The Need for the Integration of Land Use Planning and Water Quality Modeling in the Case of Fethiye Bay

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ABSTRACT

Different forms of land uses (e.g. agriculture, tourism, recreational, industrial, housing) have detrimental impacts on water bodies (e.g. rivers, lakes, coastal waters). Thus, comprehensive land use plans developed integrating water quality models would certainly provide better solutions for the sustainability of natural water resources. In this study, the inner bay of Fethiye, located along the south-west coast of Turkey, is selected as a case to identify the land use and water quality relationship. At six locations in the Bay, various physical and chemical parameters (e.g. temperature, density, salinity, pH, concentrations of dissolved oxygen, nitrite, nitrate and total dissolved solid) were monitored by monthly field and laboratory measurements for four months during summer and autumn seasons. The measured nitrite, nitrate and dissolved oxygen concentrations were then compared with the estimations of the water quality sub model of HYDROTAM-3D, which is an implicit baroclinic 3D numerical model developed to simulate hydrodynamics, transport processes and basic water quality parameters in coastal waters. The paper presents results on monitored water quality parameters and model estimations, and discusses the sea water quality of the inner bay of Fethiye emphasizing the impacts of land use patterns in the town.

Keywords: Water Quality, Ecological Model, Land Use, Fethiye Bay.

Kara Kullanımı Etkileşimli Su Kalitesi Modellemesine Gereksinim:Fethiye Körfezi Örneği

ÖZ

Arazi kullanım şekillerinin (tarım, turizm, rekreasyonal, endüstriyel, konut gibi) su kütleleri (akarsular, göller, kıyı suları gibi) üzerinde zararlı etkileri bulunmaktadır. Bu nedenle, su kalitesi modelleri ile bütünleştirilmiş kapsamlı arazi kullanım planlarının geliştirilmesi, doğal su kaynaklarının sürdürülebilirliği açısından çok daha iyi çözümler sağlayacaktır. Bu çalışmada, arazi kullanımı ve su kalitesi arasındaki ilişkiyi gösterir bir örnek olarak Fethiye iç körfezi seçilmiştir. Körfez içinde altı noktada, çeşitli fiziksel ve kimyasal parametreler (sıcaklık, yoğunluk, tuzluluk, pH, çözünmüş oksijen, nitrit, nitrat, toplam askıda katı madde gibi) yaz ve sonbahar mevsimlerinde dört ay için aylık olarak gerçekleştirilen saha ve laboratuvar ölçümleri ile izlenmiştir. Ölçülen nitrit, nitrat ve çözünmüş oksijen konsantrasyonları, daha sonra, baroklinik sayısal bir kıyısal su hidrodinamik, taşınım ve su kalitesi modeli olan HYDROTAM-3D altındaki su kalitesi modeli ile gerçekleştirilen tahminler ile karşılaştırılmıştır. Makalede, izlenen bazı su kalitesi parametreleri ve model tahminleri sunulmakta, ve Fethiye iç körfezi deniz suyu kalitesi, ilçedeki arazi kullanım özellikleri vurgulanarak tartışılmaktadır.

Anahtar Kelimeler: Su Kalitesi, Ekolojik Model, Arazi Kullanımı, Fethiye Körfezi.

1. INTRODUCTION

People depend on water resources for several aspects in daily life; agriculture, industry, well-being, etc. The protection of the long-term water quality and ecological integrity is, therefore, one of the long-term priorities. However, the quality of water all over the world is under continuous degradation due to various anthropogenic activities. Different forms of land uses (e.g. agriculture, tourism, recreational uses, industrial, housing) have detrimental impacts on quality of water bodies. The central concern for the protection of water quality is to reduce the flow of pollutants, and reverse some of the adverse environmental degradations of the past. This might be achieved by proper and applicable land use planning and management. Once the land–water relationship is identified, it leads to the need of protecting water quality through proper land-use planning by identifying cost-effective pollution prevention and pollution correction approaches that can address all the sources of pollution in a comprehensive way. Most planning agencies and local authorities do not have resources to collect extensive water quality data in developing the plans. However, a holistic approach to land-water relationship is certainly required. In this context, today, water quality models come out as a crucial tool. Integrating water quality models into land use planning would provide the development of comprehensive land use plans with better solutions to the

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conflicts between the economic and ecological interests, thus the sustainability of natural resources such as the water.

The ecosystems in coastal waters, especially in closed or semi-closed waters rely upon the complex interaction between the chemical and physical environment and the existing organisms. These ecosystems have very complicated dynamics due to the spatial and temporal variability of the parameters within the water body. Most of the marine ecological models aim to simulate the biological and chemical processes in marine environment to predict the water quality parameters, through which it is possible to define the ambient conditions. Beginning with the early marine ecosystem models, ecological processes are represented as a series of formulas driven from data assembled from field observations, e.g. [1-4].

There are several water quality models in literature developed for surface aquatic systems for different topography, water bodies, and pollutants at different space and time scales utilizing various model algorithms [5]. For instance, WASP models [6], QUAL models [7] and MIKE models [8] are among the widely used water quality models [5].

The water quality model utilized in this study is a component of HYDROTAM 3D, which is a three dimensional numerical hydrodynamic and transport model for coastal waters. Since 1990s, HYDROTAM 3D has been applied to many coastal areas in Turkey and has been verified by comparing the analytical and experimental results with the field studies [9-12]. The water quality sub model of HYDROTAM 3D is based on fundamental biological and chemical cycles of the organic matter and their relationship with the lower trophic levels in marine environment [13,14].

In this research study, inner bay of Fethiye has been selected as the coastal area to identify the land use and water quality relationship. Fethiye is one of the largest settlements and tourism destinations in Muğla Province. However, as pointed out by [15-17], the natural ecosystem of the bay in Fethiye has been damaged and its long-term sustainability is at risk. Pollution due to marina activities, yacht tourism, fisheries and houses, and also the irrigation canals and streams are observed to be the main sources affecting the biodiversity and ecological integrity and the siltation of Fethiye Bay. In the research, a monitoring study was carried out for the inner Fethiye Bay, to understand the water quality and dynamics of the Bay. At six locations determined in accordance with the aim of the study, various physical and chemical parameters (e.g. temperature, density, salinity, pH, concentrations of dissolved oxygen (DO), nitrite (NO_2^-), nitrate (NO_3^-) and total dissolved solid TDS) were measured by monthly field and laboratory measurements during summer and autumn seasons. Besides, utilizing HYDROTAM 3D, a water quality model has been prepared for the inner bay, and the measured nitrite, nitrate and dissolved oxygen concentrations have been compared with the model estimations.

2. MATERIAL AND METHOD

Water quality of the inner bay of Fethiye has been observed both through the field and laboratory measurements and also through the numerical model estimates as described in the following sub sections.

2.1. Study Area and the Main Sources of Pollution

The study area is the inner bay of Fethiye located at the south-eastern corner of Fethiye Bay, which is in the Eastern Mediterranean at the south-west coast of Turkey (Figure 1). While the Bay in general is at a location open to waves and currents from westerly directions, especially the south-west direction, the inner bay of Fethiye, where the town center is also located, is rather enclosed. The inner bay is connected to the open sea through the two openings between the mainland and Şövalye (Zeytin) island. The only possible water exchange for the inner bay is due to these two narrow openings. Therefore, being in such a protected location, the inner bay is not affected by the offshore currents, and, thus, it is quite vulnerable to pollution.

According to 2010 population census, the population of town center of Fethiye is 77237. With a population surpassing 100000 in the summer, the town is one of the biggest of Muğla Province [18]. Including the surrounding villages, total population reaches to 188259. In Fethiye, one of the main economic activities is tourism. There are around 180 bays along its 167 km coastline and 18 islands in the gulf. Besides the tourism, town economy also prominently depends on agriculture and animal husbandry activities. 55% of the population is involved in agriculture. Total agricultural area covers more than 64000 hectares where 60% of the area has irrigation farming features while 40% has dryland farming [19].

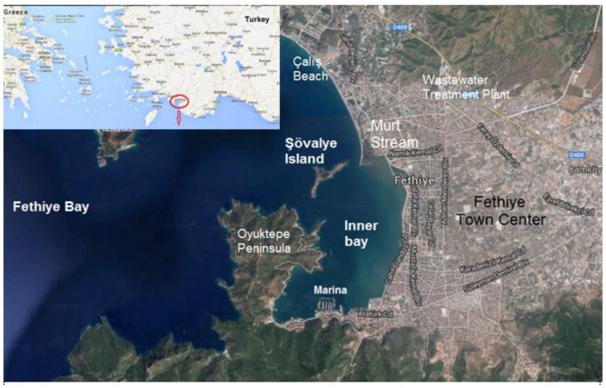

Figure 1. The study area (i.e. the inner bay of Fethiye). [20]

In the region, since the climate and physical features are suitable, mostly irrigation farming is practiced. Drainage water of the agricultural land is carried directly to the inner bay of Fethiye through Murt (Mersinli) stream and several other canals without any treatment. Thus, saline water rich in nitrate and phosphate directly flows into the inner bay of Fethiye through Murt stream and the canals.

Since 2003, Fethiye town has a wastewater treatment plant in operation. Wastewater collection network of the town center transmits the wastewater to this treatment plant which is at Çiftlik village site located east of Çalış Beach. After the treatment process, the treated water is discharged to Murt stream and together with the stream flows into sea at southeast of Şövalye Island. The settlements at western side of the bay and Şövalye Island, however, are not connected to the wastewater collection system of the town yet, and contribute to the pollution of the bay. Besides, waste discharged from the boats at Fethiye Marina and the other berthing locations inside the bay form the other pollution sources in the inner bay.

Consequently, the main sources of pollution for the inner bay of Fethiye can be listed as:

- Discharge through Murt stream which carries the discharged water from the wastewater treatment facility and the drainage water from agricultural activities in the plain,
- Discharge through other canals which carry the drainage water from agricultural activities in the plain,
- Domestic waste of settlements and tourism facilities which are not connected to the wastewater collection system,
- Wastewater due to the boats at Fethiye Marina and other berthing locations.

2.2. Field Measurements

In order to investigate the water quality parameters in the inner bay of Fethiye, firstly, six measurement locations to best represent the characteristics of the marine environment were selected (Figure 2). The measurement points of 1 and 2 were selected to represent the input water from the open sea to the inner bay. Point 4 is a measurement location selected to monitor the coastal water along the eastern coast of Oyuktepe peninsula which is relatively unsettled.

On the other hand, selecting the points 5 and 6, it was aimed to monitor the sea water quality of, respectively, the marina entrance and the outlet of the largest canal of the town center. Besides, selected at the mouth of Murt stream, point 3 was utilized to observe the effects of pollutants reaching to the sea by Murt stream due to wastewater discharged from the wastewater treatment plant and also the drainage water of agricultural activities.

At each measurement location, the physical and chemical water quality parameters (i.e. temperature, salinity, density, pH, concentration of the dissolved oxygen (DO), nitrite (NO_2^-), nitrate (NO_3^-) and total dissolved solid (TDS)) were monitored by monthly field and laboratory measurements at 0.5 m and 10 m depths from the surface for various months in summer and autumn seasons of the year 2014. The only difference related to the measurements exists for the points 3 and 6, where the measurements were carried out at 0.5 m and 3 m depths below the sea surface due to their shallower water depths.

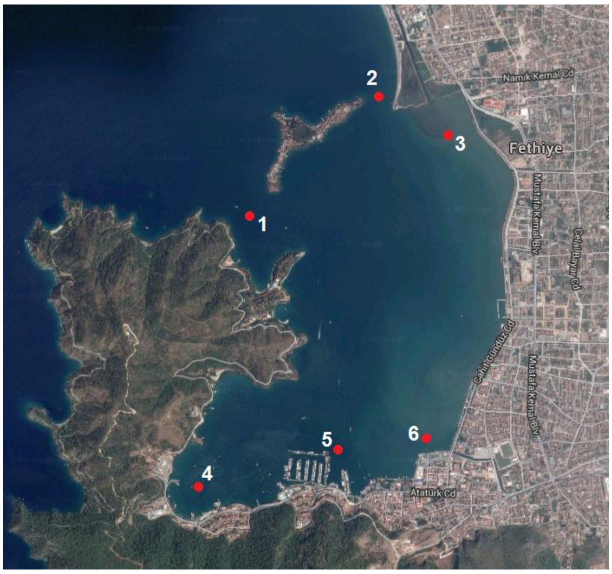

Figure 2. Measurement locations inside the inner bay. [20]

2.3. Modelling the Water Quality Parameters

In the study, besides the field measurements, a water quality model has been prepared and calibrated for the inner bay of Fethiye. The water quality model is a component of HYDROTAM 3D, which is a three dimensional numerical hydrodynamic and transport model for coastal waters. The model includes hydrodynamics, transport, turbulence, wind and wave climate, wave propagation and water quality sub-models, thus simulates circulation patterns due to wind and wave actions, pollutant transport, wave propagation over mild slopes, longshore sediment transport rates and water quality parameters. Since 1990s, HYDROTAM 3D has been applied to many coastal areas in Turkey and has been verified by comparing the analytical and experimental results with the field studies [9-14].

The water quality component of HYDROTAM 3D is an ecological model, based on fundamental biological and chemical cycles of the organic matter and their relationship with the lower trophic levels in marine environment. Model solves the conservation equations and formulations proposed by the United States Environmental Protection Agency [21]. It predicts the water quality parameters by using the formulations representing physical and biochemical mechanisms that also determine the position and momentum of contaminants in a water body and thus imitate the complex interrelations between the water quality parameters and the ecosystem. [13,14]

The rate of change of the water quality parameters are developed by assuming a homogenous distribution of all properties throughout the computational cell and can be generalized as:

$$\frac{\partial C}{\partial t} + \nabla \cdot (aC) = \sigma \tag{1}$$

where, σ is the sum of the internal sink and sources of the water quality parameter in mg/l/day.

For n number of neighboring computational cells, the formula can be extended as:

$$\frac{\partial C}{\partial t} = a_1 . \frac{\partial C}{\partial x_1} + a_2 \frac{\partial C}{\partial x_2} ... + a_n \frac{\partial C}{\partial x_n} + S_i - [K]C \quad (2)$$

where, C is the concentration of the water quality parameter in mg/l, a_i is the rate of exchange with neighboring computational cell in m/day, S_i is the source of pollution for cell "i" in mg/l/day, K is the internal rate of change of the water quality parameter [13,14].

Biochemical cycles simulated in the model are the cycles of nitrogen, phosphorus and oxygen. Organisms simulated in the model are the low trophic levels in aquatic environments i.e. phytoplankton, zooplankton and pelagic bacteria. A basic set of 14 parameters and organic pollutant types, listed in Table 1, are used to simulate closed or semi-closed water bodies [13,14].

Thus, in order to simulate the water quality properties of the study area, the water quality model has been adapted to the inner bay of Fethiye with the computational cell shown in Figure 3. The simulated water body is rather enclosed with a surface area of around 7649197 m^2 and a water volume of 85823990 m^3. The water exchange of this semi-enclosed region with the main bay is only possible through two openings, the sections 1-1 and 2-2, which have a total length of around 754 m. The cross-sectional area at 1-1 section is around 6258 m^2, and at 2-2 section, 2244 m^2.

Table 1. Parameters Simulated in the Model.

No	Parameters	Unit
1	Phytoplankton concentration	mgC/l
2	Zooplankton concentration	mgC/l
3	Bacteria concentration	mgC/l
4	Ammonia concentration	mgN/l
5	Nitrite concentration	mgN/l
6	Nitrate concentration	mgN/l
7	Particulate organic nitrogen concentration	mgN/l
8	Nonrefractory dissolved organic nitrogen concentration	mgN/l
9	Refractory dissolved organic nitrogen concentration	mgN/l
10	Inorganic phosphorus concentration	mgP/l
11	Particulate organic phosphorus concentration	mgP/l
12	Nonrefractory dissolved organic phosphorus concentration	mgP/l
13	Refractory dissolved organic phosphorus concentration	mgP/l
14	Oxygen concentration	mgO/l

Figure 3. Computational cell utilized for the inner bay of Fethiye to simulate the mean water quality parameters. [20]

Table 2. Wastewater budget and water exchange discharges utilized in the water quality model for the inner bay of Fethiye (m^3/day).

	June	July	August	September	October	November
Discharge through Murt (Mersinli) stream which carries the discharged water from the wastewater treatment facility and the drainage water from agricultural activities	27280	27280	27280	27280	27280	43200
Discharge through seven canals which carry the drainage water from agricultural activities in the plain	30240	30240	30240	30240	30240	60480
Domestic waste of settlements and tourism facilities which are not connected to the wastewater collection system	1050	1050	1050	1050	1050	2150
Wastewater due to Fethiye Marina and the boats berthing at other berthing locations	750	750	750	750	750	450
Water exchange with the open sea	476112	476112	476112	476112	476112	1326312

The required initial values of the water quality parameters to run the model were determined evaluating the results of the measurements. For instance, observations obtained at measurement point 1 were utilized as the initial values of the parameters for the offshore water entering the inner bay. However, the results of measurement point 2 were disregarded since it was too close to the mouth of Murt stream. Similarly, the results obtained at measurement point 3 were utilized as the initial values of the water quality parameters for the water entering the system through Murt stream.

The wastewater budget and the mean water exchange discharges utilized in the model runs for each month are presented in Table 2.

3. RESULTS AND DISCUSSION

Table 3 gives the averages of the measured water quality parameters; water temperature, dissolved oxygen, pH, salinity, total dissolved solid, nitrite and nitrate, obtained at points 2, 3, 4, 5 and 6 at a depth of 0.5 m below the sea surface. In Table 3, some of the parameters are missing, since they are found to be not reliable due to problems occurred in sampling and measurements, therefore they are not considered in this study. The given mean values of the parameters have been assumed to represent the inner bay of Fethiye in general for each of the corresponding measurement period of the study. However, the measurements of point 1 were assumed to represent the offshore water entering into the bay. Therefore, they were not included in the computation of the averages. Observing the parameters in the table, it is seen that the pH, salinity and sea water temperature values were in general in the standard ranges of the Mediterranean. For highly productive coastal and estuarine areas where naturally occurring pH variations approach the lethal limits of some species, changes in pH should be avoided but in any case should not exceed the limits established for fresh water, i.e., 6.5-9.0 [22].

The DO level represents one of the most important measurements of water quality and is a critical indicator of a water body's ability to support healthy ecosystems. Levels above 5 mgO/l are considered optimal, and most fish cannot survive for prolonged periods at levels below 3 mgO/l. In coastal waters, acute oxygen deficiency occurs when dissolved oxygen levels fall below 2.0 mgO/l. Anoxic or ‘no-oxygen’ conditions occur when levels fall below 0.2 mgO/l [23-25]. The dissolved

Table 3. Average water quality parameters measured in the inner bay of Fethiye at a depth of 0.5 m below the sea surface.

Date of Measurement	Sea Water Temperature (°C)	Dissolved Oxygen (mgO/l)	pH	Salinity (ppt)	Total Dissolved Solid (g/l)	Nitrite (mgN/l)	Nitrate (mgN/l)
06.06.2013	25.02	5.49	8.04	-	-	-	-
23.08.2013	30.10	5.53	8.24	38.95	38.064	-	-
28.10.2013	23.28	8.02	8.24	34.35	33.881	0.0704	2.2217
28.11.2013	19.66	7.70	8.06	37.00	36.147	0.0949	1.0665

oxygen concentrations are, as well, observed to be at normal levels and the concentrations of nitrite and nitrate are below pollution limits. In fact, similar results were also observed when all measurement points were evaluated separately.

Nitrites occur in water as an intermediate product in the biological breakdown of organic nitrogen, being produced either through the oxidation of ammonia or the reduction of nitrate. The presence of large quantities of nitrites is indicative of waste water pollution. Nitrates occur in water as the end product in the biological breakdown of organic nitrogen, being produced through the oxidation of ammonia. Excess nitrates in the surface water is often used as an indicator of poor water quality. Sewage is rich in nitrogenous matter which through bacterial action may ultimately appear in the marine environment as nitrate. Nitrite is much more toxic than nitrate. Levels exceeding 10 mgN/l and 1 mgN/l nitrate and nitrite nitrogen, respectively, are considered unhealthy for marine environments [22,25]. Figure 4, shows the variation of the nitrite and nitrate concentrations measured in the laboratory by analyzing the water samples taken at 0.5 m depth from the sea surface at the end of November. As observed in the figure, during the corresponding measurement period, although the nitrite and nitrate concentrations in the bay are in general below the critical values of pollution, relatively higher nitrite and nitrate concentrations are found at point 6 which is the mouth of the largest canal in the town center and at point 3 which is the mouth of Murt stream, respectively.

The nitrite and nitrate concentrations are the parameters representing the amount of nitrogen nutrient in water. Although the formation of nitrate is an integral part of the nitrogen cycle, thus naturally occurring in our environment, in most cases higher levels are thought to result from human activities. Because, the reasons of having nitrate in water are mainly the breakdown of fertilizers, manures, plants, animals or other organic residues by microorganisms. Thus, it can be concluded that the relatively higher concentrations of nitrite at points 6 and 3, and of nitrate at point 3 are due to the discharge water of wastewater treatment plant and the drainage water of agricultural activities carried to the sea by Murt stream and the canal.

The measurements for nitrite, nitrate and dissolved oxygen concentrations were also compared with the output of the water quality sub model of HYDROTAM-3D.

Figure 5 displays the comparison of the mean nitrite concentrations obtained through the water quality model and the field measurements. According to the model estimations, for the inner bay, the mean nitrite concentration is around 0.170 mgN/l at the beginning of the summer season and after increasing to higher values (i.e. greater than 0.250 mgN/l) decreases to the levels of around 0.110 mgN/l in the autumn months of October and November. Comparing the estimations with the averages of the nitrite concentrations at all points measured in October and November, an overestimation of around 0.16 mgN/l and a slight overestimation of around 0.01 mgN/l are observed, respectively.

The comparison of the mean nitrate concentrations obtained through the water quality model and the field measurements is also given in Figure 6. According to the model estimates, the mean nitrate concentration which is around 0.168 mgN/l at the beginning of summer season remains almost at the same levels during the whole period of the study. However, comparing with the averages of the nitrate concentrations from the field measurements, it is observed that the model estimation underestimates the measured value in October while

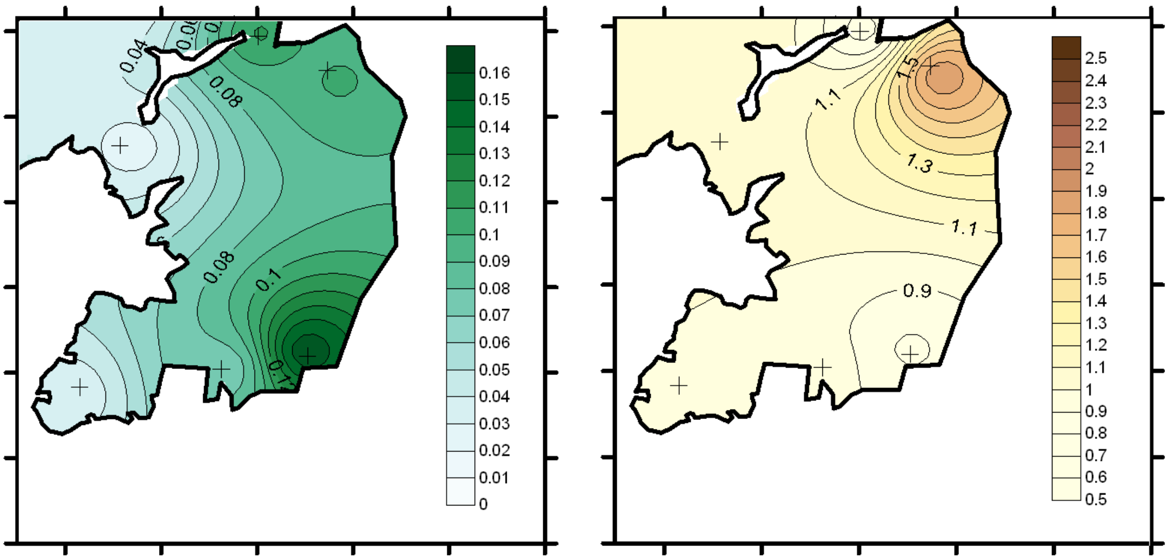

Figure 4. Variation of the (a) nitrite and (b) nitrate concentrations obtained from the measurements at a depth of 0.5 m below the sea surface in November (mgN/l).

overestimating in November. Still, the model is able to estimate the decreasing trend in the nitrate concentration from October to November.

The comparison of the results for the mean dissolved oxygen concentration is given in Figure 7. It is observed that, at the beginning of summer season, the estimated concentration of the mean dissolved oxygen is around 6.3 mgO/l, and it is overestimating slightly the measured average value of 5.5 mgO/l. For the following months, with the increase in sea water temperature, the estimations decrease to even lower values till the level of around 5.0 mgO/l. However, then, with the decrease in the temperature of the sea water in October and November, the estimated concentrations of dissolved oxygen increase to higher values till the level of around 8.0 mgO/l. The model estimations for dissolved oxygen are in general quite consistent with the measurements in

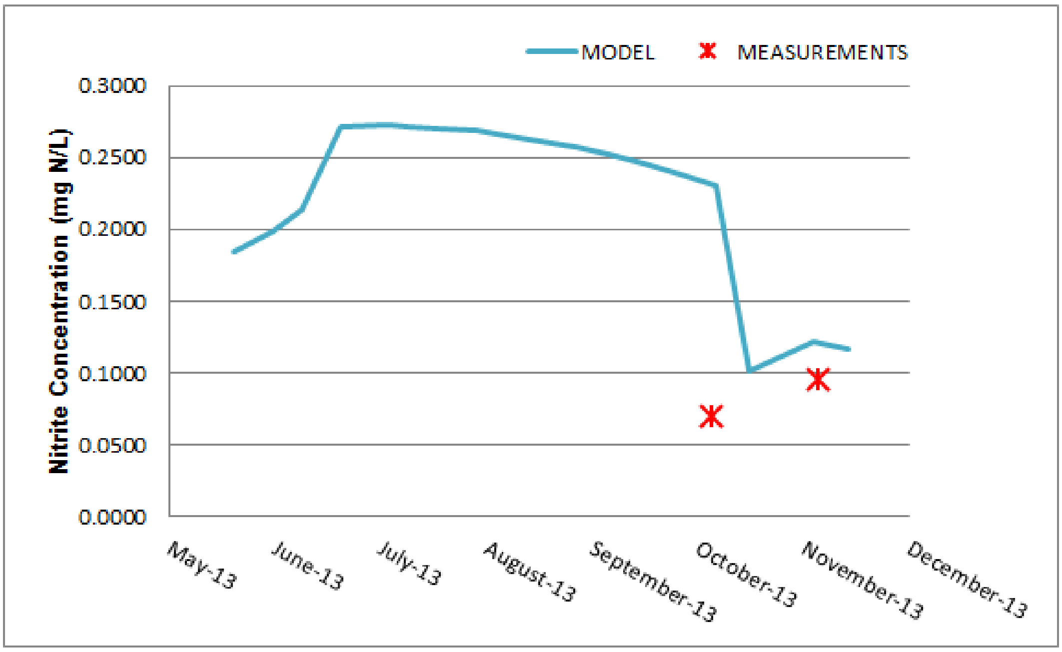

Figure 5. Mean nitrite concentrations (mg N/l) obtained through the water quality model and the measurements for the inner bay of Fethiye.

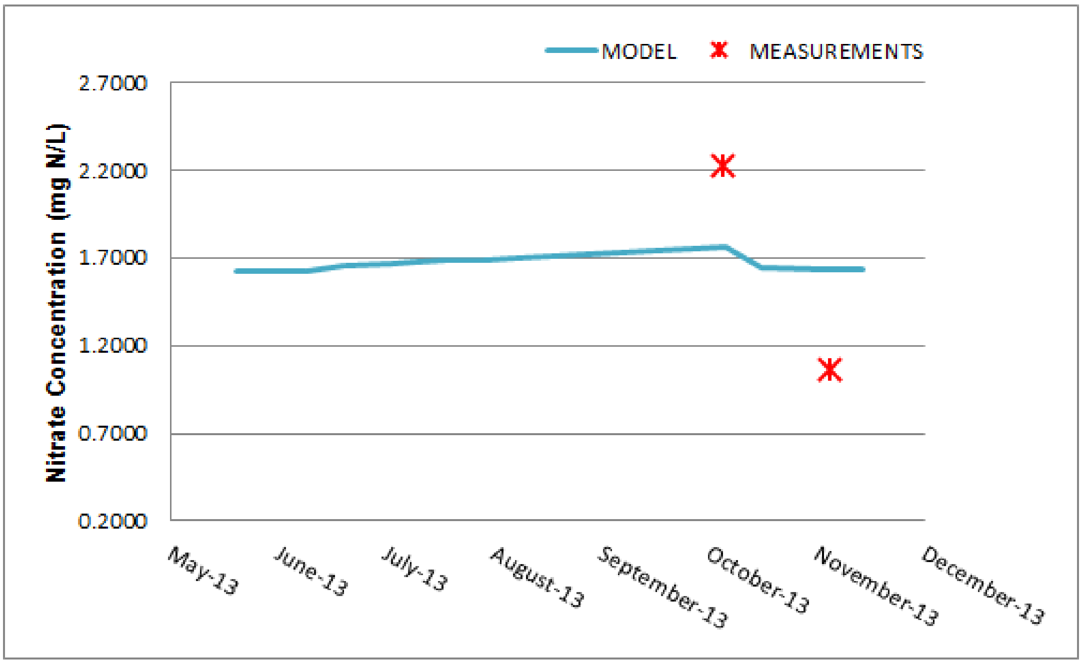

Figure 6. Mean nitrate concentrations (mg N/l) obtained through the water quality model and the measurements for the inner bay of Fethiye.

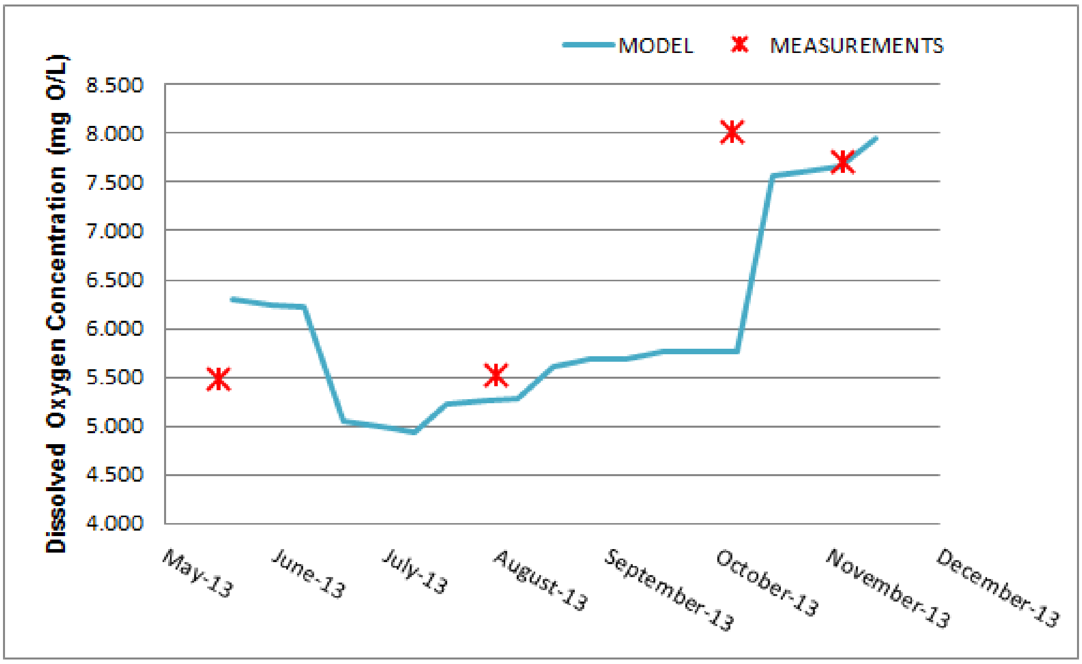

Figure 7. Mean dissolved oxygen concentrations (mg O/l) obtained through the water quality model and the measurements for the inner bay of Fethiye.

terms of both the level of concentrations and the temporal variation.

4. CONCLUSIONS

In this study, sea water quality for the inner bay of Fethiye has been studied, and discussed in relation to land use practices of the town. From six measurement locations determined in the bay, various water quality parameters were monitored by monthly field and laboratory measurements during summer and autumn seasons. Besides the measurements, a water quality model has been prepared and calibrated utilizing the physical features and the data related to the pollution sources of the bay.

At all measurement points, it was observed that, during the measurement periods, the pH, salinity and sea water temperature values were in general in the standard ranges of the Mediterranean. The dissolved oxygen concentrations were observed to be at normal levels, as well, and the concentrations of nitrite and nitrate were below pollution limits.

On the other hand, although the nitrite and nitrate concentrations were in general below the pollution levels, the effects of human activities could still be observed with the relatively higher nitrite values measured at points 6 and 3, and nitrate values measured at point 3. This is thought to be due to the source effects of Murt Stream mouth (point 3) which carries the discharge water from the wastewater treatment plant and the drainage water from agricultural activities, and of the largest canal outlet (point 6) which is close to the marina and exposed to very low currents.

The measurements for nitrite, nitrate and dissolved oxygen concentrations were also compared with the output of the water quality model component of HYDROTAM-3D. The results show that the model displays close results to the field measurements of nitrite, nitrate and dissolved oxygen concentrations, and also, successfully represents their temporal variation.

The inner bay of Fethiye is an enclosed area having weak water circulation. Therefore, it is quite vulnerable to pollution. As observed during the measurement periods also, Murt stream and the canals are very critical sources of pollution for the bay, carrying the land-based pollutants to the sea water.

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