Journal of Marine Biology and Aquatic Research
Volume 1 | Issue 1

Case Report Open Access

Mapping Water Quality by Using Geostatistical Method (Marmaris Bay, Mugla, Turkey)

Kaymaz SM*

MuglaSitkiKocman University, Fisheries Faculty, Aquatic Science Department, Mugla, Turkey

***Corresponding author:** Kaymaz SM, MuglaSitkiKocman University, Fisheries Faculty, Aquatic Science Department, Mugla, Turkey, Tel: +905553440639, E-mail: seyma.merve87@gmail.com

Citation: Kaymaz SM (2018) Mapping Water Quality by Using Geostatistical Method (Marmaris Bay, Mugla, Turkey), J Marin Biol Aqua Res 1(1):103

Abstract

In this study, low cost spatial and temporal in-situ measurement and water quality parameters of Marmaris bay are collected thought the coastal. The bathymetry of the Marmaris bay is mapped according to depth sonar measurement. Tothisaim, both *insitu*measurements and laboratory analyses of main physicochemical parameters collected from 18 different stations during autumn 2015 at depths were analysed by Empirical Bayesian Kriging (EBK) interpolation method. The results confirmed the findings of the other analyses and can be explained considering that the data refer only to autumn season and to depths and that they were used as a further example of data GIS modelling analyses. The results reveal that Total Dissolved Solid (TDS) value is equal to 27.55 mgL^{-1} in station 3 and Ammonium is equal to 0.057 mgL^{-1} in station 9. According to Turkish Water Quality Control (TWQC) standards for marine the TDS and Ammonium are closed to the limits values ($TWQC_{TDS\text{-}limit}$=30 mgL^{-1}, $TWQC_{Ammonium\text{-}limit}$=0.02 mgL^{-1}).

Keywords: Mapping; Geostatistic; Water Quality; GIS; Marmaris Bay

Introduction

Water quality can be characterized by means of the main chemical, biological physical or aesthetic (for example appearance and smell) features. The quality of waters, traceable components and features can be affected by many different factors: bacteria, algae, temperature, turbidity, suspended and dissolved solids, salinity, pH, dissolved oxygen, phosphorus and other nutrients such as nitrogen and also organic and inorganic compounds [1].

The traditional environmental monitoring includes the measure of the main parameters useful to evaluate the general environmental quality status. The researches carried on in the past years have typically focused on the measurement of physical-chemical parameters but only a few considered also biological variables. Today this traditional approach is still used in many countries and the basic measurements of water aquatic systems comprehend water temperature, salinity, oxygen concentrations, nutrients and some chemicals such as heavy metals. These parameters are useful to provide information on environmental quality differences and can be easily measured [2]. Nevertheless, traditional field-based water quality samplings have spatial and temporal restrictions.

Studies on the marine pollution evaluation have gained a new dimension thanks to the application of these advances in GIS. The most important parameters for pollution that can be mapped by means of GIS methods are total suspended solids, chlorophyll concentration and sudden temperature changes in seawater [3-5].

Geographic Information Systems for lands were launched about 35-40 years ago, however it was only about 15 years that they were also applied to the sea [6]. Combined analysis of several datasets in a GIS environment provides meaningful information for natural processes. The depiction of the analysed data in some type of display such as maps, graphs, lists, reports or summary statistics provides for the communication media of GIS results or outputs

Our ability to measure change in oceans and along coasts is increasing, not only because of improved measuring devices and scientific techniques, but also because new GIS technology is helping us better understand the marine environment[7]. In this study, a new interpolation method (Empirical Bayesian Kriging) is used to map depth and water quality parameters to assess water quality change in Marmaris Bay, Mugla, Turkey. At today the satellite's data are starting to be applied worldwide for monitoring of sea water pollution and nowadays remotely sensed data has brought global solutions of great interest for the monitoring of environmental pollution.

Wright and Bartlett (2000) recognized the peculiar contribution of GIS in the study of coastal and oceans proposing new ways of georeferenced data processing [8]. They emphasized the passage of the first GIS applications to the ocean that were simple tools for collection of data and display toward more complex integrated modelling and visualisation tools. They also remarked the primitive steps at which 3D GIS visualisation and volumetric GIS analysis is to date, underlining that marine GIS must first adapt to the characteristics of the marine world and marine data and then output results that describe the dynamic relations among the various components of the marine environment.

Today, the marine geographical interpretation by means of GIS became a key tool in the field of marine policy making, planning and conservation. The study aims to develop effective and low cost spatial / temporal water quality's maps with the purpose to monitoring sample the ecological quality throughout Marmaris Bay and in order to provide a useful instrument for the protection of such a this kind of environments. This will be reached by using multivariate statistical methods, based on spatial water quality monitoring and Geographic Information System (GIS).

The developed maps will comprise the entire Bay of Marmaris and they will permit to measure the amount of pollution of rivers and streams that feed the bay in a very short time and with high accuracy. This will also allow a continuous monitoring of the quality values at low cost along the Bay. The study results will permit to accurately and effectively maintain the protection of ecological quality and a continuous monitoring of the bay. Moreover, the maps developed in this study, could be also applied to different regions. This will allow the development of scientific methods, such as to lead to the emergence of new management tools. With the results obtained by the study, it will be possible to ensure a sustainable control of the existing activities in the study area (fishing, water sports, excursion boats, sea traffic) and evaluate their potential negative effects without damaging the marine creatures. In-situ observation, laboratory analysis and spatio-temporal maps using by GIS pollution and the calibration results obtained from water quality control standards. So, besides an effective environmental management, these case studies will serve as a source to monitor the area and promote its ecologically sustainable development. The result of studies also expected to be highly effective in ecological studies and investment decisions in the future. This study will represent a model for other Turkish coastal and marine areas. A lack in the Turkish marine areas and EBK (is the one of geostatistical methods) for interpolation of water quality parameter provided the main interest of this study.

Study Area and Data

Marmaris is a coastal city located in the district of Mugla (Southern-West of Turkey). Mugla coastline extends along 1124 kilometres and it is characterized by numerous isolated coves and bays making Mugla and Marmaris a popular summer place for the yachtsmen and sailors. Marmaris is considered as a pearl within the Mediterranean Sea due to its precious nature. Its surroundings, long coastline, outstanding landscape of pine-covered hills, isolated bays and inlets, beautiful beaches, presence of ancient sites and famous marinas attract many tourists and currently Marmaris is a famous centre for yacht tourism and blue voyage throughout Turkey [9].

For centuries since the ancient times Marmaris has been a famous coastal center of the trade market due to its strategical geographical position being located between the Aegean and Mediterranean Sea. The first settlements in Marmaris were dates on about 3400 BC with the arrival of a tribe in the region but to date it is not certain the exact date of foundation of Marmaris, but the city was known as Physkos in the 6th century BC and it was part of the Caria. Netsel marina is the most popular in Marmaris and also the best serving marinas among the Mediterranean coasts. This marina provides weather protection for over 750 yachts every year. Other famous marina is Albatros located on the East of the cove (Yalancı Straits) and it mostly serves for the charter firms having a capacity of 60 only boats. Marina has a careenage capacity of 240 yachts and boats on land. In addition to these areas, there are a lot of small and large boats in the Marmaris Municipality Marina. Marmaris hosts International Race week (in late October and early November), International Marmaris Yacht Festival (in mid-May) and Marmaris Yacht Charter show (in May) every year. Also, there is a leachate treatment plant in Marmaris (Mariç-Belbir). And a lot of fresh water resources feeding the MarmarisBay. With the simple in-situ measurement and laboratory analysis, it will be possible to ensure a sustainable control of the existing activities in the study area (fishing, water sports, excursion boats, sea traffic) and evaluate their potential negative effects without damaging the marine creatures. In this study 18 sample points (depth water) are selected close to coastal line. The measured locations in-situ and laboratory measurement data are shown in Figure1. Figure 1 also represents the location and reconstructed bathymetry map of the study area.

The data were collected monthly from September to November 2015. The samplings in the selected stations from the Marmaris Bay were carried on monthly. In every sampling station, a sample of water was collected from the depth put into 500 ml containers and stored in cold conditions for all the duration of analyses. The main physical parameters (salinity, water temperature, pH, conductivity, dissolved oxygen) were measured in situ during field work by YSI 556 MPS (Multi Probe System). Water samples were then brought to the Freshwater and Marine Biology Laboratory of Fisheries and Aquaculture Faculty of MuğlaSıtkıKoçman University where the main chemical parameters (nitrite, nitrate, ammonium, phosphate, chlorophyll-a) were measured by the support of chemical kits (HACH) and then analysed by a spectrophotometer.

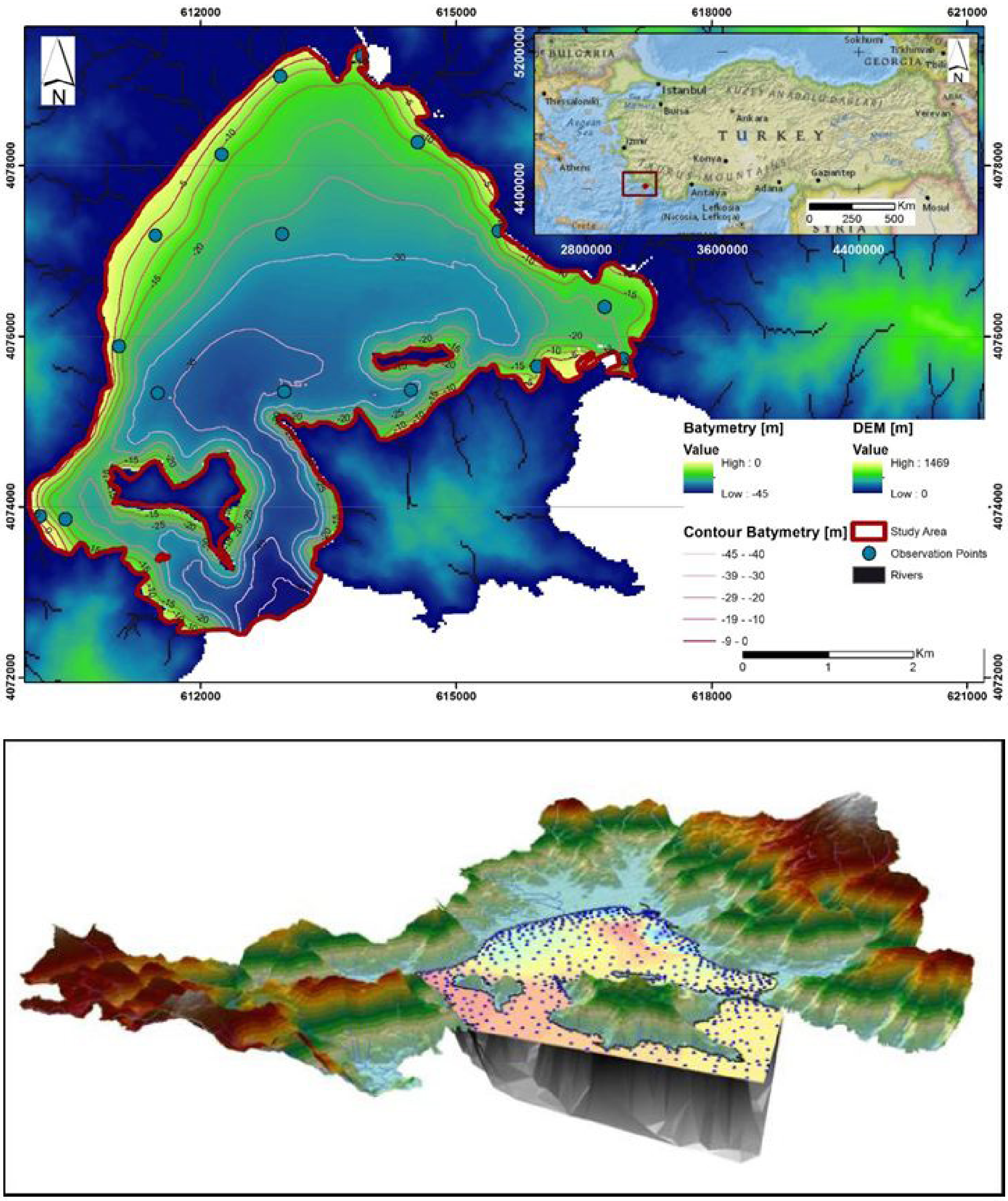


Figure 1: Study Area and Bathymetry map

Materials and Methods

The research methodology carried out during the thesis period consisted of several steps:

1) Observation and Field Works: The suitable stations for the scope of this research were selected trying to characterize the whole study area and considering working conditions. In total 18 stations, distributed throughout the Marmaris Bay, were selected.

2) Laboratory Parameters Analyses: The series of data of chemical kits were applied. The samplings in the selected stations from the Marmaris Bay were carried on autumn season and in every sampling station, a sample of water was collected from the depth then put into 500 ml containers and stored in cold conditions for all the duration of analyses. The main physical parameters (salinity (S), temperature (T), pH, electrical conductivity (EC), dissolved oxygen (DO) was measured *in situ*during field work by YSI 556 MPS (Multi Probe System). Water samples were then brought to the Freshwater and Marine Biology Laboratory of Fisheries and Aquaculture Faculty of MuğlaSıtkıKoçman University where the main chemical parameters (nitrite, nitrate, ammonium, phosphate) were measured by the support of chemical kits (HACH) and then analysed by a spectrophotometer. The data collected in 2015 the kit HACH were utilized. Theresults of analysis were evaluated by Turkish water quality standards for marine criteria (Table 1.1)

3) Elaboration of Statistical Modelling: The results of the laboratory analyses and the data collected in the field were then integrated and examined by means of statistical models to allow the estimation of the ecological quality of the Marmaris Bay as a function

Stations	North	East	Location
S1	36.852	28.278	S1 is sensitive area where has tour boats and private yachts. This station is between Marmaris Municipality Marina and Netsel Marina. This station is fed by a river "Karadere".
S2	36.843	28.285	S2 is located near the Albatros Marina.
S3	36.833	28.295	S3 is closely two hotels.
S4	36.825	28.309	S4 is closely to one river mouth and hotel marina where the circulation area is less.
S5	36.820	28.311	S5 is in the MarmarisYatch Marina.
S6	36.819	28.300	S6 is between small marina and MarmarisYatch Marina.
S7	36.833	28.283	S7 is located far from Marmaris city center about 2.49 km.
S8	36.842	28.275	S8 is located far from Marmaris city center about 1.24 km.
S9	36.850	28.267	S9 is nearby joint influence mouth of Kanlicreek and Beldibi creek
S10	36.842	28.259	S10 is located around public beach and Marmaris Water park
S11	36.833	28.267	S11 is located open water.
S12	36.817	28.283	S12 is between Bedir island and beach club.
S13	36.817	28.267	S13 is located InceBurun lighthouse where is located on Star Island. For open water diving, underwater visibility is low and interesting dive point.
S14	36.833	28.250	S14 is located near coastal area where is Icmeler Region.
S15	36.822	28.245	S15 is located near Coastal area where is Icmeler and there is a dolphin park and hotels around station.
S16	36.817	28.250	S16 is located near Coastal area.
S17	36.804	28.238	S17 is located in Small straith.
S18	36.804	28.234	S18 is located in Small straith. This station is in near publich beach where is between two rivers mouth and pier.

Table 1. Stations Coordinates and location.

Parameter	Criterion
pH	6.0-9.0
Total Dissolved Solid (mg/L)	30
Dissolved oxygen (mg/L)	Saturation more than 90%
Ammonia (mg/L)	0.02

Table 1.1. Water Quality Standards for Marine

of time and location. Specifically, a preliminary step consisted in the validation of the data set to be used for GIS analysed. This step comprised the following statistical modelling approaches carried on using Statistica STAT 10 software: Principal Component Analysis (PCA), Factor Analysis and Multivariate Analysis (MVA).

4) Spatial Prediction and Predicted Error Maps Determination using EBK: The interpolation method requires a normal distribution of data. Then a preliminary step was to test the normality distribution of data by means of Kolmogorov-Smirnov and Shapiro-Wilk normality tests. These tests compare the empirical cumulative distribution of the data sample with an expected distribution (normal in this case). A value of $p<0.05$ was chosen to reject the null hypothesis of un normal distribution.

Kriging consists in a group of statistical techniques use for optimal spatial prediction. The Kriging was firstly developed by Lev Gandin (1959) (Szentimrey et al., 2007) as application to for meteorology [10]. Then its utilization was applied to other disciplines, including agriculture, mining, and environmental sciences. Kriging is a probabilistic predictor characterized by a small prediction uncertainty than other prediction models, the ability to filter out measurement errors, and by using information on the correlation between the variable of interest and covariates. Kriging uses a single semivariogram - a function of the distance and direction separating two locations - to quantify the spatial dependence in the data. Every semivariogram can be drawn by calculating half the average squared difference of the values of all the pairs of measurements at locations separated by a given distance h that is plots on the y axis. The semivariogram is calculated by the following equation (1).

$$\gamma(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}\left\{z(x_i)-z(x_i+h)\right\}^2 \quad (1)$$

Where;

γ (h) = the experimental semivariogram value at a distance h
N (h) = the number of sample value pairs within distance h
Z (x_i), Z (x_i + h) = the sample values at two points separated by distance h.

All pairs of points separated by distance h (lagh) were used to calculate the experimental semivariogram.

In this study, a new method of Kriging was used. Empirical Bayesian Kriging (EBK) method was mentioned in the literature more than a few years ago [11-13]. EBK is a method of geostatistical interpolation that automates the difficult of building a valid kriging model. Other kriging methods require one to manually adjust model parameters, but EBK automatically calculates these parameters through a process of sub-setting and simulations [11, 14].

Empirical Bayesian Kriging (EBK), an improved method of classical kriging that allows estimating several semivariogram models and used this with semivariogram models to interpolate the data based on Bayes rules. Bayes' rule is an important issue that is examined in probability theory [15]. This theorem shows the relationship between conditional probabilities and marginal probabilities within a probability distribution for a random variable. With this form Bayes' rule explains a relationship that is accepted for all statisticians. For this concept, Bayesian rules names are used. But for some statisticians, Bayes' rule also carries a special stress. There is a certain relationship between two opposite conditionals, and this relation is called the Bayes rule[16,17]. Empirical Bayesian Kriging method diverges from the other classic kriging methods because account for the error introduced by estimating the semivariogram model by using many semivariogram models rather than a single semivariogram. This process can be resumed in the following steps: Firstly, a semivariogram models were estimated from the measurement data. Secondly, use of the estimated semivariogram, to simulate a new value for the input data locations. Thirdly, a new semivariogram model was estimated from the simulated data and calculated its weight using Bayes' rule, which shows how likely the observed data can be generated from the semivariogram [18]. EBK interpolation results for samples and its errors maps according to calculated 100 semi-variograms. EBK method has also shown its strength side to find the best variogram and reduce the error in map prediction.

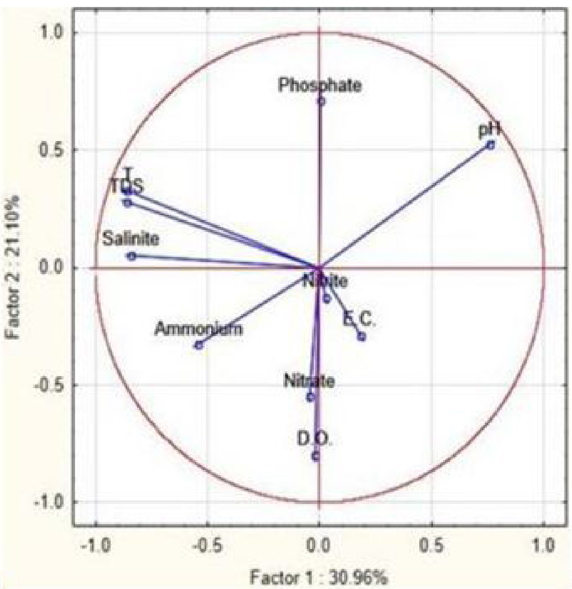
Thus, the current water quality of the bay will be available as visual and spatial distribution maps. Moreover, the analysis of the data will allow identifying the potential pollution inputs to the bay and the more critic zones. The results obtained will allow predicting the need of specific future monitor plans focusing only on the specific parameter that require more attention.

Results

Principal Component Analysis

a)

	Eigenvalue	% Total variance	Cumulative eigenvalue	Cumulative %
Factor 1	3.095518	30.95518	3.09552	30.9552
Factor 2	2.110399	21.10399	5.20592	52.0592



b)

c)

	Factor 1	Factor 2
T	-0.859852	0.325455
pH	0.761211	0.523448
D.O.	-0.018664	-0.798503
Salinite	-0.841159	0.052097
E.C.	0.181096	-0.288362
TDS	-0.859976	0.276736
Nitrite	0.026371	-0.125615
Nitrate	-0.046065	-0.549679
Ammoniun	-0.541903	-0.327686
Phosphate	0.001314	0.710718

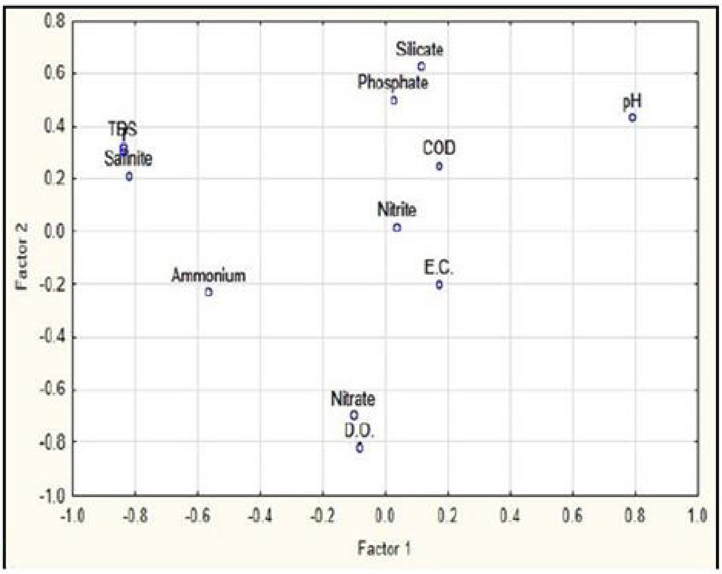
Figure 2.1: a) Eigenvalues of correlation matrix related statistics, b) Projection of the variables on the vector plane and c) Factor-variable correlations of the Principal Component Analysis (PCA) for the data of 2015 collected on depth.

Figures 2.1 showed the results of the PCA calculated by using the data series of 2015 separated for depth: (Figure 2.1). The PCA calculated for the data of depth collected in autumn 2015 showed a cumulative variance of 52.06%. Factor 1 explained the highest overall variability (30.95%) whereas the factor 2 explained only the 21.10% (Figure 2.1a). The diagram of PCA showed a close position of Temperature (T), Total Dissolved Solid (TDS) and Salinity (S) (Figure 2.1b). By the correlation coefficients values of the parameters with factors (Figure2.1c), Temperature (T), Dissolved Oxygen (DO), Salinity, TDS, Nitrate and Ammonium resulted inversed correlated with factor 1 whereas Nitrite, Phosphate, Electrical Conductivity (EC). And pH showed a positive correlation with factor 1.

Factor Analysis

The results of factor analysis calculated for the data of depth collected in autumn 2015 showed a close position of T, TDS and Salinite (group 1), silicate and phosphate (group 2), nitrate and D.O. (group 3) (Figure 2.2a). By the correlation coefficients values of the parameters with factors T, Salinite and TDS resulted inversed correlated with factor 1 whereas pH showed a positive correlation with factor 1 and significant negative correlation of D.O. with factor 2 (Figure 2.2b).

a)



b)

	Factor 1	Factor 2
T	-0.839096	0.305764
pH	0.790380	0.435881
D.O.	-0.081997	-0.815073
Salinite	-0.822754	0.215648
E.C.	0.172232	-0.197740
TDS	-0.838196	0.322987
Nitrite	0.037780	0.018509
Nitrate	-0.100656	-0.695196
Ammonium	-0.566082	-0.229352
Phosphate	0.026047	0.503216
Silicate	0.111600	0.631587
COD	0.172239	0.251567
Expl.Var	3.119473	2.389410
Prp.Totl	0.259956	0.199118

Figure 2.2: a) Projection of the variables on the vector plane, b) Factor-variable correlations of the Factor Analysis for the data of 2015 collected on depth.

Multivariate Analysis

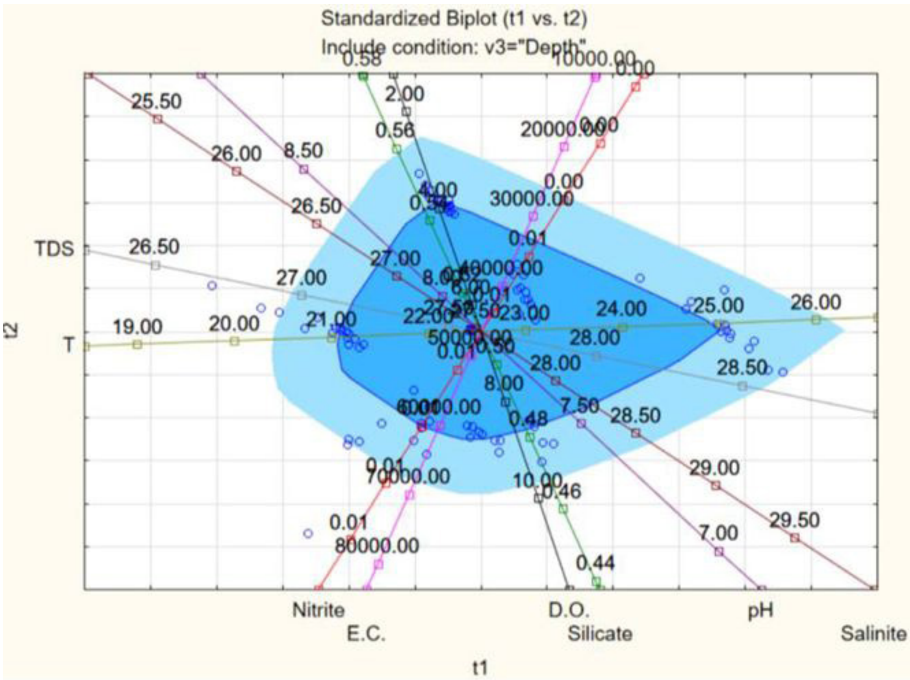


Figure 2.3: Projection of the variables on the vector plane of the Multivariate Analysis for the data of 2015 collected on depth.

The results of Multivariate Analysis calculated for the data of depth collected in autumn 2015 showed a close position of T and TDS (group 1), silicate and D.O (group 2), nitrite and E.C. (group 3) (Figure 2.3). The results confirmed the findings of the other analyses and can be explained considering that the data refer only to autumn season and to depths and that they were used as a further example of data GIS modelling analyses.

Spatial Interpolation Maps of Data Collected in 2015 on Depth

Figures 2.4 reported the maps for the EBK prediction and their standard error for the main parameters for depth seawater samples collected in autumn 2015. The analyses were done using 100 semi-variograms. The spatial estimated annual maps of seawater

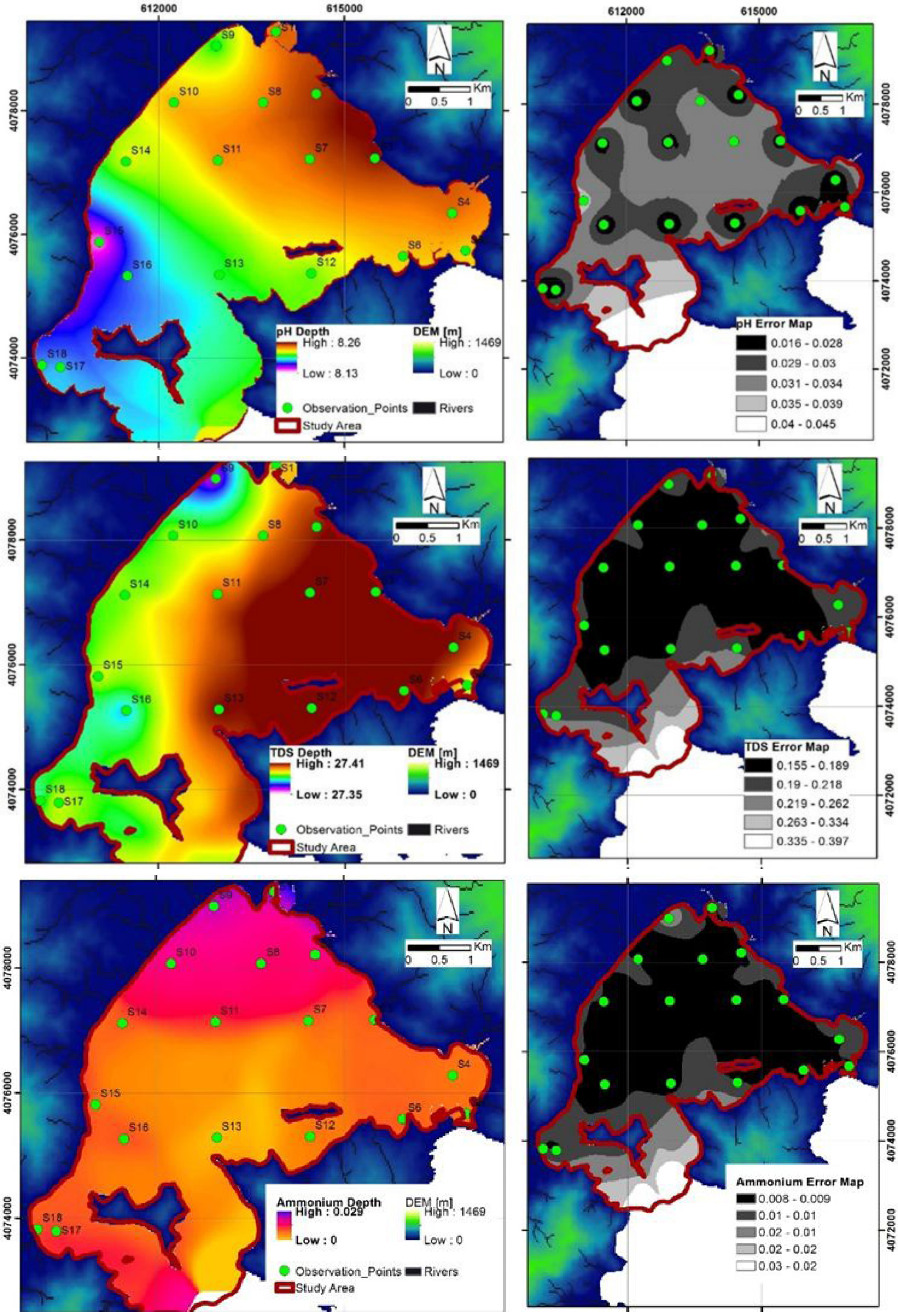


Figure 2.4: EBK interpolation and error maps for pH, TDS and Ammonium

temperature, pH, salinity, E.C and T.D.S, and in this case also for dissolved oxygen, marina areas, around marina's coastal zone and river-mouths reported the lowest values during autumn periods.Thehighest predicted Nitrite Nitrogen was in Marmaris city center area. Spatial estimated Nitrate Nitrogen value was highest in Icmeler Region. Ammonium Nitrogen value resulted highest in Icmeler and Marmaris city center stations. The highest Phosphate value was estimated in Marinas region. Spatial prediction of Silicate and C.O.D showed the lowest values in marinas region and coastal zone. Figure 2.4 show preliminary TDS, ammonium and pH EBK interpolation results for depth samples and its errors maps according to calculated 100 semi-variograms. The results presents us that in depth of Marmaris Bay (near the station 9) there is a possible domestic waste / agriculture influence. Ammonia is known to contribute to eutrophication thus should be given an emphasis in regulating the water quality.

Discussion and Conclusion

Several types of tools are currently available to characterise seawater such as *insitu* and laboratory measurements, mapping and modelling. Geographical and spatial processes analyses can provide different results on the basis of the spatial data that has been selected by the scientists. Another important variable for the studies related to geographical information sciences and statistical is the selection of scale that commends the utilization of quantitative methods to comprehend and analyse spatial patterns and processes. Particularly, in the researches using statistical method, the scale is determined by the spatial prediction [19-22]. The use of spatial-temporal prediction map can help explaining, predicting or evaluating natural processes and assists in the problem-solving step.

The present study aimed monitoring and modelling the ecological quality of Marmaris Bay with main attention on anthropogenic sourced on the environment, understanding of the pollution effects of the aquatic ecosystem, marinas and tourism effect on the Bay by investigating the main physicochemical parameters. Statistical analyses such as Principal Component Analysis, Factor Analysis, Multivariate Analysis and Regression model provide valuable information about relations among water quality parameters [23]. These calculations are widely used in image processing by GIS.Water discharges and quality (such as turbidity, salinity, electrical conductivity) parameters can change rapidly by means of heavy rainfall. For this reason, changes of these parameters during spring season can be used as main indicators of water quality and can be used for short or long term preventive planning. The physical parameters strongly influence all the components of the whole environment including the biological communities. Coastal water has more changeable water quality and readily effect of anthropogenic activities [24].

To this aim, both *insitu* measurements and laboratory analyses of main physicochemical parameters collected from 18 different stations during autumn 2015 at depths were analysed by Empirical Bayesian Kriging (EBK) interpolation method. In all selected stations seawater temperature values showed an increase in the marinas and coastal area. This trend was observed for the most of the parameters.The pH of the marine environment depends on temperature and the biochemical processes. The measured pH values showed changes but the general range was usually within the recommended pH average value of 7.80 reported by Ivanof (1972) and Ross (1979) [25, 26]. According to spatial predicted maps, an increase of pH was observed depending on tourism activities. Total Dissolved Solid measured of inorganic salts, organic matter and other dissolved materials in seawater [27]. The concentration and composition of TDS in waters is determined by the discharge, rainfalls and evaporation [28]. The available standards of utilizing TDS might be reconsidered monitoring particular ions in light of future risk evaluation.

Ammonium nitrogen values were high. This is related to the excessive use of coastal area. Marmaris is a semi-enclosed Bay where the most popular destination is vacation. Because of this, ammonium nitrogen values were observed as critical parameters for Marmaris Bay requiring a continuous monitoring. Marine research and environmental monitoring programs are important tools for the conservation and management of ecosystems. The results of this study confirmed the importance and validity of the use of spatial prediction maps to create models in order to estimate the ecological quality. More specifically, the estimated maps resulted to totally fit with the real data collected. This study, that was the first carried on within the Bays of South Turkey, represents a fundamental tool for the management of Marmaris Bay and it will be a precious source for similar studies. The data collected during the research represent a precious starting point for the creation of an integrated database that require a continuous updated and input of other data and information such as the real entity of touristic activities in the area (i.e. number of boat for seasons), fisheries data, status and density of fishes and marine organism populations throughout the Bay and other kind of information through the implementation of an integrated management of this marine Bay.

Acknowledgement

I would like to thank to Marmaris Environmentalist Association, ErsinAteş, Mustafa Özkan, Mehmet Kuzucu for their support and help in the field. I would like to express my special thanks of Mugla Sıtkı Kocman University. I owe more than a thank you to my dearest sister Betül KAYMAZ for her motivational support all the time.

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