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UNDERSTANDING MARINE EUTROPHICATION FROM AGRICULTURAL RUNOFF IN SEMI ENCLOSED AREAS: A PRESENTATION OF QUANTITATIVE METHODOLOGY

M. KARYDIS*

University of the Aegean, Department of Marine Sciences
University Hill, 81100 Mytilini, Greece

*to whom all correspondence should be addressed
e-mail: mkar@aegean.gr

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ABSTRACT

The understanding of marine eutrophication in semi enclosed areas due to agricultural runoff, assumes a more integrated approach taking into account the agricultural watershed, seasonal patterns of soil nutrients, rates of erosion and vegetation types. In the present case study in the Gulf of Geras, Lesvos, Greece, the transport of dissolved and solid phase nutrients of terrestrial origin to the marine environment was studied in detail using mathematical modelling. Fifteen criteria describing environmental and socio-economic aspects were analysed using multi criteria choice methods and a number of scenarios were evaluated. Parallel to that an eutrophication model was used to describe the problem of eutrophication in the marine environment and also to assess the environmental impact from the proposed scenarios. The emphasis was placed in the interconnection between Mediterranean type ecosystem and marine coastal eutrophication. The results showed that the coupling of multi criteria analysis together with simulation modelling, provide a powerful tool for integrated coastal management practices and assessing eutrophic trends in semi enclosed areas.

KEYWORDS: marine eutrophication, agricultural runoff, Modeling, Coastal Management, Multi Criteria Analysis

INTRODUCTION

Shallow semi enclosed Gulfs are complex system where ecological, biogeochemical and physical processes influence nutrient dynamics and at the same time act as “filters” for the terrestrial inputs (Nichols and Boon, 1994). System complexity introduces difficulties and inaccuracies in quantifying nutrient loading of the marine environment. In addition, terrestrial activities along the coastal area should be identified, understood and quantified in an integrated approach of the coastal area studied. (Turner and Bateman, 2001). It is therefore necessary to use information on demographic, agricultural, industrial, social and technological patterns of the coastal zone.

As far as the sources of nutrients and organic matter for the coastal waters are concerned, they can be classified into two groups: point and non-point sources. Point sources such as sewerage and industrial wastewater flow at discrete identifiable locations and their impacts can be measured directly (Rossi *et al*., 1992). However the longest nutrient contribution for the coastal marine environment is from non-point sources that are rather diffused and vary in space and time (Borum, 1996). They include wet dry deposition from the atmosphere, erosion of land, weathering of minerals and anthropogenic sources (Archonditsis, *et al*., 2000). Use of fertilizers, accumulation of dust and liter, washing out of soil material from agricultural and farming activities are all impacts of anthropogenic origin (Novothy and Chester, 1981).

In the present work a review of methodological procedures for quantitative assessment of coastal marine eutrophication are presented, based on modeling combined with multi criteria choice-methods. The Gulf of Geras, a semi enclosed embayment on the island of Lesvos, Greece was the basis for the review because: (a) both the terrestrial and marine environment have been studied for a number of years (b) there are adequate data on environmental and socio economic aspects (c) a number of quantitative techniques have been applied on marine processes, eutrophication assessment, scenaria developed in relation to economic activities of the area and (d) the system is well confined and almost isolated from the open sea.

THE STUDY AREA: THE PHYSICAL ENVIRONMENT

The study area is the Gulf of Gera, located on the Island of Lesvos, Greece. The Gulf of Gera is a semi enclosed marine ecosystem with a mean depth of 10m and a total volume of $9X10^8m^3$ (Figure1) The surrounding 194 Km^2 watershed is dominated by olive cultivation and is inhabited by 7.064 people according to the 1991 census (Loumou *et al*., 2000). The non-point nutrient loading from agricultural run off accounts for about 50 to 60% of the total inorganic nitrogen (Archonditsis, *et al*., 2000). In addition sewage discharges as well as discharges from olive oil processing are also substantial. The nutrient status of the Gulf of Geras has been characterized as a typical mesotrophic environment with eutrophic trends according to a eutrophication classification system for the Aegean Sea (Ignatiades *et al*., 1992; Kitsiou and Karydis, 1998).

The main characteristic of the terrestrial system is the monoculture of olive trees, located mainly on terraced hill slopes. There is a trend in the Aegean archipelago for this type of agriculture usually combined with animal husbandly sheep & goat, (Archonditsis, *et al*., 2002). Grazing effects decrease species diversity and lead to progressive land degradation. The grazed vegetative cover is more vulnerable to erosion, increases nutrient fluxes and finally enriches the marine environment with nutrient at increasing rates. The study area is given in Figure 1.

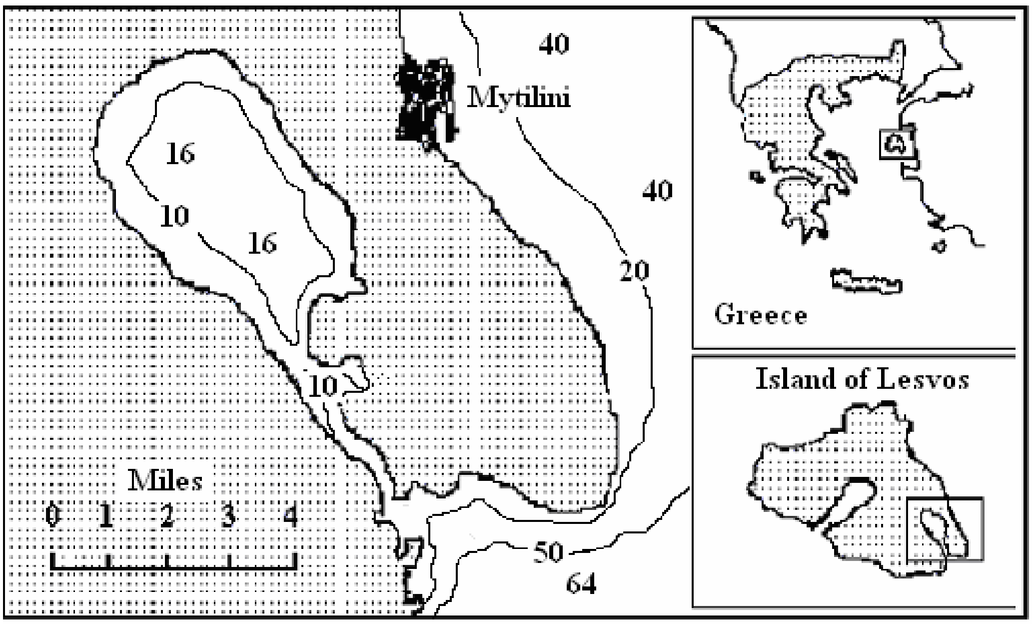

Figure 1. Gulf of Geras, Island of Lesvos Greece: the study area

THE STUDY AREA: THE ECONOMIC BACKGROUND

The local economy on the area case study is mainly based on the monoculture of olive cultivation. The use of oil substitutes has caused an economic decline followed a retainable emigration of the oil famous to continental part of Greece as well as abroad (Margaris 1992). The size of an average farm is approximately 2.3 ha with 2 ha being olive groves. In addition the application of modern agricultural practices such as irrigation,fertilization, pruning and mechanization is rather limited (Loumou, *et al*., 2000). It was estimated from data based on average animal production during the period 1984-1994 that the average Goss Margin (Gross Margin Product – Vanables Expenses) per holding was about 2200 $U.S. The result is a serious underemployment since only 25% of the average household expenditure is covered from agricultural activities (Loumou, *et al* 2000).

Tourism in the area is less developed due to substantial employment in a local tannery. A slight increase in tourism after the 1990's was coupled with the suspension of the operation of the tannery. Supplemental income resulted from employment in construction work and livestock breeding. The livestock on the area numbers about 5500 sheep and goats (Archonditsis, *et al*., 2002).

The approach for understanding the interaction between agricultural runoffs and eutrophication is twofold (a) the development of scenarios based on social economic and environmental quality criteria (Moriki, *et al*., 1996). Application of multi criteria analysis classifies the scenarios in descending order; and (b) the application of simulation modelling using an integrated approach that consisted of three interacted models: (i) terrestrial (ii) hydrodynamic and (iii) biological sub models (Archonditsis, *at al*., 2000)

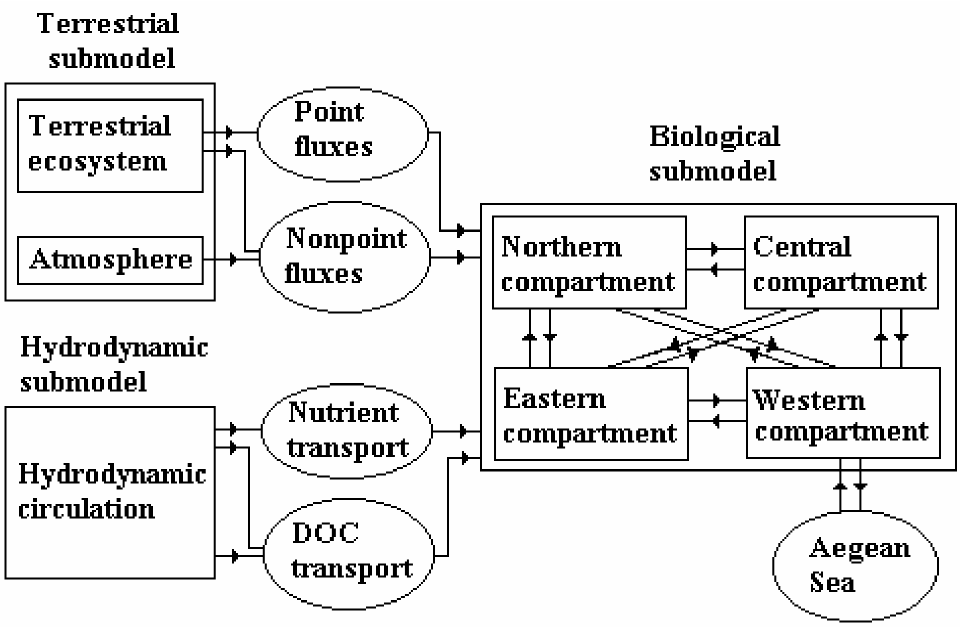

Figure 2. The flow diagram of the model

MULTI CRITERIA CHOICE METHODS

The assessment of environmental quality of coastal waters has been carried out over the last forty years mainly using methodological tools common in biological sciences. Use of biological indicators measuring diversity (Magurran, 2003; Pielou, 1984) have contributed substantially to the assessment of coastal water quality (Washington, H.G., 1984; Wilm & Dorris, 1968) some with specific emphasis to the classification of euthrophic levels. (Karydis, *et al*., 1983;, Karydis & Tsirtsis, 1996). In addition univariate (Giovanardi & Tromelini, 1992; Ignatiades, *et al*., 1992; Stefanou, *et al*., 2000) as well as multivariate statistical analysis (Heip, et al., 1988 ; Karydis, 1994). Due to environmental orientation of these studies, methods of linking multivariate community structure to environmental variables have also been proposal (Clarke & Amsworth, 1993). However successful these approaches are, the statistical models used could not incorporate social and economic variables for integrated environmental studies.

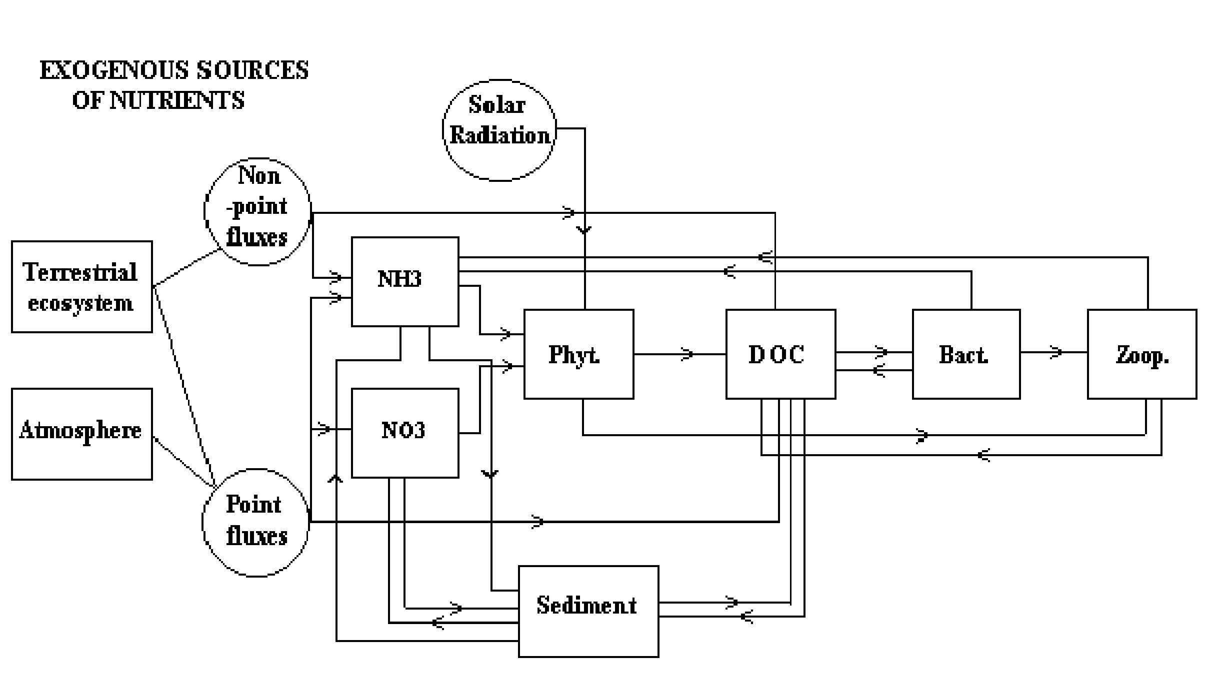

Figure 3. The flow diagram of the biological sub model

This is due to the nature of the data as well as to the fact that scaling is different; environmental variables are usually on metric scaling whereas, socio economic variables are usually expressed on ordinal and binary scaling. Lately, there is a tendency overcome this shortcoming by using multicriteria evaluation methods. This type of research is relatively new with a limited numbers of applications (Janssen, 1992; Turner & Bateman, 2001; Moriki, *et al.*, 1996). This methodology allows simultaneous analysis of economic social & environmental data. The principle of multiple criteria methods is the classification alternative choice possibilities on the basis of various criteria (NijKamp & Voogd, 1996). Multicriteria evaluation offers a variety of methods but all of them obey the same principle: the parwise comparison of scores of all the alternatives and for each criterion (NijKamp and Voogd, 1986). In the current case study the present condition and the potential environmental and socio economic aspects were described through a number of criteria; gross margin per capita, existing infrastructure, labour requirements, easiness of implementation and related activities were the socio economic criteria; variables such as marine nutrients, chlorophyll a consumption of natural resources and preservation of terrestrial ecosystem were among the environmental variables used. On the bases of the variables a number of scenaria are developed (Moriki, *et al.*, 1996; Archonditsis, *et al*,. 2002).

Considering a choice problem with I alternatives and J criteria, the effect matrix according to the scores, would be of the following type:

$$\text{Impact matrix} = \begin{matrix} b_{11} \ldots b_{1j} \\ b_{i1} \ldots b_{ij} \end{matrix}$$

Where b_{ij} is the score alternative I according to criteria j. In the that $b_{ij} > B_{2j}$ alternative I_1 dominates over I_2 for criterion j. The great advantage of multi criteria methods compared to multidimensional methods of analysis is their ability to deal with both metric and non-metric information (NijKamp & Voogd, 1986). In addition they can be used for problems in policy analysis. Four multi criteria choice methods have been used in coastal management: the concordance analysis (Nijkamp, et al,. 1991), the regime method (Hinloopen & Nijkamp 1990), the numerical interpretation method (Voogd, 1983) and the Evamix method (Nijkamp, 1989).

Concordance analysis
This method also known as ELECTRE (Janssen, 1991) is based on pairwise comparison of alternatives. The set of criteria for which alternative I_1 presents a smaller outcome than alternative I_2 is named the discordance set. The discordance index D between I_1 and I_2 is defined as the maximum difference of scores for alternatives I_1 and I_2 on those criteria for which alternative I_1 is preferred to I_2 (Nijkamp, *et al*,. 1990)

$$D(I_1\text{-}I_2)=\max_{jED_{12}}(9_{11}\text{-}9_{i2})$$

where 9ij is the standardized value of b_{ij}

The regime method
The regimes are + and -signs that each alternative takes after the pairwise comparison with the rest of the alternatives. The advantage of the regime method is that different weighs can be assigned to criteria according to their relative importance and different priorities to them.

The numerical interpretation method
This method is also based on the pairwise comparison of the alternatives. If we consider two alternatives I_1 and I_2 and two criteria J_1 and J_2 and suppose that the scores attached to criteria for each alternative are b_{11}, b_{12} and b_{21}, b_{22} respectively, alternative I_1 wins are point if

(a) When $b_{11}> b_{21}$ and $b_{12}>b_{22}$
(b) When $b_{11}> b_{21}$ and $b_{12}=b_{22}$
(c) When $b_{11}= b_{21}$ and $b_{12}>b_{22}$

The two alternatives have equal score where $b_{11}= b_{21}$ and $b_{12}=b_{22}$. In all the remaining cares of comparison alternative loses I_1 one point. The final result is the algebraic sum of the points of each alternative (Hartog, et al,. 1989)

The Evamix approach
The evamix approach represents a simple method by which multicriteria mixed data sets of both metric and non-metric form are condensed in a straightforward manner. Furthermore an additional advantage of this method is that it allows for different priorities among the criteria; a useful property since quite different criteria are more important than other reflecting the different needs and objectives of societies (Nijkamp, 1989)

MATHEMATICAL MODELLING
The application of a simulation model consisted of three interacting components (terrestrial, hydrodynamic and biological sub models) was found efficient. (Archonditsis, et al,. 2002) The flow diagram of the model is given in Figure 2. The seawater column was characterized by homogeneity.

The terrestrial sub model
The terrestrial non–point fluxes of nutrients and organic carbon are assumed as interactions between the topography, hydrology, plant cover and agricultural practices of the catchment area. The nutrient fluxes from sewerage, the local industrial activity and the atmospheric wet and dry deposition were also incorporated in the model by using theoretical coefficients in combination with experimental observations in the gulf of Gera.

These loadings were used as an input for the biological sub model describing the flow of energy through the microbial components of the marine ecosystem.

The Hydrodynamic Sub model

The Princeton Ocean Model at the Surface and sigma co-ordinate model was applied to simulate the hydrodynamic regime of the study area. The 2-D mode of the model was considered sufficient due to the similarity between the circulation pattern of the upper and bottom layers (Archonditsis, 1998). The outputs of the hydrodynamic sub model were used as inputs for the biological sub model

The biological submodel

The flow diagram of the biological sub model is given in Figure 3. Apart from the four components of the Gulf of Geras, an extra component was added characterizing the oligotrophic waters of the Aegean Sea. The Aegean Component was used for the definition of the boundary conditions. Seven state variables were included: phytoplanktonic (PHYT), zooplanktonic (ZOOP) and bacterial (BACT) biomasses, nitrate (NO_3), ammonia (NH_3) phosphate (PO_4) and dissolved organic carbon (DOC). Details concerning the biological submodel, the flukes, the variable interaction the sensitivity analysis and the goodneess-of-fit can be found elsewhere. (Archonditsis, *et al*,. 2002).

DISCUSSION

Costal zones and their hydrologically linked catchment areas come under heavy environmental pressure over the last forty years (Turner & Bateman, 2001). The resilience of the coastal catchment system in terms of its ability to cope with environmental stress has been threatened by pollution and resource over utilization. Within this framework socio – economic systems and ecological systems are in continuous interaction. Environmental changes induced by oversupply of nutrients (nitrogen and phosphorus) as well as contamination of sediments and the water column by sewage and industrial effluents, are the main problems in a coastal environment.

Although in an open system statistical methods and simulation modeling can be efficient for the assessment of water quality and the description of temporal and spatial trends, this cannot be the case for a semi-enclosed, relatively small system. The response time between the terrestrial processes and their impact on the marine environment is fairly short. In addition, the carrying capacity of those systems is rather limited. A new approach that links socio-economic activities to terrestrial processes and finally marine processes is needed. The Gulf of Geras has been used a case study area for the development of integrated methodology.

The semi enclosed and shallow ecosystem of the Gulf of Geras, Island of Lesvos, Greece, is an intensively cultivated and inhabited watershed. The environmental pressures mainly derived from agricultural runoff and point sources (sewage) that cause mesotrophic conditions in the Gulf. The development of a number of scenarios has been proved useful since the loadings produced in each case are the impact in the simulation modeling in the marine environment. The four scenarios were (i) emphasis on cattle breeding (ii) cultivation of woody plant species (iii) construction of greenhouses and (iv) development of tourism. The animal husbandry scenario was linked with the highest levels of eutrophication whereas, development of tourism had an intermediate effect. The scenario with the minimal impact was the cultivation of woody plant species. The greenhouse scenario had also intermediate effects.

The present integrated approach that links the multicriteria choice methods to simulation modeling has been proved a powerful tool. It incorporates socio- economic variables with environmental values for complex analysis. These developments can lead to further clarification of the environmental issues. Further work will reveal possible shortcomings and potential interlinking between multi objective decision support systems and simulation modeling for assessing coastal water quality. Furthermore standardized procedures can be developed that will enable policy makers to use them on a routine basis.

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