Distribution of heterotrophic bacteria and water quality parameters of Mosul Dam Lake, Northern Iraq

M. F. O. Khattab & B. J. Merkel
Hydrogeology Department, Tu-Bergakademie Freiberg, Germany

Abstract

Mosul Dam Lake is one of the largest artificial water reservoirs in Iraq, located in the north of the country. This lake is the main source of drinking water in Iraq, providing water to Mosul, Baghdad, and other cities. The surface area of the lake is 385 km^2 at the maximum operation level with a total storage volume of 11.13×10^9 m^3. The climate of the study area is arid to semi arid, with rainfall not exceeding 300 mm/year. The highest temperature in summer reaches more than 55ºC. The lake is monomictic with overturn occurring in the autumn. The difference between the lake surface and bottom temperatures during the summer is more than 17°C (31−14°C) and 2°C during winter (12−10°C). Secchi disk measurements show that Mosul Dam Lake is mesotrophic; only the outlet of Dohuk River is eutrophic. In the current study, the standard plate count agar procedure was used for analyzing 45 samples for heterotrophic bacteria. These samples have been collected from different depths and locations in the study area during two sampling campaigns in February 2011 and July 2011. Water quality parameters (pH, EC, NO_3, NO_2, PO_4, TIC, and DOC) for the same locations and depths of the sampled bacteria were measured. Results of heterotrophic bacteria analysis show that Mosul Dam Lake is contaminated with bacteria.

The river Dohuk is the major source of this pollution. Occurrence of heterotrophic bacteria during the summer exceeds the winter values by 57%. In a layer located 12–15 m below the surface of the lake with a temperature of 10.9°C, a linear correlation between heterotrophic bacteria and water quality parameters (R^2 >0.7) in winter could be observed. However, with respect to phosphorous, a logarithmic relationship with heterotrophic bacteria can be seen. In the summer season, the heterotrophic bacteria had a clear relation with most water quality parameters (R^2 >0.7) at depths of between 40 and 60 m within the

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hypolimnion zone (20–14°C). Spatial analysis shows that the heterotrophic bacteria for bottom samples correlate ($p < 0.05$) with most water quality parameters for samples which have been taken from deep regions of the lake.
Keywords: Mosul Dam Lake, heterotrophic bacteria, water quality.

1 Introduction

The term heterotrophic bacteria, also known as colony counts and previously known as standard plate count bacteria, includes all bacteria that use organic nutrients for growth and certain amounts of inorganic nutrient salts for their development [1, 2]. These organisms can be found throughout the environment in both natural and treated water, as they can also vary widely between locations and between seasons. The presence of heterotrophic bacteria in surface water has implications for public health, especially pathogenic organism [3, 4]. These organisms can cause stomach and intestinal illness including diarrhea and nausea, and can be fatal [5]. Therefore, the analysis of heterotrophic bacteria in water reservoirs can be helpful in assessing water quality. Monitoring of the microbiological quality of the water largely depends on both the spatial and the temporal variation of the bacterial populations in the aquatic systems [6]. Previous studies for heterotrophic bacteria as indicators of lacustrine water quality have focused on measurements of surface samples collected at a small number of locations [4, 7]. The objectives of this study were to explore the spatial and vertical changes with heterotrophic bacteria and other water quality parameters of the Mosul Dam Lake in northern Iraq during both summer and winter seasons. One aim was to quantify the seasonal and vertical relationship between heterotrophic bacteria and water quality parameters through the different zones of the lake. An additional aim was to estimate the occurrence of heterotrophic bacteria depending on routinely measured environmental parameters.

2 Description of study area

Mosul Dam Lake is one of the largest artificial water reservoirs in Iraq, constructed in 1985. It is located at the Tigris River about 60 km north of Mosul city and 80 km from the borders of Syria and Turkey (fig. 1). The majority of the water entering the reservoir comes from Turkey. The surface area of the lake is about 385 km^2 at the maximum operation level (330 m above sea level) with a total storage volume of 13.13 billion m^3 and a maximum water depth of 80m [8]. Mosul Dam Lake is located in an arid–semi arid region where the average rainfall does not exceed 300 mm/year and the temperature on some days during July reaches more than 55ºC.

The Tigris River discharges between 60 and 5000 m^3/sec of water into Mosul Dam Lake. The amount of outflow ranges between 100 and 1000 m^3/sec since construction of the dam in 1985 [9]. The lake does not freeze and can be classified as monomictic with a single turnover in November. The surface

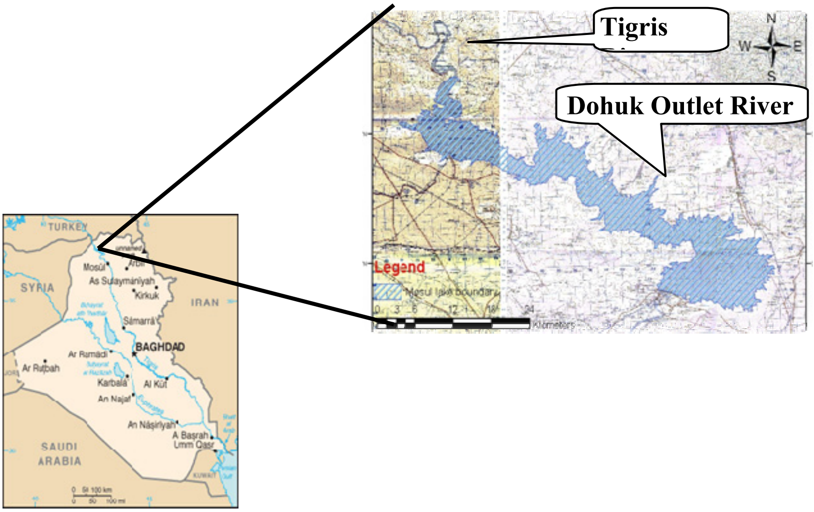

Figure 1: Location map of study area.

temperature of the lake drops to about 12°C during winter, and reaches 10°C at the bottom of the lake. Surface and bottom temperatures during the summer are on average 31°C and 14°C respectively. Therefore, thermal stratification persists throughout most of the year [10, 11]. The Mosul Dam Lake is, according to the overall water clarity, mesotrophic. Secchi disk measurement results a range between 6.1 and -2.5 m. The Dohuk river outlet, however, produced an anomalously low value of 0.9 m (eutrophic condition) [6] (fig. 2).

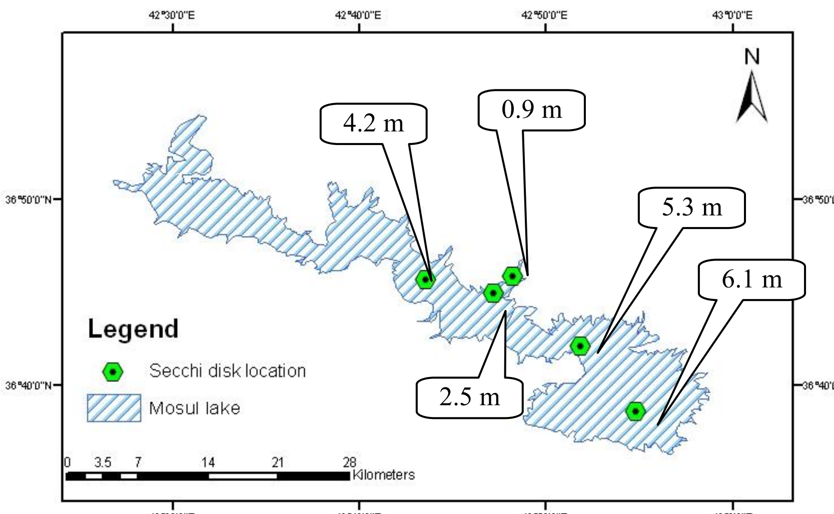

Figure 2: Map showing locations and Secchi disk values for the study area.

3 Materials and methods

3.1 Collection of water samples

Water samples were collected in February 2011 (26 samples from 12 locations) and July 2011 (19 samples from 11 locations (fig. 3)). Sampling was conducted at different depths using a Van Dorn water sampler and sterile 100 ml glass bottles. Bottled samples were stored inside a cool box for up to 6 hours before reaching the laboratory. Bacterial samples were transferred to the Research Center of Environment and Pollution Control at Mosul University in Iraq.

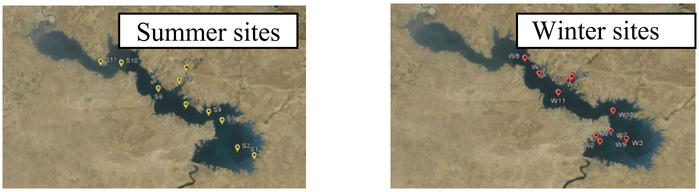

Figure 3: Locations of water samples.

Samples for (total inorganic carbon) TIC and (dissolved organic carbon) DOC were transferred to the geological department of TU Bergakademie Freiberg, Germany.

3.2 Water quality parameters

The Multi-Parameters Water Quality Sonde (YSI 6600 V2) and Multi Water Quality Checker (WTW Multi 3430) were used to measure pH and EC. NO_3, NO_2, and phosphorous were measured by means of a HACH Portable Colorimeter DR/890 in the field [13]. The total inorganic carbon (TIC) and dissolved organic carbon (DOC) were measured by liquiTOC II and liquiTOC. Measurement of DOC took place after filtering through 0.45 micrometer filters.

3.3 Heterotrophic bacteria analysis

Analysis of heterotrophic bacteria has been undertaken by an aliquot of the sample or by dilution several times to minimize the bacterial population to a number which can be counted and then transferred to a sterilized petri dish. Once in the petri dish, the sample is mixed with liquefied nutrient agar and incubated at 30–37°C for 24–48 hrs, according to the Standard Methods for the examination of water and waste water 2005 [14].

4 Results and discussion

4.1 Heterotrophic bacteria indicator

The frequency of heterotrophic counts is commonly used as an indicator of comprehensive microbiological quality [15]. These organisms can include bacteria, yeasts and molds, and can be found throughout the environment in both natural and treated water [16]. The heterotrophic plate count of water samples in all locations over two seasons were found to be higher than European guidelines for drinking water standards (100 cfu/ml at 22°C and 37 cfu/ml at 37°C, [17] (fig. 4)). The highest count of heterotrophic bacteria – during February – was 9000 cfu/ml. The highest count of heterotrophic bacteria – during July – was 210000 cfu/ml (fig. 4). Both were sampled close to the Dohuk outlet river (fig. 3). The difference between these values reaches more than 57%. This indicates that temperature is the dominant factor affecting bacterial growth [18], in addition to the increased agricultural activity adjacent to the lake.

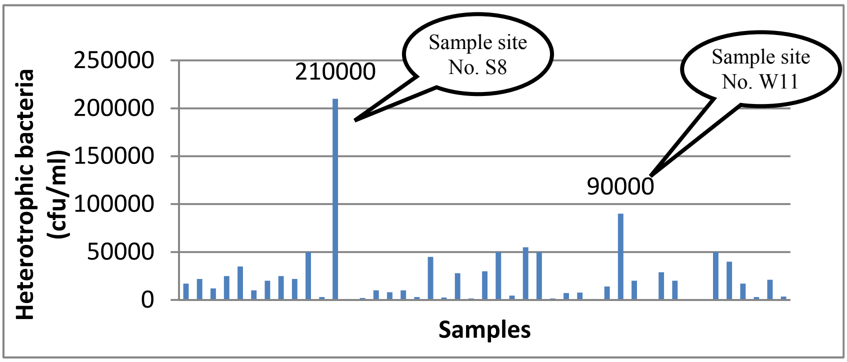

Figure 4: Heterotrophic bacteria values.

4.2 Seasonal analysis

In order to evaluate the relationship between heterotrophic bacteria and water quality parameters with the depth of lake during the winter and summer season, a simple regression analysis was done. The systematic regression analysis for winter samples shows a clear linear relation between heterotrophic bacteria and water quality parameters for samples located at depths of between 12 and 15 m with R^2 >0.7. Phosphorous has logarithmic relationship with the heterotrophic bacteria at a temperature of 10.9°C (fig. 5). The increase of heterotrophic bacteria parallels an increase of other water quality parameters within this area of the lake and has an inverse relationship with water depth. Figure 6 shows the location of this zone with temperature variations and dissolved oxygen values with depth. These samples are located within the thermocline zone, which is characterized by a rapid decrease in temperature and dissolved oxygen [10, 19]. The heterotrophic bacteria production in this zone is limited by water quality parameters. This is because organic debris tends to settle. At this zone, decomposition of DOC also changes whereby there is less algal production. As light and oxygen are reduced these nutrients increase [20, 21]. During the summer season the polynomial regression models show that the heterotrophic bacteria are related to other water quality parameters with R^2 >0.7. The bacterial demand for nutrients is apparent [22] for the samples located below depths of

40 m (fig. 7). The nutrients (NO_3, NO_2 and phosphorous) have a positive correlation with heterotrophic bacteria within the hypolimnion of the lake. Within the hypolimnion, the concentrations of phosphate species NO_2 and NO_3 increase during the stratification period due to biological decomposition of sedimented organic matter. Organisms utilize most of the nutrients in the upper layers of the lake [10, 23]. The hypolimnion layer shows a positive relation with DOC which is consistent with the results of Maki *et al.* [24]. There is also an inverse relation with pH, related to increasing anoxic bacterial production, which causes pH reduction [25, 26].

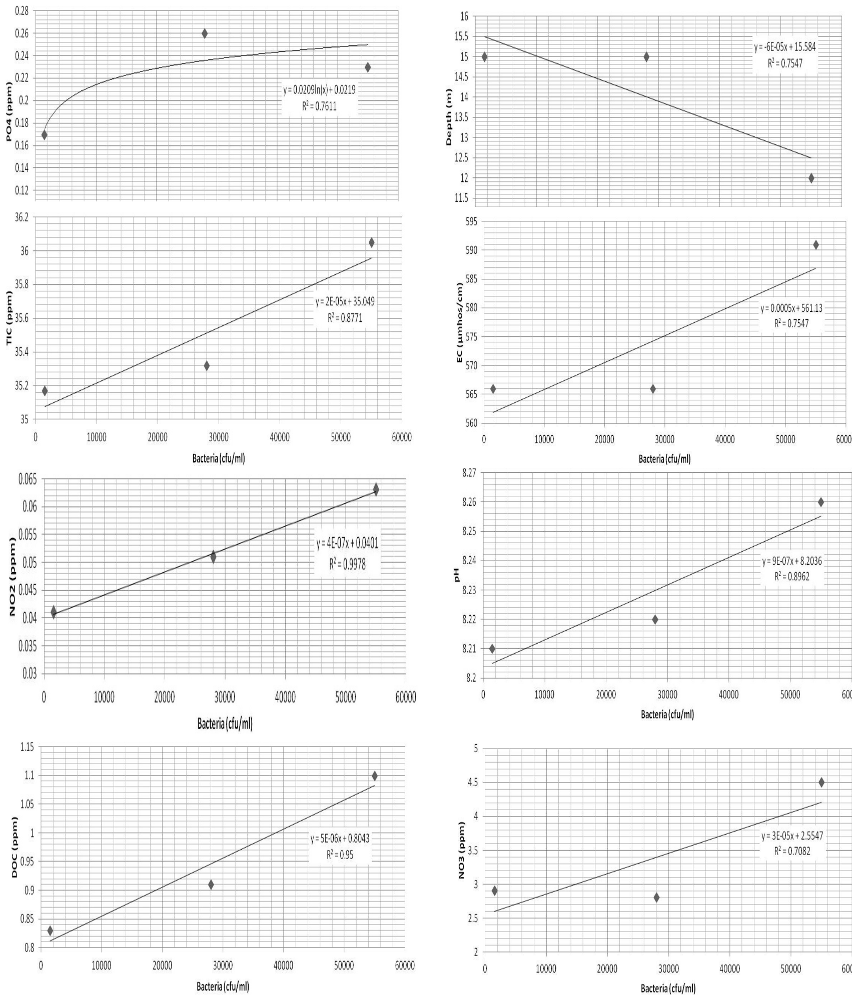

Figure 5: Regression analysis during winter for heterotrophic bacteria and other water quality parameters at 12–15 m depth.

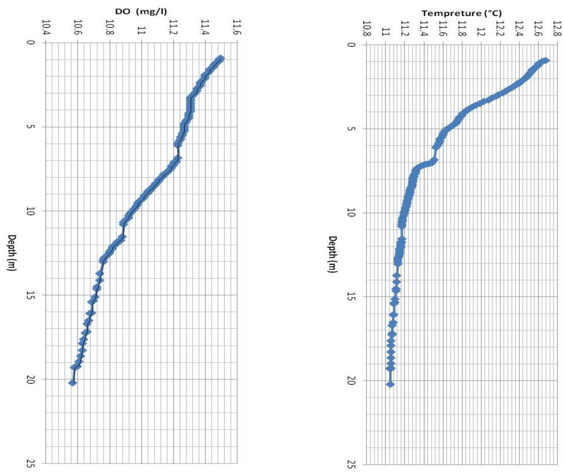

Figure 6: Variation of temperature and dissolved oxygen from the lake surface to 20 m depth during February 2011.

4.3 Seasonal analysis

ArcGIS 10 has been applied for results of lake bottom samples to show the spatial distribution of heterotrophic bacteria with water quality parameters for Mosul Dam Lake. The spatial interpolation technique by the inverse distance weighting (IDW) method was used for this simulation. This method is rather simple when compared with other methods of interpolation [27, 28]. Output grid cell values are estimated by defining or selecting a set of sample points. Cell values are determined using a linearly weighted combination of a set of sample points and controls. The significance of known points upon the interpolated values is based upon their distance from the output point, thereby generating a surface grid as well as thematic contour lines [29]. The spatial distribution for heterotrophic bacteria at shallow regions shows an increase of bacterial count toward the outlet of the Dohuk River correlated with an increase in NO_2, NO_3 and TIC (fig. 8). The relation between heterotrophic bacteria near the lake bottom and water quality parameters at shallow depths relates to the fact that near bottom layers are mixed by waves and currents [30]. The Tigris River enters the lake from the north and affects the Dohuk River outlet in the middle of the lake, in addition to influencing the fluctuation of lake water levels. The spatial distribution of heterotrophic bacteria at deeper regions responds to an increase in bacteria count toward the outlet of the Dohuk River, suggesting that the main source of bacterial pollution comes from the Dohuk River (fig. 9).

Figure 12 shows that the heterotrophic bacteria are closely related to water quality parameters, especially P, DOC, TIC, EC, and pH. These relations have been expressed by polynomial regression analysis, R^2 >0.6 (fig. 13). A multiple regression analysis (SPSS 11.5) was used to evaluate the environmental factors responsible for the spatial distribution of heterotrophic bacteria at the bottom of Mosul Dam Lake. Table 1 shows Pearson correlation matrix for heterotrophic

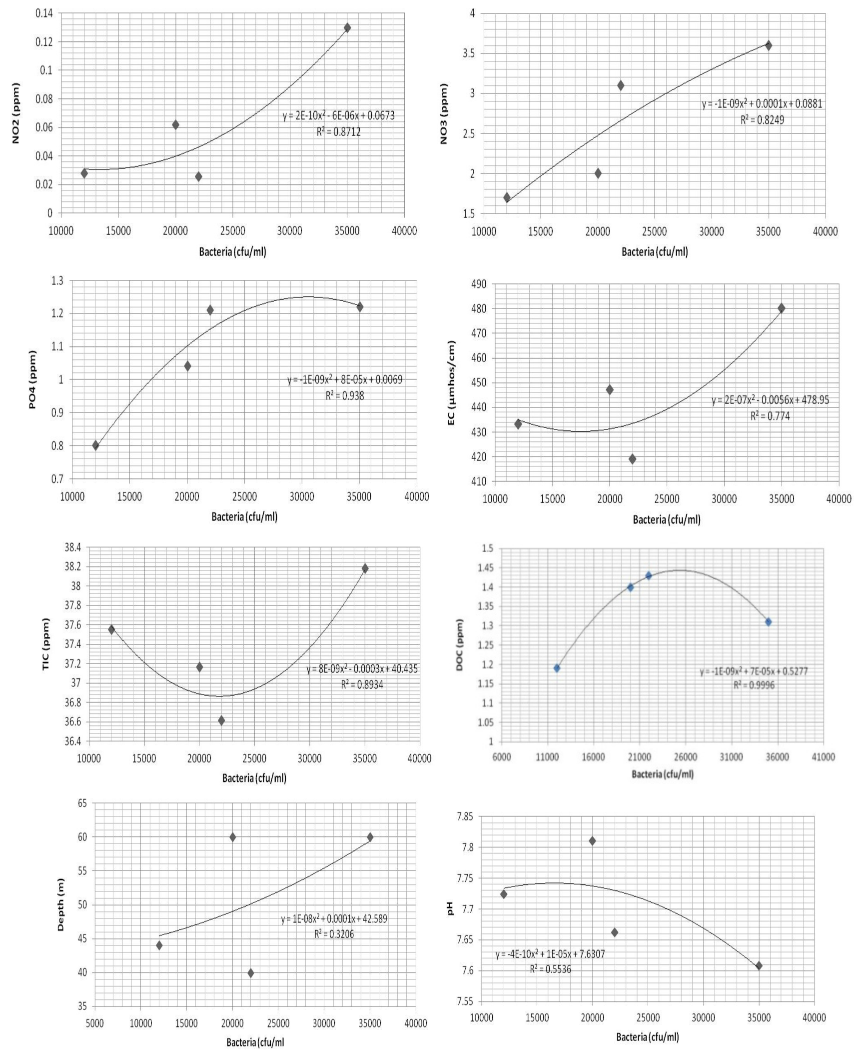

Figure 7: Regression analysis during summer for heterotrophic bacteria and other water quality parameters for samples which were taken from depths >40m.

bacteria (HB) and the environmental factors which are most associated with it. Correlation varied from EC(R=0.7) to P (R=0.914). The result of multiple regression analysis on the factors that influence HB (P, DOC, TIC, EC and pH) is significant ($\rho < 0.05$).

H.B = 495160.5+187.094 EC-67698.2pH + 18725.155DOC + 7919.126P - 1822.186 TIC.

From this equation we can identify quantitatively the effect of environmental parameters on the distribution and production of heterotrophic bacteria within the hypolimnion zone.

Table 1: Pearson correlation matrix for heterotrophic bacteria and DOC, TIC, pH, EC and PO4 for samples which are near the bottom at deep regions of the lake.

	H. B	EC	P	TIC	pH	DOC
H.B	1.000	-.700	.914	.824	-.883	.795
EC		1.000	-.893	-.726	.929	-.824
P			1.000	.853	-.952	.936
TIC			.	1.000	-.860	.720
pH					1.000	-.807
DOC						1.000

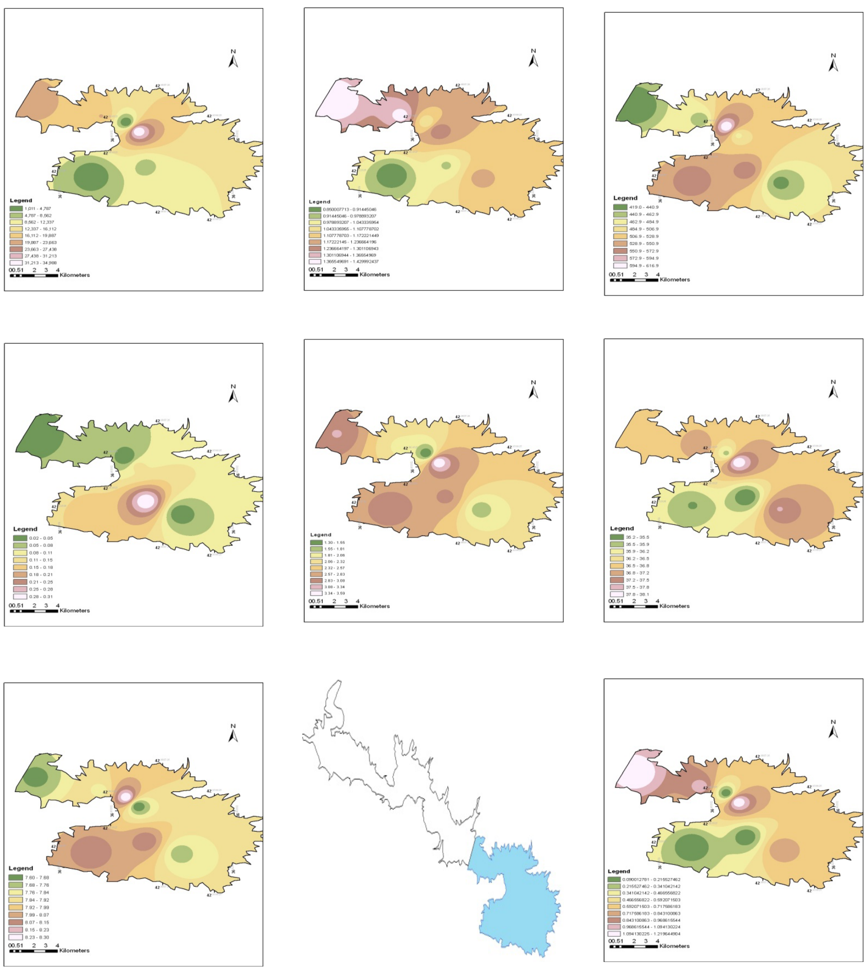

Figure 8: Spatial distribution for heterotrophic bacteria and water quality parameters for near-bottom samples at shallow regions of the lake.

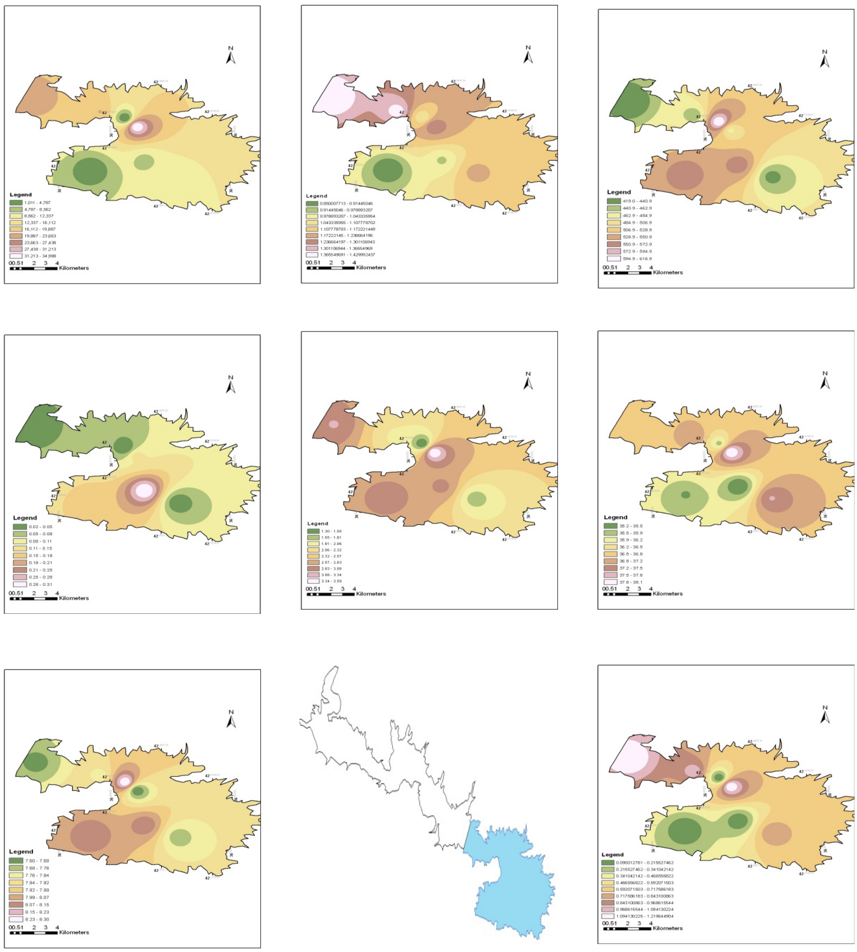

Figure 9: Spatial distribution for heterotrophic bacteria and water quality parameters for near-bottom samples at deeper regions of the lake.

5 Recommendation

Although the results presented in this work are based only on observational analysis over one year, they provide a picture of the water quality parameters and heterotrophic bacteria distribution of Mosul Dam Lake. Establishing a water treatment plant at the mouth of the River Dohuk would play an important role in maintaining the quality of the lake water. Increasing the number of samples and monitoring water quality throughout the year for different parts of the lake will give better constraints on the environmental situation of the lake and on how best to manage the lake in the future.

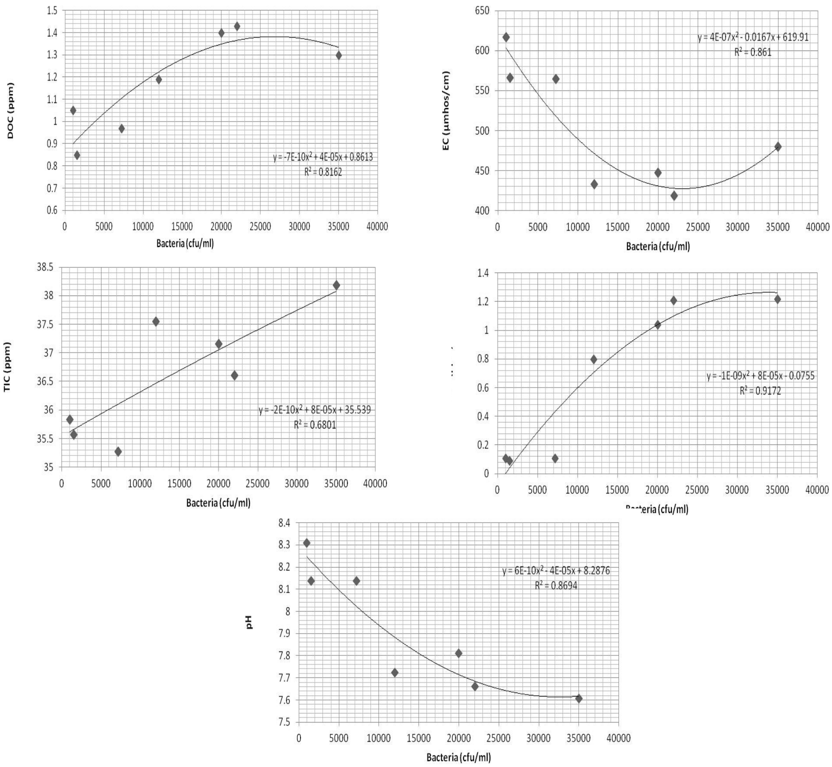

Figure 10: Regression analysis for heterotrophic bacteria and DOC, TIC, pH, EC and P for samples which are near bottom at deep regions of the lake.

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