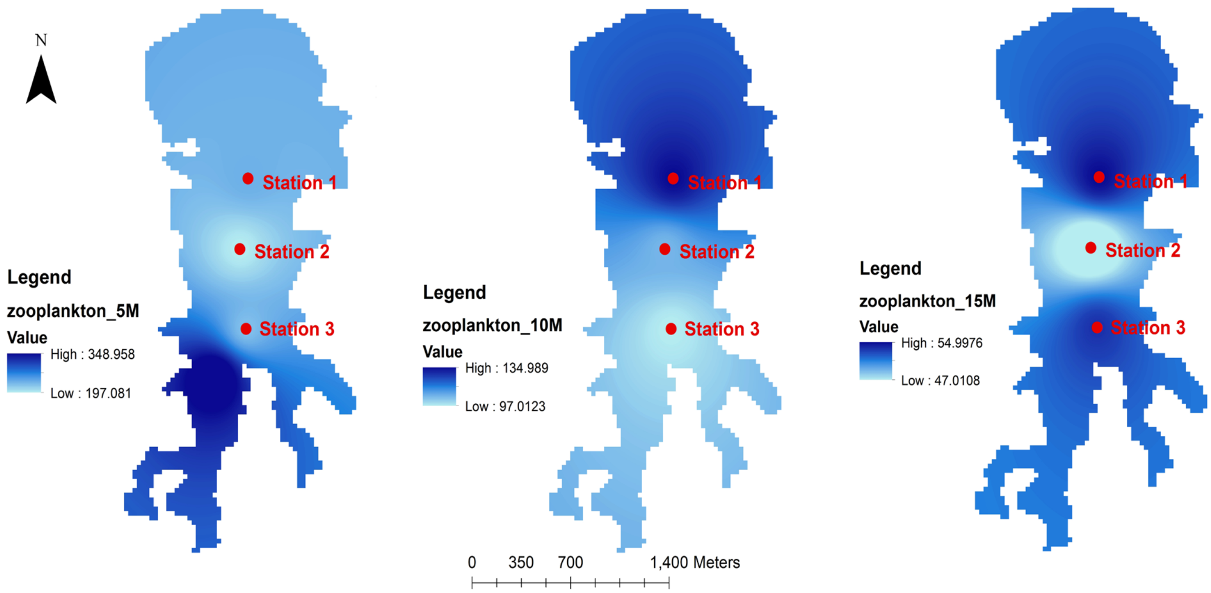

Figure 11. Variations of zooplankton abundance (ind L^{-1}) at different stations in the study of water quality and zooplankton species abundance in Teluk Bahang Reservoir, 2014-2015.

± 115 ind L^{-1}); while the lowest mean abundance was recorded at Station 2 (197 ± 61 ind L^{-1}). At 10 m depth, the highest and lowest mean abundance was recorded at Station 1 (135 ± 46 ind L^{-1}) and Station 3 (97 ± 17 ind L^{-1}). Station 1 demonstrated the highest mean abundance of zooplankton at 15 m depth (55 ± 9 ind L^{-1}); whereas the lowest mean abundance was recorded at Station 2 (47 ± 5 ind L^{-1}).

Among the 28 taxa, Rotifera dominated with 22 taxa, followed by Cladocera (4 taxa) and Copepoda (2 taxa) (**Table 2**). Rotifera was the dominant group, which recorded the highest relative abundance (78.71%), followed by Cladocera and Copepoda, which accounted 12.15% and 9.14% respectively (**Table 2**). Among the Rotifera, *Ptygura* sp. was the main constituent with a relative abundance of 55.083%. Several species (*Asplanchna* sp., *Brachionus calyciflorus*, *B. forficula*, *Lecane lunaris* and *L. papuana*) recorded very low percentages, which were less than 0.01%, in the study sites. *Bosminopsis deitersi* with the relative abundance of 8.99% was predominant in Cladocera. For Copepoda (9.14%), Cyclopoida contributed 9.05% of relative abundance; while Harpacticoida only accounted for 0.09%. In the present study, the abundance of cladocerans was low. According to *Helenius et al.* (*2015*), the

Table 2. Relative abundance of zooplankton taxa in Teluk Bahang Reservoir, 2014-2015.

Taxa	Relative abundance (%)
Rotifera	78.705
Anuraeopsis fissa	3.960
Anuraeopsis navicula	0.528
Anuraeopsis sp.	0.217
Ascomorpha sp.	0.146
Asplanchna sp.	0.005
Bdelloidea	0.160
Brachionus calyciflorus	0.005
Brachionus forficula	0.005
Collotheca sp.	3.813
Conochilus sp.	0.746
Keratella cochlearis	0.335
Keratella tecta	7.005
Keratella sp.	0.085
Lecane hamata	0.231
Lecane lunaris	0.009
Lecane papuana	0.014
Notommata sp.	2.371
Polyarthra sp.	0.584
Ptygura sp.	55.083
Trichocerca pusilla	0.297
Trichocerca similis	1.056
Trichocerca sp.	2.052
Cladocera	12.151
Bosminopsis deitersi	8.988
Diaphanosoma excisum	0.231
Diaphanosoma sarsi	0.723
Diaphanosoma sp.	2.210
Copepoda	9.143
Cyclopoida	9.053
Harpacticoida	0.090

predation eliminated cladocerans efficiently compared to copepods, and this led to pattern changes in rotifer abundance. *Haberman et al.* (*2007*) stated that cladocerans were reported to be more abundant in eutrophic lakes. Hence, this indicates that the Teluk Bahang Reservoir is relatively clean. *Ismail et al.* (*2019*), however, points out that good water management in the reservoir such as controlling water retention time and flushing rate also contribute to the dominance and abundance of certain zooplankton species.

Zooplankton distributions are strongly affected by oxygen variability (*Wishner et al. 2018*). In the present study, mean abundance of zooplankton decreased with an increase in depth since DO decreased with increasing depth. Furthermore, their main food source, which is phytoplankton, is abundant in upper water layers as observed by *Khalifa et al.* (*2015*). This supports the fact that zooplankton in the present study were most abundant at 5 m, followed by 10 m and 15 m, across all sampling stations.

Kehayias et al. (*2013*) also stated that zooplankton abundance was characterized by a sharp decline with depth. Although zooplankton were distributed throughout the water column, they were usually more concentrated in the upper water, mainly at the top 5 m (*Burns and Mitchell 1980*). At 15 m depth, which was anoxic, the very low abundance of zooplankton was detected. A similar idea was initiated by *Doubek et al.* (*2018*) that most individual zooplankton genera avoided anoxic hypolimnia and remained in the epilimnion during the daytime in reservoirs. Thus, the current study clearly explains the patterns of zooplankton distribution at three different depths associated with dissolved oxygen.

All the water quality and zooplankton distribution data in the present study were produced in the form of map illustrations using the GIS technique. *Delgado and Marin* (*1997*) suggested that GIS, which was used to examine zooplankton components in aquatic ecosystems, may help resource managers to better utilize the available data and make a correct decision for sustainable water resources management.

CONCLUSION AND RECOMMENDATIONS

Geographic Information System (GIS) mapping is a useful tool in analyzing and illustrating the trends and pattern changes of the spatial-temporal abundance of zooplankton. In Malaysia, analyzing freshwater zooplankton data using GIS has never been explored. Our study could be a pilot study of GIS mapping on freshwater zooplankton in Malaysian reservoirs.

Based on the study, zooplankton abundance is primarily controlled by fluctuations in physical environments and nutrient concentrations of water quality, which then cause variation and high seasonality among sampling stations. In fact, the physicochemical and biological analyses were further emphasized in this study as a holistic indicator that is capable of assessing reservoir's water quality. The information can provide a basis for evaluating the drinking water quality, and the presentation can also be a tool for the catchment-related analysis of the natural conditions, the landscape water and material balance in a drinking water reservoir. Moreover, the findings may contribute as a bases for the evaluation of the temporal and spatial development of the drinking water quality. Thus, GIS mapping, seem to be useful information and may serve as a future reference in ecological research. These will provide valuable information to support effective water quality management to policymakers and the resource managers involved in watershed management and water supply services. Further research is recommended to implement GIS accompanied with field data in determining water parameters and population abundance as it is a practical technique for the assessment of any aquatic ecosystems.

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