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Nutrient Concentrations in Seven Irrigation Reservoirs (Lake Karla Watershed Thessaly Greece) †

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Abstract: The construction of irrigation reservoirs is a technical global solution for enhancing the agricultural production especially in arid and semi-arid areas. These water bodies are treated as technical projects and not as freshwater ecosystems. Eutrophication in new reservoirs becomes a hot issue in the world. The aim of the present study is to present the assessment of the key-eutrophication parameters in seven reservoirs located in the catchment area of Lake Karla. We suggest that the studied artificial ecosystems are sensitive in nutrients concentrations especially in the warm-dry period, influenced mainly by agricultural activities in the watershed.

Keywords: nutrients; eutrophication; reservoirs; Lake Karla watershed

1. Introduction

The increasing water demand to cover the needs of raising production and the climate change impacts make today the optimal use of water resources imperative, especially in semi-arid regions like Greece [1]. This optimal use is achieved through sustainable management of water resources targeting to their high quantitative and qualitative status. Irrigation reservoirs are actually, surface water resources and ought to be monitored as the Water Framework Directive—WFD (2000/60/EC) demands. Most of them host species supporting the local biodiversity acting as valuable ecosystems and are included in the Natura 2000 Network. This fact, in combination with the pressures that these systems receive, urges the need of monitoring program implementation.

Many scholar studies, around the world, have pointed out the important role that the irrigation reservoirs play and the urgent need of their water resources management [2–5]. The issues regarding the anthropogenic pressures on these systems affecting water quality are commonly the same around the world, especially in Mediterranean area [5–8]. Most of the irrigation reservoirs are located in rural basins and are supplied by the runoff water, which is characterizes by high values of nutrient concentrations. The last two facts have as a result the eutrophication which has undoubtedly been the most crucial threat for these water bodies [4,9–12].

The irrigation reservoirs of Lake Karla watershed belong to the Special Protection Zone GR1430007 “Reservoir area of former Lake Karla” of Natura 2000 Network. However, they have never been treated as protected aquatic ecosystems, until the implementation of a water quality monitoring program by the Management Body of Ecodevelopment Area of Ka.Ma.Ke.Ve. The main goal of environmental monitoring programs in the Natura 2000 sites of the Karla-Mavrovouniou-Kefalovrisou Velestinou Ecodevelopment Area is the assessment of their trophic status, throughout the analysis of spatial and temporal changes of key-eutrophication parameters such as nutrients concentrations. Thus, by detecting the impacts of the main threats and pressures imposed upon the protected area, the evaluation of the effectiveness of the implemented management practices and plans is achieved.

2. Materials and Methods

Lake Karla watershed of Eastern Thessaly has a total extent of 1.171 km^2 (Figure 1). The basin lies between the latitude of 39°20′56′ to 39°45′15′ N and the longitude of 22°26′10″ to 23°0′27″ E. The climate is typical Mediterranean. The average annual temperature ranges between 16–17 °C and the mean annual precipitation varies from about 500 to 700 mm [13]. According to the database of CORINE Land Cover 2000 for Greece [14], almost 68% of the basin surface is being cultivated, being one of the most productive agricultural regions of Greece. The major crops are cotton, wheat, alfa-alfa, corn, tobacco and orchards [15]. The main basin's water resources consumption occurs to cover the irrigation needs of these cultivations. These water resources originate primarily from Lake Karla groundwater system and secondarily form Pinios River and the surface runoff of the drainage basin.

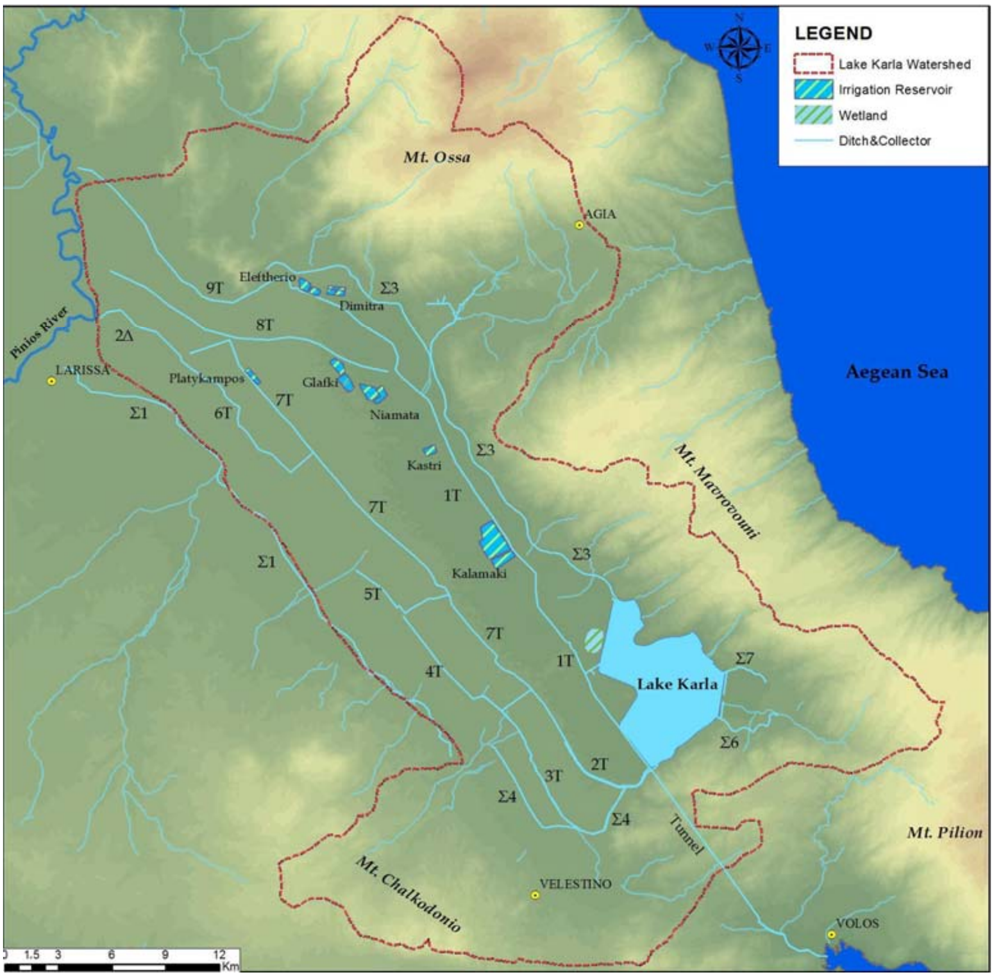


Figure 1. Orientation map of Lake Karla watershed indicates the irrigation reservoirs, the ditches and collectors and the Lake Karla.

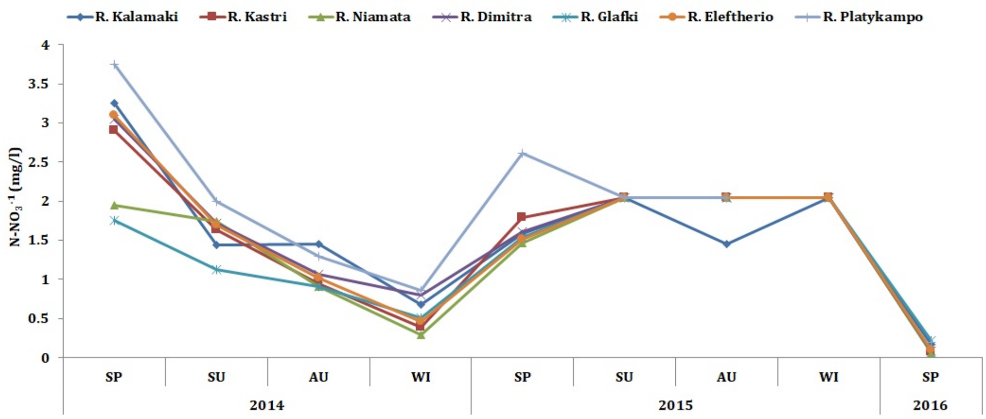
After the drainage of Lake Karla (1962), a surface water storage project took place consisting of seven irrigation reservoirs to satisfy both the intense agriculture of water demanding crops and flood control needs. These reservoirs are supplied by the surface runoff of the Lake Karla basin and the floodwaters of Pinios River [16].

Over the years, the area of Lake Karla watershed experienced radical changes of its land uses and today consists of the reservoir of Lake Karla and a series of smaller reservoirs, dams, canals and pipelines distributed over the southeastern area of Thessaly plain. These seven irrigation reservoirs (Table 1) were selected as studied sites and are characterized by their shallow depth, which is less than four meters. Regarding their surface, six of them have a less than 60 hectares extent, except the reservoir of Kalamaki, which has a 200 hectares surface area. Their volume ranges from 900,000 m^3 to 5,500,000 m^3. The reservoirs water supply period lasts from April until September. Water level data for all reservoirs were either unavailable or incomplete. Platykampos and Niamata reservoirs are partially or totally drained after the cultivation period (October–December). Total or partial drainage of aquatic ecosystems has a negative effect on water quality and does not coincide with sustainable management practices [17,18].

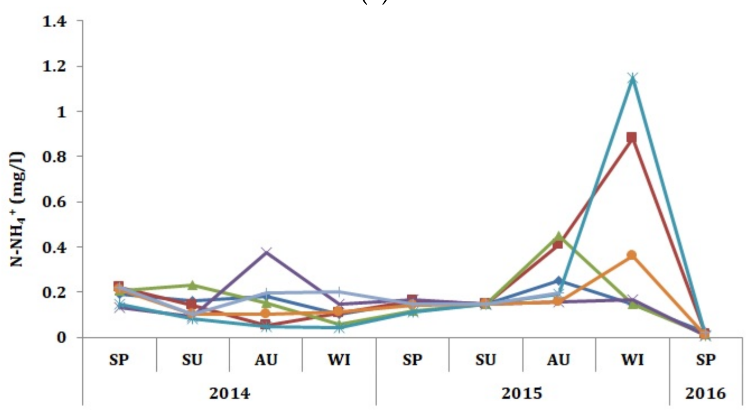
All the studied sites had a designated sampling point to ensure uniformity of sampling areas. Monthly water samples for nutrients were collected from the upper 50 cm of the water column of each reservoir during the period March 2014 to May 2016. These samples were analyzed for total phosphorus, nitrate-nitrogen and ammonia-nitrogen concentrations, using a HACH DR/3900 colorimeter nutrient test kit with detection limits of 0.05, 0.01, and 0.015 mg/L, respectively. Concentrations values were grouped seasonally since Platykampos and Niamata reservoirs were totally or partially drained during autumn and winter months. Annual, seasonal and spatial variations were tested by one-way ANOVA (effects: years, seasons, stations), followed by Tukey HSD post hoc. Relations between water quality parameters were tested by Pearson's correlation. Statistical analyses were performed with SPSS Statistics 20.

3. Results

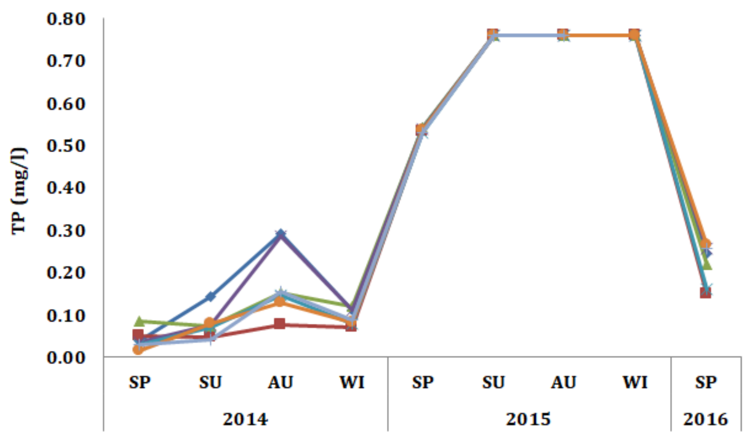
Water quality data are summarized in Table 1 and the seasonal variation of nutrient parameters is presented in Figure 2.



(**a**)



(**b**)



(**c**)

Figure 2. Seasonal variation of (**a**) Nitrite; (**b**) Ammonium and (**c**) Total phosphorus concentration in the seven studied irrigation reservoirs in the basin of Lake Karla during the sampling period (Spring 2014 until Spring 2016). SP: Spring, SU: Summer, AU: Autumn, WI: Winter.

Table 1. Descriptive statistics of nutrient concentrations for each reservoir during the sampling period 2014–2016. SE: standard error, min: minimum, Max: maximum.

Reservoir	NO_3–N (mg/L) Mean ± SE Min-Max	NH_4–N (mg/L) Mean ± SE Min-Max	TP (mg/L) Mean ± SE Min-Max
Kalamaki	1.5667 ± 0.2902	0.1511 ± 0.021	0.4056 ± 0.1003
	0.17–3.25	0.02–0.25	0.04–0.76
Kastri	1.54 ± 0.3006	0.2367 ± 0.0889	0.3567 ± 0.1123
	0.07–2.9	0.01–0.88	0.05–0.76
Niamata	1.3922 ± 0.2614	0.1694 ± 0.0416	0.3856 ± 0.1044
	0.06–2.04	0.01–0.45	0.07–0.76
Dimitra	1.6056 ± 0.2866	0.1583 ± 0.0324	0.3994 ± 0.1027
	0.09–3.05	0.01–0.38	0.04–0.76
Glafki	1.3511 ± 0.2322	0.2156 ± 0.1184	0.3667 ± 0.1095
	0.21–2.04	0.01–1.15	0.03–0.76
Eleftherio	1.5544 ± 0.3059	0.1511 ± 0.0319	0.3761 ± 0.1086
	0.10–3.10	0.01–0.36	0.02–0.76
Platykampo	1.8463 ± 0.3857	0.155 ± 0.0238	0.3288 ± 0.1098
	0.19–3.75	0.02–0.22	0.03–0.76

The seasonal variation of nitrate-nitrogen concentration differed significantly among years ($p < 0.05$, F = 13.63) and between reservoirs ($p < 0.05$, F = 2.788), and did not differ significantly between seasons ($p > 0.05$, F = 0.831). The lowest concentration of nitrate-nitrogen was observed in the reservoir of Niamata (0.06 mg/L) and the higher value was observed in the reservoir of Platykampos (3.75 mg/L). In all reservoirs, the higher concentrations of nitrate-nitrogen were recorded during spring and summer, while during the autumn and winter were the lower.

The seasonal variation of ammonium concentration differed significantly between years ($p < 0.05$, F = 6.468) and seasonally ($p < 0.05$, F = 2.774) and did not differ significantly between stations ($p > 0.05$, F = 0.311). Ammonium concentration seems to have higher concentrations in spring and summer at all reservoirs, with the exception of the winter of 2015. During the winter of 2015, the concentration ofammonium exhibited higher values in the reservoir of Glafki (1.15 mg/L) and the reservoir of Kastri (0.88 mg/L). Also, ammonium concentrations were positively correlated with nitrate-nitrogen (r = 0.353, $p < 0.01$) suggesting that these two processes are interrelated.

The seasonal variation of total phosphorus concentrations varied significantly between years ($p < 0.05$, F = 6.847) and between stations ($p < 0.05$, F = 5.516) and did not differ statistically significant seasonally ($p > 0.05$, F = 0.720). Concerning the concentration of total phosphorus, a standard seasonal variation was not distinguished, although significant differences of the mean values between the year 2014 and 2015 were recorded (Figure 3). During autumn and winter of 2014, total phosphorus concentration was low (<0.1 mg/L) for the reservoirs of Kastri, Glafki, Eleftherio and Platykampos, while for Kalamaki, Niamata and Dimitra reservoirs, the mean values ranged between 0.11 mg/L and 0.15 mg/L (Figure 2). After the summer of 2015 the mean values of TP concentration for all reservoirs ranged between 0.68 mg/L to 0.69 mg/L.

According to the results of the Pearson correlations (Table 2), a statistically strong positive correlation was found between the total phosphorus concentration and the ammonium ions (r = 0.375, $p < 0.01$). A statistically strong positive correlation was found between the concentration of ammonium ions with nitrate-nitrogen ions (r = 0.353, $p < 0.01$).

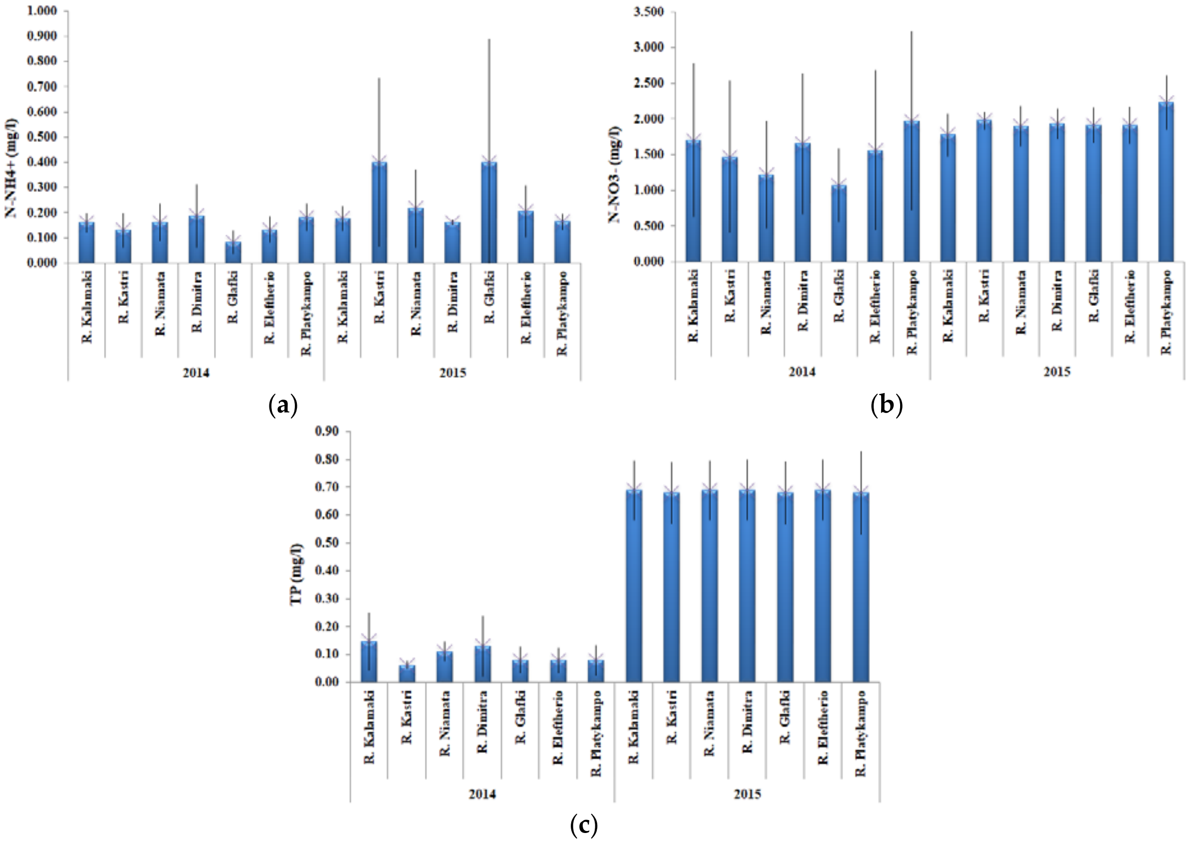


Figure 3. Bars represent mean values of nitrite, ammonium and total phosphorus concentrations at each reservoir during the sampling period. (**a**) nitrite concentrations; (**b**) ammonium concentrations; (**c**) total phosphorus concentrations.

Table 2. Pearson correlations between the nutrient variables measured during the current study in seven irrigation reservoirs of Thessaly plain (* = significance level, $p \leq 0.05$, ** = significance level, $p \leq 0.01$).

		TP	NH_4	NO_3
TP	Pearson Correlation	1	0.375 **	0.298 *
	Sig. (2-tailed)		0.003	0.019
	N		62	62
NH_4	Pearson Correlation		1	0.353 **
	Sig. (2-tailed)			0.005
	N			62
NO_3	Pearson Correlation			1
	Sig. (2-tailed)			
	N			

Increased concentrations of ammonium ions are often observed in eutrophic and hypertrophic lakes which are characterized by high total phosphorus concentrations. In fact, nitrate nitrate-nitrogen concentration variation in eutrophic lakes is more complex compared to ammonium, as in surface lake waters seem to rise accordingly to the lake trophic status [19]. Even more, nitrate concentrations can affect phosphate release from anoxic sediments, maintaining oxidized Fe ions and stimulating the total microbial activity [20]. Overall, the complexity of internal and external biogeochemical processes in rural environments which affects the physicochemical characteristics of irrigation reservoirs often restricts the nutrient concentration behavior assessment.

4. Discussion and Conclusions

Eutrophication is the main water quality problem in reservoirs. They have larger inputs of nutrients and stronger water-level fluctuations than natural lakes, leading to eutrophication and shifts in their biological communities [21,22]. The attainable ecological potential of a reservoir will greatly depend on (among other factors) the quality and the quantity of the input water, which will greatly depend on its position along the river [23] and on the influences from the catchment. Although the studied reservoirs there are not included at the national inventory, their monitoring is quite important since they are connected to management activities taking place at catchment level.

The behavior of nitrate and ammonium concentrations determines the lake trophic state [22]. Nitrate is one of the most important indicators of water pollution which represents the highest oxidized form of nitrogen. In rural basins, the most important nitrogen input derives from the use of fertilizers in agriculture [24–28]. The increase of nitrate in some reservoirs of this study is probably due to a much longer retention time and may be more influenced by irregularities in application of fertilizers. The highest $NH4^{+}$-N concentrations were recorded in April probably due to the intense use of fertilizers, as spring is the cultivation period along Pinios River.

The River Basin District of Thessaly Management Plan has proposed a limited value as a boundary between good/moderate status for physicochemical data on rivers, lake, transitional and coastal water bodies, which varies between 25 mg/L, 1 mg/L and 0.2 mg/L respectively. Comparing the results of this research with the boundaries of the Approved Management Plan, the TP concentrations exceeded the recommended value of phosphorus concentration in all seven reservoirs during 2015 and in the reservoir Dimitra and Kalamaki in autumn 2014. The mean concentration of ammonium in the reservoir of Kastri and Glafki, during 2015, exceeded the recommended limit, which is less than 0.2 mg/L for the welfare of fish (cyprinids), according to the European Directive 2006/44. Usually, high concentrations of ammonium indicate pollution due to waste or agricultural fertilizers [22]. The mean concentration of ammonium in the study reservoirs did not exceed the recommended value of ammonium according to the River Basin District of Thessaly Management Plan, which has integrated the nutrient threshold values set by the Water Framework Directive 2000/60/EC.

However, apart from TP, in order to define an irrigation reservoir trophic status, additional data such as chlorophyll a concentration and Secchi disc measurements, are needed [21] which were not available during this study. Alternative, at the moment, the determination of an inland water body ecological status could be achieved by the system proposed by by the European Program ECOFRAME which requires geographic criteria and TN, TP, Ph and Secchi disc depth Data [29].

Considering the above, a continuation and intensification of the Reservoirs Monitoring Program is necessary, as well as the addition of more physicochemical and ecological parameters such as eutrophication and biodiversity indexes. Furthermore, a minimum ecological water level has to be defined to avoid the complete or partial drainage of the reservoirs.

Author Contributions: I.K. conceived and designed the Monitoring Programme; I.V. and M.C. performed the sampling and the laboratory analysis; M.C. analyzed the data; P.S., M.C. and I.V. wrote the paper.

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Conflicts of Interest: The authors declare no conflicts of interest.

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