Visualisation and analyses of nutrient data in a coastal lagoon through GIS

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Abstract
The paper aims to visualise the annual nutrient data, total nitrogen, TN, and total phosphorous, TP, in a coastal lagoon system through the aid of geographical information system (GIS) to better understand the prevailing situation and the seasonal fluctuation patterns, and to analyse the transformed form according to current national and international regulations. The selected area situated at the southwest of Turkey is a sensitive coastal area where agriculture, tourism, fishery are the major way of living. The dual layer flow in the lagoon system necessitated the preparation of visualised forms as surface layer representing freshwater, bottom layer representing saline characteristics that also gave a chance to compare both layers. ArcView3.2 is used to map out the data at each of the 16 stations for both TN and TP parameters. Only two seasons of the year are shown as examples of visualisation. The evaluation of results and analyses were conducted according to national standards for saline and brackish water and to international classification of OECD for freshwaters for determining the trophic states. However, due to the lack of a specific standard or criteria set for lagoon systems, no accurate identification of trophic status could be achieved. In general, the lagoon system tends towards mesotrophic state from the oligotrophic state and the significant variation in both layers and seasons were detected for TN rather than TP. Such attempts using new computer technologies aid to improve and promote research studies on monitoring water quality, modelling and management for sustainable development.

Keywords
Eutrophication; GIS; lagoons; nutrient data; visualisation; water quality

INTRODUCTION

Nutrients are a concern because inputs of nitrogen and phosphorous derivatives into an aquatic environment can lead to eutrophication. Deposition of nutrients in receiving water is mainly due to direct and/or indirect effects of human activity depending on the land-use profile of a coastal ecosystem like lagoons and rivers. To cope with this problem, ecological modelling studies have gained popularity among scientists and researchers working in the field of water quality monitoring and management (Christensen *et al*., 2002). They are nowadays dealing with the eutrophication concept in a wider sense, taking into consideration the environmental conditions prevailing at the area of concern like soil characteristics, hydrological conditions, land-use, social characteristics of the watershed, and climatic conditions (Scharin, 2002). Up to date, traditional attention had been given to the water body itself, with spatially consistent parameters. However, it is now obvious that the watershed should be well defined in all aspects so as to obtain sufficient input data needed by ecological modelling for sustainable management. Definition of the current properties of the watershed together with the water quality data would then lead to modelling studies. Most of the modelling studies require the integration of geographical information systems (GIS) as such; various scenarios for future can easily be applied besides presenting the present situation. GIS has the ability to give rise to gather geographical data belonging to geographical items, to verify and store data, data base calculation of these data, to analyse and conduct queries and to indicate geographical data and information in a systematic manner. In this paper, part of an ongoing study on ecosystem modelling of a selected coastal lagoon will be mentioned related to the visualisation and analyses of nutrient data of receiving water by means of GIS. Dalyan Lagoon is selected as the target region as seen in Figure 1, with an area of approximately 130 km^2. It is situated at the Southwest of Turkey, where the Koycegiz Lake joins the lagoon and the Lagoon ends in the Mediterranean Sea. Part of the watershed has been declared as a Special Protection Area and is one of the sensitive coastal regions of the country in terms of flora and fauna. Rarely found caretta-caretta sea turtles utilise the area as their nesting and breeding sites. Investigation of the current land use profile puts forth the importance of forest areas, agricultural activities, and wetlands. Besides its ecological significance, the area necessitates environmental protection due to its tourism capacity, historical background, fishery and agricultural activities.

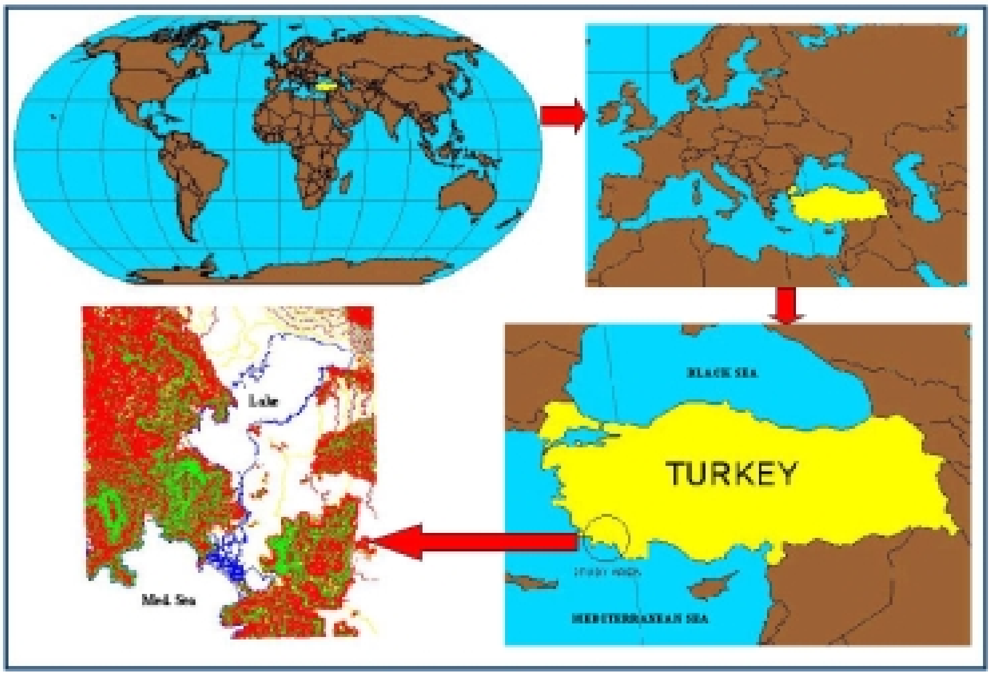

Figure 1. The location of the study area

The carried out activities involve considerable efforts in data collection and creation of database related to climatic conditions, soil characteristics, administrative boundaries, land use, and topographic data in the form of coverage's (Seker *et al.*, 2002). The ongoing activities are focused mainly on the completion of GIS data on water quality, and on the land based sources of pollutants. In this study, visualisation of seasonal nutrient data, namely total nitrogen, TN, and total phosphorous, TP, in water environment will be explained and analyses of the existing data will be accomplished by means of national standards set for eutrophication limits in coastal waters like lakes, rivers, etc., and by OECD standards set for classifying trophic level in freshwaters. However, there is no international/ national standard or criteria stated for brackish waters. The hydrodynamic characterisation of this choked lagoon system has a vital importance in nutrient dynamic evaluations. There is a dual layer flow along the channel system, the upper layer flows towards the sea with a freshwater characteristic, whereas the lower layer with high salinity flows towards the lake. For this purpose a pair of water samples are being collected at each monitoring station belonging to two different depths (Gurel, 2000). The national standards for coastal areas referring to tolerable limits for eutrophication control is mainly set for sea water, (TWPCR, 1988) whereas the OECD classification is for freshwaters in which they are classified as oligotrophic, mesotrophic, eutrophic and hypertrophic according to TN, TP, chlorophyll-a concentrations and secchi disk depths (Vollenwieder, 1982), given in Tables 1 and 2, respectively.

Table 1 National Limit values for eutrophication control in lakes, wetlands and reservoirs (TWPCR, 1988)

Parameters	Natural protection areas and recreational purposes	Various beneficial uses (including saline, brackish and soda water)
TN (mg/Lt)	0.1	1
TP (mg/Lt)	0.005	0.1

Table 2 Eutrophication classification values of OECD (Vollenweider, 1982)

Parameters	oligotrophic	mesotrophic	eutrophic
TN (mg/Lt)	0.307-1.630 average 0.661	0.361-1.387 average 0.753	0.393-6.1 average 1.875
TP (mg/Lt)	0.003-0.0177 average 0.008	0.0109-0.0956 average 0.0267	0.0162-0.386 average 0.0844

Description of the watershed, lagoon, monitoring system and parameters analysed

Based on comprehensive surveys in the watershed, land-based pollutants loading were found to arise especially from diffuse pollutants. Forests and 23% cover almost 63% of the watershed by agricultural land (Seker *et al.*, 2002). As there exist no industries in the watershed, and as only 6 small residential sites in the form of villages are present, the land has not so far been highly deteriorated. However, fertilisers and pesticides are being applied on agricultural land where intensive agricultural activities prevail. The important crops cultivated at the area are typical of Mediterranean region like cotton, citrus fruits, corn, wheat, etc. Due to the climatic conditions cotton, citrus fruits and corn are highly irrigated during summer months. Irrigation return flow during summer period is the only means of water and pollutant transport to the receiving water. During the rest of the year, intense surface run-off through rivers and creeks ending in the lake and the lagoon is usually observed due to precipitation. During summer, weak flow conditions thus weak mixing and circulation in the lagoon lead to strong stratification along the channel. During spring, freshwater entrance to the system is so high either through surface run-off or rivers, carrying high amounts of excess fertiliser loads, which can easily be observed by investigating the nutrient data.

The lagoon system consists of the main channel and of two lakes, where Stations 3 and 4 represent Alagol Lake, and Sulungur Lake by Stations 9,10,11,12 shown in Figure 2. The rest of the monitoring and sampling stations are scattered along the main channel.

The location of monitoring stations is determined according to the factors stated as follows (Gurel, 2000);

- Stations forming the boundary conditions for the system are to be selected.
- Dalyan Lagoon system consists of channel systems and lakes. Monitoring stations are needed to observe the interaction between channels and lakes.
- Stations representing the lake systems are necessary.
- Stations along the channels are needed to detect the spatial variations in the channel systems.
- Stations near the pollution sources are required.

Taking into account these factors, 16 monitoring stations are selected for the Dalyan Lagoon System. Station 0 and Station 14 represent the two boundary conditions. So far, five cruises (1999-2000) were realised to the area, to observe seasonal variations in the system. Sampling from two layers (surface and bottom layers) was conducted at each station to monitor the horizontal and vertical salinity gradients. Surface water samples were collected from 0.5 m depth. Bottom water sampling depths were chosen according to the depth of the stations and vertical salinity gradients. But these depths are above the bottom level of the channel.

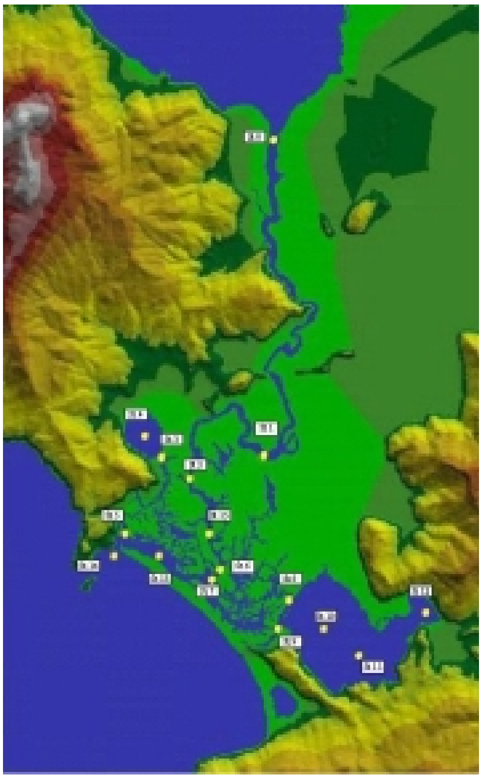

Figure 2 The monitoring station

Cruise 1 to 5 represent summer, spring, summer, autumn, and winter conditions, respectively. The first cruise results were rather used to set down the sampling and experimentation methods, and to overcome and minimise the difficulties and troubles faced during experimentation. The rest of the experimentation values are considered during the discussion of results in the visualised form which further led the authors to achieve overall seasonal evaluations.

The sampling and monitoring parameters in accordance with the aim of the study involved nitrogen and phosphorous species and dissolved reactive silicate. The other parameters are chosen according to the mechanisms and processes that will affect the nutrient dynamics in the system. Being indicators of primary production, chlorophyll-a and particulate organic carbon parameters are added to the list. Physical structural characteristics, salinity and temperature are important parameters that are used to understand the hydrodynamic characteristics of the system. Furthermore, acting as supporting parameters, salinity, secchi disc depths, light intensity, pH, dissolved oxygen, total suspended solids are also chosen as they aid the overall evaluation of nutrient dynamics. For the determination of organic content of water, BOD_5 and total organic carbon are also added to the list of parameters analysed.

The paper is prepared as a reference work summarising the methodology of selecting the monitoring stations and sampling points in the lagoon system, present the seasonally measured nutrient data in the most visualised manner through aid of GIS. Queries will be conducted and evaluations will be made according to the above-referred standards.

Visualisation and analyses of nutrient data by means of GIS

In order to better visualise the seasonal variation in nutrient data both spatially and temporally, Arc View desktop GIS software has been chosen to map out the data. Arc View 3.2 is used to map out the specific TN and TP data at each of the 16 stations listed in Table 3. TN and TP data were chosen as the basis of the interpolation. Sampling and monitoring stations have been transformed to a shape file as a first step. The next step was to take all data tables from MS Excel and import them separately for the surface and bottom layer data into Arc View. The final step was to interpolate the grid for the five cruise data. Interpolate grid is a global function which creates a grid that stores values interpolated from a point feature data set (Seker *et al.*, 2001). Therefore, it will be easy to determine the nutrient fluctuations during different times of the study.

In this study, only the visualised forms of Cruises 3 and 5 are given as examples presenting the summer and winter conditions of the lagoon system, where each cruise data are separately visualised for surface and bottom layer conditions in terms of both nutrients, TN and TP. As referred previously, the dual layer flow in the system necessitated the analyses of both layers individually. As seen from the legend of the visualised maps, 5 different concentration ranges are chosen to demonstrate and to analyse the current situation of the system. As a general evaluation, it can be stated that the trophic state of the main channel and of the two lakes tend from oligotrophic state to mesotrophic state according to OECD classification criteria, and can still be utilised for various beneficial means according to the National classification for both of parameters, TN and TP. The seasonal fluctuation pattern indicates the expected results and correlate well with the typical occurrences worldwide. In terms of TN, spring concentrations are higher compared to the other seasons, followed by winter, autumn and summer. The higher bottom layer concentrations of TN perform a similar trend seasonally which may be due to accumulation of particulate N near the bottom layer as the main source of nitrogen is fertilisers.

However, there is not such significant variation in TP values among the seasons and even between the two layers. It is easily observed from the visualised maps that the concentrations of excess nutrient loads where a majority arise as non-point pollutants are closely related to the land-use type of the watershed and the net precipitation values indicating rainfall conditions and irrigation effects.

Table 3 TN and TP data for all the cruises according to the Stations

		Cruise 1	Cruise 2	Cruise 3	Cruise 4	Cruise 5	Cruise 1	Cruise 2	Cruise 3	Cruise 4	Cruise 5
Station	Depth	TN	TN	TN	TN	TN	TP	TP	TP	TP	TP
	(m)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
st.0	0,5		0,5745	0,1602	0,5390	0,5040		0,0117	0,0087	0,0175	0,0087
	4		0,6330	0,2698	0,2730	0,5950		0,0119	0,0110		0,0096
st.1	0,5	0,4378	0,7350	0,3205	0,3850	0,5250	0,0191	0,0229	0,0155	0,0105	0,0144
	3	0,2526	0,6933	0,2171	0,2170	0,5740	0,0358	0,0127	0,0176	0,0218	0,0134
st.2	0,5	0,2863	0,8167	0,2576	0,4270	0,5250	0,0260	0,0167	0,0112	0,0202	0,0120
	3	0,1540	0,4270	0,2576	0,5670	0,5530	0,0205	0,0066	0,0140	0,0253	0,0153
st.3	0,5	0,2237	0,6697	0,2495		0,5320	0,0205	0,0137	0,0152	0,0135	0,0149
	2	0,2189	0,5791	0,2759	0,3430	0,5460	0,0191	0,0128	0,0148	0,0356	0,0150
st.4	0,5	0,2814	0,6992	0,2556	0,2730	0,5530	0,0497	0,0121	0,0147	0,0159	0,0150
	3	0,3440	0,7844	0,2708	0,2870	0,3780	0,0205	0,0280	0,0127	0,0121	0,0161
st.5	0,5	0,2321	0,7110	0,2800	0,5040	0,4200	0,0177	0,0086	0,0093	0,0117	0,0138
	1,5	0,1997	0,7826	0,2242	0,4060	0,5740	0,0302	0,0119	0,0091	0,0106	0,0154
st.6	0,5	0,2381	0,6178	0,3205	0,4340	0,5950	0,0205	0,0079	0,0154	0,0153	0,0115
	2,5	0,1540	0,4500	0,1866	0,2100	0,4760	0,0177	0,0040	0,0055	0,0099	0,0224
st.7	0,5	0,1924	0,6211	0,2657	0,6440	0,6020	0,0191	0,0287	0,0138	0,0126	0,0113
	2,5	0,1395	0,6537	0,2089	0,2030	0,4200	0,0247	0,0127	0,0113	0,0141	0,0156
st.8	0,5	0,3416	0,8404	0,4585	0,3920	0,4480	0,0219	0,0136	0,0138	0,0155	0,0106
	2	0,2526	0,6506	0,3530	0,3080	0,3570	0,0191	0,0075	0,0105	0,0171	0,0081
st.9	0,5	0,2718	0,7497	0,3084	0,5390	0,4410	0,0330	0,0072	0,0093	0,0146	0,0132
	2	0,2550	0,8641	0,3165	0,5950	0,5075	0,0162	0,0065	0,0102	0,0177	0,0187
st.10	0,5	0,2935	0,6210	0,2962	0,7070	0,5810	0,0203	0,0172	0,0142	0,0175	0,0112
	3,5	0,2694	1,3254	0,2759	0,4690	0,8960	0,0191	0,0179	0,0146	0,0179	0,0246
st.11	0,5	0,9454	0,6127	0,3205	0,5670	0,6160	0,0149	0,0034	0,0155	0,0193	0,0094
	6	0,7722	3,1873	2,1142	1,3020	1,0850	0,0497	0,0187	0,0420	0,0179	0,0246
st.12	0,5	0,3007	0,7197	0,3084	0,5565	0,5880	0,0149	0,0050	0,0151	0,0148	0,0090
	3	0,3536	1,5173	0,2475	0,5530	2,7160	0,0247	0,0183	0,0180	0,0168	0,2232
st.13	0,5	0,1636	0,5265	0,2455	0,1680	0,5670	0,0189	0,0156	0,0122	0,0134	0,0127
	1,5	0,1708	0,7751	0,2028		0,6020	0,0163	0,0103	0,0088	0,0069	0,0111
st.14	0,5	0,1973	0,5300	0,1197	0,4270	0,4270	0,0176	0,0147	0,0061	0,0069	0,0040
	1,5	0,1491	0,3752	0,1217	0,1645		0,0122	0,0044	0,0077	0,0067	
st.15	0,5		0,5495	0,2860	0,3780	0,4970		0,0061	0,0140	0,0188	0,0085
	2		0,6880	0,1095	0,2870	0,7630		0,0106	0,0050	0,0150	0,0176

The analyses of Figure 3 and 4, given as examples of visualised maps for two seasons, indicate that TN at surface layer generally vary between 0.188-0.255 mg/L and 0.503-0.540 mg/L in summer and winter, respectively. The bottom layer values vary between 0.112-0.509 mg/L in summer and between 0.364-0.832 mg/L in winter. This fact points out that the most stable condition prevails during summer where no precipitation and very high evaporation was detected. Fresh water feeding the system either through direct rainfall, surface run-off or through rivers is the significant transport agent carrying excess nutrients. The trophic state of the summer conditions state oligotrophy, however, the winter conditions tend to present mesotrophic state in terms of TN. TP values at surface layer generally vary between 0.010-0.014 mg/L and 0.008-0.013 mg/L in summer and winter, respectively. The bottom layer values vary between 0.005-0.020 mg/L in summer and between 0.008-0.051 mg/L in winter. As such, no significant fluctuation is detected between layers and seasons. Similarly, the TP values refer to the OECD classification as tending towards mesotrophic state in all the seasons. It is important to note that any changes on agricultural activities will directly affect the water quality in terms of TN and TP.

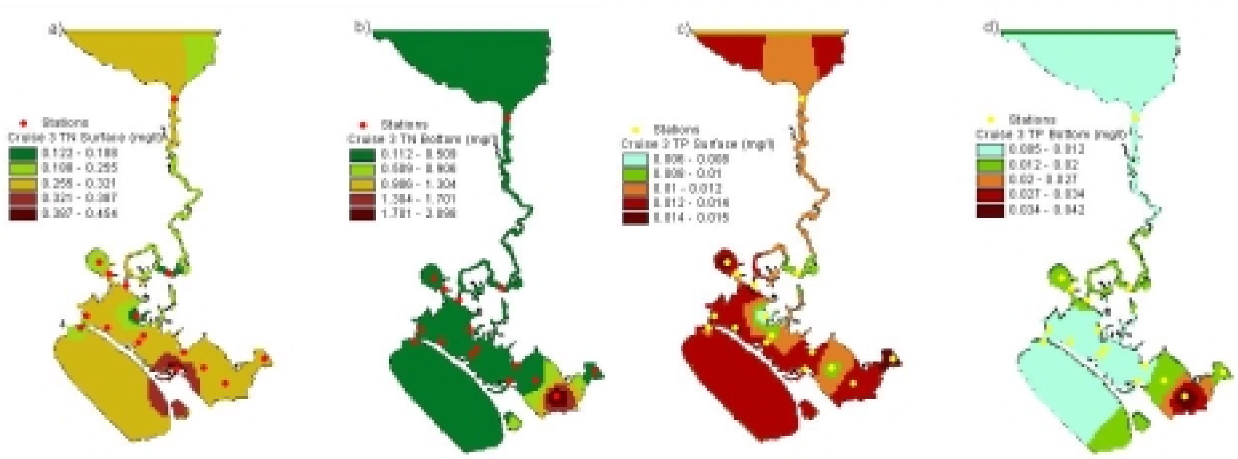

Figure 3 Visualisation of Cruise 3 TN and TP Data

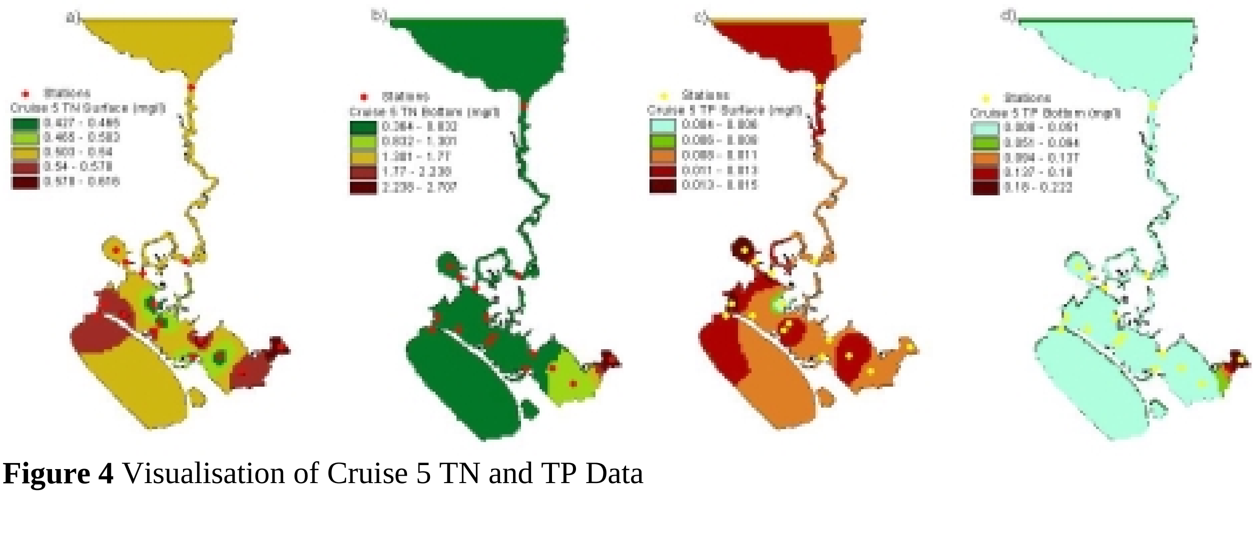

Figure 4 Visualisation of Cruise 5 TN and TP Data

Thus, monitoring the land use changes is so important to assess its impact on water quality in future (Meissner et al., 1999).

CONCLUSIONS AND RECOMMENDATIONS

Visualisation and analyses of water quality parameters through GIS aid to better understand the prevailing situation in the target areas and compare the findings with current regulations as attempted in this study, and to establish pollution scenarios and their outcomes by varying the degree of parameters which will further form a basis for pollution abatement and waste allocation. However, such studies may be further enriched by utilising long-term water quality measurements and may be enlarged by linking the land-based pollutants by the water quality data in the same visualised map. The concentration and the load of non-point sources are closely related to land use type of the watershed and meteorological conditions. The transformation of land data like land use distribution, soil characteristics, climatic conditions into GIS and evaluation of water quality simultaneously will enlighten modellers, managers, decision-makers and local authorities responsible for management of especially sensitive coastal areas for establishing precautions to be taken against pollution.

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