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Research Article

EFFECT OF LANDUSE TYPE ON POLLUTION LOADS AT GULF OF IZMIT

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ABSTRACT
The gulf of İzmit lies at the eastern edge of the Sea of Marmara, which is the smallest inland sea that connects the Black Sea to the Aegean through the Bosporus and the Dardanelles. İzmit city is located on the hill slopes in northern and southern side of the gulf. On the eastern side, the flat agricultural zone surrounding the gulf has been subject to rapid urbanization for a couple of decades. The water quality in the Sea of Marmara has already degraded due to the pollution carried by the Danube River into the Black Sea, which reaches the Marmara through strong currents in Bosphorus. Since 20% of Turkey's population resides in and the economic activity takes place around the Marmara, besides the discharges of wide range of industry and refinery, the urban wastewaters and the urbanization on coastal areas are main sources of pollution. This paper investigates the effect of the changes in landuses, defined in the CORINE system 1990, on the surrounding basin of the gulf of İzmit by using Environmental Protection Agency's Storm Water Management Model (SWMM). The coastal area is divided into sub-basins considering the elevations extracted from the topography data provided by Global Digital Elevation Model and the landuse types according to CORINE data. The pollutants build-up in the basin and wash-off with the surface discharges are modeled by using SWMM. The changes in the land-based pollutants on a long term simulation are discussed for the year 1990 and for the recent status.

Keywords: *Land Based Pollution, Runoff, SWMM, Urbanization*

1. INTRODUCTION

The main factors affecting water quality in the gulf of İzmit (Figure 1.) are the point pollution loads caused by the industrial wastewater, the urban wastewater and the distributed pollution loads arising from agriculture and animal husbandry activities in the surrounding basins There are 13 organized industrial zones and 35 ports located on the coast of the İzmit gulf employing 150,260 people in total (TURKSTAT, 2019).

Fig. 1. The gulf of İzmit (Google Earth, 2019)

The majority of the industrial zones are concentrated in Gebze, Körfez and Dilovası, on the northern coast of the İzmit gulf. The major part of the industrial pollution loads are derived from the wastes of the TÜPRAŞ oil refinery located in eastern side of the gulf, in Körfez and the oil spills from the tankers delivering crude oil from global markets heading towards the ports of the refinery, which processes 10 million tons/year crude oil (Günday, Ünlü and Günay, 2006). On the inner bay of İzmit, there are three organized industrial zones (OSB) namely, Arslanbey OSB in Kartepe, Asım Kibar OSB and Alikahya OSB in İzmit, which cover 460ha area in total. The coast of the inner bay is also surrounded by smaller industrial land zones, which contains 2,597 small industrial facilities and employ 19,000 people (TURKSTAT, 2019). At the eastern coast of the bay the main industrial zone of İzmit (İzmit Sanayi Bölgesi) lies between Kumla and Kiraz creek. Main products from the industrial zones of İzmit consist of automotive parts, automotive sub-industry, machinery, iron-steel, chemicals, plastics, rubber, electrical machinery and metal products.

Besides the pollution from industrial areas, the gulf of İzmit struggles with troubles of sea pollution reaching to the bay from Marmara Sea. According to 2018 census 20.7% of Turkey's population resides in İstanbul and Kocaeli province (TURKSTAT, 2019). The majority of the Turkey's economic activity also takes place around the Marmara, especially on the coastline between the Bosporus and Izmit bay. As a result of industrialization in the region, the nearby natural and agricultural areas have been urbanized in the last decades and urban pollution also became a stress on waters of Izmit bay. Previous research focuses on the oil and heavy metal pollution in Izmit bay from industrial sources (Ergül, Varol and Ay, 2013; Pekey, 2007; Günday, Ünlü and Günay, 2006). Orhon et al. (1991) investigates the pollutants from land based sources; municipal and industrial wastewater flow to the eastern part of the bay. Morkoç, Okay and Erdinçliler (2008) determined the land-based sources of pollution in İzmit bay by monitoring samples from channels and coastal waters. The results show that the water quality of the bay has been deteriorated from rapid urbanization and industrialization.

2. MATERIAL AND METHODS

2.1. Processing of the Geographical Data

In order to investigate the changes in landuses, the surrounding basin is divided into 16 sub-basins, which discharge the surface streams to the inner bay. The total basin area is 992.33km2. The biggest sub-basin has 358.427km2 surface area, which drains through Kiraz Creek. The second biggest creek that flows to the bay is Akarca creek, which has 276.555 km2 sub-basin area. Ağadere, Çınarlı, Cevizli, Nüzhetiye and Kazıklı brooks are the other streams that drains surface waters to the bay. The altitude map (Figure 2.) is obtained by using data of the Advanced Spaceborne Thermal Emission and Reflection Radiometer, Global Digital Elevation Model version 2 (ASTER GDEM v.2) with 72m horizontal resolution (ASTER GDEM Validation Team, 2011).

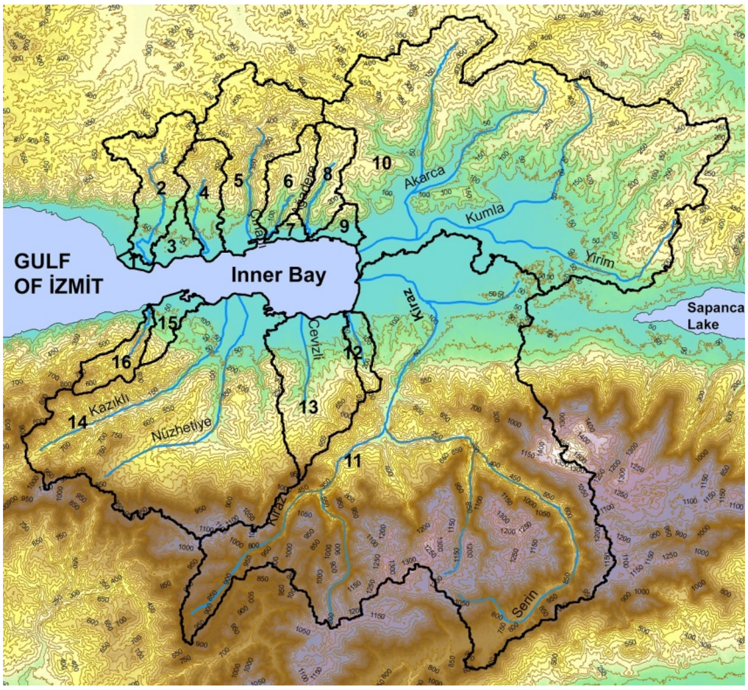

Fig. 2. Basin borders for Izmit inner bay and altitude map

The urbanization of the city between 1990 and 2012 is investigated by using CORINE Land Cover classification data (CORINE, 2019). The change of landuse in the sub-basins between 1990 and 2012 is shown in Figure 3.

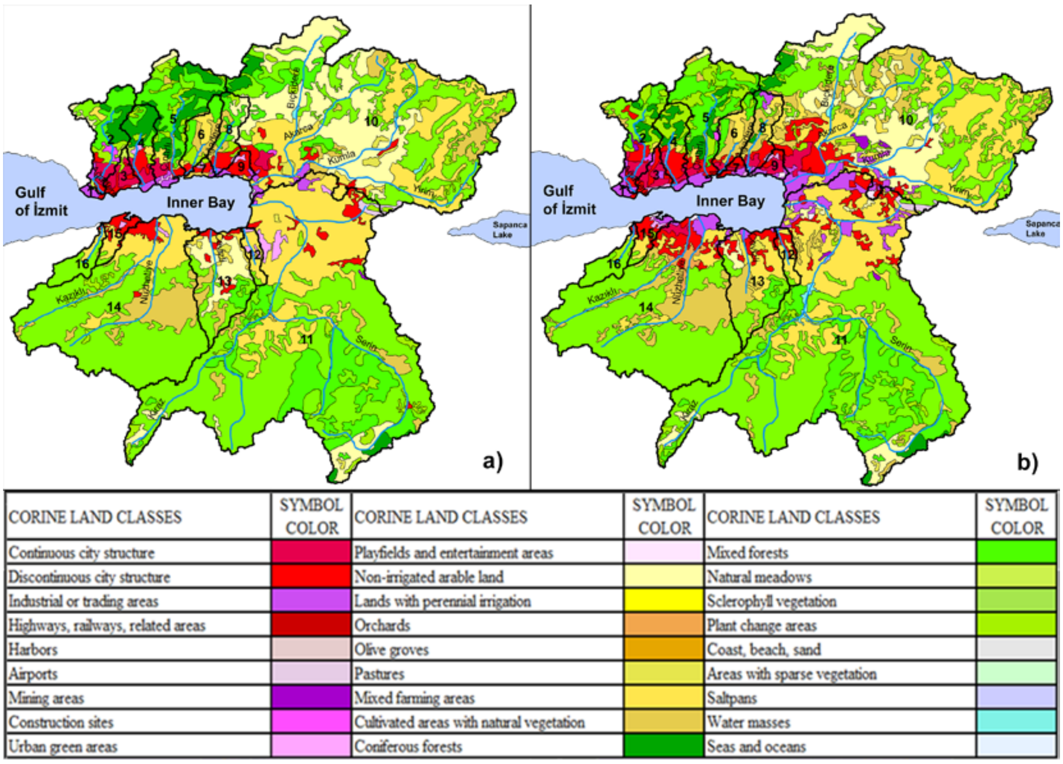

Fig. 3. Landuse in the basin according to CORINE a) 1990, b) 2012

The types of landuse and changes for the same period are given in Table 1. As it is observed in Table 1., maximum increase rates are recorded in artificial surfaces. Contrarily, the areas of the forests and agricultural areas in the basin shrink until year of 2012.

Table 1. Types of landuse in the surrounding basin

Corine Landuse Classes		Area (ha)		Change (%)
Level-1	Level-3	Corine 1990	Corine 2012	
1. Artificial surfaces	1.1.1. Continuous urban fabric	1,123.01	1,578.57	40.57%
	1.1.2. Discontinuous urban fabric	3,686.74	6,205.88	68.33%
	1.2.1. Industrial or commercial units	965.71	3,489.06	261.29%
	1.2.2. Road and rail networks and associated land	-	79.74	-
	1.2.4. Airports	219.21	185.03	-15.59%
	1.3.1. Mineral extraction sites	23.91	263.41	1,001.46 %
	1.3.3. Construction sites	143.26	144.87	1.13%
	1.4.1. Green urban areas	748.33	245.58	-67.18%
	1.4.2. Sport and leisure facilities	41.77	162.88	289.90%
2. Agricultural areas	2.1.1. Non-irrigated arable land	11,375.67	7,588.05	-33.30%
	2.2.2. Fruit trees and berry plantations	-	395.00	-
	2.3.1. Pastures	486.41	369.99	-23.93%
	2.4.2. Complex cultivation patterns	19,582.57	17,832.35	-8.94%
	2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation	6,249.80	8,923.80	42.79%
3. Forest and semi natural areas	3.1.1. Broad-leaved forest	37,434.94	37,521.78	0.23%
	3.1.2. Coniferous forest	3,163.97	1,898.27	-40.00%
	3.1.3. Mixed forest	10,589.33	8,329.45	-21.34%
	3.2.1. Natural grasslands	162.07	231.67	42.94%
	3.2.4. Transitional woodland-shrub	3,029.95	3,457.33	14.11%
4. Wetlands	4.1.1. Inland marshes	29.65	29.65	-
5. Water bodies	5.1.2. Water bodies	112.85	300.41	166.20%
	5.2.3. Sea and ocean	63.61	-	-
	Total:	99,232.75	99,232.75	

2.2. Hydrological and Hydrodynamic Modelling of Sub-Basins

The flow rates of surface streams and distributed pollution loads in the sub-basins surrounding the bay are determined by using SWMM v5.1. The SWMM is a simulation model for surface flow hydraulics and water quality for short or long periods with dynamic wave method. It performs hydrologic, hydraulic and water quality simulations for surface flows. SWMM conceptualizes a sub-catchment as a rectangular surface that has a uniform slope S and a width W that drains to a single outlet channel as shown in Figure 4-a). Overland flow is generated by modeling the sub-catchment as a nonlinear reservoir, as sketched in Figure 4-b).

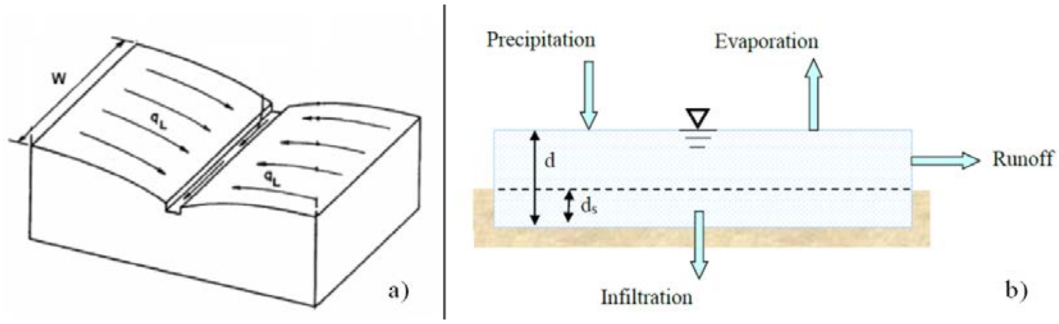

Fig. 4. a) Idealized representation of a sub-catchment b) Nonlinear reservoir model of a sub-catchment (Rossman and Huber, 2015)

The net change in depth d per unit of time t is calculated as the difference between inflow and outflow rates over the sub-catchment as in Eq. (1), where i is rate of rainfall + snowmelt (mm/s), e is the surface evaporation rate (mm/s), f is the infiltration rate (mm/s), q is the runoff rate (mm/s) per unit area.

$$\frac{\partial d}{\partial t} = i - e - f - q \qquad (1)$$

The equation above represents a surface runoff of an idealized, uniform rectangular sub-catchment area. Nevertheless, urban areas usually contain a mix of land surface types. In order to represent this type of lands, SWMM allows each sub-catchment to have different hydrological and hydraulic properties such as, imperviousness, Manning's coefficient, depression storage. The 3 year averaged daily precipitation data from nearest 3 stations (İzmit-17066, Gölcük-17067 and Başiskele-18409) is used in the model. In this way, the intensity of seasonal precipitation could also be simulated in the model.

The drainage routes of the surface flows and their length are determined on topographic DEM maps by using the ArcMap 10.2.2 (ESRI, 2013). The cross sections of the stream bed are defined according to the topography as irregular open channels with floodplains. The flow is assumed as gradually varied flow equations and calculated depending on the mass conservation and momentum equations with dynamic wave routing. The model of the basin, sub-catchments and drainage lines defined in the SWMM are shown in Figure 5.

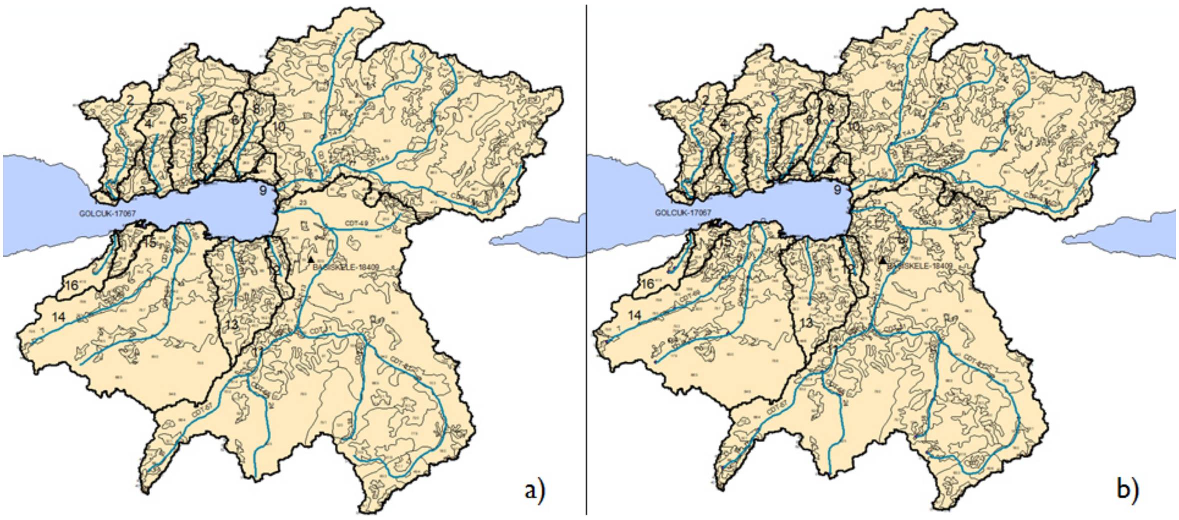

Fig. 5. Model of the basin, sub-catchments and drainage lines in the SWMM for a) 1990, b) 2012

The three year averaged daily precipitation data from nearest three stations (namely İzmit, Gölcük and Başiskele) is used in both models. The discharges to the bay from top four streams are showed in the time-series. Figure 6. a) illustrates the flow across the surface of SUB-BASIN -2 discharging through Ağadere Creek, Figure 6. b) shows SUB-BASIN-10 discharging through Kumla Creek, Figure 6. c) is of SUB-BASIN- 11 discharging through Kiraz Creek, and Figure 6. d) displays SUB-BASIN-14 discharging through Kazıklı Creek.

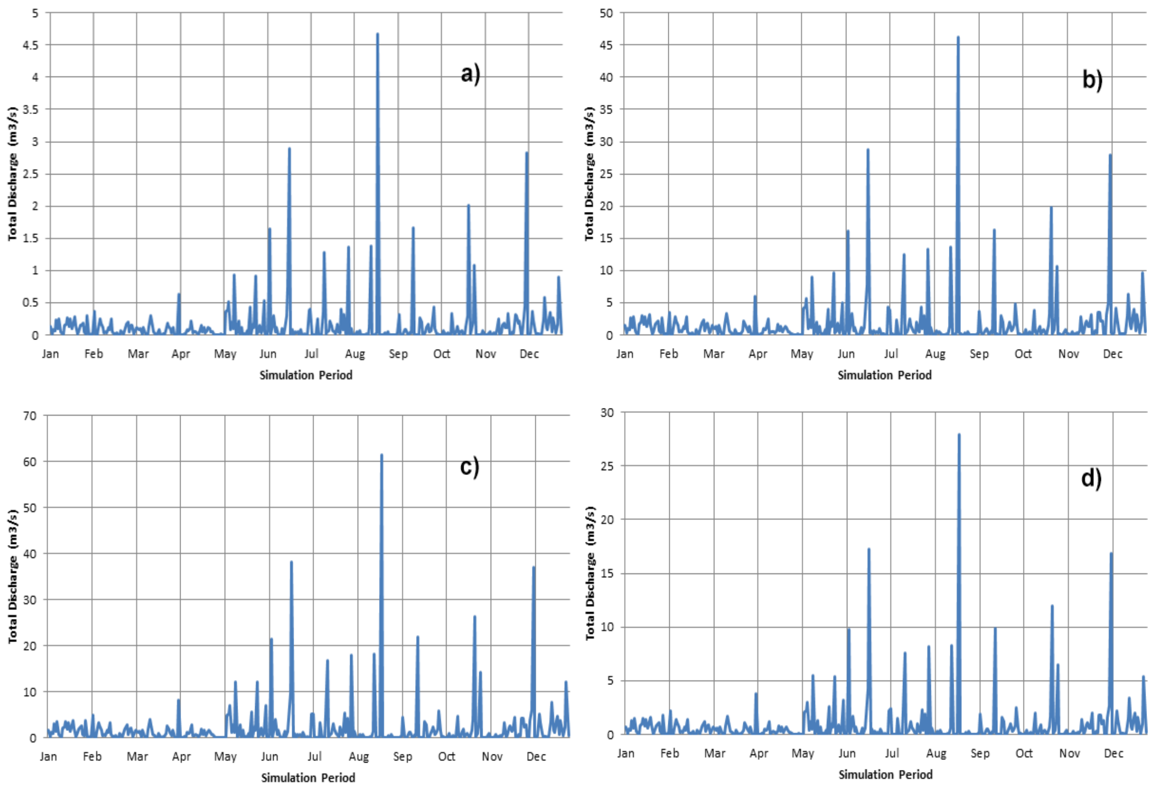

Fig. 6. Flow rates at outfall points of sub-basins 2 (a), 10 (b), 11 (c) and 14 (d) in the SWMM model of 1990

2.3. Build-up of Distributed Loads in the Land

The build-up and transfer of the pollutants in the field are calculated by build-up and wash-off processes. The build-up process calculates the accumulated mass of pollutant loads in the field defined on the model depending on the landuse type. This process can be expressed by the semi saturation curve. The build-up amount is a function depending on the number of consecutive days without precipitation (Rossman and Huber, 2015). The average values of annual pollutant loads according to landuse types presented in the report of the national surface flow program results (EPA, 1985; Cebe and Balas, 2018) are used as reference values for the pollutant load build-up values defined in the model. According to the literature survey, the average values for the pollutant build-up for various landuse types are also taken into consideration (Cebe and Balas, 2018). For the agricultural lands, on the other hand, nitrogen and phosphorus pollutant build-up values calculated by total fertilizer usage data were used (TURKSTAT, 2019).

2.4. Wash-off of Distributed Loads from the Land by Surface Flow

The wash-off process is expressed by the following equation depending on the amount of surface flow in the SWMM model (Rossman and Huber, 2015).

$$W = C_1 \cdot Q \qquad (2)$$

Here, W is the amount of wash-off load (mg/s), C_1 is the wash-off coefficient, and Q is the amount of surface flow (mm). The wash-off coefficient C_1 refers to the average concentration of pollutant in the surface flow. In this method, it is assumed that the concentration of pollutant in the surface flow does not change during the flow (Gironás, Roesner and Davis, 2009). The average concentration method was applied as the calculation method in the wash-off of Samsun bay distributed loads from the lands and the average concentrations of pollutants were defined as the average values measured in the EPA (1985) program as presented in Table 2.

Table 2. Concentration of average surface water quality parameters in surface flows by landuse (EPA, 1985)

Pollutant	Residential Area	Mixed	Commercial	Open Space
TSS (mg/L)	101	67	69	70
BOD (mg/L)	10	7.8	9.3	-
COD (mg/L)	73	65	57	40
Total N (µg/L)	1900	1288	1179	965
$NO_2 – NO_3 – N$ (µg/L)	736	558	572	543
Total P (µg/L)	383	263	201	121
Dissolved P (µg/L)	143	56	80	26

The estimated pollutant concentrations in surface flows from the biggest four streams are shown in Figure 7. Highest concentration levels are observed in the stream discharging from SUB-BASIN 2, which has the highest percentage of urban and industrial zone in nineteen ninety. And the lowest concentration levels are observed from SUB-BASIN 14 which has almost no residential and industrial zone in that year.

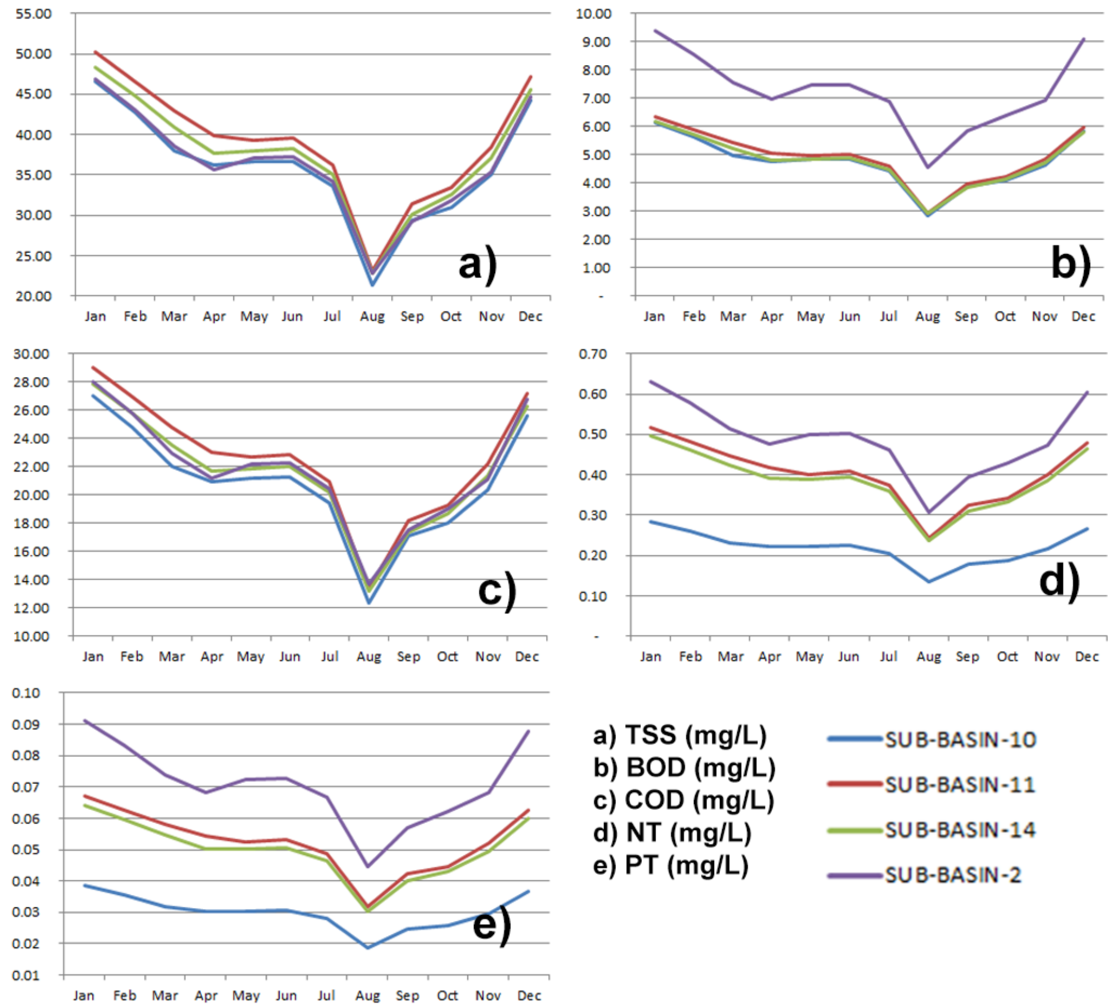

Fig. 7. Estimated pollutant concentrations of surface streams from sub-basins 2, 10, 11 and 14

Annual total pollutant loads estimated by the SWMM for the year 1990 are presented in this Table 3. Highest pollutant loads are calculated in SUB-BASIN 11 and 10, which have the largest basin areas. Therefore, Kiraz brook and Kumla brook, which drains SUB-BASIN 11 and 10 into the bay, are expected to be heaviest pollution concentration rates.

Table 3. Annual total pollutant loads drained through surface flows for 1990

Area	Total TSS (tons)	Total BOD (tons)	Total COD (tons)	Total NT (tons)	Total PT (tons)
SUB-BASIN-1	171.43	17.14	123.06	3.20	1.25
SUB-BASIN-2	2,743.88	557.10	1,642.43	37.14	19.29
SUB-BASIN-3	681.59	372.45	477.55	12.33	5.01
SUB-BASIN-4	1,601.36	344.95	1,001.65	24.27	11.77
SUB-BASIN-5	4,902.66	791.00	2,877.02	64.65	34.74
SUB-BASIN-6	1,437.27	182.06	835.22	10.30	5.50
SUB-BASIN-7	302.33	30.04	199.14	4.17	1.77
SUB-BASIN-8	1,663.30	199.20	1,014.20	16.81	8.07
SUB-BASIN-9	513.78	47.39	361.69	9.07	3.62
SUB-BASIN-10	29,755.39	3,916.09	17,240.20	178.98	95.99
SUB-BASIN-11	38,658.20	4,880.40	22,321.35	392.50	216.46
SUB-BASIN-12	664.62	71.28	379.81	2.53	1.42
SUB-BASIN-13	4,174.36	524.37	2,448.41	28.45	14.67
SUB-BASIN-14	16,322.75	2,080.91	9,396.21	165.56	91.79
SUB-BASIN-15	769.51	84.36	498.21	8.81	3.68
SUB-BASIN-16	1,062.40	135.87	610.72	12.39	6.89
Total	105,424.80	14,234.61	61,426.87	971.14	521.93

Table 4. shows the annual total pollutant loads for the year 2012. As the result of the urbanization and the expansion of the industrial zones, we observe increase in the pollution loads discharging from every sub-basin to some extent. Maximum rate of change of pollution loads are calculated from SUB-BASIN 14 and 10, where an intensive increase in urbanization has been recorded between 1990 and 2012.

Table 5. Annual total pollutant loads for 2012 and their rate of increase since 1990

Area	Total TSS (tons)	Total BOD (tons)	Total COD (tons)	Total NT (tons)	Total PT (tons)
SUB-BASIN-1	183.48	18.06	127.79	3.20	1.33
SUB-BASIN-2	3,379.25	711.10	2,135.49	46.47	25.11
SUB-BASIN-3	758.80	406.29	518.81	12.62	5.07
SUB-BASIN-4	2,051.55	436.55	1,265.04	29.95	14.76
SUB-BASIN-5	5,766.11	935.01	3,089.78	70.97	39.20
SUB-BASIN-6	1,522.75	185.55	850.31	10.85	5.58
SUB-BASIN-7	398.37	38.54	239.35	5.45	2.14
SUB-BASIN-8	2,178.54	265.04	1,279.17	22.16	10.79
SUB-BASIN-9	561.69	52.45	410.27	9.67	4.08
SUB-BASIN-10	43,283.39	6,158.72	25,600.75	258.07	141.32
SUB-BASIN-11	39,315.38	5,371.47	23,356.61	420.02	227.24
SUB-BASIN-12	853.43	95.24	525.68	3.21	1.90
SUB-BASIN-13	5,141.98	634.35	3,063.63	34.56	17.18
SUB-BASIN-14	24,068.35	3,061.86	14,133.83	240.50	135.64
SUB-BASIN-15	1,032.68	103.70	619.12	11.40	4.58
SUB-BASIN-16	1,029.71	135.75	609.54	12.22	6.43
Total	131,525.46	18,609.70	77,825.15	1,191.31	642.35
Increase %	24.758%	30.736%	26.696%	22.672%	23.071%

3. CONCLUSION

This study shows that there is a significant relationship between landuse and water quality of the surface streams. Model results demonstrate that the pollution loads build up in the basin are also significant as those created by the urban wastewater. It requires emphasizing that the reduction of pollutants arising from the basin according to landuses needs extra measures, such as terracing, settling tanks, employing simple treatment systems, forming green bands on drainage lines, and removal of pollutant loads in the land. Surface stream and water quality models integrated with geographic information systems (GIS) and digital landuse maps can provide powerful guidelines to planners in devising viable watershed development plans and in evaluating alternative land management decisions.

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