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Pollution loads and surface water quality in the Kızılırmak Basin, Turkey

S.Ç. Ayaz[a,*], Ö. Aktaş[a], S. Dağlı[a], C. Aydöner[a], E. Atasoy Aytış[a], L. Akça[b]

[a]*TÜBİTAK Marmara Research Center, Environment Institute, 41470 Gebze, Kocaeli, Turkey*
Tel. +90 262 6772942; Fax: +90 262 6412309; email: selma.ayaz@mam.gov.tr
[b]*Ministry of Forestry and Water Works, Ankara, Turkey*

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ABSTRACT

A detailed study on the calculation of pollution loads and surface water quality classification was one of the most important outputs of the project on the preparation of watershed protection plans for the Kızılırmak Basin. For this purpose, the pollution loads for chemical oxygen demand (COD), total suspended solids, total nitrogen, and total phosphorus (TP) were calculated. The water quality classes of surface waters were determined based on Turkish regulations using the data obtained by the State Hydraulic Works between the years 2003 and 2009. The pollution loads and the surface water quality of rivers were displayed as maps using the geographic information systems. The connection between point and non-point pollution sources and water quality was examined. According to the obtained data, the main factors, which lead to environmental pressure on the surface waters in the Kızılırmak Basin, are non-point-source pollution originating from widespread agriculture and livestock breeding, solid waste dumping sites, and excessive salinity due to the natural formation and point-source pollution due to untreated domestic and industrial wastewaters. As a result of these pressures polluted rivers, namely Acıçay, Delice, Sarımsaklı, Kırşehir, and Yozgat creeks, were determined as hot spots in the basin. The water was polluted (Quality Class III) or highly polluted (Quality Class IV) in these rivers as measured by parameters such as COD, biochemical oxygen demand, ammonium nitrogen (NH_4-N), TP, total dissolved solids, sulfate (SO_4^{2-}), and sodium and chloride ions (Na^+, Cl^-).

Keywords: Kızılırmak Basin; Surface water quality; Watershed Protection Action Plan; Geographical information systems (GIS); Point and non-point pollution loads

1. Introduction

The increasing water demand due to the growing population, scarcity of water resources, overconsumption, and pollution of water in parallel to developing industrial and agricultural activities have all increased the importance of water resources management on watershed basis. The water resources potential and the water quality in a watershed need to be known and identified well to manage the sources in an integrated and effective manner. Turkey has already initiated ten projects on the watershed protection action plans

*Corresponding author.

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within the past few years. Within the scope of such projects, the actual situation prevalent in a basin was determined as regards the water resources potential, point and non-point sources of pollution, and water quality to define the measures that are undertaken for pollution prevention and water resource protection.

The Kızılırmak River Basin is one of the largest watersheds in Turkey. It is very important to determine the water quality of present water resources in the Kızılırmak Basin and to analyze the related pressures such as point and non-point pollution loads and their influences. Both point and non-point sources lead to pollution in the surface waters, where as the non-point sources, such as agriculture particularly, adds to nitrogen and phosphorus pollution [1]. It is obligatory to consider the present situation of water quality in action plans for watershed protection. Within the concept of the project on the drawing up of a watershed protection action plan for the Kızılırmak Basin, domestic, industrial, and diffuse (non-point) pollution loads were calculated and the quality of surface water was determined.

2. Materials and methods

The pollution loads exerted by municipal and industrial wastewaters, working or abandoned solid waste disposal sites, and non-point sources were calculated. The pollution load calculations for non-point sources were carried out using a practical methodology. The unit loads of each pollution source were selected from depicted ranges cited in the literature. Information on the number of animals and the amount of fertilizers used in the basin was gathered from various state units, namely Turkish Statistical Administration and Ministry of Agriculture. The pollutant loads from the point and non-point sources were mapped using the geographic information systems (GIS) for each watershed. The amount of pollutant loads was calculated according to the unit loads [2].

The pollutant loads were also calculated for 2020, 2030, and 2040 based on the 30-year projections of urban populations. The purpose of making such population projections is to estimate the future population changes as realistic as possible. Within the scope of the project, the population projection scenarios were developed for 30 years (until 2040) for the residential areas based on urban/rural, summer/winter, and equivalent populations. The scenario, which best reflects the characteristics of the watershed area, was selected and used in the load calculations.

Solid waste leachates constitute an important portion in the formation of pollution. In the calculation of pollutant loads originating from the leachates of solid waste disposal sites in the watershed, future pollution loads were realistically estimated taking the present situation as the basis.

The non-point pollution loads were calculated based on the important nutrients: nitrogen (N) and phosphorus (P). In order to provide the basis for future planning, the nutrient loads calculated for 2010 and the estimations for 2020, 2030, and 2040 were reported as area-based distributions.

The surface water quality classes were determined based on the water quality criteria in the Turkish Water Pollution Control Regulation (Table 1) and the data were shown in maps prepared with GIS. For water quality classification, the measurements and analysis of water resources between 2003 and 2009 obtained by the State Hydraulic Works (DSI) were used. The surface water quality classes were determined based on the quality classes criteria for terrestrial water resources described in Table 1 of the Water Pollution Control Act. According to the above mentioned table, the water quality is categorized from good quality to worse, respectively classes I–IV. As long as there were sufficient data, for each station, water quality classes (I, II, III, IV) were determined for chemical oxygen demand (COD), BOD_5, NH_4-N, NO_2-N, and NO_3-N, which are important water quality parameters in terms of organic matter and nitrogen pollution. The water quality classes were defined as Class I: high quality, Class II: less polluted, Class III: polluted, and Class IV: highly polluted. The water quality parameters were also determined with respect to the main parameter groups (A: physical and inorganic parameters, B: organic parameters, C: inorganic pollution parameters) mentioned in the same table. All these data were incorporated in the into maps using the GIS. The water quality could not be determined with respect to group D: bacteriological parameters owing to lack of data.

In the determination of water quality, characteristic values, showing 90% percentiles of measurements, were calculated for each parameter and these values were compared with the limits defined in the regulation. The characteristic values, can be calculated by adopting various methods considering different statistical distributions. In the present work, characteristic values were calculated using the Gumbel method [3] However, in such cases when the characteristic value is near the boundary value showing the water quality class, the Hazen method [4] has been also employed. In this case, the highest characteristic value calculated was taken into consideration.

Table 1
The surface water quality criteria for the mostly measured parameters (adapted from [5])

Water quality parameters	Water quality classes			
	I	II	III	IV
(A) Physical and inorganic–chemical parameters				
Temperature (°C)	25	25	30	>30
pH	6.5–8.5	6.5–8.5	6.0–9.0	Out of 6.0–9.0
Dissolved oxygen (mg O_2/L)	8	6	3	<3
Chloride (mg Cl^-/L)	25	200	400	>400
Sulfate (mg SO_4^{2-}/L)	200	200	400	>400
Ammonium (mg NH_4^+-N/L)	0.2	1	2	>2
Nitrite (mg NO_2^--N/L)	0.002	0.01	0.05	>0.05
Nitrate (mg NO_3^--N/L)	5	10	20	>20
TDS (mg/L)	500	1,500	5,000	>5,000
Color (Pt–Co)	5	50	300	>300
Sodium (mg Na^+/L)	125	125	250	>250
(B) Organic parameters				
COD (mg/L)	25	50	70	>70
BOD (mg/L)	4	8	20	>20
(C) Inorganic pollution parameters				
Iron (μg Fe/L)	300	1,000	5,000	>5,000
Manganese (μg Mn/L)	100	500	3,000	>3,000
Boron (μg B/L)	1,000	1,000	1,000	>1,000
Aluminum (mg Al/L)	0.3	0.3	1	>1
(D) Bacteriological parameters				
Total coliform (numbers/100 mL)	100	20,000	100,000	>100,000

3. Results and discussion

3.1. Pollution loads

By the year 2010, only 14 of the 310 residential centers (municipalities and villages with $N > 2000$) had their domestic wastewaters treated at the wastewater treatment plants in the Kızılırmak Basin. These treatment plants in the watershed served 1,387,038 people, which refer to 37% of the watershed population. Fractions of the pollutant loads from urban wastewater sources, which were discharged to the watershed, were 51% for COD (56,317 tons/year), 67% (5,777 tons/year) for total nitrogen (TN), and 69% (973 tons/year) for total phosphorus (TP).

The removal ratios calculated for the industrial pollution load produced are 69% for COD, 66% for total suspended solids, 20% for TN, and 7% for TP. The industrial wastewater produced in the watershed is discharged into the receiving media with a ratio of 99.4% into the watershed area and the remaining 0.6% into the Black Sea (out of watershed). The COD, TN, and TP loads reaching the watershed population were 12,574, 540, and 55 tons/year, respectively, for the year 2010.

The point-source pollutant loads from the sanitary landfill leachates in the Kızılırmak Basin for the year 2010 stand at the levels of 70 tons/year for COD, 17 tons/year for TN, and 0.18 ton/year for TP. These loads are expected to drastically increase when the sanitary solid waste landfills will be launched into operation by the year 2016 according to the Solid Waste Master Plan. Therefore, the loads will reach a value of 1,532 tons/year for COD, 291 tons/year for TN, and 3 tons/year for TP by the year 2020. Subsequent loads from the sanitary landfill leachates are expected to slowly decrease through 2040.

The non-point nitrogen pollution is dominantly caused by agricultural activities and livestock breeding. In the Kızılırmak Basin, fertilizers lead the sources of non-point pollutants in terms of N with a ratio of 57% in total, followed by pollution caused by land use (forest, grass field, meadow, and surface runoff from urban and rural settlements) with 22%, and livestock breeding with 14%. Atmospheric deposition, landfill leachates, and septic tanks contribute 7% in total in terms of TN. An investigation of the non-point loads in terms of TP showed that the largest portion (83%) belongs to an agricultural fertilizer use. The fertilizer use is followed by livestock breeding (11%), phosphorus from grass fields, meadows, and forests (5%), and from septic tanks (1%). TN and TP non-point loads reaching the watershed were 45,577 and 5,885 tons/year, respectively, for the year 2010. The distributions of non-point TN and TP loads throughout the basin are shown in Figs. 1 and 2, respectively.

A comparison of pollution loads from non-point sources with point sources from urban areas, industrial facilities, and solid wastes shows that loads originating from point sources comprise a smaller fraction in total loads as expected. For 2010, the fraction of point sources is 13% in terms of TN and 15% in terms of TP. The total point-source nitrogen load was calculated as 6,250 tons/year for 2010 and will increase to 7,895 tons/year in 2040. The total point-source phosphorus loads will increase from 1,018 tons/year to 1,356 tons/year during this 30-year time span. Despite such small changes in loads from point-sources, the amount of change is much higher in the case of non-point sources. The total non-point source nitrogen load of 45,577 tons/year in 2010 is expected to decrease to 31,734 tons/year in 2040 with about a 40% decrease. Similarly, the total non-point phosphorus load will decrease from 5,885 tons/year to 3,596 tons/year. The summary of the total pollution loads in the Kızılırmak Basin is shown in Table 2.

3.2. Surface water quality

Kızılırmak is a river basin, which comprises of the main Kızılırmak River and its branches. Throughout the main Kızılırmak River, considering nitrogenous parameters, NH_4-N ranges between Classes II and IV, NO_2-N is in Classes III and IV, and NO_3-N is in Classes I and II (Fig. 3). On the other hand the TP ranges between Classes II and IV. In terms of other Group A (physical-inorganic) parameters, sodium (Na^+), chloride (Cl^-), and sulfate (SO_4^{2-}), which show salinity of the river, were in Classes III-IV, and total dissolved solids (TDS) was in Classes II-III. Therefore, the Kızılırmak River is generally housed in Class IV for Group A parameters (Fig. 4). Considering organic parameters, COD is usually in Class I or II (Fig. 3). However, Group B (organic) parameters were generally in Class II and in some places even in Class III

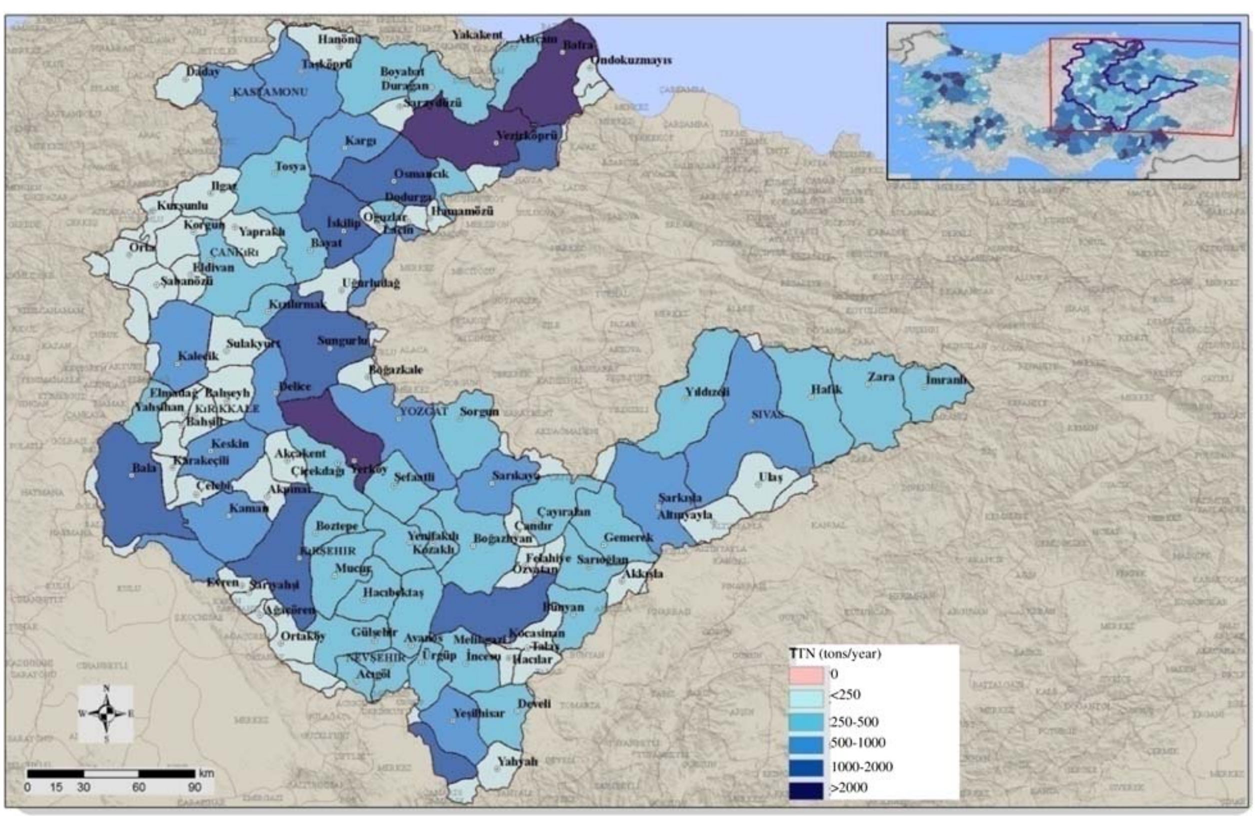

Fig. 1. The distribution of total non-point TN loads in the Kızılırmak Basin.

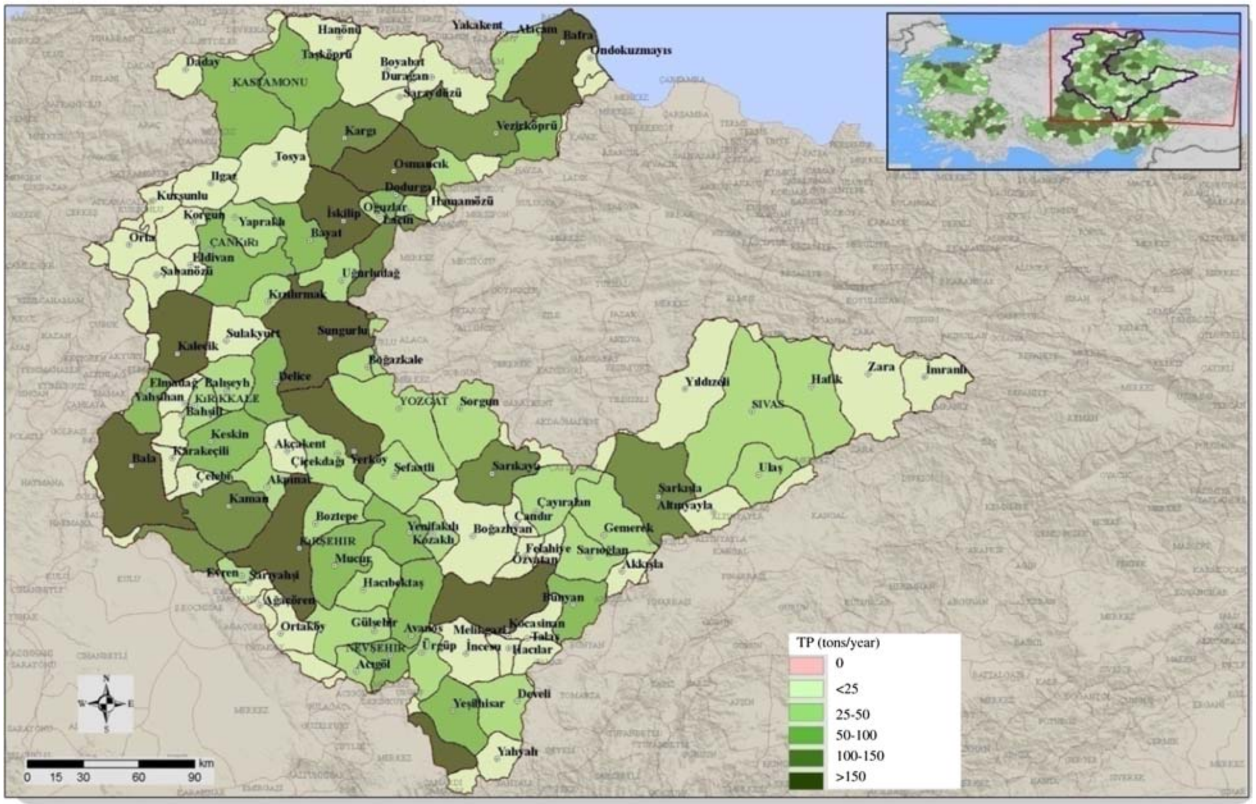

Fig. 2. The distribution of total non-point TP loads in the Kızılırmak Basin.

Table 2
Total pollution loads in the Kızılırmak Basin

Years	Load (tons/year)							
	TN				TP			
	Point		Non-point	Total	Point		Non-point	Total
	Domestic	Industrial			Domestic	Industrial		
2010	5,756	494	45,577	51,828	967	50	5,885	6,903
2020	5,066	413	38,605	44,085	948	45	4,719	5,712
2030	6,442	372	35,198	42,012	1.135	41	4,156	5,331
2040	7,564	331	31,734	39,629	1.320	36	3,596	4,952

(Fig. 5) owing to the biochemical oxygen demand (BOD) parameter, which is subject to more stringent limits. Group C (inorganic pollution) parameters, including heavy metals, belonged to some places in Class II, but were usually in Class III (Fig. 6). Particularly for Group B and C parameters, similar characteristics were observed in the main creeks, which feed the main Kızılırmak River. Table 3 shows the water quality classes in the Kızılırmak Basin based on various important parameters. Although, organic, nitrogenous, and phosphorus parameters are usually particularly considered to be important, parameters showing the inorganic salts are equally important in the Kızılırmak Basin owing to the unusually high concentrations of sodium, chloride, sulfate and total dissolved solids.

Table 3 shows that the most important problem affecting the surface water pollution in the basin is salinity. Although there are quite a few creeks including Gökırmak, Devrez, Kırşehir, and Yozgat Creeks which are an exception, salinity is observed in most of the creeks in the basin such as Karasu-Delice, Acıçay,

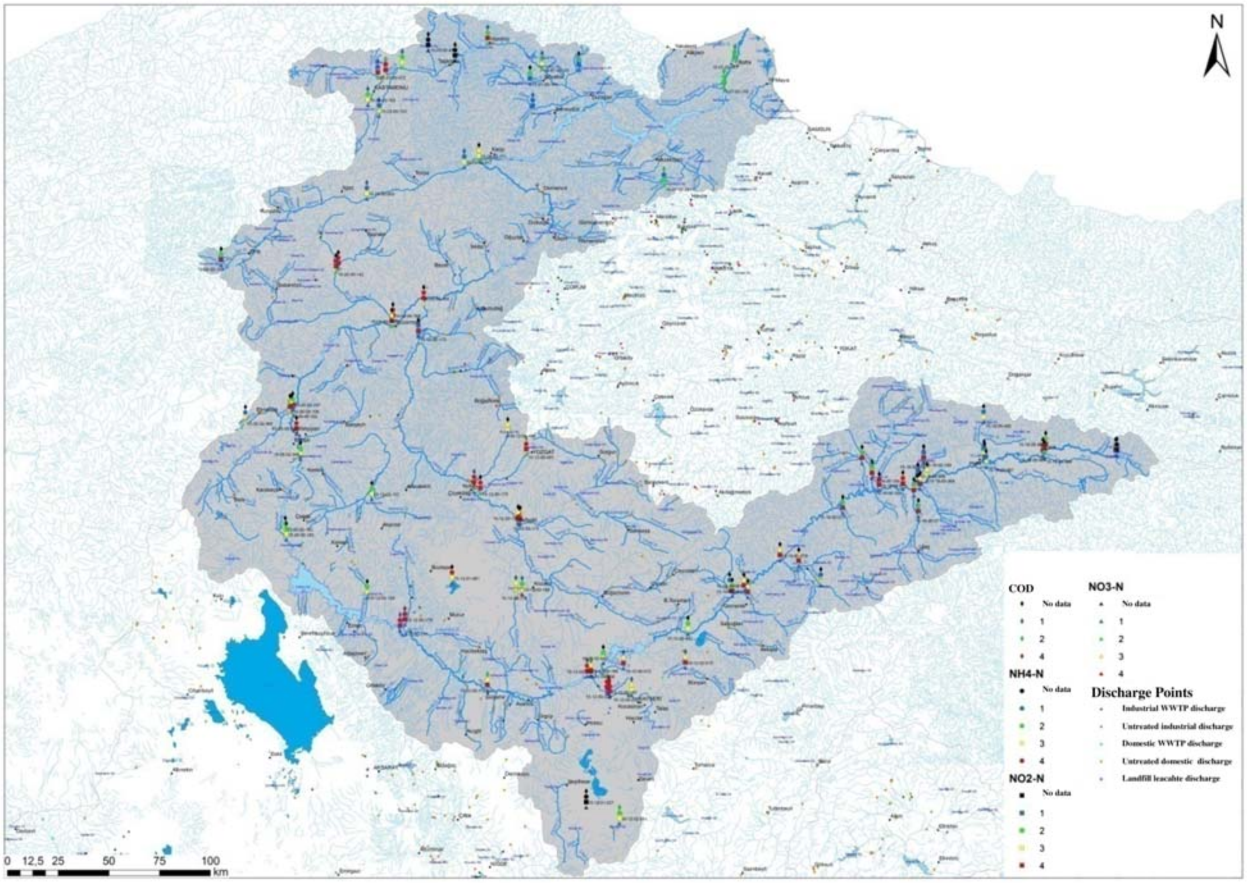

Fig. 3. The water quality classes for the Kızılırmak Basin based on important parameters (COD, NH_4-N, NO_2-N, and NO_3-N).

Sarımsaklı, Acısu, Fadlım, Tecer, Osugülüç, Göksu, and Kasımbey Creeks in addition to the main Kızılırmak River. This problem is specific to the region and is caused naturally by the geological properties of the land.

Another important problem widely encountered in the watershed is that the total phosphorus parameter belongs to Class III (polluted) or Class IV (highly polluted) in the Kızılırmak River as well as in the Acıçay, Tatlıçay, Karasu, Sarımsaklı, Kırşehir (Kılıçözü), and Yozgat Creeks. A recent study showed that the TP concentrations may vary to a large extent within a river, with high concentrations in the cultivated areas, due to the use of fertilizers [6]. On the other hand, ammonium nitrogen (NH_4-N) is placed in Class III or Class IV in Kırşehir, Acıçay, Delice, Sarımsaklı, Acısu, and Yozgat Creeks and in the Kızılırmak River just after its connections with Sarımsaklı and Kırşehir Creeks (Fig. 3). Nitrate (NO_3-N) pollution, corresponding to Class III, was observed only in the Acıçay and Delice Creeks. These streams, where nitrogen and phosphorus pollution was observed, are obviously affected by agricultural non-point pollution.

On the other hand, domestic and industrial point discharges also play an effective role in the pollution of streams in the Kızılırmak Basin. Particularly in Kırşehir, Acıçay, and Sarımsaklı Creeks, organic matter pollution (Class IV) and the low dissolved oxygen levels related to this pollution, were observed owing to domestic and industrial discharges. Also, Yozgat and Delice Creeks and Kızılırmak River just after its connection with Kırşehir Creek are polluted (Class III) in terms of organic matter (Fig. 5). A recent study also showed that the concentration of organic matter vary widely within a river owing to domestic wastewater discharges [6].

A previous study in 2004 by the State Hydraulic Works (DSİ) showed water quality belonging to generally Class II in terms of NH_4-N throughout the basin [7]. However, in Sarımsaklı, Tatlıçay, and Çoruhözü Creeks which receive the domestic and industrial discharges emanating from Kayseri, Çankırı, and

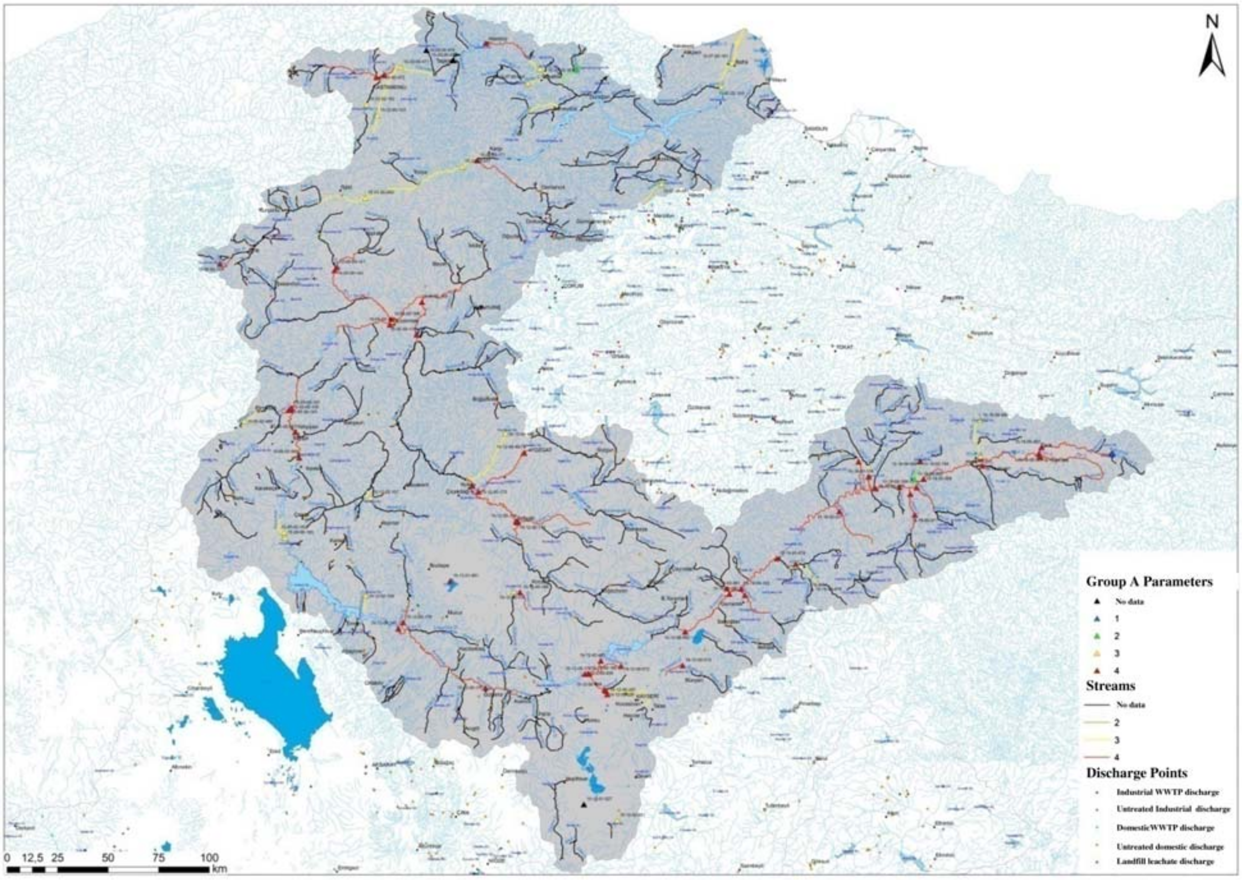

Fig. 4. Water quality classes for Kızılırmak Basin based on group A (physical–inorganic) parameters.

Kırıkkale cities, respectively, NH_4-N is in Class IV. On the other hand, Acıçay and Delice Creeks were in Class III as regards the ammonia pollution. The same study showed that phosphorus was in Class III, and the organic matter (BOD) was in Class I throughout the basin. However, BOD was found to be in Class IV in Sarımsaklı, Tatlıçay, and Çoruhözü Creeks, Class III in Acıçay Creek, and Class II in Delice Creek [6]. A comparison of these findings with the results of our study shows that there has been no improvement in the water quality since 2004.

3.3. Highly polluted streams in the basin

Natural pollution leading to salinity was a general problem in the Kızılırmak Basin. However, few streams were also highly polluted by the anthropogenic point and non-point sources. Acıçay, Yozgat, Delice, Kırşehir, and Sarımsaklı Creeks were determined to be polluted (Class III) or highly polluted (Class IV) in terms of organic matter, nitrogenous, and phosphorus parameters, which represent the wastewater discharges and agricultural pollution (Table 3). Hence, these streams were determined as hot spots in the watershed.

3.3.1. Acıçay Creek

Acıçay Creek, when combined with Tatlıçay Creek, receives the point and non-point pollution loads originating from the Çankırı City as well as Korgun and Yapraklı Towns. Consequently, it is highly polluted (Class IV) in terms of organic matter, ammonium, and total phosphorus, and polluted (Class III) in terms of nitrate. Figs. 1 and 2 show that non-point TN and TP pollution loads are not very high compared with the Basin in general. Anyway, the nitrogen originating from livestock breeding and phosphorus originating from both livestock breeding and agricultural fertilizers (data not shown) in Çankırı contributed to the pollution. However, the most important problem in Acıçay Creek was the pollution caused by the incoming untreated wastewater discharges, particularly from the city center of Çankırı, which is the most populated town of the Acıçay subbasin.

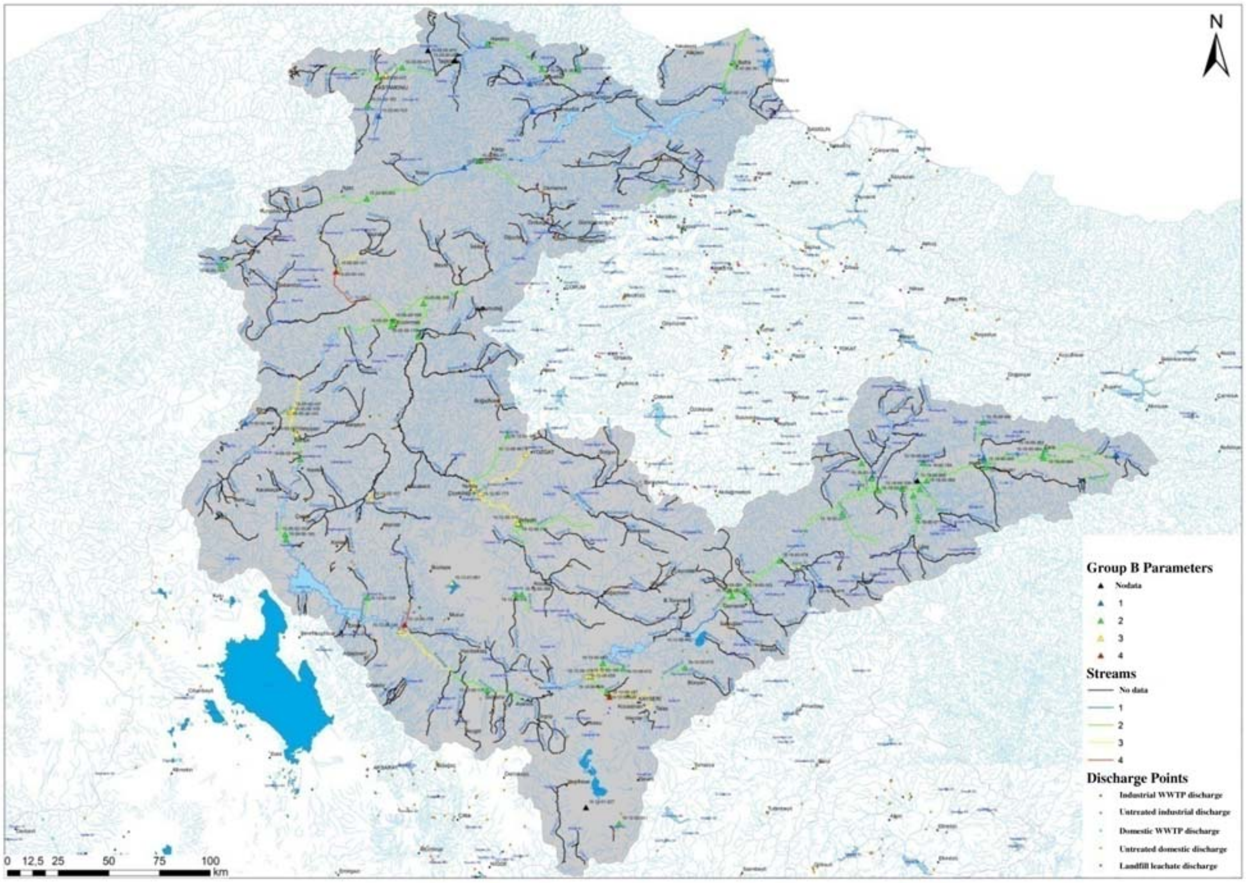

Fig. 5. Water quality classes for Kızılırmak Basin based on group B (organic) parameters.

3.3.2. *Yozgat Creek*

It is highly polluted (Class IV) in terms of ammonium and total phosphorus and polluted (Class III) in terms of organic matter (Table 3). Point sources originating from the Yozgat city center and non-point sources originating from land use and livestock breeding are the main sources of pollution in the stream.

3.3.3. *Delice Creek*

It is polluted by point and non-point sources originating from Yerköy Çiçekdağı, Şefaatli, Kozaklı, and Boğazlıyan towns before its connection with Yozgat Creek, and from Yozgat, Delice, and Sungurlu towns after its junction with Yozgat Creek. The water quality is polluted or highly polluted in terms of organic, nitrogenous, and phosphorus parameters. Yerköy contributes the most to TN and TP loads (Figs. 1 and 2) since it is a region with dense agriculture and livestock breeding. Also, TN and TP originating from agriculture and land use in Sungurlu contribute to non-point pollution in the stream. In addition, town centers, namely Yerköy, Şefaatli, and Boğazlıyan without domestic wastewater treatment plants, contribute to pollution of the stream as important point-sources in the subbasin.

3.3.4. *Kırşehir (Kılıçözü) Creek*

It is highly polluted (Class IV) in terms of organic matter, ammonium, and total phosphorus (Table 3). Untreated domestic and industrial discharges seem to have the highest impact on the stream's pollution. However, the domestic WWTP taken into operation in 2010 is expected to increase the water quality. In addition, non-point sources particularly originating from agriculture and land use (Figs. 1 and 2) contribute to the pollution of streams. However, a high water quality in terms of nitrate (Class I) indicated that the effect of nitrate containing fertilizers was negligible.

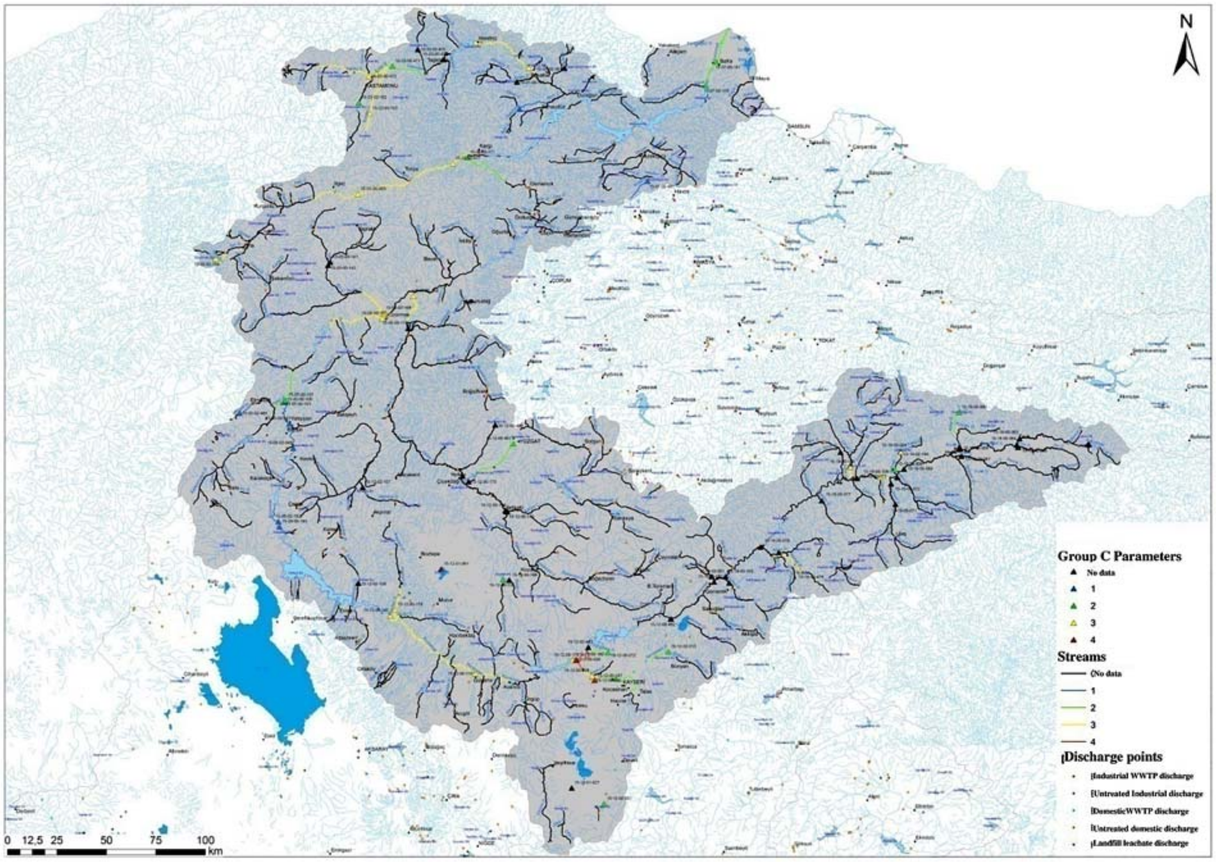

Fig. 6. Water quality classes for Kızılırmak Basin based on group C (inorganic pollution) parameters.

Table 3
Water quality classes in the Kızılırmak River and important creeks in Kızılırmak Basin based on various parameters

	COD	BOD	NH_4-N	NO_3-N	TP	Na^+	Cl^-	SO_4^{2-}	TDS
Kızılırmak River	I–II	II	II–IV	I–II	II–IV	III–IV	III–IV	III–IV	II–III
Gökırmak Creek	I	I–II	II	II	I–III	I	I–II	I–III	I–II
Devrez Creek	I	I–II	I–II	I	II	I	I	I	I–II
Karasu–Delice Creek	–	II–III	III–IV	I–III	II–IV	IV	IV	III–IV	III–IV
Acıçay Creek	–	III–IV	IV	II–III	III–IV	IV	IV	IV	IV
Kırşehir Creek	IV	IV	IV	I	IV	I	II	I	II
Sarımsaklı Creek	II–IV	II–IV	III–IV	I	III–IV	I–IV	II–IV	I–IV	II–III
Yozgat Creek	II	III	IV	II	IV	I	II	I	II
Acısu Creek	–	II–III	I–IV	I	–	III–IV	III–IV	IV	III

3.3.5. Sarımsaklı Creek

It is polluted (Class III) or highly polluted (Class IV) in terms of organic matter, ammonium, and total phosphorus (Table 3). Although the wastewaters are treated, domestic and industrial discharges originating from the developed and highly populated city center of Kayseri are the main sources of pollution in the stream. In addition, non-point loads of TN and TP are much above the basin averages (Figs. 1 and 2) and contribute highly to nitrogen and phosphorus pollution in the stream. However, high water quality in terms of nitrate (Class I) indicated that the effect of nitrate containing fertilizers was negligible.

A comparison of the results obtained for various pollution loads and water quality showed that the water quality of the rivers passing from areas polluted with point or non-point sources, is detiriorating. The point sources contribute to the pollution in terms of organic matter, nitrogen, and heavy metals, whereas the non-point sources particularly contribute to nitrogen, phosphorus, salinity, and suspended and dissolved solids' pollution.

The available data and the results of the study may provide quite a few recommendations. The water quality measurements for the determination of organic content by the DSI are usually measured as COD and BOD. Since the other organic parameters are not measured, it is obvious that the actual water quality could turn out be even worse than assessed. In addition to that, out of 21 units in the C group, only 3–4 parameters are usually measured. In particular areas where the industry is concentrated, the measurement of heavy metals will be very useful. It is highly recommended to broaden the water quality monitoring network and increase the number of monitored water quality parameters. The parameters for measuring the ecological and biological pollution should also be determined.

It is possible to decrease the point and non-point pollution loads by taking several protective measures. Kızılırmak Basin is a region where intense agriculture and livestock breeding are practiced, trigerring off nitrogen and phosphorus pollution. To decrease the non-point loads, particularly in the subbasins of the above-mentioned streams defined as hot spots, it is recommended to restrict the use of chemical fertilizers, to combine individual animal farms in organized areas, and to reuse solid and liquid animal wastes after being separately collected. In addition, the solid waste dumping sites, which significantly add to the non-point source pollution, should be rehabilitated and sanitary landfills constructed. The domestic wastewaters also lead to putting up pressure on the streams designated as hot spots, particularly due to high organic and nitrogen loads. To decrease the point loads, the wastewater treatment infrastructure should be immediately completed, particularly in the subbasins of the hot spots.

4. Conclusions

A detailed water quality classification study was not previously carried out for the Kızılırmak Basin. Thus, it was one of the most important outputs of the project. According to the obtained data, the main factors which lead to environmental pressure on the surface waters in the Kızılırmak Basin are widespread agriculture and livestock breeding, untreated domestic and industrial wastewaters, solid waste dumping sites, and excessive salinity due to the natural formations. As a result of these pressures, the polluted rivers, namely Acıçay, Delice, Sarımsaklı, Kırşehir, and Yozgat creeks, were determined as hot spots in the basin. Water was polluted (Class III) or highly polluted (Class IV) in these rivers with respect to the parameters COD, BOD, NH_4-N, TP, TDS, SO_4^{2-}, Na^+, and Cl^-.

Acknowledgments

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