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Optimization and reduction of industrial load in a wastewater basin

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ABSTRACT

In this study, a method for specification and reduction of industrial wastewater load has been determined in a wastewater basin. The operation of industrial pre-treatment plants is not very efficient in the basin and causes operational problems both in sewer and central treatment plants. Also, heavy metals from anthropogenic activities are among the most widespread pollutants. However, there is a few research for the heavy metals reaching the treatment plants from the urban sewer. In the study, a comprehensive survey and analysis study was carried out for 20 parameters of the industries with the highest load. These parameters were found to have a burden on the municipal wastewater treatment plant at rates ranging from 85% to 99%. By the proposed load reduction method, approximately 99% of the industrial wastewater could be treated and discharged at the legislation limits in the study basin. The reduction in the pollutant load was also examined in detail by two parameters and it was calculated that the organic load will be decreased to 6,331 kgCOD/d (chemical oxygen demand) as 85% and, Zn to 6.8 kg/d with a 94% decrease. The findings of the study clearly indicated that the removal of a higher amount of pollutants is achieved with the use of fewer industrial wastewater pre-treatment plants and the protection of the environment is ensured.

Keywords: Basin; Characterization; Industrial; Optimization; Pollutant; Wastewater

1. Introduction

The use of water and the generation of wastewater production has increased after industrial development. Collection and treating industrial wastewater are necessary to protect public health and prevent pollution of water resources [1,2]. Industrial wastewater is highly polluted and should be treated before released into the environment [3,4]. The content of industrial wastewater differs according to the product type, amount of water used and other factors [5–8].

Heavy metals from anthropogenic activities are among the most widespread pollutants. However, there are a few research for the heavy metals reaching the treatment plants from urban sewer and/or watersheds [9]. In a study conducted in the Seine River (Paris), 7.9 kg/d Cu and 13 kg/d Ni could be discharged into the river even after the wastewater treatment plant and around half this load is in the labile metal form [10]. For that reason, metal fluxes of the river increased, especially during low-flow periods. Similarly, the distribution of heavy metals in the wastewater treatment effluent and sludge was studied in Thessaloniki city and found that more than half of Cd, Cr, Pb, Fe, Ni and Zn metals are kept in the treated effluent [11].

Istanbul, with its 14 million inhabitants as Turkey's most populous city, corresponds to approximately 18% of the country's population and are also contained about 31% of the country's industry. Rapid, uncontrolled and illegal urbanization in the last decades accompanied by insufficient infrastructure has caused a chaotic city type including many industries within the city. It is also the most intensive city

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in the country in terms of industry. Production processes of 6,321 industries operating in Istanbul are the main source of industrial wastewater [12]. Dense population and economic activities in a limited area and chaotic urbanization cause increasing pressure on the natural resources of the city.

In the city, the main urban wastewater consisting of domestic and industrial wastewater and also rainwater is collected by the sewerage system. However, in the areas where the infrastructure system is not available or inadequate, the receiving water media is used to discharge (lakes, streams, etc.). Moreover, in Istanbul, 86% of the industrial wastewater-producing industries are scattered in the city but not inside an organized industrial zone (OIZ). For example, only 107 industries were in the OIZ of the studied basin. In addition to large-scale industrial plants, the number of small-scale plants is quite abundant in the city. Based on the amount of wastewater originating, the daily wastewater of 643 facilities is below 5 m^3. This figure corresponds to 77% of the total industrial installations [12,13].

In the industries that built a treatment plant according to the current legislation in Istanbul, monitoring of treatment efficiency is not easy if generated daily wastewater flow is very low or the discharges are not given hourly but over a long period of time. Moreover, the operation of these plants is not very efficient. Then, these types of industrial discharges and wastewater content cause operational problems both in the sewerage line and in the central municipal treatment plants. Furthermore, there is a risk that these pollutants will migrate to the receiving medium if there is no collector system in the location of the factory or if there are floods in infrastructure systems in rainy weather. For this reason, effective and feasible methods to ensure full control of industrial wastewater pollution are needed to be investigated. The established wastewater pre-treatment plants (WTPs) can be controlled by only periodic inspections but not frequently. In that case, while the WTPs can be observed by a momentary status at the time of inspection, the operation remains out of control at other times and is not controlled by water administration.

In the existing wastewater management model, it is inevitable that the burden of industrial pollution on the central municipal treatment plants and the receiving environment is inevitable because of the exemptions from WTP installation and insufficient control of the operation of the established WTPs. It has also been found that WTPs installed for very low wastewater sources have no operational practice and it is difficult to control the unintentional and/or illegal discharge of these wastewaters. Because of all these reasons, there is a need to develop a wastewater control method that will ensure that the majority of industrial wastewater sources, which are scattered in the area, should be controlled. In order to meet this need, in this study, an industrial load reduction method (LRM) has been used to ensure reducing the loads by local detection of industrial pollutant sources in the Ambarli Wastewater Catchment Basin (AWCB) in Istanbul. This basin is one of the biggest and most important industrial areas in the city.

Effective and feasible methods to ensure full control of industrial wastewater pollution are needed to be investigated. Especially, heavy metals from anthropogenic activities are among the most widespread pollutants. However, there are only a few research for those pollutants reaching the treatment plants from the urban sewer. In this study, the amount of the industrial pollutant load that may affect the central wastewater treatment plant is calculated to lower the targeted pollutant loads in the basin in 2016. Thus; energy, time and economic savings can be achieved by controlling the sewer system with a lower number of industrial wastewater treatment plants and also lower the pollutant load (organic and metals) in the basin area. Moreover, operating fewer industrial treatment plants by planning a waste LRM is another useful output.

2. Materials and methods

2.1. Study area and the existing industries

This research was conducted in the AWCB, with an area of approximately 438 km^2, which covered Beylikduzu, Esenyurt and Arnavutkoy districts and a major part of the Avcilar and Basaksehir districts. Sazlidere Dam, as the aquatic area which provides drinking water, and a major part of the catchment basin of the Kucukcekmece Lake and a part of the Alibeykoy catchment basin is also within the boundaries of the AWCB basin. Fig. 1 gives the location of the Basin.

The AWCB is a sensitive basin because of the intensity of industrial facilities and the water catchment basins it covers. In the study, it was determined that there are 832 facilities releasing industrial wastewater and a total of 6,967 m^3 wastewater is released daily [12,13]. In the AWCB, there are various production sectors, mainly the industries that produce metal, textile and food stand out both with respect to the number of facilities and various amount of wastewater released. Three power plants and eight petroleum products storage facilities were among the other important facilities in the basin. Some industrial facilities (258 of them) are at the same time in the water catchment basin. In the study basin, there is one OIZ, including 107 industries; but other industries were scattered in the area. There are 2 treatment plants in the OIZ and the untreated process wastewater or pre-treatment output from some industries and domestic wastewater are treated here. For the 725 industries outside the OIZ, a treatment plant, required as in the legislation, must be installed and these plants must be periodically controlled. The existing state of the industries in the basin is given in Table 1. In the AWCB, there is Ambarli Advanced Biological Wastewater Treatment Plant (ABWTP), which is designed according to the average wastewater flow rate of 400,000 m^3/d. According to the data from the Istanbul Water and Sewerage Administration (ISKI) (abbreviated as ISKI in Turkish), the amount of urban wastewater treated in the plant was 201,905 m^3 in 2015 [12]. In Istanbul, the total industrial wastewater amount and daily treated municipal wastewater (biological and pre-treatment systems) in 2015 were 55,898 and 3,170,432 m^3, respectively [12].

The industries in the coastal region of the basin and the industries in the Arnavutkoy district, except for the animal husbandry establishments, are connected to the sewage line. Accordingly, of the 832 industries in the basin, 766 is subject to the Sewage Usage and Discharge Regulation, in Turkish and the rest is subject to the Water Pollution Control Regulation, in Turkish.

Fig. 1. Location of the Ambarli Wastewater Catchment Basin.

2.2. Classification of wastewater

In the study, some facilities, such as hotels, hospitals, schools, restaurants, were excluded and the data were produced by investigating the processes and wastewater from industrial facilities. Each industrial facility identified was coded by letters and numbers (e.g., T_1, T_2, …, T_n). In order to determine the pollutant load of the basin, pollution properties and loads of each industrial facility were identified. All data including wastewater analysis and waste load values from industries entered into a Microsoft-Excel file and used for calculation. Although the industrial classification approach firstly based on pollution characteristics [14], new industrial categories were established since the industrial variation in the AWCB is high. With this aim, the number of sub-categories was increased and made more specific. During categorization, it was determined that some facilities did not belong to a single category/sub-category with respect to their activities but belong to more than one category/sub-category. The categorization of such facilities was based on the main production activity. As the main part of the study, an industrial waste LRM was adopted in the categories considered as important pollutants based on the characteristics.

The wastewaters of the industries in the study basin were monitored in a total of 20 pollutant parameters, considering the conventional parameters as chemical oxygen demand (COD), oil and grease, total suspended solids (TSS), phenol, total-N, total-P, total-S, Cu, total-Cr, Zn, Ni, Pb, As, Cd, Ag, Sn, Hg, F, total-CN and detergent. Averages of wastewater characterization values were determined for each parameter using local analysis data and partially from literature data [13].

2.3. Determination of the categories and LRM

In determining the category and LRM, the data from wastewater samples from the industries in the study basin and in general in Istanbul, the average pollutant concentration values of the categories were produced using the data from characterization sample analyses of at least 3, but in general 6–10 samples [13].

Table 1
Existing wastewater treatment situation of industrial plants

Industrial groups	Industry	Number of existing WTP	Non-WTP	Treated wastewater quantity (m^3/d)	Non-treated wastewater (m^3/d)
Metal	187	116	71	1,016	66
Chemistry and related	144	50	94	379	83
Paper and related	23	8	15	17	4
Textile	142	99	43	3,154	278
Leather	1	1	–	–	–
Oil and related	134	18	116	296	101
Solid waste	1	–	1	–	3
Mineral	71	8	63	27	201
Food and related	129	21	108	1,145	198
Total	832	321	511	6,034	934

As the first stage of method determination for load reduction, which is the essential part of the study, principal polluting sources were identified and the following approaches were considered in the LRM (i) all industrial plants with wastewater flow greater than 5 m^3/d must establish (pre-) treatment plants according to the regulation of ISKI. For that reason, the study was based on this regulation. In the facilities with a wastewater flow of less than 5 m^3/d, the treatment plant was determined on the basis of the pollution load. In these cases, principal wastewater sources were identified (those containing significant pollutants and/or high pollutant load). Generally, it was determined with the highest COD (as organic matter load) and/or the highest heavy metal parameter. Industrial facilities with less than 5 m^3/d correspond to 77% of the total installations in the city and 641 of the 832 industries in the AWCB, (ii) wastewater categories containing heavy metal, CN and phenol parameters and/or high acidity and alkalinity were also considered principal pollutant sources, (iii) COD parameter load was applied in two ways: Food production categories, car overwashing and carpet washing plants with a load of more than 1.5 kg of COD/d are considered as significant sources. Outside of these categories and, other product categories with the potential of toxic or resistant organic matter, the industries with a COD load of more than 0.1 kg/d are considered to be principal sources and wastewater is transported to a planned common treatment plant, (iv) plastic processing industry wastewaters have been considered important pollutants. The reason for this is assumed that these plants create a significant amount of pollution as a result of the use of water in cycles, (v) the wastewater of the facilities with low wastewater volume will be transported to a common treatment plant, (vi) treatment plants of high wastewater flow industries will also be monitored by remote sensing system, (vii) no wastewater management is envisaged for categories providing discharge limits regardless of the amount of wastewater, (viii) wastewater of animal feeding areas is planned to be transported and treated in a separate common treatment plant in the nearest area, (ix) marble, soil products and concrete production industries are not principal because they do not use wastewater treatment but have recycled system.

After analysis of all industrial wastewater, all pollution load of industries was calculated and compared by Microsoft-Excel tables and LRM was applied for Ambarli Basin.

3. Results and discussion

In the study, the wastewater that is used in pollutant load calculations were identified as process wastewater and other sources than processes (i.e., equipment maintenance and emission wastewater). The daily average of the total industrial wastewater generated in the AWCB was calculated as 6,967 m^3, and it was determined that the 6,674 m^3/d of this amount came from 766 facilities that had an effect on ABWTP and the 293 m^3/d came from 66 facilities affecting the receiving medium (river, lake, etc).

In the categorization study, the industries in the AWCB were firstly divided into 43 categories. Then, most of them were divided into sub-categories, and finally, 75 subcategories were established. It can be seen that the petroleum products category ranked the first with 131 facilities, the finishing process of woven fabrics ranked the second with 121 facilities and the finishing processes of the metals industry ranked the third with 111 facilities. On the basis of wastewater amount, the highest was in the woven fabrics finishing processes with 3,038 m^3/d, the second was the confectionery industry category with 941 m^3/d and the third was the metal finishing processes with 586 m^3/d wastewater.

It was observed that pollutant parameters COD, TSS, oil and grease, tot-N, Zn and Cu of industrial wastewater in the AWCB were the important parameters that had higher concentrations than the other parameters. It is also found that the newly formed categories are different from the literature values because of the reasons arising from mixed regional production processes. As an example of this, the differences determined in the textile industry are given in Tables 2 and 3.

The LRM was used as (i) building a common wastewater treatment facility for industries with low flow rate (treatment of all in one plant) and (ii) treatment at the source or monitoring method with a remote sensing system for high flow rate industries. Hence, it is stated that a better system can be established by WTP installation and

Table 2
Textile industry wastewater characterization in Turkey

Category	Parameter-average concentration (mg/L)						
	COD	BOD_5	TSS	Oil and grease	Tot-Cr	Phenol	Sulfur
Wool washing	9,000	3,000	4,000	3,000	–	–	–
Fabricated production	1,200	300	200	–	–	–	–
Mesh fabric finishing	1,000	350	300	53	0.5	0.24	0.2
Stock and yarn finishing	1,200	500	40	–	5		2
Woven fabric finishing	1,200	650	300	14	0.04	0.04	3
Carpet finishing	2,000	700	100	30	0.005	0.001	0.002
Non-woven fabric	3,850	1,230	80	–	–	–	–
Jeans washing	1,000	300	300	–	–	–	–

Table 3
Textile industry characterization in AWCB

Sub-categories	Parameter-average concentration (mg/l)								
	COD	TSS	Oil and grease	Tot-Cr	Phenol	Tot-S	Tot-N	Tot-P	Surfactants
Woven fabric finishing (textile dyeing)	2,790	90	–	0.11	0.9	5	19	15	85
Woven fabric finishing (textile washing)	1,450	300	–	–	–	9	40	15	85
Woven fabric finishing (textile printing)	4,300	2,400	–	–	–	5.5	–	–	–
Non-woven fabric operations	10,150	700	–	–	–	7.9	–	–	–
Stock and yarn finishing	1,200	40	100	5	–	2	–		85
Other textile washing (carpet washing)	1,200	150	25	–	–	0.7	–	15	15
Other textile washing (textile washing)	250	80	–	–	–	0.2	–	–	15

remote sensing system for 178 industries, by transporting the industrial wastewater to a common wastewater treatment plant (CWTP) for 483 industries and by the wastewater treatment-reuse system for all the 59 mineral industries in the cement, marble and soil products category.

It was planned to install 2 CWTPs. In the first, 33 m^3/d wastewater from 58 animal husbandry activities category in the rural region was planned to be treated, and discharge could be used for agricultural irrigation in the region. The wastewater from 425 industries in categories other than the husbandry category was transported to a CWTP to be installed in the Beylikduzu province, almost in the center of the basin.

The reflection of the control of industrial pollution in the AWCB was identified in detail by using the COD and the zinc parameters as an example. The LRM application decreased the COD load in the basin by 85%. The reflection of the LRM for zinc load is 94%. This value corresponds to approximately 6.5% of the total zinc load in the AWCB. The remaining amount of zinc is composed of treated industrial wastewater discharges, and/or the industrial discharges in the categories that zinc concentration values are below the discharge limits.

It was determined that 49% of the total industrial wastewater in the basin was originated from textile industries, 19% from food and 16% from metal group industries. These three groups accounted for 84% of the total wastewater. The main reason is the number of textile industries. In Turkey, this group of industries is concentrated in Istanbul where there exist hundreds of textile plants [15]. In the previous study conducted in another wastewater catchment basin in Istanbul, the findings showed that more than 60% of the wastewater in the basin originates from those industries [14]. In this study, important differences were determined in the characterization study of industrial groups between the literature and local values. It should be emphasized here that local-based characterization studies in identifying pollutant loads are very important for real values.

The pollutant investigation with 20 parameters in the study showed that the high-level pollutants in the AWCB were determined as the COD (40,693 kg/d), oil and grease (4,990 kg/d), TSS (7,235 kg/d) and surfactants with 312 kg/d (See for all pollutants in Section 3.1 – Industrial load in Istanbul City). Considering the COD and Zn loads mentioned above, the average COD and Zn concentrations of the industrial wastewater in the AWCB were calculated as 5,895 and 15 mg/L, respectively. Conducting industrial classification in detail for each industrial group and determining the characterizations at the local basis ensured that the pollutant load of the AWCB was determined on a real scale and resulted in a better determination. In this study, the Zn and Cu loads, all of which were in the category of metals, were determined as 105 and 103 kg/d, respectively. It is reported that in the Tuzla Wastewater Catchment Basin, the Zn pollutant load was determined as 140 kg/d and the Cu load was 28 kg/d [14].

Unless principal industrial pollutant sources are controlled by effective and applicable wastewater management, it is inevitable that industrial pollutants can reach the receiving water sources, because of direct discharges or insufficiency and lack of the sewage system and with flooding in the combined sewage system. On the other hand, 96% of the industrial wastewater formed in the AWCB establishes a load on the infrastructure system at the same time. The pollutants carried in the sewage system would bring about problems both in the sewer lines and in the ABWTP such as by making the operation of the system more difficult and leading to the transfer of the pollutants in the final receiving medium. Consequently, the pollutant loads calculated above result in a potential load on the receiving medium unless effective industrial wastewater management is defined.

In LRM, it was determined that 720 out of 832 industries were principal pollutants and wastewater measures were considered necessary. The other 112 industries were not principal with respect to pollutant type and load. By helping of LRM: (i) wastewater discharge of 59 industries (i.e., marble, soil products and concrete industries) are prevented by the wastewater treatment and used recycle system, (ii) The wastewater from 483 industries with low flow rates is transported to 2 CWTPs and treated at discharge limits. In the existing state, there were treatment plants in 163 industries with low flow rates. In the LRM, these WTPs are canceled and wastewater is transported to the CWTP together with the other 320 principal pollutant wastewater sources with low flow rates. Hence, ISKI could lower the economic and administrative burden which are required for the control of the facilities by using technical staff, (iii) The wastewater from 178 principal pollutant sources with high flow rates will be treated at sewage discharge limits by treatment at the source and remote sensing-control systems. In the existing state, in addition to the WTPs installed in 158 industries with high flow rates, 20 more WTPs being installed in industries of high flow rate wastewater. In this way, 6,885 m^3/d of the total 6,967 m^3/d wastewater in the AWCB will be completely under control. The total wastewater flow rate of the WTPs in 321 of the 832 industries is approximately 6,034 m^3/d.

On the basis of the present findings, insightful contributions of the study to industrial wastewater management literature can be drawn as follows: (i) industries are classified based on the pollutant analysis. The pollutant type and load of each industrial source and industrial category are determined seperately and these data allow the evaluation of the polluting potential of each industry and category on the receiving water medium and municipal treatment plant, (ii) since the characterization data are obtained by the studies conducted in the AWCB and Istanbul in general, they determine the pollutant load of the AWCB at a real scale and are a source of information for similar studies to be conducted in the wastewater catchment basins, (iii) importance of using local characterization data has been clearly demonstrated, (iv) 96% of the 934 m^3/d wastewater exempted by controlling through LRM, and the amount of untreated wastewater is reduced to 83 m^3/d, (v) number of treatment facilities that have to be inspected and monitored in priority was reduced from 321 to 178, preventing loss of energy and time, (vi) considering that most of the industries in Istanbul are outside the OIZs and are spreaded in the city, it is believed that LRM is the most effective wastewater control system in full control of industrial pollution (including common wastewater treatment, remote sensing system, etc).

3.1. Industrial load in Istanbul City

Istanbul is the most crowded city in Turkey. According to data from the Ministry of Industry and Technology, the number of registered industrial enterprises in the city is 27,234 and Istanbul is the most intensive industrial city with a total rate of 31% in the country. According to ISKI's data, 6,321 industries operating in Istanbul are producing industrial wastewater from the production processes of the plant [12]. The distribution of the facilities by sectors is shown in Table 4. Daily total wastewater from the facilities is 55,898 m^3. Distribution of the plants in the sectors as follows: first of all, 2,283 units are related to the petroleum industry and the second with 1,239 plants in the metal industry. In the distribution of wastewater, the highest amount of wastewater originates from the leather sector with a flow rate of 13,354 m^3/d and the textile is the second with a flow rate of 12,435 m^3/d. Approximately 14% of these facilities operate in OIZ, while the rest is separated in the city. Name of OIZs in Istanbul are Beylikduzu, Ikitelli, Dudullu, Istanbul Anatolia, Istanbul Leather, Istanbul Tuzla Chemical Industries, Tuzla and Birlik OIZ. In 2015, the amount of urban wastewater (industrial process wastewater and domestic wastewater) amounted to 317,432 m^3/d in Istanbul [12]. The city is divided into 24 wastewater collection basins.

3.1.1. Industrial load in AWCB

It was determined that there are 832 facilities releasing industrial wastewater and a total of 6,967 m^3 wastewater is released daily in the AWCB. In the study, pollutant parameters contained in the wastewater in the AWCB, the total pollutant loads in decreasing order were found as: COD (40,693 kg/d), TSS (7,235 kg/d), oil and grease (4,990 kg/d), surfactants (312 kg/d), total-N (235 kg/d), total-P (75 kg/d), Zn (105 kg/d), Cu (103 kg/d), nickel (44 kg/d), total-Cr (35 kg/d), total-CN (32 kg/d), total-S (22.1 kg/d), Sn (15 kg/d), fenol (9.1 kg/d), F (2.8 kg/d), Pb (1.69 kg/d), Cd (0.4 kg/d), Ag (0.6 kg/d) and As (0.02 kg/d).

Study data also indicates that primarily metal industries and other industries in the categories covering printing and textile printing industries and small-scale chemical production-processing activities produce wastewater which was low in volume but high in pollutants and toxicity. The daily 293 m^3 wastewater flow rate of the 66 industries deemed as the receiving medium discharge, accounted for approximately 4% of the industrial wastewater flow rate of the AWCB. The pollutant load of the receiving medium (i.e., the lakes and streams in the basin) was calculated as follows: COD (2,073 kg/d), TSS (1,233 kg/d), oil and grease (375 kg/d), total-N (34 kg/d), total-P (13.3 kg/d), Zn (0.9 kg/d), Cu (1 kg/d), nickel (2 kg/d), total-Cr (0.6 kg/d) and total-CN (1 kg/d). The average concentration levels of these pollutant load (amounted to 293 m^3/d receiving medium discharge flow rate) were calculated as COD (7,075 mg/L),

Table 4
Distribution of COD and Zn reduction quantities in load reduction method

Categories	Number of industries	Flow rate (m^3/d)	Flow rate, %	COD (kg/d)	COD-remaining (kg/d)	COD-removal (%)	Zn-existing (kg/d)	Zn-remaining (kg/d)	Zn-removal (%)
Aluminum forming	5	14	0.2	150	12	92			
Metal tinting	22	422	6.1	329	326	1			
Metal finishing	111	586	8.4	6,577	540	92	99	3	97
Other chemicals	10	10	0.1	138	4	97			
Soap and detergent	18	35	0.5	390	29	92			
Paint and ink	13	28	0.4	162	20	87			
Plastic processing	28	69	1.0	255	65	74			
Adhesives and insulating materials	6	26	0.4	598	22	96			
Pharmaceutical	4	248	3.6	378	247	35			
Cosmetics	10	16	0.2	110	15	86			
Printing	46	19	0.3	678	10	98			
Paper	23	20	0.3	1,155	15	99			
Woven fabric finishing	121	3,038	43.6	6,941	3,002	57			
Stock and yarn finishing	9	359	5.2	431	355	18			
Power plants	3	187	2.7	1,113	75	93			
Petroleum products	131	207	3.0	592	165	72			
Animal breeding	58	33	0.5	663	16	98			
Slaughterhouses and meat products	8	125	1.8	481	124	74			
Dairy	4	52	0.8	215	51	76			
Confectionery	25	941	13.5	18,479	939	95			
Food production	20	181	2.6	404	167	59			
Total pollutant load of the 21 categories	675	6,616	95	40,239	6,199	85	99	3	97
Total AWCB pollutant load	832	6,967	100	40,693	6,331	85	105	6.8	94

TSS (4,211 mg/L), oil and grease (1,280 mg/L), total-N (116 mg/L), total-P (45 mg/L), Zn (3 mg/L), Cu (3.4 mg/L), nickel (6.8 mg/L) and total-CN (3.4 mg/L).

3.2. Heavy metals and effects on the water system

In the AWCB, the change that would be seen in the current pollutant load pressure through controlling 720 of the 832 industries was monitored taking into account the COD and Zn pollutant parameters and it was calculated that the COD with a value of 40,693 kg/d was reduced by 85% to 6,331 kg/d and that the Zn with a value of 105 kg/d was reduced by 94% to 6.8 kg/d (Table 5). Daily COD in the discharged industrial wastewater (106.3 kg of the daily total of the 6,331 kg) comes from 112 industries that were not principal with respect to pollutant type and load. LRM decreases the COD and Zn concentrations of the industrial wastewater of the AWCB to approximately 909 and 1 mg/L.

Heavy metals are among the most widespread anthropogenic pollutants. However, there are not many researches on the levels of heavy metals reaching the treatment plant of urban watersheds [9]. UK Water Industry Research studied a catchment to identify diffuse sources for the urban concentrations of metals [9]. It is found that runoff is also a pollution source, especially in industrial areas. For all metal types, runoff concentrations were higher in the samples of the light industrial areas than in the domestic wastewater samples.

Similar to the current case in the Ambarli basin, heavy metals may be discharged into the water environment by sewer and urban wastewater treatment plants. The risky pollutant, heavy metals cannot be removed sufficiently in wastewater treatment plants. In a study conducted in the Seine River (Paris), the plant which treats the wastewater of 6.5 million equivalent people gave a daily load of 7.9 kg Cu and 13 kg Ni to the river and 3 kg Cu and 9.5 kg Ni of this load are in the labile metal form [10]. The Seine river basin in Paris has long been impacted by metal inputs from industrial discharges. Metal fluxes of the River Seine increased due to urban wastewater discharge, more than other pollution sources, such as surface runoff and industrial discharge, especially during low-flow periods. Similarly, in another study, metal pollution load in the East China Sea is estimated that loads of metals are about 4,600 kg/d As, 3,000 kg/d Pb and 2,000 kg/d Ni [16]. Moreover, World Bank reported that the main rivers of China have had polluted water levels, despite increasing urban wastewater treatment capacity in the country [17].

The main part of this study focused on heavy metals from industrial discharges. In many countries, the fate of heavy metals from mainly anthropogenic sources (Cd, Pb, Mn, Cu, Zn, Fe and Ni) were investigated in the treatment plants in recent years. For example, distribution of heavy metals in the effluent and sludge was studied in the treatment plant of Thessaloniki city and found that Mn and Cu are primarily (>70%) accumulated in the sludge, but 47%–63% of Cd, Cr, Pb, Fe, Ni and Zn metals are kept in the treated effluent [11]. Heavy metal levels from urban sources can also be observed in the treatment plant sludge. Results of recent studies show that heavy metal concentration of treatment sludge varies widely in different cities and countries [18–21]. In most cases, it is found that the concentration of Zn is highest, followed by the concentration of Cu [22]. It can be seen from the literature studies that heavy metals can be present in high amounts in sewage and can reach the receiving environment from the treatment plant outlet.

Recently, metal emissions have decreased in many countries by the help of new legislation and cleaner technologies. Also, regulations for heavy metal waste disposal became tougher in Europe [23]. It is known that heavy metals are toxic and some have a biomagnification effects. In the last decades, authorities of many industrial cities, encouraging industrial sectors, concentrated on environmental sustainability. Transferring the industries out of the cities and intensify them in an area have provided better pollution control. Similar to other industrial cities in developing countries, the Halic estuary area in Istanbul had high industrial pollution in the past years [24]. However, pollution removal and rehabilitation had not been supplied by treatment only but polluted sediment removal into a remote area was required. The transfer of industrial facilities to the surrounding cities was also a must [24]. Moreover, in fact, it should be known that the sea region around Istanbul receives many types of pollution not only from local wastewater sources but also from marine transportation and the Danube River, by currents of Bosphorus [25-27].

Especially in developing countries, if there is no important pollution in the local area to attract the public's great response, industrial production has priority over the environment. Therefore, industries only do some or even no treatment [28–30]. The industrial sector contributes not only a high amount of organic and nitrogen loads but also other pollutants such as heavy metals [31]. Heavy metal removal and treatment have been studied for a long time and there are too many research studies in the scientific literature to remove heavy metals with many different materials, mainly cheaper ones, such as cotton, tea waste, etc [32-35]. However, almost no pilot plant larger than lab-scale reactors is reported to supply cheaper solutions in reality, even though these research studies report very high treatment rates. Therefore, testing different adsorbents for heavy metal removal under field conditions needs to be studied in future researches.

In the current study, it was clearly seen that the industries do not have an environmentalist view. Small firms may even think that the treatment is insignificant. Therefore, sufficient financial investment and willing efforts are not used for the construction and operation costs of the treatment plants. Industrial companies can see the treatment plants as a burden and only funding them to avoid punishment.

In recent years, fractions of heavy metals have been analyzed and it has been tried to find more detailed information about metals' sources. The amounts of anthropogenic heavy metals originating from cities' discharge can be revealed by water or sediment studies. For example, it was found higher heavy metal contents in the urban river sediments and the impacts of urbanization in the Pear River Estuary [36]. Urban river sediments exhibited higher pollution levels especially in the surface sediment layer (0–10 cm). It is shown that heavy metals were higher in the exchangeable and carbonate fractions when compared with rural river sediments. This result showed that mainly anthropogenic activities increased the active forms of metals. Heavy metal levels increase in built-up areas [37]. Also, it was revealed that urbanization increases not only heavy metal contents but also the spatial distribution of them [38]. Similarly, it was indicated that the amount of Cr and Cd concentrations in the Yellow River mostly reflect the anthropogenic effect [39]. It is seen that higher bioavailability of metals was related to their higher availability in the exchangeable fraction.

Zhang et al. [40] found high inputs of Cr, Cu and Zn metals from anthropogenic sources when doing a comparative study in the urban river sediments. Those heavy metals were found as mobile form (in exchangeable fractions) and posed ecological risks. Duodu et al. [41] showed that loosely bound metals in estuary sediment exceeded 30% of the total metal concentration for Ag, As, Ca, Cd, Co, Cu, Hg, Mn Ni, Pb and Zn. These high amounts of leaching from the sediment indicate that those metals are signifying anthropogenic contribution and in the bioavailable form.

3.3. Effect of the LRM

Of the 832 industries in the AWCB, the average industrial wastewater daily flow rate (Q) of 191 industries was determined as 5 m^3 or more, and for others, Q was below 5 m^3 in 641 industries. In 436 of the industries with $Q < 5$ m^3, the amount of wastewater was less than 1 m^3/d. Of the wastewater sources defined as having a low flow rate ($Q < 5$ m^3/d), 146 industries were in the metal category, 151 were in the printing, paint production, detergent production, plastic processing, production of rubber and other chemicals and these categories contained toxic parameters.

The industries and amount of wastewater that are controlled by LRM are given in Table 6 with respect to industrial groups. With the determined LRM, for example, in the categories of the metal industry, 76 of 116 WTP compliance with the transport criteria are canceled, and with the other 69 industries, the wastewater from a total of 145 metal industries are being carried to CWTP. In addition to the 40 industries with high flow rates WTP, two WTPs will be installed in two high flow rate industries, and thus, a total of 1,081 m^3/d wastewater from the metal industry can be controlled, while 116 m^3/d by transportation/common treatment and 965 m^3/d by the WTPs in the industries. In the existing state, 65.65 m^3/d wastewater from the 71 industries in this industrial group is not treated according to Water Authority's regulation.

A similar situation is seen in Table 6 for the chemical, paper, textile, leather, food and other industry categories. The LRM application controlled all the industries in the categories containing principal pollutant parameters and all the industries having principal pollutant load based on COD. The first common WTP will be installed for 58 breeding farms (33 m^3/d wastewater) and the second CWTP for other industries complying with transportation criteria (approximately 375 m^3/d). In 2 common WTPs being installed, 408 m^3/d wastewater will be treated. This amount is 6% of the total industrial wastewater in the AWCB. The number of 178 WTPs are treating 6,276.2 m^3/d wastewater from principal pollutant sources with high flow rates, which is approximately 90% of the total industrial wastewater formed in the AWCB, using the remote sensing control system. For the approximately 201 m^3/d wastewater (approximately 3% of the wastewater in the AWCB) from 59 facilities in the marble, concrete and soil product categories, a wastewater treatment-recycle system will be installed; thus, it is envisaged that there would not be any wastewater discharges from these industries.

According to these results, 96% of the wastewater formed in the AWCB is treated and discharged from common WTPs and the WTPs installed at the source of the wastewater. Since the zero discharge system is provided for 201 m^3/d wastewater, approximately 6,885 m^3/d wastewater, which corresponded to 99% of the wastewater in the AWCB, is under control. The remaining 82 m^3/d wastewater, for which wastewater treatment is not necessary, covered 91 external car wash facilities, 4 carpet washing and 2 laundry washing facilities, 1 cosmetic, 14 food and related industries, making a total of 112 industries other than the criteria for principal pollutant sources and corresponded to 1.1% of the total wastewater in the AWCB.

Hence, by pollutant type and load-based industrial wastewater management, the wastewater from 720 of the 832 industries are subjected to treatment, and the volume of the treated wastewater reached to 6,885 m^3 (approximately 99% of the total wastewater). In the existing state, WTPs in 321 industrial wastewater sources is present, and approximately 6,034 m^3 of the wastewater in the basin is treated.

Again, in the existing state, 321 installed WTPs are present in the industries. With the LRM system, a total of 163 WTPs installed in low flow rate industries that are not operated and controlled efficiently are removed and the number of existing WTPs is reduced to 158, and WTPs are installed at a total of 20 principal pollutant sources with high flow rates, making the total number of WTPs in the AWCB as 178. The pollutant load based wastewater management provided the installation of WTPs at 20 industrial wastewater sources that did not have treatment and reduced the number of industries that must be monitored and controlled by 51%, from 321 to 178. Then, it is ensuring that the pollutant load on the AWCB is reduced with less energy, in less time and at a lower controlling cost.

3.4. Monitoring the LRM in AWCB

The reflection of the control of industrial pollution in the AWCB to pollutant parameters were identified using the COD and the zinc parameters as an example. The LRM application decreased the COD load in the basin by 85%, from 40,693 to 6,331 kg/d. The reflection of the LRM for zinc load is 94%, from 105 to 6.8 kg/d. This value corresponds to approximately 6.5% of the total zinc load in the AWCB. The remaining amount of 6.8 kg/d zinc is composed of treated industrial wastewater discharges, and/or the industrial discharges in the categories that zinc concentration values are below the discharge limits.

After all the reductions, the final COD load in the AWCB decreased to 6,331 kg/d. Of this amount, a part of approximately 106 kg/d originated in 112 industries is not deemed as principal pollutant sources. The effect of LRM on the change in Zn pollutant load is provided. By treating a total of 6,276 m^3/d wastewater in the WTPs to the sewage discharge limits, 88 kg of the daily 94 kg zinc load is eliminated. This reduction corresponded to 84% of the total zinc load in the AWCB.

Table 5
Number of industrial wastewater sources and sectors in Istanbul

		Industrial category								
		Petroleum	Metals	Minerals-not metal	Food	Textile	Chemical	Leather	Other	Total
Facilities with industrial wastewater	Number	2,283	1,239	619	615	863	600	15	87	6,321
	Q (m^3/d)	4,826	5,722	9,038	5,656	12,435	2,745	13,354	2,122	55,898
Those with treatment facilities	Number	26	631	38	64	397	172	5	19	1,352
	Q (m^3/d)	617	5,455	1,018	4,566	10,705	2,426	13,353	2,071	40,211
In-plant measures	Number	98	81	484	136	11	92	6	17	925
	Q (m^3/d)	326	16	7,961	401	40	54	1	4	8,803
Transport of wastewater	Number	8	248	8	1	3	77	2	8	355
	Q (m^3/d)	3	90	1	3	1	27	1	3	129
No pre-treatment requirement in the legislation	Number	1,147	218	57	361	428	248	2	41	2,502
	Q (m^3/d)	3,827	125	37	582	1,223	222	1	7	6,024
Pre-treatment requirement	Number	4	61	32	53	24	11	0	2	187
	Q (m^3/d)	53	34	21	104	467	14	0	0	693

Table 6
Pollutant load reduction method of controlled industries and amount of wastewater

Industrial groups	Number of industries	Removed WTP	Remaining WTP	Newly installed WTP	Total WTP	Total flow (m^3/d)	No. of transfer (industries)	Transferred flowrate (m^3/d)	AWCB total flow (m^3/d)	Total purified wastewater (m^3/d)	Number of no-WTP industries	Untreated wastewater (m^3/d)
Metal	187	76	40	2	42	965	145	115.8	1,081	1,081	–	–
Chemistry and related	144	37	13	1	14	389	129	70	459.3	459.3	1	0.01
Paper and related	23	6	2	–	2	12.5	21	7.3	19.8	19.8	–	–
Textile	142	25	74	11	85	3,332	51	80.3	3,432	3,413	6	19.3
Leather	1		1		1	7.2			7.2	7.2	–	–
Oil and related	134	11	7	1	8	287	35	47.1	394.4	334.4	91	60
Solid waste	1	–	–	–	–	–	1	3	3	3	–	–
Mineral	71	7	1	(59 recycling system)	1	21	11th	6.2	228	228 (including recycling systems)	–	–
Food and related	129	1	20	5	25	1,261	90	78.2	1,342	1,339.2	14	2.8
Total	832	163	158	20	178	6,276	483	407.9	6,967	6,885	112	82.1

4. Conclusion

In this study, the pollutant loads were calculated by classifying 832 industrial facilities, and a LRM was determined based on the pollutant type and waste load. By this method, the high flow rate of the major pollutant wastewater sources is treated in the WTPs installed in the source while the low-flow wastewater resources are treated by common WTPs.

Reducing the pollutant load, in turn, reduces the pollutant load on the receiving medium, contributing to the effective operation of central treatment plants and protecting the aquatic environment from pollutant discharge. The recommended LRM in the study reduces the number of industries that must be continuously monitored and controlled by approximately 45% and ensures saving time and energy for control.

Finally, some future perspectives and recommendations for sustainable management of wastewater basins and treatment plants could be summarized as follows: (i) mapping the industrial wastewater pollutant loads of all wastewater catchment basins, (ii) revising the industrial wastewater control/discharge legislation considering the pollutant type and load to ensure the control of all important pollutants, (iii) installing remote sensing system for high-volume industrial wastewater to control easily and efficiently, (iv) assessing the transport of the food industry wastewater to some treatment inlets after investigating the nutrient needs, (v) research of the recovery of substances contained in the wastewater considering the industrial categories, (vi) establishment of specialized OIZ should be done as a recommendation to gather the industries in an area.

The study does not include an economic analysis but it is obvious that LRM will be economic from the benefits obtained such as; use of fewer industrial WTPs, less time of inspection by water administration, and also energy, time and economic savings by controlling less industrial facilities.

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