A theoretical approach for the domestic and rural impact on the water quality of coastal lagoons

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Abstract

A simple theoretical model was applied to study the impact of domestic and agricultural activities on the water quality of Nestos River lagoons (Vassova, Eratino and Keramoti). The amounts of total nitrogen and phosphorus released by each activity taking place at the broader watershed of the above lagoons were estimated in terms of the effluent discharge coefficients reported by LOICZ. It resulted that 51.5 ton N and 10.6 ton P reach the water of the above lagoons each year. The non-point agricultural runoff (41.1%), household activities (32.2%) and livestock activities (26.7%) are the main contributors to the above nitrogen input. Livestock wastes (60.6%) and domestic human wastes (29.7%) are the main phosphorus contributors. The contribution of non-point agricultural runoff in terms of phosphorus loading was limited (9.7%). The dissolved inorganic nitrogen and phosphorus parts of the above amounts entering the lagoons were compared to those observed at the water of the lagoons during the period 1994-96. The theoretical approach seemed to slightly underestimate the amounts of dissolved inorganic nitrogen and phosphorus, although this discrepancy might occur from the entry of nutrients through the mouth of each lagoon.

Résumé

Un simple modèle théorique a été employé pour étudier l'impact des activités ménagères et agricoles sur la qualité des eaux des lagunes de la rivière Nestos (Vassona, Eratino et Keramoti). Les taux totaux d'azote et de phosphore dégagés par chaque activité qui se déroule à la périphérie de ces lagunes ont été estimés sous forme de coefficients de décharge des eaux résiduaires comme décrit par LOICZ. Il en résulte que 51,5 tonnes d'azote et 10,6 tonnes de phosphore s'accumulent dans les eaux de ces lagunes chaque année. L'épandage agricole (41,1%), les activités ménagères (32,2%) et l'élevage (26,7%) contribuent le plus à apporter de l'azote. Les déchets provenant de l'élevage (60,6%) et les déchets urbains (29,7%) contribuent le plus à apporter du phosphore. L'épandage contribue dans une moindre mesure à apporter du phosphore (9,7%). Les quantités d'azote et de phosphore inorganiques dissoutes et atteignant les lagunes ont été comparées à celles observées dans l'eau des lagunes durant la période 1994-1996. Il semble que l'approche théorique sous-estime légèrement les taux d'azote et de phosphore inorganiques dissouts, quoique cette différence puisse être attribuée à l'apport d'éléments à travers l'ouverture maritime de chaque lagune.

1. Introduction

Coastal lagoons have been considered as complex natural ecosystems being in a natural balance, from which they easily deviate due to the environmental degradation caused by alterations in hydrology, pollution and human activities (Miller et al., 1990). On the other hand, coastal lagoons are providing significant food resources, since fishing and aquaculture have constituted one of the oldest forms of coastal resource exploitation (Vallejo, 1982). Thus, the fluctuation of water quality parameters (physical, chemical and biological) in a coastal lagoon may directly influence the fishery production dynamics of the ecosystem (Chauvet, 1988).

The integrated management approach of coastal lagoons should consider the study of their environmental characteristics, aiming towards the understanding of the mechanisms and patterns of the system (OECD, 1982). Nutrients and nutrient availability, from the adjacent drainage basin, are important for the processes of lagoon biological communities. The presence of nitrogen and phosphorus, in particular, influence primary production of a lagoon, the growth of macrophytic and benthic organisms and therefore, fishery production. Main sources of nitrogen and phosphorus in the lagoons include nitrogen fixation, phosphorus re-suspension from the bottom sediments to the water column of the lagoon and nutrient-rich water mass entry during tidal flow, precipitation, surface drainage and groundwater (Nixon, 1982). The latter two sources are considered as the most important under the presence of extensive agricultural, industrial and urban activities in the broader watershed of the lagoon (Correll et al., 1992).

The Nestos River lagoons (Vassova, Eratino and Keramoti lagoons) play a significant role for the local economy, due to their ecological value as well as due to their fishery exploitation. However, the present increase of human activities (agricultural, industrial and urban) in the broader drainage basin of these lagoons, have led to the environmental degradation of these sensitive ecosystems. This results in the rare occurrence of eutrophication phenomena in the lagoon waters and the continuous decrease of fishery production (Sylaios et al., 1998; Theocharis et al., 2000; Sylaios and Theocharis, 2001).

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Table 1. *Cultivated area per crop (ha) at the drainage basin of the Nestos river lagoons, during the period 1994-1996.*

Cultivated Crops	1994	1995	1996	Average
Rice	270	271	263	268
Corn	5,111	3,420	4,722	4,417.6
Cereals	1,787	1,804	1,540	1,710.3
Sugar beets	232	382	425	346.3
Alfalfa	355	343	310	336
Asparagus	522	558	652	577.3
Kiwifruit	90	90	85	88.3
Beans	801	1,025	1,168	998
Cotton	856	2,210	2,660	1,908.6
Total Area	10,024	10,103	11,825	10,650.4

Since these lagoons act as sinks of nutrients, received mostly from land, the monitoring and management of agricultural activities at the broader watershed directly affects water quality and environmental functioning of their ecosystem. Data provided by the local agricultural cooperative shows that during the period 1994-1996, on average corn (4,417.6 ha), cotton (1,908.6 ha) and cereal (1,710.3 ha) crops were mostly cultivated at the area of interest (Table 1). The various fertilization types (basic or surface), the periods and the amounts of fertilizers applied (kg/ha) per crop, as well as the fertilizer type (nitrogen : phosphorus : potassium, N:P:K) in the cultivated areas of Nestos river lagoon drainage basin are presented in Table 2. It is shown that asparagus (1,550 kg/ha/year), kiwi fruits (1,500 kg/ha/year) and corn crops (1,300 kg/ha/year) require the highest fertilization loads. Therefore, the total nitrogen applied as fertilizer in the agricultural areas, adjacent to the lagoons of interest (Table 3), was found to reach on average 2,247 ton N/year during the period 1994-1996 (2,395 ton N during 1994, 2,080 ton N during 1995 and 2,268 ton N during 1996), with corn crops (62.4%) and cotton (14.1%) having overall the higher nitrogen requirements. Similarly, the total phosphorus was calculated on average as 742 ton P/year during the period 1994-1996 (758 ton P during 1994, 707 ton P during 1995 and 762 ton P during 1996), with corn crops (48.3%), cereals (13.7%) and cotton (12.8%) having the higher contribution (Table 3).

Table 2. *Fertilization types, periods and amounts of fertilizers applied per crop at the cultivated areas of the drainage basin of Nestos river lagoons.*

Cultivated Corps	Fertilization Type	Period of Application	Amount applied (kg/ha)	Fertilizer Type (_:_:_)		
Rice	Basic	April (30%) - May (70%)	400	20	10	10
	Surface	June (50%)- July (50%)	250	25	0	0
Corn	Basic	March (100%)	800	22	11	0
	Surface	June (100%)	500	25	0	0
Cereals	Basic	__member (100%)	300	16	20	0
	Surface	November (100%)	200	25	0	0
Sugar Beets	Basic	February (100%)	400	11	15	15
	Surface	November (100%)	200	26	0	0
Alfalfa	Basic	March (100%)	500	0	20	0
Cotton	Basic	March (100%)	500	20	10	10
	Surface	March (100%)	200	33.5	0	0
Asparagus	Basic	January (100%)	300	20	10	10
	Surface	January (100%)	250	0	0	30
	Basic	June (100%)	500	11	15	15
	Basic	July (100%)	500	33.5	0	0
Kiwifruit	Basic	March (100%)	1,000	11	15	15
	Surface	June (100%)	400	33.5	0	0
	Surface	June (100%)	100	13	0	46
Beans	Basic	March (100%)	500	8	16	24
	Surface	May (100%)	100	25	0	0

The estimation of the nutrient sources, pathways and fluxes from the broader watershed into these lagoons is considered essential for the management and planning of the appropriate interventions aiming to the control of the occurrence of eutrophication phenomena. In this paper, an attempt was

Table 3. *Amounts of nitrogen, phosphorus and potassium (in ton) applied at the cultivated areas of the Nestos lagoons drainage basin, per type of crop, during the period 1994-1996.*

Crop	1994			1995			1996		
Rice	39	11	11	39	11	11	38	11	11
Corn	1.755	450	0	1.174	301	0	1.278	327	0
Cereals	178	107	0	180	108	0	154	92	0
Sugar Beets	22	14	14	37	23	23	41	25	25
Alfalfa	36	0	0	34	0	0	31	0	0
Asparagus	147	55	172	158	58	184	184	68	215
Kiwi Fruits	23	14	18	23	14	17	22	12	17
Beans	52	64	96	66	82	123	76	94	140
Cotton	143	43	43	369	110	110	444	133	133
____	2.395	758	354	2.080	707	468	2.268	762	541

made to quantify the amounts of nitrogen and phosphorus entering the aquatic environment of Nestos river lagoons, as a result of the agricultural, industrial and urban development in the watershed of Chrisoupolis area. This is very important for the evaluation of the overall nourishing loads, which flow from the drainage basin into the water body of interest, and to find out the importance of the different point and non-point sources of release.

2. Material and methods

The influx of nutrients in the water of coastal lagoons can be evaluated both by means of experimental (direct) and theoretical (indirect) assessments. The first method, which is based on the direct monitoring of the inflowing water quality characteristics, allows a precise quantification of nitrogen and phosphorus loadings. However, it is hardly being used due to its high cost in terms of time and resources. Furthermore, this method is unable to quantify the environmental impact of each human activity on the deterioration of the lagoon water quality, and thus it has a limited management contribution to the improvement of the ecosystem.

The second method is undoubtedly much more frequently used, although provides only crude estimates of the real situation of the case study. The theoretical assessment method accounts for each activity taking place at the broader watershed, is based on representative export coefficients, and estimates the amounts of nitrogen and phosphorus loaded into the aquatic ecosystem of the lagoon. This method has been incorporated into the LOICZ Biogeochemical Modeling Guidelines (LCOIZ, 1996) for the determination of the nutrient budgets at semi-enclosed coastal ecosystems as lagoons, lakes and estuaries. Recent research (Mosello and DeGuili, 1982; Casula et al., 1999) presented that the determination of nourishing loads following both the experimental and the theoretical approach, when applied to the lagoons of Sardinia, gave almost similar results with small deviations (2.7% for nitrogen and 15.5% for phosphorus).

The theoretical evaluation of nourishing loads is carried out be means of the different sources of nutrient losses. Nutrient sources can be divided into point sources (generally manmade such as urban, industrial or animal wastes) and non-point sources (generally derived from losses of cultivated and uncultivated land, precipitation or urban runoff). For the theoretical estimate of nutrient loads it is therefore necessary to collect data concerning the land use, population, agricultural, industrial activities and animal wastes and to elaborate them by means of the application of the appropriate effluent discharge coefficients. This evaluation allows an indicative estimate of nutrient loadings, since it is based on the fact that the effluent discharge coefficients for single source of release, calculated without taking into account the differences among the drainage basins, can be generalized.

Table 4. *Effluent discharge coefficients released from the various economic activities.*

Activity	Units	Nitrogen Effluent Discharge Coefficient	Phosphorus Effluent Discharge Coefficient
Household			
Solid Waste	kg/person/year	0.71	0.07
Domestic Sewage	kg/person/year	1.53	0.18
Detergent	kg/person/year	----	0.18
Non-point Agricultural Runoff			
Cultivated Soil	Kg/ha/year	2.00	0.10
Uncultivated Soil	Kg/ha/year	12.00	0.20
Livestock			
Cattle	Kg/cow/year	2.74	0.40
Piggery	Kg/pig/year	0.57	0.18
Sheep	Kg/sheep/year	0.25	0.023
Horses	Kg/horse/year	3.10	0.50
Poultry	Kg/bird/year	0.0024	0.1

Table 4 presents the effluent discharge coefficients of nitrogen and phosphorus for various economic activities taking place in a drainage basin, as reported in the literature. These coefficients have been modified for the Nestos river lagoons case, since only 50% of the household and livestock wastes was estimated to be disposed at the watershed of interest (accounted as 50% of the total nitrogen and phosphorus released by each activity), in contrast to the whole of agricultural wastes that is released at the watershed (accounted as 100% of the total nitrogen and phosphorus released by agricultural areas). The effluent discharge coefficients for the main nutrient sources occurring at the drainage basin of the lagoons Vassova, Eratino and Keramoti are presented in Table 4. According to these values, data concerning the land use and the corresponding human activities at the overall drainage basin of Nestos river lagoons were collected (National Statistical Service of Greece, 1991). Following LOICZ methodology (LOICZ, 1996), the amounts of total nitrogen and phosphorus (in kg/yr) entering the lagoons of Nestos river were expressed in terms of dissolved inorganic nitrogen and dissolved inorganic phosphorus (in mol/yr). Therefore, the amount of inorganic nitrogen and phosphorus entering the lagoons each year at dissolved phase could be computed and compared to the values obtained from nutrient field data (nitrates, nitrites, ammonia and phosphates) collected during the period 1994-1996 from various locations of Vassova, Eratino and Keramoti lagoons (Sylaios et al., 1997; Theocharis et al., 2000; Sylaios & Theocharis, 2001).

3. Results and discussion

The sources of inorganic nitrogen and phosphorus that can be accounted for the drainage basin of the lagoons of Nestos River are the agricultural, livestock and domestic wastes, while there also exist limited effluents produced from the erosion of the non-cultivated areas (Table 5). Results show that the total amount of nitrogen and phosphorus released from the various sources at the drainage basin of Nestos river lagoons are of the order of 51.5 ton N/year and 10.6 ton P/year, respectively. It occurs from the theoretical assessment approach that the main nitrogen sources are the non-point agricultural runoff (21.2 ton N/year; 41.1%), household activities (16.5 ton N/year; 32.2%) and livestock activities (13.7 ton N/year; 26.7%). The higher nitrate contribution (20.2 ton N/year) results from the water flowing across the adjacent agricultural land, thus transporting nitrogen into the lagoon water bodies of river Nestos. Domestic sewage (11.3 ton N/year) and livestock wastes from cattle (6.51 ton N/year) and sheep (6.58 ton N/year) contribute also to the increase of nitrogen load entering the lagoons. Low effluent discharge values of nitrogen result from pigs (0.5 ton N/year), poultry (0.1 ton N/year) and horses (0.04 ton N/year) animal wastes and from non-cultivated areas (1.01 ton N/year).

Table 5. *Nutrient sources, activity levels, modified effluent discharge coefficients and total amounts of nitrogen (N) and phosphorus (P) loads entering Nestos river lagoons.*

Nutrient Sources		Effluent Discharge Coefficients		Total amounts of nourishing loads (kg/yr)	
Activity	Level of Activity	_	_	_	_
Household					
Solid Wastes	14,786 inhabitants	0.355 kg/person/yr	0.035 kg/person/yr	5,249.0	517.5
Domestic Sewage	14,786 inhabitants	0.765 kg/person/yr	0.090 kg/person/yr	11,311.2	1,330.7
Detergent	14,786 inhabitants	----	0.090 kg/person/yr	——	1,330.7
Total Household Impact				16,560.2	3,178.9
Livestock					
Cattle	4,755 cows	1.37 kg/cow/yr	0.20 kg/cow/yr	6,514.3	951.0
Sheep	52,711 sheep	0.10 kg/sheep/yr	0.011 kg/sheep/yr	6,588.8	606.1
Pigs	1,829 pigs	0.285 kg/pig/yr	0.09 kg/pig/yr	521.2	164.6
Horses	27 horses	1.55 kg/horse/yr	0.25 kg/horse/yr	41.8	6.7
Poultry	95,043 birds	0.0012 kg/bird/yr	0.05 kg/bird/yr	114.0	4,752.1
Total Livestock Impact				13,738.3	6,480.5
Non-point Agricultural Runoff					
Cultivated Areas	10,106 ha	2.00 kg/ha/yr	0.10 kg/ha/yr	20,212.0	1,010.6
Non-cultivated Areas	84.3 ha	12 kg/ha/yr	0.2 kg/ha/yr	1,011.6	16.8
Total Agricultural Impact				21,223.6	1,027.4
Total Nutrient Loads				51,522.1	10,686.8

In terms of the main phosphorus nourishing loads entering the water of the Nestos river lagoons, it occurs that the highest contribution comes from the livestock activities of the area (6.4 ton P/year, 60.6%) and the domestic human activities (3.1 ton P/year, 29.7%). Poultries (4.7 ton P/year), domestic sewage (1.3 ton P/year) and detergents (1.3 ton P/year) are the main sources of phosphorus being transported over the land surface to the lagoons receiving water bodies. The contribution of non-point agricultural runoff in terms of phosphorus loading was limited (1.02 ton P/year, 9.7%). Limited impact also results from the pigs, sheep and cattle animal wastes (0.1 ton P/year, 0.6 ton P/year and 0.9 ton P/year, respectively) and the household solid wastes (0.5 ton P/year). Minimum input of phosphorus occurs from the uncultivated land (0.01 ton P/year) and horse wastes (0.006 ton P/year).

The above amounts of total nitrogen and phosphorus include the dissolved inorganic nitrogen part (DIN, nitrite+nitrate+ammonium), the dissolved organic nitrogen part (DON) and the particulate nitrogen (PN). Following LOICZ methodology, it occurs that the amount of 51.5 ton N/year corresponds to 1,366,391 moles of dissolved inorganic nitrogen (DIN) per year, which equals to 5.24 kg N/day or 1.91 ton N/year in the dissolved inorganic form. Monthly data of dissolved inorganic nitrogen obtained from the lagoons Vassova, Eratino and Keramoti during the period 1994-1996 showed that the average annual amount of inorganic nitrogen being in dissolved form in the water of these lagoons was of the order of 1.19 ton N for Vassova lagoon, 1.33 ton N for Eratino lagoon and 0.52 ton N for Keramoti lagoon. Similarly, the amount of 10.6 ton P/year that was calculated to reach the water of Nestos river lagoons corresponds to 171,930 moles of dissolved inorganic phosphorus (DIP) per year, which equals 0.65 kg P/day or 0.24 ton P/year in the dissolved inorganic form. Field data showed that the average amount of dissolved inorganic phosphorus in the water of Nestos River lagoons was of the order of 0.46 ton P for Vassova lagoon, 0.73 ton P for Eratino lagoon and 0.25 ton P for Keramoti lagoon.

Since the amounts of dissolved inorganic nitrogen and phosphorus appear to be of the same order of magnitude as those estimated by the theoretical approach, it occurs that this method has provided a good estimate for the quantities, the sources and their degree of contribution to the total and dissolved inorganic nitrogen and phosphorus entering the lagoons. Furthermore, the excessive amounts of dissolved inorganic nitrogen and phosphorus observed at the water of these lagoons (as compared to that computed by the theoretical approach) are expected to enter the lagoons through their mouth (the small elongated channel that connects the lagoon with the adjacent coastal sea).

4. Conclusions

The LOICZ theoretical methodology was applied to study the impact of domestic and agricultural activities on the water quality of Nestos River lagoons (Vassova, Eratino and Keramoti) and to compare results to real datasets. It resulted that 51.5 ton N and 10.6 ton P enter the aquatic environment of the above lagoons each year. The non-point agricultural runoff (accounting for 41.1%), household activities (accounting for 32.2%) and livestock activities (accounting for 26.7%) are the main contributors to the above nitrogen input. Livestock wastes (accounting for 60.6%) and domestic human wastes (accounting for 29.7%) are the main phosphorus contributors. The contribution of non-point agricultural runoff in terms of phosphorus loading was limited (9.7%). The dissolved inorganic nitrogen and phosphorus parts of the above amounts entering the lagoons were compared to those observed at the water of the lagoons during the period 1994-96. The theoretical approach seemed to slightly underestimate the amounts of dissolved inorganic nitrogen and phosphorus, although this discrepancy might occur from the entry of nutrients through the lagoon mouth.

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