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ORIGINAL ARTICLE

Effects of basin activities and land use on water quality trends in Tahtali Basin, Turkey

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Abstract Bi-weekly water quality data from seven monitoring stations located within Tahtali Watershed, İzmir, Turkey and digital land use/land cover data of the same watershed are analyzed in this study. To examine the changes in land use associated with urbanization, the satellite images of the main pool of the Tahtali reservoir prior to filling and subsequent to filling, respectively, are analyzed. Aerial photos of the basin taken in 1995 (October) are compared with images taken in 2005 (November) from the IKONOS satellite through use of several GIS techniques. New residential buildings, greenhouses, and industrial buildings are presented in separate layers, and changes in basin activities are quantified. The effects of urbanization on the water quality are investigated through statistical analysis. The seasonal Kendall test is applied to the water quality parameters monitored bi-weekly at seven stations within the basin for the duration 1997–2005. There was no trend in phosphorus, but there was a negative trend in boron and nitrate and a positive trend in the parameters of biological oxygen demand (BOD) and chemical oxygen demand (COD). The improvement in nitrate concentrations is attributed to the new regulations on the use of fertilizers in greenhouses. However, increase of BOD and COD concentrations is related to the growing settlement areas and industrial zones, which point to the insufficient wastewater treatment within the basin. Soil erosion within the basin is also quantified by the universal soil loss equation using available maps. Estimated total soil loss rate increased about 2.5 times that of 1995 when the changed land use composition in 2005 is considered in the calculations.

Keywords Land use · Water quality · USLE · Tahtali reservoir

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Introduction

As a result of population increase and urban development worldwide, available water resources have significantly diminished in the last 50 years. Approximately one billion people lack access to safe drinking water today and quality of the water is lowest in the developing countries where it is needed most. The major challenges encountered by the developing countries today are: high unaccounted water rate (roughly 40 %) due to leaking pipelines or broken meters, high water withdrawal rate (roughly 80 %) for agriculture due to inefficient irrigation systems, deterioration of water quality due to lack of wastewater treatment facilities, and the increase in the incidence of some infectious diseases due to climate change such as malaria (already infecting 300 million people each year), cholera, and yellow fever (Lawson et al. 2008).

Human activities cause land degradation, loss of cropland, pasture, forest and woodlands, which leads to degradation of the water quality in the watershed via point (discharges from sewage treatment plants, and industrial discharges) and nonpoint (runoff from fields/roads) pollution sources. In general, domestic sewage in residential areas and crop fertilizers used in agricultural lands are mostly responsible for contamination by nutrients and sediments, whereas urbanization and industrialization may lead to an increase in the concentration of the heavy metals observed in surface waters.

Several previous studies examined the relationship between spatial distribution of land use and water quality at watershed level (Scott 1992; Agarwal et al. 2000; Forney et al. 2001; Tong and Chen 2002; Tang et al. 2005; Demirci and Mcadams 2006; Fachrul and Hendrawan 2007). These studies pointed out that water quality deterioration was due to point discharges of industry or residential settlements. The challenge is how to quantify these relationships and how to incorporate the results into planning of water resources. Demirci and Mcadams (2006) studied the effects of domestic wastewater in combination with the industrial discharges that caused pollution in Küçük Çekmece Basin, Turkey. Scott (1992) analyzed the geographical and statistical relationships between landscape parameters and water quality indices at the Muddy Fork Watershed, USA, by utilizing remote sensing and GIS modeling techniques. Their site was considered to be highly susceptible to infiltration of pollutants resulting in non-point source contamination of water resources. The results of their research indicated that increased levels of nitrates and phosphorus contamination in both ground water and soil could be linked to pastures characterized by well-drained soils and proximity to henhouses. Tong and Chen (2002) used both statistical and GIS analyses to examine the effect of land use on water quality. They found that most of the nitrogen loading in the system came from agricultural lands followed by impervious-urban lands, pervious-urban lands, forests and finally barren lands. During storm events, forests exported more nitrogen then pervious-urban lands. A similar pattern was observed for phosphorus loading and fecal coliform.

This paper presents an effort to relate changes in land use prior and after construction of a reservoir to water quality of its watershed. GIS analysis is adopted to quantify the changes in land use and statistical analysis is utilized to relate these changes to the water quality within a major watershed in the city of Izmir, Turkey. The satellite images from the periods prior (1995) and after (2005) filling of the main pool of the Tahtali reservoir are analyzed using GIS, and change of land use during this period within the watershed is quantified. For this purpose, the aerial photos of the basin in October 1995, which comprised 130 sections on a scale of 1/5,000 were compared with those images from the IKONOS satellite in November 2005 with a resolution of 1 m. New residential buildings, greenhouses and industrial buildings are presented in separate layers to document changes in basin activities since 1995. Later on, changes in all 130 sections are merged and the thematic maps of the basin are obtained.

Statistical tests are applied to determine increasing/decreasing trends and to describe regional correlations between the water quality parameters and land use activities. For water quality parameters, which were measured bi-weekly for the period 1997–2006, a seasonal Kendall test was done. The seasonal Kendall test is selected for this analysis mainly because it is applicable to data sets with limited data; the test tolerates data, which are correlated and have deficiencies. Trend analysis showed whether parameters, including total phosphorus, nitrate boron, chemical oxygen demand (COD) and biological oxygen demand (BOD) increased/decreased, and if these changes can be related to the effects of urbanization and industrial development, which are presented as a result of the GIS analysis.

This study also investigates and quantifies soil erosion in the basin by the universal soil loss equation (USLE) for two different land use compositions and soil maps from 2 years, i.e., 1995 and 2005. Thus the effect of changes in land use in 10 years could be quantified via computation of soil erosion rate in the basin.

Materials and methods

Study area

The effects of land use are investigated in Tahtali Basin (Fig. 1) in Izmir, Turkey. Tahtali Basin covers an area of approximately 550 km^2, and the reservoir located within the basin provides about 40 % of the water supply to the city of Izmir, the third largest metropolitan area in Turkey with a population of over 3 million. Tahtali Dam was projected as a rock-filled dam and completed in 1996; the reservoir was filled with water in 1998. The capacity of the dam is 175 million m^3 and it generates 5 million m^3 water per month. The dam is currently operated by IZSU (Izmir Water and Sewage Administration) (Çaliskan and Elçi 2009; Ileri et al. 2007). The main water sources are Tahtali and Sasal Rivers merging downstream of the basin where the reservoir is located. In Tahtali Basin, there are 17 villages where approximately 75,000 people live (as of 2005).

Paper and textile industries and manufacturing plants of chemicals and metals are active within the basin since 1960. In addition, discharges from a furniture and wood processing facility in the Kısıkköy area caused pollution of the basin during its period of operation. A biological wastewater treatment plant commenced operation in 2001. From the time the dam was constructed, permissions to open rock, clay, and mine quarries are not given within the protection zone of the reservoir; moreover, the existing quarries were shut off. New regulations were enforced for agriculture and greenhouse activities within the basin.

As of 2005, land use map of study area obtained from “General Directive of Rural Services” indicated that 29 %

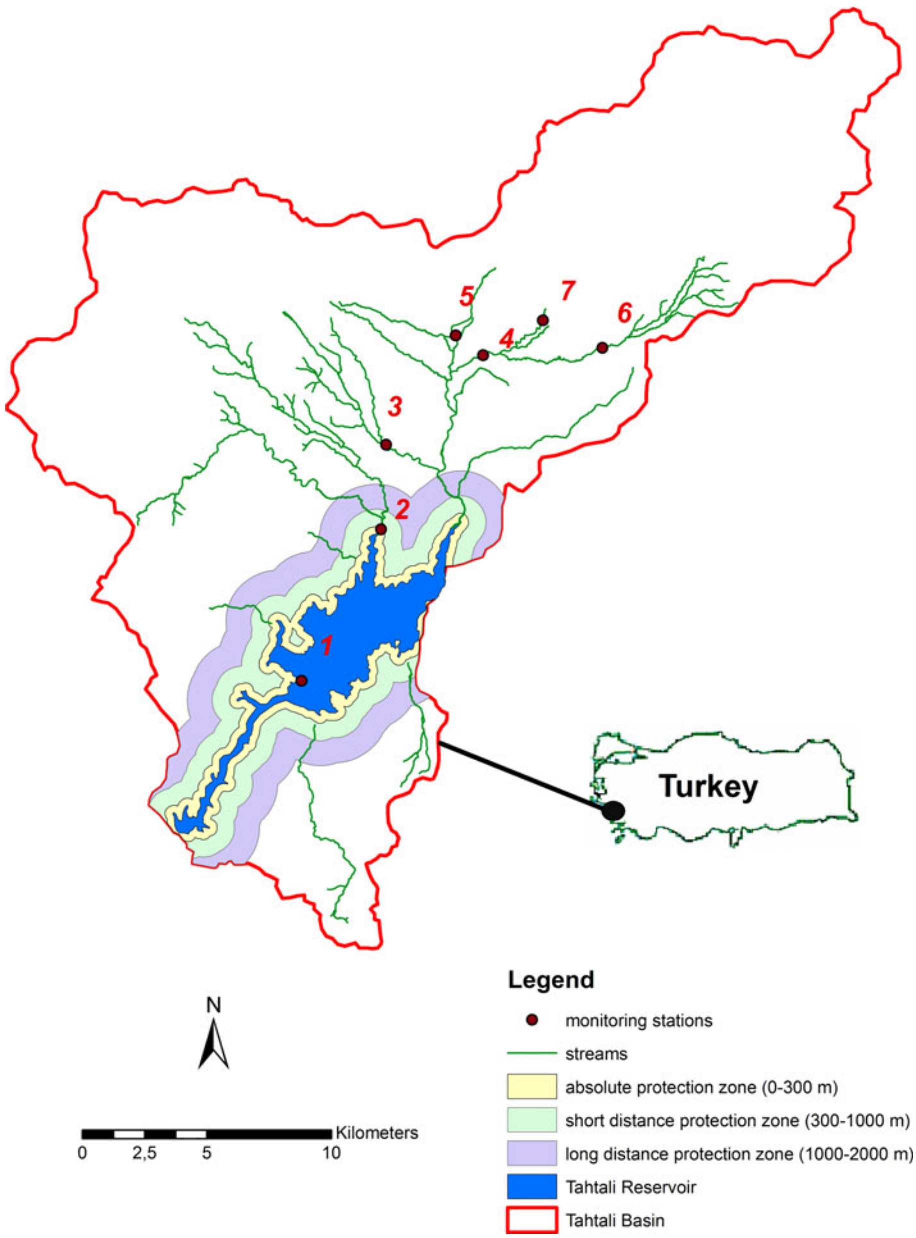

Fig. 1 Location map of the study site: river network, protection zones, and water quality monitoring stations within the basin. The names of the stations are provided in Table 1

of the basin is covered with forest, 37 % of the basin is heath bell and 22 % of the area is agricultural field. The soil of the basin is composed of brownish soil without lime (24 %), red–brown Mediterranean (35 %), and colluvial type (18 %) (Fig. 2).

Land use analysis

Aerial photographs of the basin taken in October 1995 and IKONOS satellite images taken in November 2005, are compared using Geographical Information Systems (GIS) functions. Data existence, availability, and the resolution of the images are considered for the selection of the dates on which images were taken. Radiometric resolution of the satellite images is 11 bit, geometric resolution is 1 m of which projection type is UTM with corresponding datum of ED50. Digital elevation model prepared using vector elevation data of the study area is utilized to orthorectify the 1/5,000 scale satellite images.

Previous research indicated that domestic discharges, discharges from industrial facilities and water recycling from greenhouses are mostly responsible for deterioration of water quality. Thus, three categories of land use in the basin are given special attention: residential settlements, industrial facilities, and greenhouses. The changes in land use in these three classes are analyzed for two different years, 1995 and 2005. A commercial GIS package, MapInfo Professional 8.0 is utilized in the analysis. Each

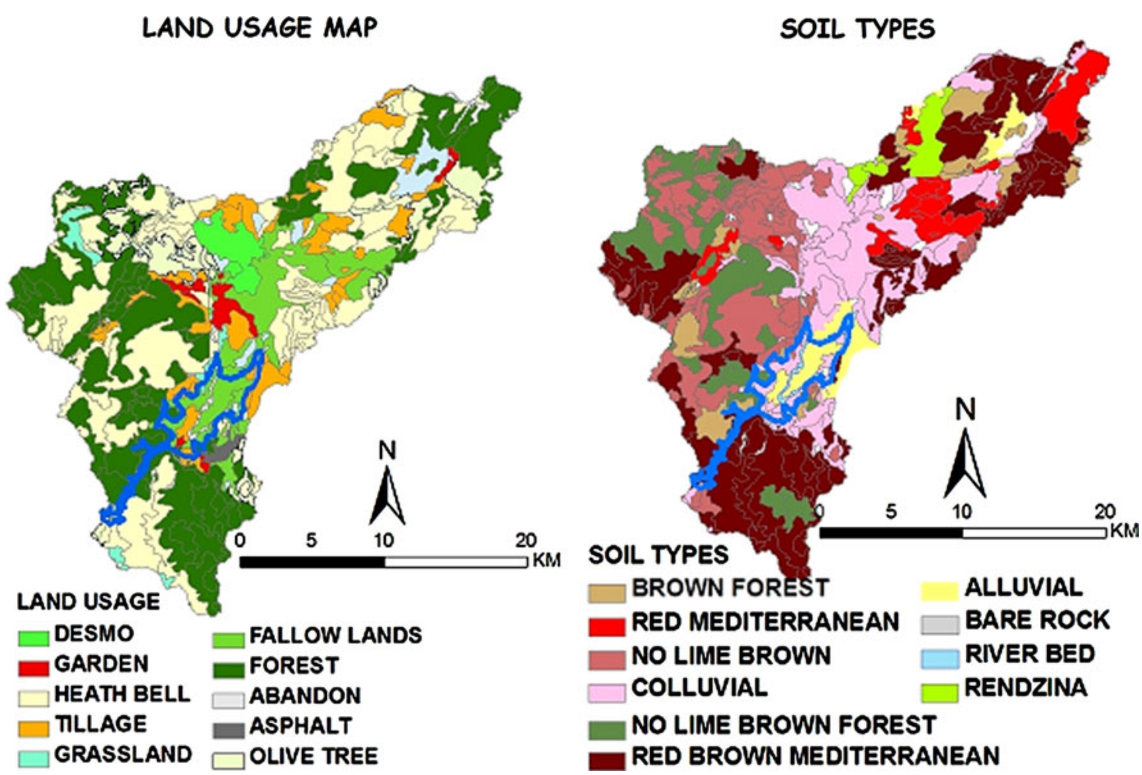

Fig. 2 Land use and soil maps of the study site (year 2005)

1/5,000 scale digitized map obtained from IZSU (total of 130 maps) is transformed into raster format and greenhouses, industrial and residential buildings selected in the corresponding years are used to create thematic maps.

Water quality analysis

Upon quantifying the changes in land use, the relationships between the land use activities and the water quality parameters are investigated. For this purpose, first the water quality data monitored bi-weekly by IZSU on six different streams within the basin and at the merging point of Tahtali and Sasal Rivers which is located in the reservoir are obtained for the duration of the land use analysis. Figure 1 shows the locations of monitoring stations and the corresponding names of the stations are listed in Table 1.

The variation of the water quality parameters in time (1997–2005) is assessed by trend analysis. Missing data and short duration data in water quality parameters and effect of flow to water quality due to seasonal changes make trend analysis complicated. Seasonal Kendall test statistics, which are not affected from limited data and missing values, is utilized in this study considering inner dependence of data.

The seasonal Kendall test is a modified version of the non-parametric Mann–Kendall test for monotonic trend. The test is based on the cyclical, seasonally varying nature of water quality in a year. The seasonal effect is reduced by making comparisons between data from similar seasons. It is a rank-based method, which does not look for any known distribution. In this method, sampling periods are named as "season" and the method can be applied to missing and little duration data (Hirsch et al. 1982; Hirsch and Slack 1984; Helsel et al. 2006). "Z" standard normal variable is calculated and compared with "$Z_{1-\alpha/2}$" value in the Standard Normal distribution table, in order to decide whether there is a trend in a determined "α" significant value. If $|Z| \geq Z_{1-\alpha/2}$, "Ho" hypothesis shows that there is no trend in a determined "α" significant value, it is rejected (it means that there is a trend). If $Z < 0$, there is a decreasing trend, if $Z > 0$, there is an increasing trend. The seasonal Kendall test is applied with 90 % confidence interval using monthly measured data as explained in USGS (2006).

Table 1 Water quality monitoring stations

Station #	1	2	3	4	5	6	7
Station name	Tahtali Lake	Şaşal Bridge	Menderes Şehitoğlu	Tahtali River	İstasyon District	Mersinli Kahve	Aydın Motorway

Quantification of soil erosion

The universal soil loss equation (USLE) is implemented for prediction of soil erosion for two different land use compositions (1995 and 2005) within the basin. USLE method considers six factors whose values can be specified numerically for a given location (Elçi et al. 2009; Perovic et al. 2012):

$$A = R \times K \times L \times S \times C \times P \quad (1)$$

where A is the average annual soil loss in t/ha year; R is the rainfall erosivity factor in MJ mm/h ha year; K is the soil erodibility factor in t ha h/ha MJ mm; L is the slope length factor (unitless); S is the slope steepness factor (unitless); C is the cropping management factor (unitless); and P is the supporting practice factor (unitless).

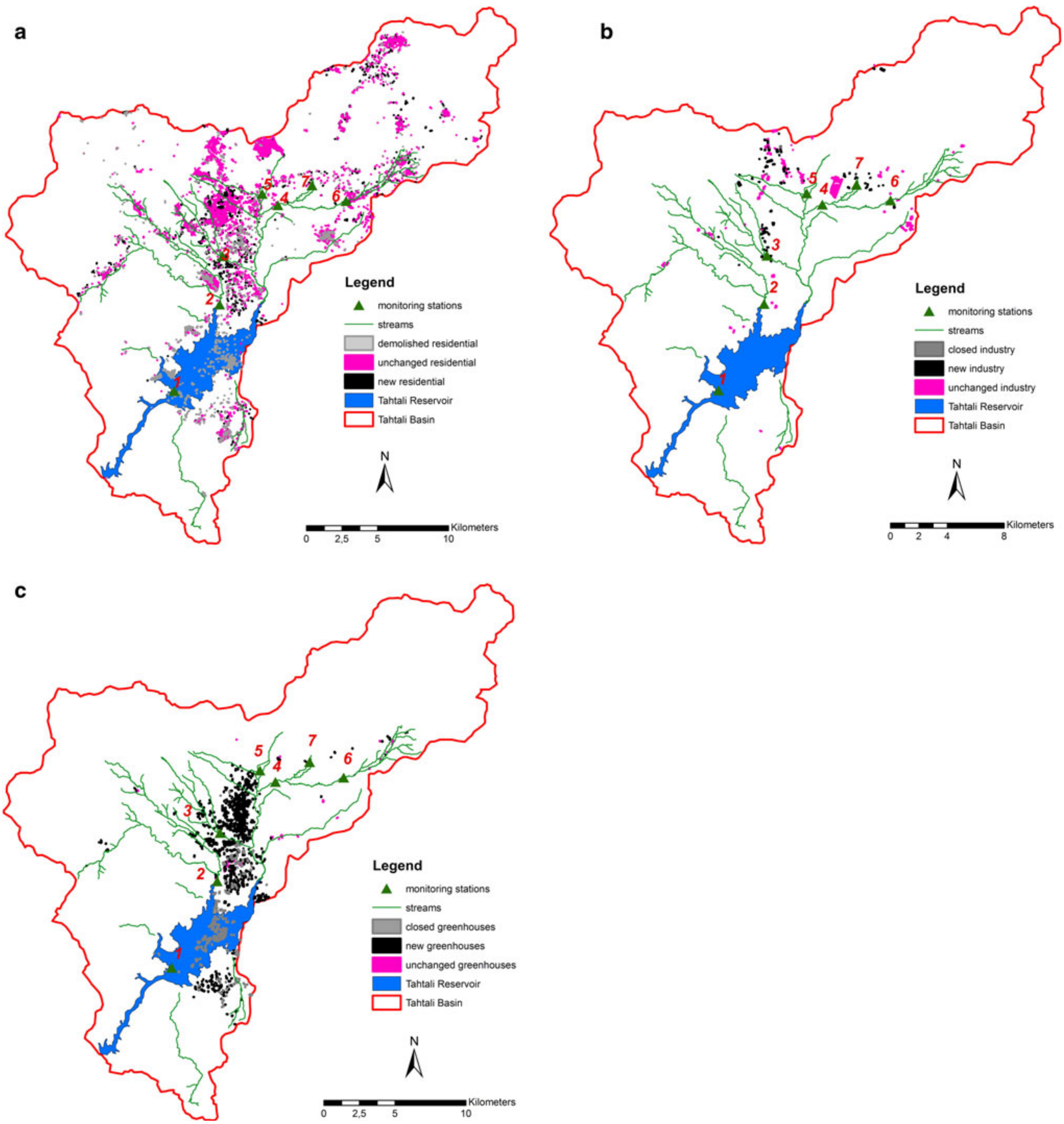

Fig. 3 Results of the land use analysis for **a** residential, **b** industrial usage, and **c** greenhouse usage in the basin

The average annual R value calculated for Izmir ($R = 166$) is used to predict the soil erosion in Tahtali Basin. Soil erodibility factor represents the average long-term soil response to erosive power of rainfall/runoff and varies with soil characteristics. The infiltration rates vary between 0 and 1, where higher K values indicate that soil is more sensitive to erosion. In general, erosion is very low or none in alluvial soil types; low or medium in colluvial soil types and high in soils including silt and iron in its structure. Slope length is the horizontal distance along the flow path, from the origin of the overland flow to the deposition point. As the slope length increases, erosion rate increases. The equation by McCool et al. (1989) was utilized for slope length in the study. Slope steepness factor represents the effect of slope on soil erosion. If the slope of the land is high, more erosion occurs in the area. Slope steepness factor affects the rate of erosion more than the slope length. In the analysis, distributed slope values for each polygon are calculated and implemented to the USLE equation (Elçi et al. 2009).

The crop management factor represents the effect of cropping and management practices on the soil erosion and reflects how the vegetal cover absorbs the energy of rain. The vegetal cover can reduce the drop size and provides mechanical protection by increasing the infiltration capacity of soil. Undisturbed forests provide the best soil protection, whereas heath bell lands are considered high erosive. Erosion of soils is highest in fallow lands (10 % of total basin area) where crop management factor is set to 1 in these lands. The supporting practice factor represents the effects of practices including terracing contouring, silt fences and subsurface drainage. The average practice factor is taken as 0.44 as provided by Oguz et al. (2006) for Menemen/Izmir (ranged between 0.10 and 0.92).

For the year 1995, 315 polygons representing different land usages and soil types in the basin and 245 polygons for the year 2005 are used in the computation of erosion rate (Fig. 2). The annual soil erosion loss for each polygon is calculated.

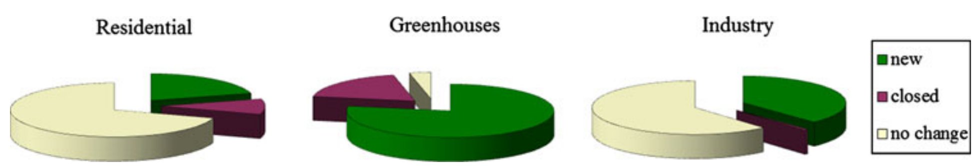

Fig. 4 Summary of the land use changes for residential buildings, industrial buildings, and greenhouses in the basin

Table 2 Selected water quality parameters (*TP* total phosphorus, *BOD* biological oxygen demand, *COD* chemical oxygen demand) monitored within the basin, S refers to summer and W refers to winter season

	1997 S					2005 S				
	TP (mg/l)	BOD (mg/l)	Boron (mg/l)	COD (mg/l)	Nitrate (mg/l)	TP (mg/l)	BOD (mg/l)	Boron (mg/l)	COD (mg/l)	Nitrate (mg/l)
1	0.041	2.33	0.18	5.33	6.01	0.000	2.86	0.10	8.42	0.85
2	0.004	1.00	0.16	4.00	1.10	0.017	2.17	0.11	9.34	1.60
3	0.027	0.33	0.22	5.33	11.36	0.000	3.00	0.16	7.20	3.22
4	0.027	2.00	0.17	5.33	8.73	0.200	3.00	0.28	8.57	4.44
5	0.197	2.00	0.87	5.33	17.13	0.370	3.14	0.29	9.14	3.90
6	0.107	1.33	0.24	5.33	28.67	0.050	2.50	0.15	8.00	7.65
7	0.165	1.66	0.15	4.00	4.77	0.000	2.67	0.12	8.00	2.70
	1997 W					2005 W				
	TP (mg/l)	BOD (mg/l)	Boron (mg/l)	COD (mg/l)	Nitrate (mg/l)	TP (mg/l)	BOD (mg/l)	Boron (mg/l)	COD (mg/l)	Nitrate (mg/l)
1	0.077	1.00	0.22	8.00	9.70	0.000	4.14	0.13	9.50	0.23
2	0.000	1.00	0.17	4.00	6.15	0.050	3.75	0.22	9.00	0.78
3	0.020	1.00	0.29	4.00	13.75	0.100	3.00	0.31	10.00	2.40
4	0.030	1.50	0.56	8.00	18.85	0.100	2.66	0.37	6.67	2.80
5	0.020	1.00	0.86	11.50	16.40	0.130	4.00	0.35	8.00	2.56
6	0.000	1.00	0.24	4.00	36.50	0.100	2.00	0.43	4.00	2.70
7	0.016	1.00	0.27	4.00	9.25	0.100	4.00	0.54	8.00	3.90

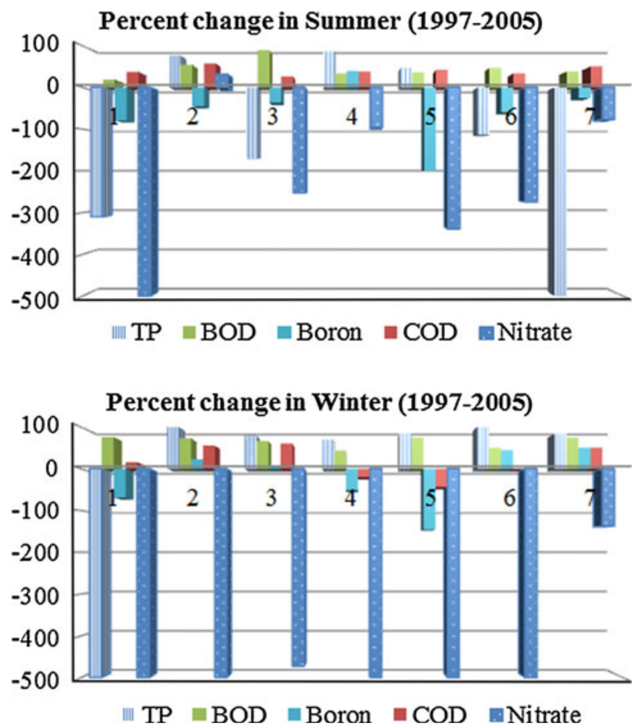

Fig. 5 Comparison of water quality parameters monitored in 1997 and in 2005

Results and conclusions

In this study, the effects of land use changes in Tahtali Basin between 1995 and 2005 are summarized, and the effects of these changes on water quality at seven different monitoring stations are discussed. Figure 3a shows the recently built, demolished, and existing residential buildings in both years. Figure 3b shows the recently built, closed, and existing industrial facilities. Figure 3c presents the changes in land use for greenhouses between 1995 and 2005. Comparison of land use changes indicated an increase of 61 % in industrial areas, 26 % in residential areas, and 35 % in greenhouse areas from 1995 to 2005 (Fig. 4).

Water quality parameters monitored at seven stations including boron, total phosphorus, nitrate, BOD, and COD are compared for two different years as provided in Table 2. Results indicated that at the station located within the lake (station #1), the total phosphorus, nitrate, and boron values diminished significantly (Fig. 5). This decrease is related to the protection zones established surrounding the reservoir after construction of the dam (Fig. 1). In both spring and winter measurements, the amount of total phosphorus increased at stations 2, 4, and 5. This increase can be related to the increased use of detergents because of urban development. The spatial variability of the new residential buildings coincides with the sub-watersheds of the monitoring stations 2, 4, and 5. Although substantial increase in greenhouses at the upstream of station #3 is documented by the land use analysis, neither total phosphorus nor nitrate values increased; on the contrary, the values have significantly decreased. This decrease can be attributed to new regulations in the use of fertilizers. In Tahtali basin, the measurements of BOD, indicator of amount of oxygen uptake by micro-organisms and COD, indicator of the mass of oxygen consumed by organic pollutants increased pointing out the insufficient treatment of domestic and industrial waste water. Measured boron values are higher in summer season at station #4 and at stations #6 and #7 in winter season (Fig. 5).

The seasonal Kendall test is used to assess the increasing/decreasing trends in the monitored parameters during the study period. Test statistics calculated for each station are given in Table 3. According to the results, there is no trend in phosphorus, negative trend in boron and nitrate, and positive trend in the parameters of BOD and COD. The main reason for the improvement in nitrate concentration can be explained by the controlled usage of fertilizers in greenhouses. Generally, BOD points out the pollution degree of industrial wastes or sewer system, hence, the values of BOD and COD increased as expected due to the intensification of urbanization. The improvement in nitrate concentrations can again be attributed to the new regulations for use of fertilizers in greenhouses. However, as expected, with the increase of the settlement areas and industrial zones, the values of BOD and COD increased as a result of insufficient wastewater treatment within the basin.

The universal soil loss equation (USLE) is utilized for prediction of soil erosion considering two different land

Table 3 Test statistics obtained from application of seasonal Kendall test, (−) indicates decreasing trend

	1. Tahtali Lake	2. Saşal Bridge	3. Menderes Şehitoğlu	4. Tahtali River	5. İstasyon District	6. Mersinli Kahve	7. Aydın Highway
Nitrate	0.012	0.000	−0.270	−0.160	−0.257	−0.425	−0.020
Boron	−0.008	0.062	−0.004	0.003	−0.067	−0.017	−0.003
COD	0.000	0.667	0.333	0.000	0.250	0.400	0.400
BOD	0.000	0.125	0.000	0.167	0.250	0.100	0.000
TP	0.000	0.000	0.000	0.000	0.000	0.000	0.000

use compositions (1995 and 2005) within the basin. The results indicated that the estimated total soil loss rate increases about 2.5 times that of 1995 when the changed land use composition in 2005 is considered in the calculations. This analysis pointed out how susceptible the area is to erosion, and the necessity of investigation of the effects before applying any land use development activities in the area.

In summary, this study revealed the importance of temporal and spatial remote sensing data to detect the changes in water quality as a result of human activities in the basin. The application of GIS tools is essential for analyzing different attribute data and understanding and quantifying changes in land use activities. Land use maps provided not only information for reclamation of land degradation but also sound database for watershed planning.

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