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ORIGINAL ARTICLE

Relationships Among Land Use Patterns, Hydromorphological Features and Physicochemical Parameters of Surface Waters: WFD Lake Monitoring in Greece

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Abstract The national monitoring network of waters in Greece, in the context of Water Framework Directive (WFD), comprises 50 lake water bodies, both natural and artificial. The aims of the study are: (i) to present the pressures resulting from land cover and population density at river basin level; and (ii) to link catchment area features with physicochemical results from the first period of WFD monitoring. Land cover, population data in the catchment and physicochemical parameters were the main variables used in order to assess the lakes of the Greek WFD monitoring network. Intensive agriculture and urbanization, described as population density, proved to be the main pressure of severe impacted lakes as they were both highly associated with total phosphorus. Principal Components Analysis was used to position the Greek lakes along physical and chemical attributes, such as secchi depth, total phosphorus and ion concentrations and separate them according to their water quality. Clear reservoirs and natural lakes with high secchi depth were separated from more impacted ones with low secchi depth revealing a gradient of eutrophication, the most crucial anthropogenic pressure in Greece and in the Mediterranean area. The sustainable management of Greek lakes requires mitigation measures at a catchment scale, in order to regulate land uses, as well as site specific measures when needed.

Keywords Greek lakes · Land uses · Water quality · WFD · Monitoring

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1 Introduction

Several studies have shown the influence of catchment characteristics and changes in land uses to water quality and integrity of ecosystems downstream (EEA 2012; Liu et al. 2015; Soranno et al. 2015). According to Nõges (2009), nutrient inputs are profoundly affected by catchment and lake area through surface and groundwater drainage, while nutrient retention, a fundamental property of every aquatic ecosystem, is linked to its geomorphological, hydrological, edaphic and biotic characteristics (Hansson et al. 2005). To address this issue, the Water Framework Directive (WFD) provides for management planning at river basin level. In this context, it uses hydromorphological, physicochemical and biological information to assess the ecological status of surface waters and thus, the success of measures taken to protect and, where necessary, restore aquatic ecosystems (EC 2000; Hering et al. 2010; Moe et al. 2013; Tsakiris 2015). In applying WFD provisions, land cover and population density are included in the pressure criteria that separate impacted from non-impacted lakes (Pahissa et al. 2015).

In Greece, catchment areas have undergone substantial agricultural, industrial, and urban transformation over the recent years (Kagalou 2010). Moreover, the complex geomorphology of the country, the uneven distribution of precipitation and different regional demands for irrigation and drinking water are some of the characteristics that affect hydromorphological and physicochemical features of Greek lakes (Zacharias et al. 2002; Alexakis et al. 2016); this in turn strongly governs various ecosystem functions (Schindler and Scheuerell 2002). Furthermore, intensive agriculture activities, domestic and industrial inflows have changed the surface water distribution and use (Skoulikidis et al. 1998).

These compelling land cover changes have been reported from various Greek lakes resulting in dramatic water quality degradation (Papastergiadou et al. 2007; Papastergiadou et al. 2008; Stefanidis et al. 2016). Their impacts are obvious not only on a local scale, but also on a much larger scale in Mediterranean-climate areas, where the need for integrated water resources management is already discussed (Latinopoulos et al. 2016). This holistic approach ensures that more than one strategies are used to achieve the objectives of WFD for environmental protection.

The national monitoring network for lakes in Greece has been operational since 2012 (JMD 140384/2011), collecting data of biological, physicochemical and hydromorphological variables. The establishment of long term data series will not only set the base for the assessment of water quality and trends of Greek lake ecosystems, but also serves to establish the link with existing pressures. As a result, appropriate mitigation measures can be taken at the river basin scale, as the WFD implementation scheme suggests. The aims of the study are: (i) to present the pressures resulting from land cover and population density at river basin level; (ii) to link catchment area features with physicochemical results from the first period of WFD monitoring.

2 Materials and Methods

2.1 Study Area and Data Sets

The Greek National Water Monitoring Network (JMD 140384/2011) comprises 50 lake water bodies, both natural and man-made reservoirs. Most water bodies have one sampling station each, except transboundary lakes Megali Prespa, Mikri Prespa and Doirani, which have two sampling stations each (Fig. 1). Fifty-three stations have been established in total, 27 of which

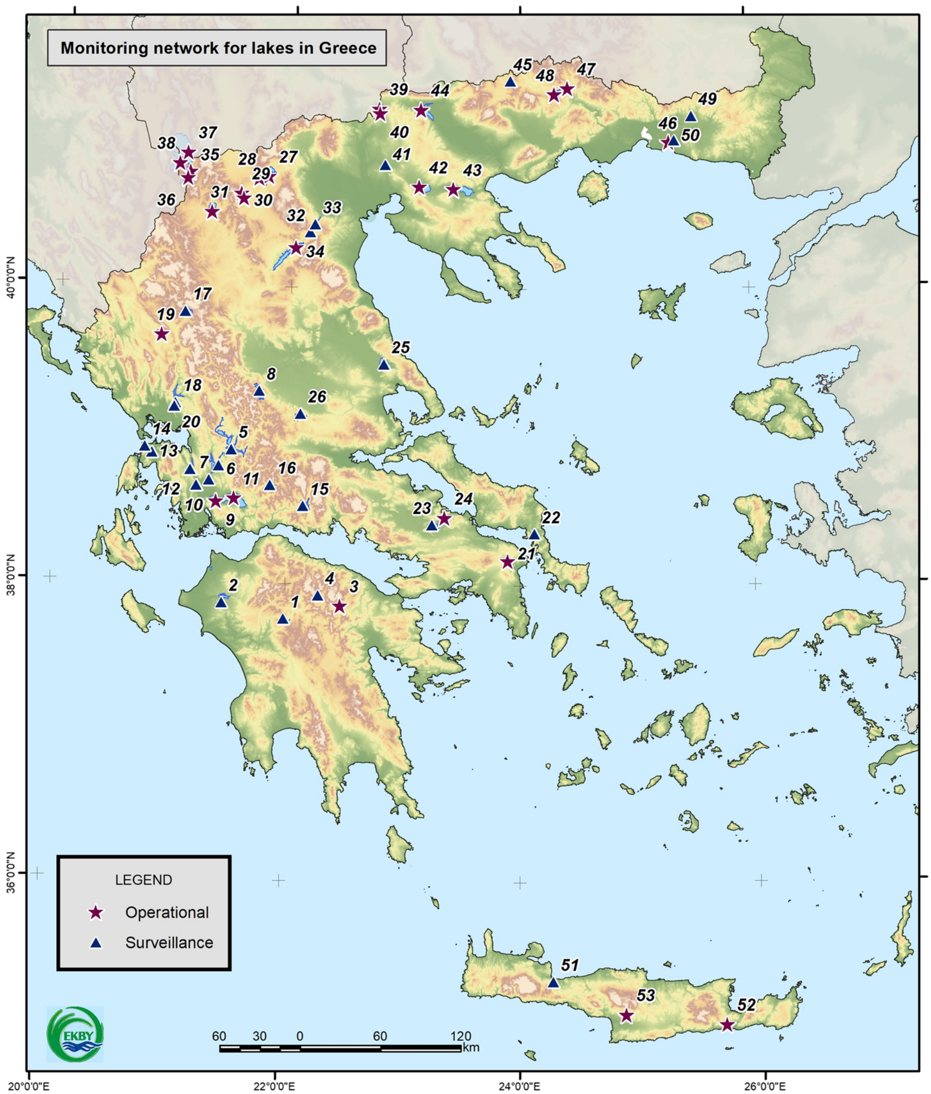

Fig. 1 Monitoring network for lakes under operational monitoring (stars) or surveillance monitoring (triangles) in Greece. Reservoirs: (1) T.L. Ladona, (2) T.L. Pineiou, (4) T.L. Feneou, (5) T.L. Kremaston, (6) T.L. Kastrakiou, (7) T.L. Stratou, (8) T.L. Tavropou, (15) T.L. Mornou, (16) T.L. Evinou, (17) T.L. Pigon Aoou, (18) T.L. Pournariou, (20) T.L. Pournariou II, (21) T.L. Marathona, (25) T.L. Karlas, (26) T.L. Smokovou, (32) T.L. Sfikias, (33) T.L. Asomaton, (34) T.L. Polyfytou, 44) T.L. Kerkini, (45) T.L. Leukogeion, (47) T.L. Platanovrysis, (48) T.L. Thisavrou, (49) T.L. Gratinis, (50) T.L. N. Adrianis, (52) T.L. Bramianou, (53) T.L. Faneromenis. Natural Lakes: (3) Stymfalia, (9) Lysimacheia, (10) Ozeros, (11) Trichonida, (12) Amvrakia, (13) Voulkaria, (14) Saltini, (19) Pamvotida, (22) Dystos, (23) Yliki, (24) Paralimni, (27) Vegoritida, (28) Petron, (29) Zazari, (30) Cheimaditida, (31) Kastorias, (35) Mikri Prespa A, (36) Mikri Prespa B, (37) Megali Prespa A, (38) Megali Prespa B, (39) Doirani 1, (40) Doirani 2, (41) Pikrolimni, (42) Koroneia, (43) Volvi, (46) Ismarida, (51) Kourna

are subject to surveillance monitoring and 26 to operational. The main hydrological and morphological features of the lakes included in the analysis are presented in Table 1. Following the WFD requirements, the surface area varies from 0.5 km^2 for the smallest one (Feneos reservoir) to 274 km^2 (transboundary Lake Megali Prespa). The mean depth

Table 1 Morphological features of Greek lakes

Lake	Catchment area (km^2)	Surface area (km^2)	Mean depth (m)	Lake volume (hm^3)
Amvrakia	121.10	12.69	23.73	291.80
Cheimaditida	35.09	9.12	1.01	11.35
Doirani	354.03	32.37	4.54	147.032
Dystos	57.46	–	–	–
Ismarida	358.76	2.01	0.90	1.81
Kastoria	314.99	31.01	3.72	115.52
Kerkini	11,866.49	55.77	2.19	123.10
Koroneia	781.38	–	–	–
Kourna	10.78	0.60	15.00	7.50
Lysimacheia	254.32	13.04	3.51	45.81
Megali Prespa	1147.70	274.00	17.00	4800.00
Mikri Prespa	268.08	46.60	3.95	184.13
Ozeros	57.41	10.48	3.80	38.84
Pamvotida	528.79	22.80	5.48	115.60
Paralimni	74.50	10.47	4.94	51.86
Petron	219.24	11.97	3.14	36.54
Pikrolimni	40.62	6.67	2.07	13.79
Saltini	13.05	–	–	–
Stymfalia	216.42	–	–	–
T.L.Adrianis	6.63	–	–	0.95
T.L.Asomaton	67.91	2.46	20.79	51.48
T.L.Bramianon	26.41	0.74	10.06	7.41
T.L.Evinou	352.91	3.07	34.86	107.01
T.L.Faneromenis	90.94	–	–	–
T.L.Feneou	16.67	0.46	10.48	4.87
T.L.Gratinis	68.41	0.76	13.80	10.56
T.L.Karlas	1662.72	29.44	0.90	26.53
T.L.Kastrakiou	541.55	25.51	33.17	798.69
T.L.Kremaston	3567.81	70.46	47.74	3782.88
T.L.Ladona	767.26	–	–	29.14
T.L.Leukogeion	53.04	1.04	7.6	7.9
T.L.Marathona	118.29	2.19	15.88	34.79
T.L.Mornou	584.08	17.73	39.10	693.31
T.L.Pigon Aoou	86.96	11.45	20.85	238.73
T.L.Pineiou	705.18	17.93	15.00	265.60
T.L.Platanovrysis	399.57	3.00	26.42	67.61
T.L.Polyfytou	5518.65	62.86	22.22	1617.12
T.L.Pournariou	1809.67	19.03	29.14	554.56
T.L.Pournariou II	6.55	0.55	11.82	6.50
T.L.Sfikias	172.91	3.95	23.22	90.17
T.L.Smokovou	368.61	–	–	–
T.L.Stratou	225.92	7.03	9.65	71.78
T.L.Tavropou	167.01	20.88	14.70	303.50
T.L.Thisavrou	4246.43	13.11	38.37	509.66
Trichonida	401.86	93.25	29.48	2748.78
Vegoritida	1791.55	47.39	26.13	1222.24
Volvi	1282.74	72.94	12.54	914.42
Voulkaria	74.43	7.91	0.95	7.53
Yliki	2403.31	21.60	20.89	451.28
Zazari	99.29	3.02	4.74	12.05

varies from 0.9 m (Lake Ismarida and Karla reservoir) to 46.7 m (Kremasta reservoir). Pournari II reservoir has the smallest catchment area (17 km^2). Lake volume is also presented in the table, with Megali Prespa having the highest value (4800 hm^3) and Adriani reservoir the smallest one (0.95 hm^3).

Physicochemical features were measured seasonally and each month from May to October. Samples were taken from the euphotic zone (2.5 x secchi depth). In particular: Transparency was measured with a secchi disc. Temperature, pH, oxygen, conductivity and total dissolved solids were measured with portable meters (ThermoScientific instruments). Filtrations for chlorophyll *a* measurements were carried out through Whatman GF/F glass-fiber filters and chlorophyll *a* was estimated using standard methods (APHA 2012). Analyses for Na^+, K^+, Cl^- and SO_4^{2-} were carried out with the use of Ion Chromatography (EN Standard 1999, 2009 modified). Analyses of total phosphorus (TP) were carried out in unfiltered water using the ascorbic method following persulfate digestion (APHA 2012). Data used for this study were taken from samplings carried out in 2015.

The 2012 national Corine Land Cover (CLC) spatial datasets from Greece, Albania, FYROM, Bulgaria and Serbia were downloaded from the Copernicus Land Monitoring Service: http://land.copernicus.eu/pan-european/corine-land-cover. Lake catchment areas were superimposed on CLC spatial datasets. Categories of CLC in the catchment areas were grouped as follows: Artificial land use (ALU), CLC code Class 1; Intensive agriculture (IA), CLC codes 2.1, 2.2, 2.41, 2.4.2; Natural and semi-natural land use (NASN), CLC codes 3.1.1, 3.1.2, 3.1.3, 3.2, 3.3, 4 and 5.

Population density was calculated as inhabitants per square kilometer (inhabitants/km^2) in the catchment areas, using data from the resident population census of 2011 from the Hellenic Statistical Service. Morphological parameters for transboundary lakes were estimated including data from sharing countries. Population data for the transboundary catchments of Kerkini and Thisavros were retrieved from the web site of the international network of water environment centers for the Balkans (http://www.inweb.gr) and population data for transboundary lakes Doirani and Megali Prespa were obtained from Katsavouni and Petkovski (2004) and Mantziou (2014), respectively.

2.2 Statistical Analyses

Data analyses were performed only in stations sampled for at least two months, from May to October. Physicochemical data from very shallow natural lakes Koroneia, Saltini, Pikrolimni, Stymfalia and Dystos were not included, due to either outlier values or lack of data caused by drought. Values below the quantification limit were replaced with the value of quantification. Variables were tested for skewness and log transformed when needed. Pearson's correlation analysis was conducted in order to elucidate possible relationships between parameters. Principal Component Analysis (PCA) was used to interpret the major patterns of variation within the data and ordinate the lakes with respect to selected physicochemical variables. Statistical analyses were conducted using R statistical software (R Core Team 2014). Land cover and population density graphs were made in excel software.

3 Results

Among natural lakes, intensive agriculture seemed to be a considerable land use (mean value around 32%) within their catchments (Fig. 2). The highest value was observed in the catchment of Pikrolimni (82.90%) and the lowest at Kourna catchment (<3%). The land covers of the catchment areas of reservoirs are shown in Fig. 3. They are mostly covered by natural and semi-natural areas (mean value ~71%). Specifically, the catchments of Feneos,

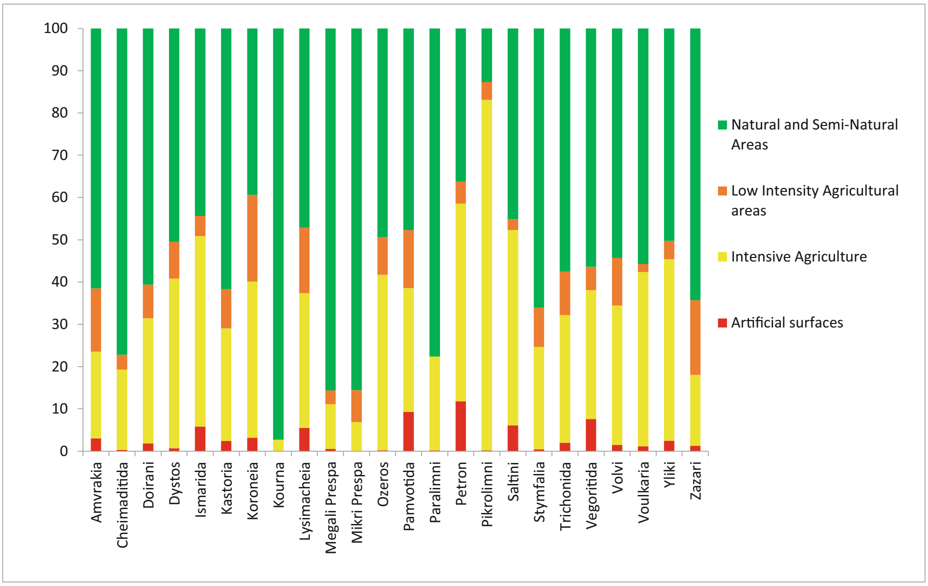

Fig. 2 Land cover of Greek natural lakes catchment areas

Gratini, Piges Aoou, Leukogeia and Platanovrysi reservoirs are covered with natural and semi-natural areas by more than 95%. Notable exceptions are the Adriani reservoir, located at lowlands and surrounded by agricultural areas, Pournari II, Karla and Bramiana reservoirs. The latter is located on Crete and constructed mainly for irrigation purposes. The Pineios reservoir, located at the lowlands in the Peloponnese and Marathonas reservoir near Athens are also covered by agricultural areas (both intensive and low intensity) by more than 55% and around 45% of their catchment area, respectively. In the latter artificial land use makes up more than 10% of the catchment surface.

As Fig. 4 shows, Lysimacheia and Pamvotida are the two natural lakes with the highest population density (~244 and 235 inhabitants/km^2, respectively), followed by Ismarida (~170 inhabitants/km^2). Pamvotida is the shallow urban lake of Ioannina city and the other two lakes, Lysimacheia and Imsarida, are located next to major towns, Agrinion and Komotini, respectively, accommodating other settlements as well, in extended agricultural areas. The catchment area of the urban Lake Kastoria has relatively high values of population density as well (>80 inhabitants/km^2). In contrast, the catchments of lakes Voulkaria, Kourna, Cheimaditida and Saltini do not have settlements at all, whereas those of lakes Paralimni, Pikrolimni and Mikri Prespa exhibit the lowest values of population density (<10 inhabitants/km^2). The population density of the catchment areas of reservoirs is generally low (<35 inhabitants/km^2) with the marked exceptions of Marathonas and Karla reservoirs (Fig. 5). The former is located at the outskirts of Athens (~180 inhabitants/km^2) and the latter is located at the northern end of Magnesia regional unit next to the city of Volos (~100 inhabitants/km^2).

Boxplots in Fig. 6 show TP mean data plotted against intensive agriculture and population density groups. Intensive agriculture activities affirmed their high impact on TP loading in water bodies, both reservoirs and natural lakes. There were three groups of intensive agriculture categories with distinct total phosphorus median values. The same pattern was evident in population density groups which showed the same positive relationship with TP, as expected.

With regard to the physicochemical aspects, Tables 2 and 3 present the mean values of the physicochemical parameters which were used in PCA analysis in natural lakes and reservoirs.

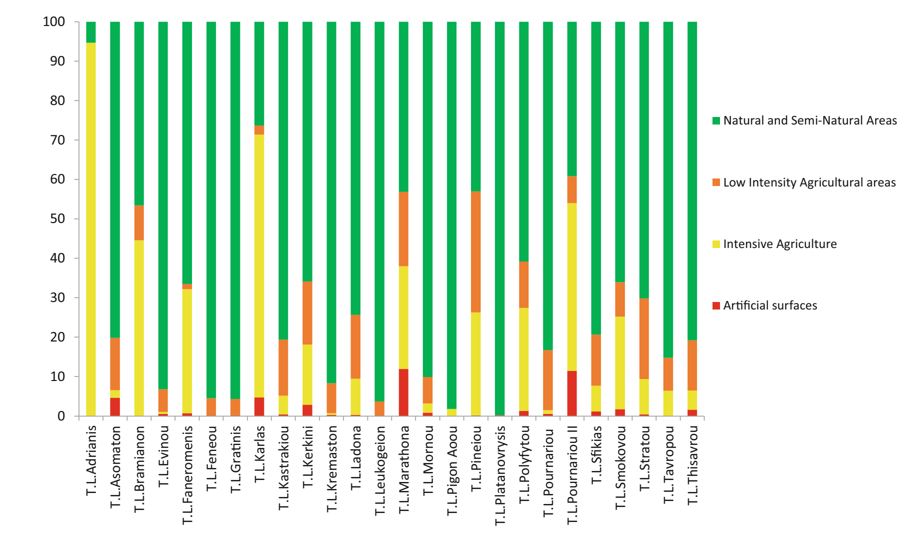

Fig. 3 Land cover of Greek reservoirs catchment areas

In natural lakes, PCA revealed the ordination of Greek lakes in two PCs, with eigenvalues above 1 ($\lambda_1 = 2.13$ and $\lambda_2 = 2.13$, respectively) which explained 84.04% of the data total variance (Fig. 7a). The variables with the highest scores in the first axis were electrical conductivity, sodium and chloride ions, and accounted for 56.81% of the total variance. The second axis was highly associated with secchi depth and TP, revealing a clear gradient from deep, clear water bodies to shallow more impacted ones.

The same gradient was evident in reservoirs, as TP and secchi depth were the principal drivers of the second axis, with the former being now the strongest one (Fig. 7b). The high score of TP (>0.6) grouped together the clear reservoirs in the bottom left quadrat of the plot. The most influential variables of axis 1 explained 50% of the total variance. These parameters, electrical conductivity, sulphate and sodium ions separated the two reservoirs from Crete, T.L.

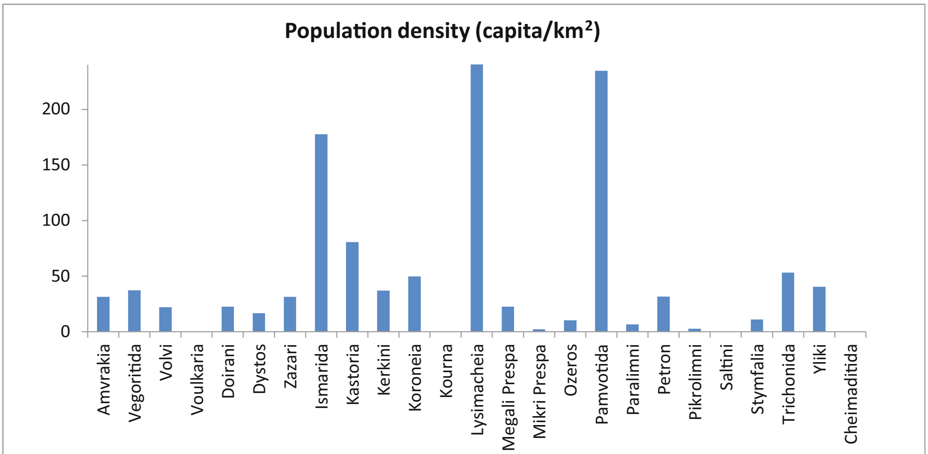

Fig. 4 Population density of natural lakes catchment areas

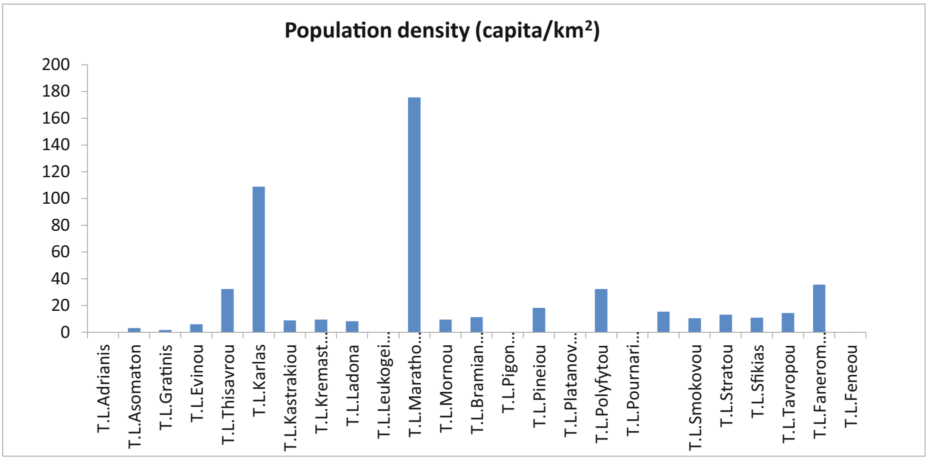

Fig. 5 Population density of reservoir catchment areas

Faneromenis and T.L. Bramianon, from the others. One reservoir, T.L. Pournariou, is also isolated from the others, as it is highly associated with calcium ions. The two axes, with eigenvalues above 1 ($\lambda_1 = 1.72$ and $\lambda_2 = 1.39$, respectively), captured 81.94% of total variance. All the principal components loadings for the selected variables are given in Table 4.

4 Discussion

The Water Framework Directive (WFD) focuses on the relation between anthropogenic pressures at river basin level and ecological status of surface waters, as it is widely accepted that changes in land use impact on water quality (EEA 2012; Soranno et al. 2015). According to the findings of our study, land cover and population density of the catchments play an important role in the physicochemical features of lakes in Greece, as boxplots revealed a pattern of high population densities and intensive agriculture related to high TP values. The use of fertilizers for agriculture purposes and the undeniable urbanization of a growing population seem to be the major sources of phosphorus and nitrogen loadings to aquatic

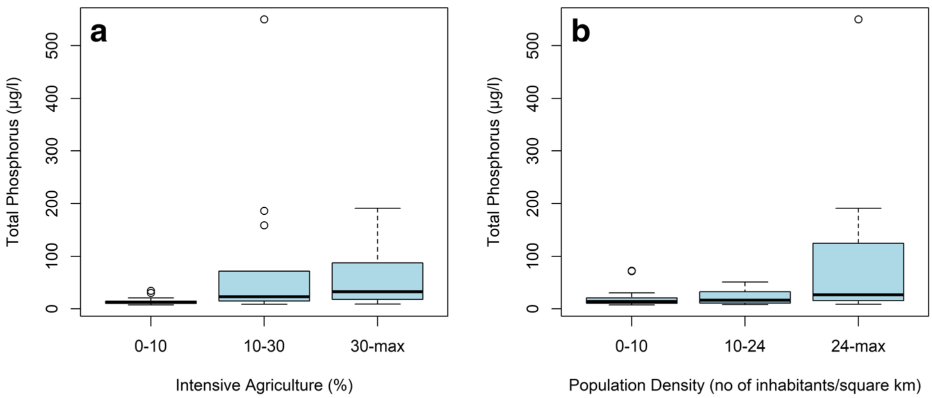

Fig. 6 Boxplots of Intensive Agriculture (**a**) and Population Density (**b**) groups in relation to TP

Table 2 Mean values of physicochemical parameters of Greek natural lakes

Lake	TP (μg/L)	EC (μS/cm)	SD (m)	Na^+ (mg/L)	K^+ (mg/L)	Ca^{2+} (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)
Amvrakia	13.14	1130.54	6.44	47.31	3.42	142.07	63.36	378.89
Cheimaditida	71.68	375.75	1.12	35.08	8.72	24.63	16.05	16.48
Doirani	36.34	847.73	2.27	78.02	16.24	32.06	48.19	124.28
Kastoria	42.55	311.50	2.06	14.86	5.14	21.90	9.48	11.72
Kourna	7.39	1520.25	6.33	162.94	8.98	112.05	169.12	260.18
Lysimacheia	85.26	408.20	0.78	18.76	3.32	26.48	15.64	17.14
Megali Prespa	22.89	248.19	5.37	6.52	3.54	22.10	7.49	10.06
Mikri Prespa	30.28	293.35	1.92	7.00	7.59	25.99	4.55	4.57
Ozeros	32.39	270.53	1.48	12.77	3.13	28.13	13.33	13.71
Pamvotida	186.29	310.48	0.54	19.94	3.55	22.05	23.76	9.55
Paralimni	13.50	495.18	2.90	39.93	2.31	28.58	44.09	19.18
Petron	90.20	805.50	0.39	73.08	14.55	36.67	64.37	177.96
Trichonida	12.46	379.13	10.54	16.96	3.36	24.81	18.23	21.86
Vegoritida	26.66	662.50	2.59	39.21	6.32	31.38	32.01	92.20
Volvi	51.04	1036.62	1.53	160.76	10.60	18.30	114.74	60.74
Voulkaria	72.86	1154.60	0.30	182.24	13.23	34.89	308.39	41.92
Yliki	18.75	323.50	3.38	15.87	3.11	25.29	15.27	36.65
Zazari	550.33	180.96	0.97	9.55	3.50	17.19	5.53	11.01

ecosystems (Carpenter et al. 1998; Withers et al. 2014). Land use change is the most severe force driving alterations and deterioration of aquatic ecosystems. Its impacts are associated with eutrophication (Soranno et al. 2015), gradual conversions (e.g., habitat alterations, invasion of alien species) and even total modifications of ecosystem functions (e.g., turbid conditions, food web changes) (Moss 1998; Zogaris et al. 2009). Stefanidis and Papastergiadou (2012) suggested that the size of the catchment area might contribute to the

Table 3 Mean values of physicochemical parameters of Greek reservoirs

Lake	TP (μg/L)	EC (μS/cm)	SD (m)	Na^+ (mg/L)	Ca^{2+} (mg/L)	SO_4^{2-} (mg/L)
T.L.Asomaton	20.44	382.48	4.38	8.05	32.12	22.80
T.L.Bramianon	10.89	1305.67	1.57	165.54	54.86	109.77
T.L.Faneromenis	17.43	466.77	1.23	32.55	27.61	209.15
T.L.Feneou	11.08	339.10	8.75	3.17	32.36	16.63
T.L.Gratinis	14.51	339.14	2.62	15.91	30.92	34.30
T.L.Kastrakiou	13.02	290.96	6.04	11.93	35.43	10.80
T.L.Kremaston	10.20	248.55	3.60	7.14	29.54	9.38
T.L.Ladona	14.17	356.86	3.18	4.76	39.46	20.15
T.L.Leukogeion	34.34	165.06	1.12	22.69	18.72	7.85
T.L.Marathona	8.75	361.03	5.35	16.05	37.96	23.94
T.L.Mornou	10.68	232.75	6.76	5.11	32.51	14.43
T.L.Pigon Aoou	10.54	220.84	4.14	16.37	19.50	4.67
T.L.Pineiou	17.85	351.22	3.44	14.76	28.45	20.97
T.L.Platanovrysis	20.75	177.20	5.24	5.00	21.35	11.21
T.L.Polyfytou	16.35	371.82	3.86	7.35	24.47	24.42
T.L.Pournariou	8.23	461.40	6.80	17.34	74.53	96.73
T.L.Pournariou II	9.18	469.60	4.18	14.87	70.75	125.31
T.L.Sfikias	12.45	380.53	4.25	7.71	32.43	27.68
T.L.Smokovou	14.94	375.78	2.93	8.66	27.56	42.40
T.L.Stratou	10.14	286.80	2.84	11.75	35.29	11.13
T.L.Tavropou	8.18	191.25	4.16	2.60	28.39	6.31
T.L.Thisavrou	14.63	189.30	5.04	5.40	25.11	13.07

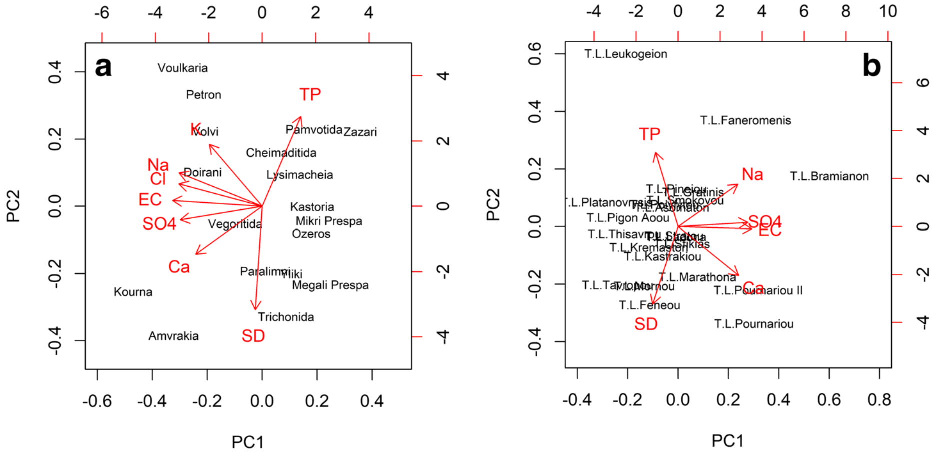

Fig. 7 PCA biplots of selected physicochemical variables in Greek **a** natural lakes and **b** reservoirs dataset

land use impacts on water quality of lake; these strong relationships between catchment area size and water quality are evident in Greek lakes (Mavromati et al. 2017).

In our dataset, a gradient of TP along the second PCA component, separate clear reservoirs and natural lakes with high secchi depth from impacted lakes with low secchi depth. For example, lakes Kourna, Amvrakia, Trichonida, Paralimni and Feneos, Tavropos and Pournari reservoirs are clustered together, as they have low TP and high secchi depth values. It can be argued that these features could be attributed to their catchment land use, population density and hydromorphological characteristics. Based on these characteristics, lakes Kourna, Paralimni and Feneos have been selected as reference sites, for the development of the national aquatic macrophyte index, in the context of WFD lake assessment of ecological status (Zervas et al. 2018). In contrast, urban Lake Pamvotida, along with lakes Zazari, Cheimaditida and Lysimacheia are clustered on the top left quadrat of the plot, highly associated with TP. There is no doubt that highly eutrophic lakes are primarily

Table 4 Principal components loadings for the selected variables in natural lakes and reservoirs

Variable	Component	
	PC1	PC2
Natural lakes		
TP	0.20	0.55
EC	−0.46	0.04
SD	−0.04	−0.63
Na	−0.44	0.21
K	−0.27	0.38
Ca	−0.34	−0.29
Cl	−0.43	0.14
SO_4	−0.42	−0.08
Reservoirs		
TP	−0.11	0.61
EC	0.54	−0.07
SD	−0.23	−0.59
Na	0.46	0.28
K	0.41	−0.44
SO_4	0.51	0.034

affected by waste water inputs and intensive agriculture activities (Skoulikidis et al. 1998). Specifically, regarding the urban lakes, as lakes Pamvotida and Kastoria, it is well documented that they tend to receive high nutrient loads and show higher trophic status than non-urban ones (Naselli-Flores 2008). Papastergiadou et al. (2010) discussed that the increase of cultivations and urban areas in the northern and southern parts of Pamvotida resulted in severe habitat degradation in the riparian zone of the lake. There are some notable exceptions, as to the impact of catchment land uses to water quality. In particular, in Marathonas reservoir, the high population density and agricultural and artificial landforms of its catchment are not reflected in its physicochemical characteristics. The high water quality of this reservoir can be attributed to the fact that it is managed for drinking water supply of Athens, and thus, it also receives water from high quality Mornos, Evinos and Yliki water bodies and not just from its catchment area (EYDAP SA Athens Water Supply and Sewerage Company: http://www.eydap.gr/en/TheCompany/Water/WaterSources/; Kanakoudis 2004). On the other hand, the high TP values of Leukogeia reservoir cannot be attributed to land use patterns and more research needs to be carried out in order to link its status to eutrophication pressure. Moreover, other uses in the catchment, not included in our study, such as animal husbandry, could potentially influence water quality parameters of certain lakes, like Ozeros and Voulkaria, as noted in the recent River Basin Management Plan (Ministerial Decision 901/2017) and like Lake Cheimaditida whose watershed changed significantly over the last century from peatland to farmland and pasture (Papastergiadou et al. 2010).

It could be argued that overall, anthropogenic pressures are more relaxed in the catchments of reservoirs than in the natural lakes. Most reservoirs are built on mountainous and semi-mountainous areas, where forest and forested areas prevail and human settlements are scarce. In contrast, most of the natural lakes are lowland or urban, where land cover has been modified over the years (Kagalou 2010) and population density is higher compared to mountainous areas, rendering them further vulnerable to nutrient loading from their catchments.

It has been proven extremely challenging to find minimally impacted lakes across Europe (Poikane et al. 2010); these aquatic water bodies face multiple stressors including nutrient inputs from point and non-point sources, water abstraction and morphological changes (EEA 2012). In general, Mediterranean lakes overall seem to experience strong catchment effects, based on catchment to lake ratio (Alvares-Cobelas et al. 2005). According to the same authors, proposed approaches at catchment level include developing and/or improving wastewater treatments, increasing natural vegetation cover, water-saving measures and increasing environmental protection.

Greece is no exception. The majority of Greek lakes have been degraded from macrophyte-dominated clear water state to a more turbid phytoplankton state, as described in the River Basin Management Plans (http://wfdver.ypeka.gr/en/home-en/). Furthermore, as Kolada et al. (2005) suggest, lakes with large catchment areas are more susceptible to degradation. In such cases, we suggest that efficient restoration and mitigation strategies could focus rather at catchment level than in lake itself. Similar findings are presented by Alexakis et al. (2013), recommending that response actions should be in the direction of reduced application of fertilizers and chemicals in the cultivated land of the catchment, removal of the point-contamination sources from the catchment, appropriate land-use management and biomanipulation.

It is clear that in order to achieve the WFD goals for "good" ecological status of all surface waters, land use planning should incorporate not only site-specific mitigation measures but also intervention at a catchment scale. The sustainable and cost-effective management of Greek lakes requires the coordination of an integrated and holistic approach which covers both water quality and land uses. Further investigation is essential for proper understanding the underlying relationships within the catchment areas watershed and long-series data is the key for implementing the integrated proposed solutions.

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