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Assessing impact of activated sludge treatment plant effluent on selected environmental factors: case study of Kerman wastewater treatment plant effluent

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A B S T R A C T

Constructing a wastewater treatment plant (WWTP) by itself does not address environmental concerns. The performance of these treatment plants should be evaluated to achieve the desired environmental standards and life cycle assessment (LCA) is among the most commonly used methods. In this study, two LCA models were employed to evaluate the environmental and economic aspects of activated sludge treatment plant effluent management. This descriptive, cross-sectional study was conducted in the Environmental Health Engineering Research Center, Kerman University of Medical Sciences, from March 21, 2018, until March 21, 2019. Since it was a case study, an activated sludge WWTP with a population of about 700,000 people was selected in Kerman, Iran. The data of the system inputs and output effluent, the amount of energy and chemicals consumed in the treatment plant during the study, and the amount of methane (CH_4) and carbon dioxide (CO_2) emissions were determined. SimaPro 9.1.0.8, IMPACT 2002$^+$, and the ecological scarcity method (ESM) were used to analyze the data. The impact of WWTP effluent was assessed in 14 categories by IMPACT 2002$^+$ software. The results showed that WWTP effluent had the greatest impact on the environment in 11 categories, including organic respiration, inorganic respiration, ionizing radiation, terrestrial toxicity, terrestrial acidification and nutrition, eutrophication, global warming, non-renewable energy, mineral extraction, ecotoxicity, and ozone depletion, in the first six months of the year and 100% adverse effect on the environment in three categories, including carcinogenesis, non-carcinogenesis, and aquatic toxicity, in the second six months. Environmental impact assessment of the studied activated sludge treatment plant effluent using both IMPACT 2002$^+$ and ESM showed no significant difference in the first half of the year compared to the first six months.

Keywords: Life cycle assessment; Activated sludge; Wastewater treatment plant effluent management; Environmental factors

1. Introduction

Evaluating wastewater treatment plant (WWTP) effluent is important due to its direct impact on the environment and, ultimately, community health as well as the use of treated wastewater in industries or agriculture to save water resources [1]. In WWTP effluent management, depending on the amount of effluent production and composition, there are different methods that consider the economic costs as well as different environmental loads [2]. Life cycle assessment (LCA) is a comprehensive approach to examining the environmental aspects of a product, process, or service throughout its life cycle, that is, from cradle to grave. LCA as the most commonly used method is an international

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standard method that can analyze the inputs and outputs of a wastewater treatment system in accordance with the life cycle of products or processes [3,4]. This method considers the whole life cycle of a product from extracting raw materials to producing, using, and finally disposing and quantifying the potential adverse effects associated with these stages in accordance with International Organization for Standardization (ISO) 14040-3 [5].

Emmerson et al. [6] compared the environmental impacts of biofiltration with activated sludge. The results showed that the energy used in the operation phase of the treatment plant significantly contributed to the adverse environmental impacts of the treatment process. Dixon et al. [7] compared biofiltration with a reedbed system (RBS) and found that RBS had lower energy consumption and CO_2 emissions than biofilter. However, it was significantly more suitable than biofilter in terms of solid outputs. Machado et al. [8] compared natural systems (wetlands) with activated sludge processes and reported low environmental impacts of the natural treatment system in the global warming indicator. Renou et al. [9] compared different methods of environmental impact assessment in LCA-based studies and found no significant difference in the categories of the greenhouse effect, natural resource depletion, and acidification among the results of different methods. However, a significant difference was observed in human and environmental health indicators.

Corominas et al. [10] critically reviewed 45 papers dealing with LCA in wastewater treatment in India. Investigating the four stages of LCA and the methods used to evaluate the effects showed various definitions of the functional unit and system boundary within the constraints of the ISO standards. Therefore, it is necessary to develop wastewater treatment standards to ensure the quality of LCA application.

Hong et al. [11] investigated several sludge treatment scenarios (anaerobic digestion-incineration and landfill) and showed that anaerobic digester reduced dry sludge volume and energy storage. Landfill technology had the highest and incineration technology had the lowest environmental loads. Parsajou and Fataei [12] assessed the environmental aspects of the life cycle of Khalkhal WWTP in Iran. For this purpose, the data of the system inputs, output effluent, and amount of consumed energy and chemicals were collected and, according to the available information, the amount of CH_4 and CO_2 emissions was quantified. The data were analyzed by SimaPro, CML2001, and Eco-Indicator 99 and the results showed that, in both methods, chlorine (Cl) gas had the greatest effect (100%) on ozone depletion, which could have adverse effects on the environment. Eskandari et al. [13] investigated the performance of the wastewater treatment systems of the Research Institute of Petroleum Industry (RIPI) using the LCA method in Tehran, Iran. In this study, the impact assessment was depicted in 13 categories and all the data were entered into the software based on the level of impact in each category. The results represented that electricity consumption, chloride, and oil were the most effective factors. This case study aimed to evaluate the effect of activated sludge treatment plant effluent on environmental factors, for which Kerman Wastewater Treatment Plant was selected.

2. Materials and methods

This descriptive, cross-sectional study was conducted in the Environmental Health Engineering Research Center, Kerman University of Medical Sciences, from March 21, 2018, until March 21, 2019. Each LCA study has a goal and scope, functional unit, inventory analysis, and system boundary [14]. In this study, the four stages of LCA were performed according to ISO 14044 standard as follows:

- *Goal and scope definition*: The LCA scope included studying the treatment plant effluent using activated sludge. For this purpose, Kerman WWTP effluent with a population of 700,000 people was selected to determine the salient points of the life cycle as well as whether the system had the lowest environmental impacts and energy consumption.
- *Functional unit*: The functional unit was defined as m^3 of the treatment plant effluent to evaluate the performance of the Kerman Treatment Plant.
- *System boundary*: This parameter specifies the studied area that should be consistent with the intended goal. The system boundary should also be carefully defined; otherwise, it becomes difficult to quantify the inputs and outputs due to the extensive life cycle.

In this study, according to the available information, the system boundary was determined according to Fig. 1.

- *Inventory analysis*: In this study, the required data including the amount of suspended solids, amount of oxygen required for oxidizing organic and inorganic compounds, amount of oxygen consumed per day, amount of energy consumed per day, and amount of CH_4 and CO_2 emissions per day were calculated for treating m^3 of the effluent.

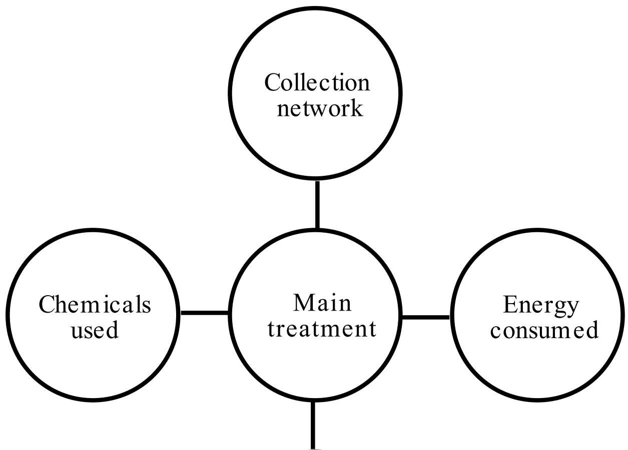

Fig. 1. System boundary for evaluating the life cycle of the treatment plant effluent using activated sludge process.

Finally, pollutant emissions and consumption information were included on the list of global impact indicators (including global warming, primary energy use, energy consumption, etc.).

Table 1 presents the inventory list of the studied WWTP effluent using an activated sludge process in the specified period.

Table 1
Inventory list of the studied WWTP effluent using activated sludge process in the specified period

Parameter	Input	
	First six months in 2018	Second six months in 2018
Biochemical oxygen demand (BOD_5), mg/L	366	405
Chemical oxygen demand (COD), mg/L	667	595
Total soluble solids (TSS), mg/L	401	427
Total phosphorus-Total nitrogen (TP-TN), mg/L	16–75	39–86
Proper temperature, °C	42	36
Electricity, kWh	11340000	107730000
O_2, kg	10633	10101
Ca(OCl)Cl, ton	5.5	4.5
Arsenic, kg	0.005	0.008
Zink, kg	0.0001	0.005
Lead, kg	0.0001	0.005
Mercury, kg	0.0001	0.005
CH_4, kg/d	1,824.38	1,733.16
CO_2, kg/d	898.6	853.6

2.1. SimaPro

SimaPro is a professional tool for analyzing the environmental impacts of a product or service and includes various impact assessment methods, in each of which specific environmental factors are evaluated. This software has several versions and contains a wide range of information. In this study, the following two methods were used:

- Ecological scarcity method

This method examines the impacts of sludge effluent in 5 categories, including emissions to the air, surface water, groundwater, energy resources, and natural resources, and is considered a moderate method among the impact assessment models and factors.

- IMPACT 2002+

IMPACT 2002+ consists of 2 sets of impact categories, 18 midpoint impact categories (e.g., climate change, ozone depletion, eutrophication, etc.), and 3 damage categories (damage to human health, ecosystem diversity, and resource availability). It is also considered a moderate method among the impact assessment models and factors. The obtained data were analyzed using SimaPro and CML2001 basic data.

3. Results

3.1. Environmental impact assessment of treatment plant effluent by IMPACT 2002+ method

Fig. 2 presents the effective parameters for the treatment plant effluent using the activated sludge process and the influenced categories per m^3 of effluent in the first half of 2018 by IMPACT 2002+ method.

The analysis of the cumulative percentage of component involvement in each impact category showed that

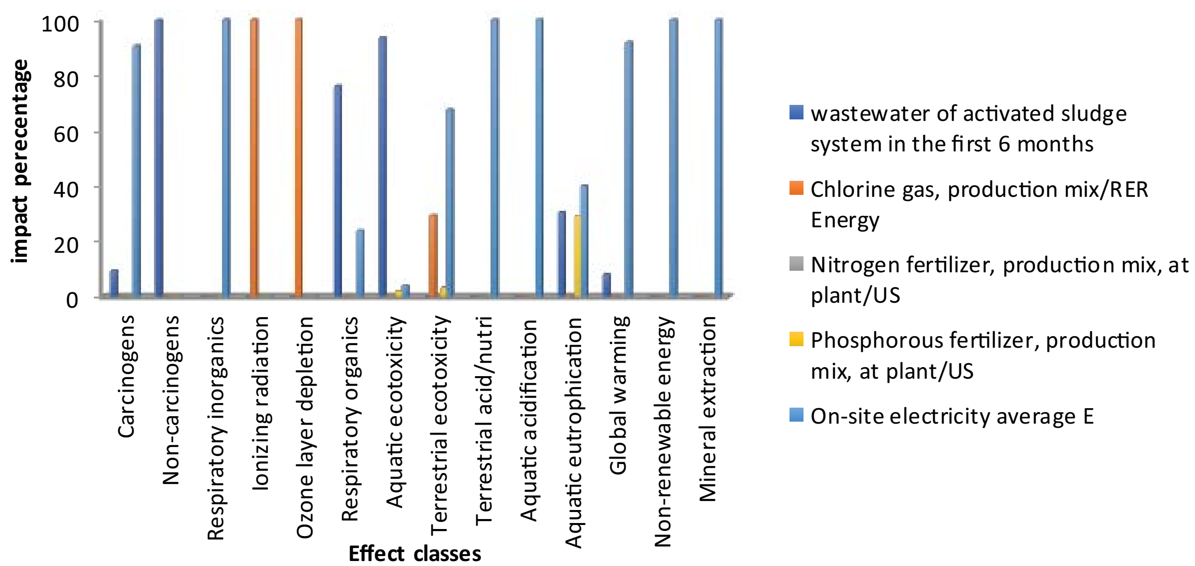

Fig. 2. Environmental impacts per m^3 of treatment plant effluent using activated sludge process in the first half of the year by IMPACT 2002+ method.

electricity consumption (817.58%), treatment plant effluent using activated sludge process (317.41%), chlorine consumption (230.25%), effluent phosphorus (34.46%), and effluent nitrogen (0.29%) had adverse impacts on the human environment, respectively.

Fig. 3 presents the results of environmental impacts per m^3 of treatment plant effluent using activated sludge process in the second half of the year by IMPACT 2002$^+$.

The analysis of the cumulative percentage of component involvement in each impact category showed that electricity consumption (834.67%), treatment plant effluent using activated sludge system (331.09%), chlorine consumption (227.94%), effluent phosphorus (5.77%), and effluent nitrogen (0.51%) had adverse impacts on the human environment, respectively.

Fig. 4 presents the comparative results of environmental impacts per m^3 of treatment plant effluent using an activated sludge system in the first and second halves of the year using IMPACT 2002$^+$.

Table 2 compares the performed calculations and the impacts of the components involved in each impact category in the first and second halves of the year using IMPACT 2002$^+$.

3.2. Environmental impact assessment of treatment plant effluent by ecological scarcity method

Fig. 5 illustrates the effective parameters for treatment plant effluent using activated sludge process and the influenced categories per m^3 of effluent in the first six months by ecological scarcity method (ESM).

This method evaluated the environmental impacts of activated sludge-based treatment plant effluent on 5 impact categories, including 1) emissions to the air, surface water, and groundwater, and 2) energy consumption resources and natural resources. The effective parameters for impact categories included the treatment plant effluent by activated sludge process (as the assessed product), chlorine consumption (as the chemical used), electricity consumption (as the energy used in the system), as well as effluent phosphorus and nitrogen (as nutrients in wastewater). In this method, impact categories are expressed as

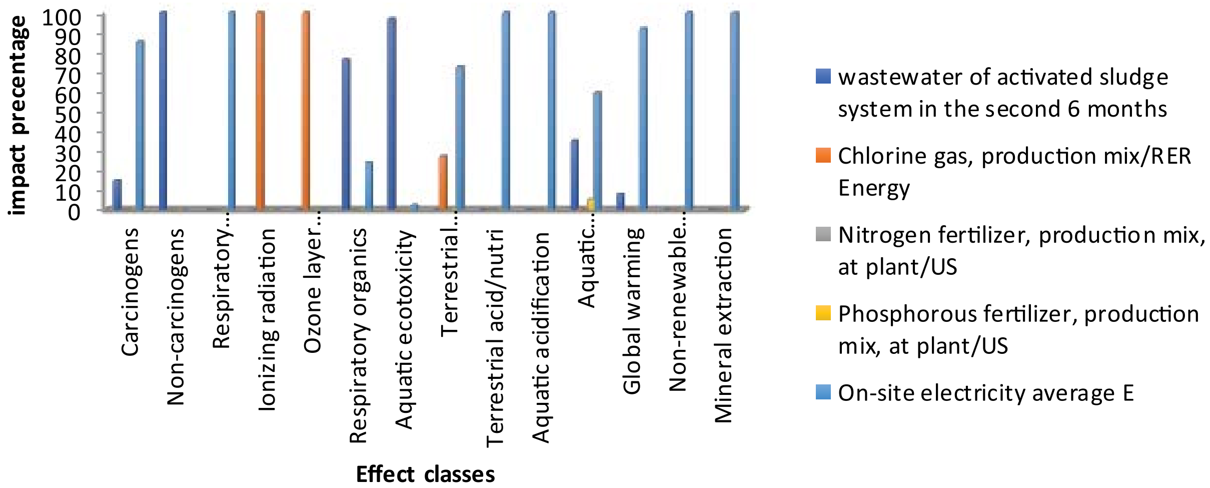

Fig. 3. Environmental impacts per m^3 of treatment plant effluent using activated sludge process in the second half of the year by IMPACT 2002$^+$.

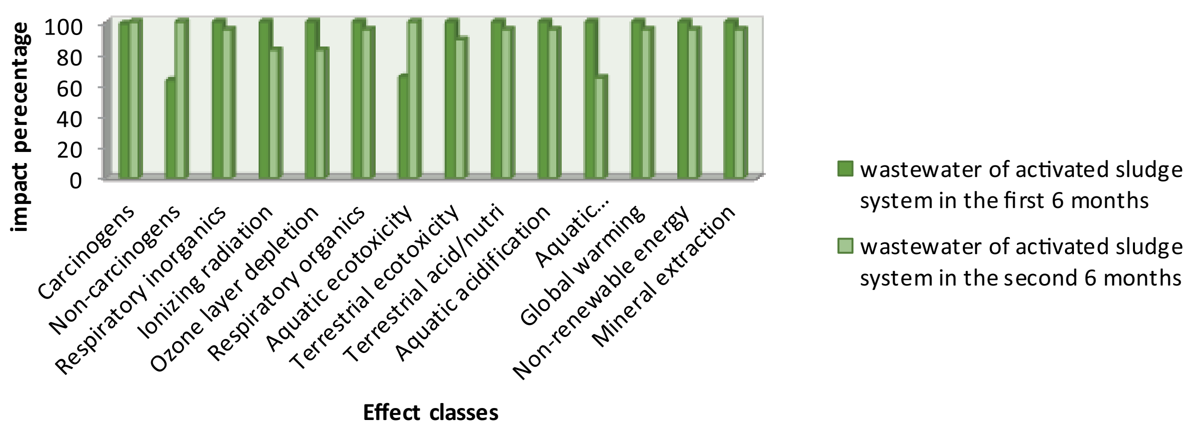

Fig. 4. Comparing the environmental impacts per m^3 of treatment plant effluent using activated sludge process in the first and second six months using IMPACT 2002$^+$.

Table 2
Comparing the performed calculations and the impacts of the components involved in each impact category in the first and second halves of the year using IMPACT 2002+

Impact categories	Environmental impacts of treatment plant effluent in the first six months	Environmental impacts of treatment plant effluent in the second six months	Environmental impacts of treatment plant effluent in the first six months in percentage	Environmental impacts of treatment plant effluent in the second six months in percentage
Carcinogenesis, kg C_2H_3Cl-eq	52.28633291	52.89490845	98.8	100
Non-carcinogenesis, kg C_2H_3Cl-eq	51.63348983	82.5705892	62.5	100
Inorganic respiration, kg $PM_{2.5}$-eq	169.6907647	161.2055102	100	95
Ionizing radiation, Bq C-14-eq	125.0518219	102,315,127	100	81.8
Ozone depletion, kg CFC-11-eq	1.13625E-06	9.2967E-07	100	81.8
Organic respiration, kg C_2H_4-eq	14.40808652	13.68759479	100	95
Ecotoxicity, kg TEG-water	2,077.468197	3,204.742234	64.8	100
Terrestrial toxicity, kg TEG-soil	24.50497011	21.70657011	100	88.6
Terrestrial acidification and nutrition, kg SO_2-eq	3,428.776188	3,257.325797	100	95
Aquatic acidification, kg SO_2-eq	1,341.312329	1,274.241429	100	95
Eutrophication, kg PO_4 P-lim	0.017224055	0.0110523475	100	64.2
Global warming, kg CO_2-eq	182,000.7031	172,899.9428	100	95
Non-renewable energy, mJ primary	2,400,012.886	22,880,000.767	100	95
Mineral extraction, mJ surplus	0.731995438	0.695323036	100	95

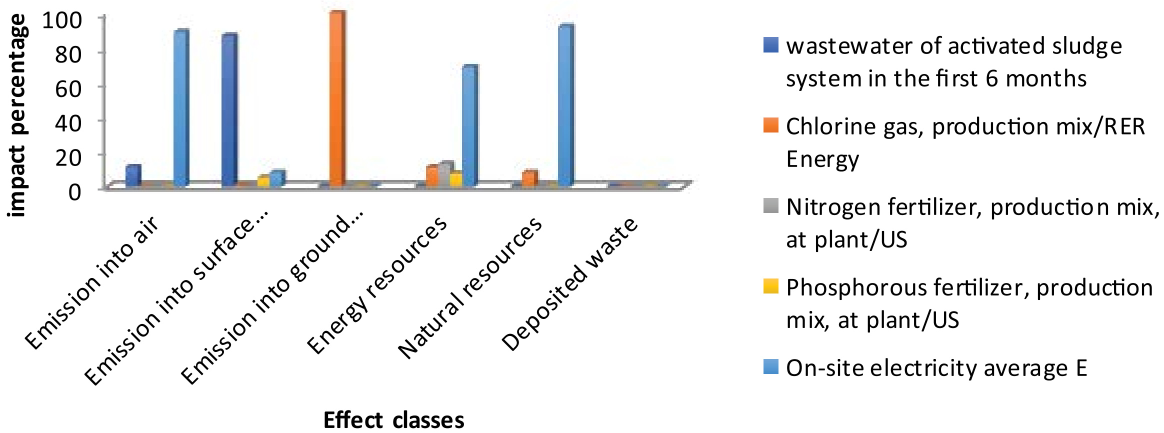

Fig. 5. Environmental impacts per m^3 of treatment plant effluent using activated sludge process in the first six months by ESM.

characterization factors in terms of environmental loading point.

Fig. 6 shows the results of the environmental impact assessment per m^3 of treatment plant effluent using the activated sludge process in the second half of the year by ESM.

As can be observed, the amount of nitrogen and treatment plant effluent increased in the second half of the year, which could be due to the increased temperature. However, other parameters decreased compared to the first half of the year.

Fig. 7 indicates the comparative results of the environmental impacts per m^3 of treatment plant effluent by activated sludge process in the first and second halves of the year using ESM.

Table 3 shows the comparative results of the performed calculations and the impacts of the components involved in each impact category in the first and second halves of the year using ESM.

4. Discussion

An impact assessment was divided into 14 impact categories, for which a combination of four methods, including CML (Center of Environmental Science of Leiden University), IPCC (Intergovernmental mental panel on climate change), Eco-Indicator, and IMPACTS 2002+, was used and four damage categories, including damage to human health, ecosystem quality, climate change, and resources,

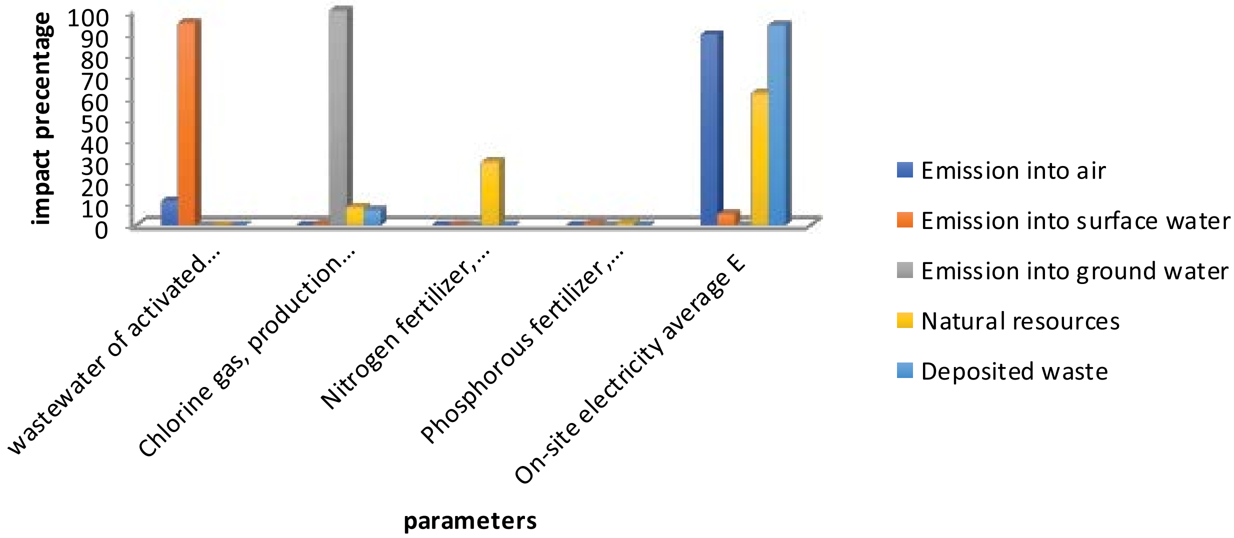

Fig. 6. Environmental impacts per m^3 of treatment plant effluent using activated sludge process in the second half of the year by ESM.

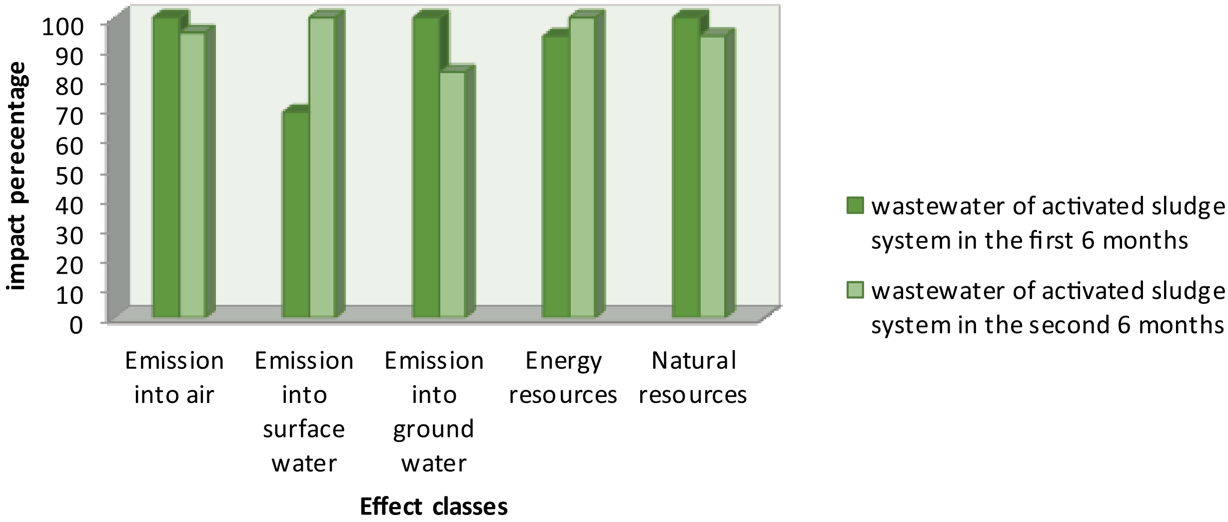

Fig. 7. Comparing the environmental impacts per m^3 of treatment plant effluent by activated sludge process in the first and second halves of the year using ESM.

Table 3
Comparing the performed calculations and the impacts of the components involved in each impact category in the first and second halves of the year using ESM

Impact categories	Environmental impacts of treatment plant effluent in the first six months	Environmental impacts of treatment plant effluent in the second six months	Environmental impacts of treatment plant effluent in the first six months in percentage	Environmental impacts of treatment plant effluent in the second six months in percentage
Emissions to the air, UBP[a]	118,522,968.4	112,596,386.7	100	95
Emissions to surface water, UBP	46,801.39955	68,401.25327	68.4	100
Emissions to groundwater, UBP	2.271294463	1.858331833	100	81.8
Energy resources, UBP	17.27704506	18.41846808	93.8	100
Natural resources, UBP	33.45137362	33.45137362	100	93.9

[a]Unit environmental loading points.

were predicted for the interpretation phase. The impact categories of carcinogenesis and non-carcinogenesis were expressed in kg $C_2 H_3$ Cl-eq in the air. The assessment units of impact categories of inorganic and organic respiration were kg $pm_{2.5}$-eq and kg $C_2 H_4$-eq in the air, respectively. BqC-14-eq represented the assessment index of the impact category of ionizing radiation, which was equal to the number of decayed nuclei per second. The assessment unit of the impact category of ozone depletion was kg cfc-11-eq in the air. In the impact category of aquatic ecotoxicity, kg TEG (triethylene glycol) water was the assessment index; so, the impact category of terrestrial ecotoxicity was also expressed in kg TEG soil. The impact category of terrestrial acidification/nutrition and aquatic acidification was expressed in kg SO_2-eq. In the impact category of eutrophication, the assessment unit was kg PO_4^{-3} in water consumption. The global warming, non-renewable energy, and mineral extraction impact categories were expressed in kg CO_2-eq, MJ primary, and mJ surplus, respectively.

In the carcinogenesis impact category, electricity consumption (90.5%) and activated sludge treatment plant effluent (9.48%) had the greatest impacts on human health, respectively, and other parameters had a minor impact. In the non-carcinogenesis category, activated sludge treatment plant effluent (99.93%) had the highest impact and other parameters had a slight impact. In the inorganic respiration category, electricity consumption (99.99%) showed the greatest impact, while in the organic respiration impact category, treatment plant effluent (76.09%) and electricity consumption (23.9%) had the most adverse environmental impacts. Parameters such as effluent nitrogen and phosphorus did not play a significant role. In the ionizing radiation category, chlorine with 100% contribution was the only effective parameter in radioactivity. Also, chlorine had the greatest impact (100%) on ozone depletion. In the aquatic ecotoxicity impact category, treatment plant effluent (93.39%), electricity consumption (3.89%), and effluent phosphorus (2.12%) had the highest impacts, respectively; but, other parameters showed no significant impact. In the terrestrial toxicity category, electricity consumption with 67.43% had the maximum adverse impact. In the impact categories of terrestrial acidification/nutrition and aquatic acidification, electricity consumption with 99.99% was the most effective parameter and other parameters were not such important. Also, in the eutrophication impact category, electricity consumption (40.02%), treatment plant effluent (30.39%), and effluent phosphorus (29.18%) had the highest impacts, respectively; other parameters had a minor impact. In the global warming category, electricity consumption with 91.88% and treatment plant effluent with 8.11% had the most adverse environmental impacts, respectively. In the impact categories of non-renewable energy and mineral extraction, electricity consumption with 99.99% and 99.92%, respectively, had the greatest impact and other parameters were not such effective.

In the carcinogenesis impact category, electricity consumption with 84.99% and treatment plant effluent with 15% had the greatest impact and other parameters had a minor contribution. In the non-carcinogenesis category, treatment plant effluent with 99.98% had the highest impact and other parameters had a minor impact. In the inorganic and organic respiration categories, electricity consumption (99.99%) and activated sludge treatment plant effluent (76.15%), respectively, had the most adverse impact. In the ionizing radiation category, chlorine with 100% contribution was the only effective parameter for radioactivity. Also, chlorine had the greatest impact (99.99%) on ozone depletion. In aquatic ecotoxicity and terrestrial toxicity impact categories, treatment plant effluent with 96.86% and electricity consumption with 72.32% had the greatest impacts. In the impact categories of terrestrial acidification/nutrition and aquatic acidification, electricity consumption with 99.99% was the most effective parameter and other parameters were not such important. Also, in eutrophication and global warming impact categories, electricity consumption with 59.24% and 91.88%, respectively, had the most adverse environmental impacts. In the impact categories of non-renewable energy and mineral extraction, electricity consumption with 99.99% had the greatest impact and other parameters were not such effective.

Analyzing the cumulative percentage of component involvement in each impact category (Fig. 3) showed that electricity consumption (834.67%), treatment plant effluent (331.09%), chlorine consumption (227.94%), effluent phosphorus (5.77%), and effluent nitrogen (0.51%) had adverse impacts on the human environment, respectively. According to Fig. 3, in the eutrophication impact category, phosphorus showed a relatively less impact in the second six months than the first half six months and other impact categories had similar impacts in both halves of the year. Overall, it was evident that electricity consumption had the highest adverse impact among the environmental impact categories.

Comparing the environmental impacts per m^3 of activated sludge treatment plant effluent in the first and second six months by IMPACT 2002^+ method showed that activated sludge treatment plant effluent had the greatest impact on the impact categories of organic and inorganic respiration, ozone depletion, ionizing radiation, terrestrial toxicity, terrestrial acidification/nutrition, eutrophication, aquatic acidification, global warming, non-renewable resources, and mineral extraction in the first six months. However, the most adverse impacts were observed on carcinogenesis, non-carcinogenesis, and aquatic toxicity categories in the second half of the year. The comparative results also suggested that temperature can be an important factor in increasing toxicity in different impact categories, indicating that the severity of the impacts increased in the first half of the year and warm seasons.

In their study, Mohammadi and Fataei [15] compared aerated lagoon and activated sludge wastewater treatment systems using LCA method in SimaPro software and CML2001. The results demonstrated that the activated sludge system affected the impact categories of global warming, photochemical oxidation, ozone depletion, aquatic toxicity, and acidification by 63.9%, 14.7%, 54.3%, 53.8%, and 60.2%, respectively, while the aerated lagoon system had 100% impact on all the mentioned categories. In other words, the activated sludge system had a minimal impact on all the categories and the lowest environmental load.

Parsajou and Fataei [12] assessed the environmental aspects of the life cycle of Khalkhal WWTP in Iran. For this purpose, the data of the system inputs, output effluent, and amount of energy and chemicals consumed were collected; according to the available information, the amount of CH_4 and CO_2 emissions was quantified. The data were analyzed by SimaPro, CML2001, and Eco-Indicator 99 and the results showed that the activated sludge, effluent phosphorus, and effluent nitrogen affected impact categories of carcinogenesis, ecotoxicity, and fossil fuel by 100%, 55%, and 28%, respectively. Also, electricity consumption (88.99%) and Cl gas (100%) in both methods had the highest effect on ozone depletion, which could lead to adverse environmental impacts. Eskandari et al. [13] investigated the performance of the wastewater treatment system of the Research Institute of Petroleum Industry (RIPI) using the LCA method in Tehran, Iran, and found that electricity consumption, chloride, and oil were the most effective factors. Electricity consumption (99.96%) and Cl (0.04) had the highest and lowest impacts on the global warming category, respectively. Also, Cl (98.44%) and phosphorus (0.03%) had the highest and lowest impacts on the ozone depletion category. In the impact category of human toxicity and non-carcinogenesis, Cl with 78% and phosphorus with 0.31% had the highest and lowest effects, respectively. In the impact categories of carcinogenesis and ionizing radiation, Cl with 96.81% and 72.80%, respectively, had the highest effect on the environment.

Hernández-Padilla et al. [16] studied two WWTPs, including extended aeration (EA) and pond system (PS), in Latin America and the Caribbean (LAC) using SimaPro software, IMPACT 2002^+, ReCiPe, and IMPACT $World^+$ (IW^+). The collected data were entered into the software to be evaluated in three databases. The results showed that, in the EA system, electricity consumption with 98% had the highest effect on the impact category of climate change using IMPACT 2002^+, while in PS, biogenic methane had the greatest effect on this category. Also, phosphorus with 97% and 96% had the greatest impact on aquatic eutrophication in PS and EA systems, respectively. Nitrogen compounds and electricity consumption had the highest effects on the inorganic respiration category in PS and EA systems, respectively. In general, the EA system had a less effect on global warming than PS and, therefore, had better performance in the human health category [16].

Garfi et al. [17] assessed the environmental impacts of wastewater treatment systems in small communities using LCA. To this end, three scenarios, including activated sludge system and nature-based systems of wetland and algal pond, were considered and the impacts were evaluated by SimaPro software. The results showed that nature-based systems were eco-friendly, while the conventional activated sludge system had the most adverse environmental impacts due to high electricity and chemical consumption. The assessment was carried out in 7 categories, including metal resource depletion, fossil fuel resource depletion, climate change, ozone depletion, terrestrial acidification, drinking water eutrophication, and seawater eutrophication. The results revealed that the operation phase had the greatest impact on climate change and ozone depletion categories, and the transportation phase had the least impact on all the categories in the conventional treatment system. In all three scenarios, the operation phase had the greatest environmental impact. It can be concluded that adverse environmental impacts of conventional treatment systems were 2 to 5 times more than those of nature-based systems. However, natural systems had similar performance. Therefore, nature-based systems were recommended as a more suitable alternative in small communities [17].

Li et al. [18] evaluated the life cycle of a WWTP in Kunshan, China, using SimaPro software and the CML2000 method. In this study, the three phases of operation and maintenance, construction, and transportation were considered. The assessment was carried out in six categories, including abiotic resource depletion, global warming, terrestrial ecotoxicity, photochemical oxidation, acidification, and eutrophication. The operation and maintenance phase had the greatest impact on abiotic resource depletion (1.72 E+06) and global warming (5.24 E+0.8) categories. Also, the operation and maintenance phase had the highest contribution to the terrestrial ecotoxicity category (6.93 E+05), while the transportation phase showed no impact. The operation and maintenance phase had the greatest impact on photochemical oxidation (9.34 E+04), acidification (2.41 E+06), and eutrophication (2E+07) categories. Comparing the categories indicated that global warming and eutrophication received the greatest environmental impact in the studied WWTP. Buonocore et al. [19] evaluated the life cycle indicators of urban wastewater and sewage sludge treatment in Italy. Based on the analysis, the greatest environmental impact was observed on global warming and human toxicity.

Alyaseri and Zhou [20] investigated the environmental performance of the sludge incineration process in a WWTP using the LCA method in the United States. The results showed that the most significant impacts were associated with resource depletion and damage to human health, which mainly occurred in the operation phase (electricity and fuel consumption as well as combustion-related emissions). Singh et al. [21] assessed the environmental impacts of an integrated fixed-film activated sludge (IFAS) reactor using SimaPro software and IMPACT 2002^+ method. The results revealed that the main negative impacts were observed on eutrophication, ecotoxicity, and erosion. Hong et al. [11] evaluated the environmental and economic impacts of the life cycle of sewage sludge treatment in China. The results showed that anaerobic digestion was a good solution to reducing environmental and economic loads. Direct emission of heavy metals from landfills and incineration processes was also considered to be an important factor for reducing environmental and economic loads. Dehydration and incineration were found to be the most environmentally and economically appropriate methods in sewage sludge treatment due to energy recovery. Flores et al. evaluated the environmental performance of the constructed wetland systems for winery wastewater treatment using the LCA method in southwestern Europe. The results showed that the wetland system scenario was the most eco-friendly option due to treating winery waste on-site with low energy and chemical consumption, while the activated sludge system was the worst scenario environmentally [22]. The results of the mentioned studies were in line with those of the present study, which confirmed the efficiency of the method used.

Data analysis showed that, in the impact category of emissions to the air, electricity consumption with 88.83%

had the most adverse environmental effect and the activated sludge treatment plant effluent contributed by 11.16%. Nitrogen, phosphorus, and chlorine had a slight effect in this category. In the impact category of emissions to surface water, treatment plant effluent with 86.63% showed the most adverse environmental impact, followed by electricity consumption (7.93%), effluent phosphorus (4.89%), chlorine consumption (0.531%), and effluent nitrogen (0.00263%), respectively. In the impact category of emissions to groundwater, chlorine consumption showed the highest contribution (100%) to environmental degradation.

In the impact category of energy resources, electricity consumption (68.84%), effluent nitrogen (12.86%), chlorine consumption (11%), and effluent phosphorus (7.28%) had the greatest contribution to resource depletion, while treatment plant effluent had no effect in this category. In the impact category of natural resource consumption, electricity consumption (92.02%) and chlorine consumption (7.97%) had the highest effect on resource waste, while effluent nitrogen as well as phosphorus and treatment plant effluent had no effect in this category. Analyzing the cumulative percentage of component involvement in each impact category showed that electricity consumption (257.62%), chlorine consumption (119.501%), treatment plant effluent (97.79%), effluent nitrogen (12.86%), and effluent phosphorus (12.17%) had the most adverse effects on the environment, respectively.

Data analysis revealed that, in the impact category of emissions to the air, electricity consumption with 88.83% had the most adverse environmental effect and the activated sludge treatment plant effluent contributed by 11.16%. Nitrogen, phosphorus, and chlorine had a slight effect in this category. In the impact category of emissions to surface water, treatment plant effluent with 94.15% showed the most adverse environmental impact, followed by electricity consumption (5.15%), effluent phosphorus (0.38%), chlorine consumption (0.29%), and effluent nitrogen (0.0043%), respectively. In the impact category of emissions to groundwater, chlorine consumption showed the highest contribution (100%) to environmental degradation. In the impact category of energy resources, electricity consumption (61.35%), effluent nitrogen (29.42%), chlorine consumption (8.44%), and effluent phosphorus (0.78%) had the greatest contribution to resource depletion, while treatment plant effluent had no effect in this category. In the impact category of natural resource consumption, electricity consumption (93.05%) and chlorine consumption (6.94%) had the highest effect on resource waste, while effluent nitrogen and phosphorus as well as treatment plant effluent had no effect in this category. Analyzing the cumulative percentage of component involvement in each impact category (Fig. 6) showed that electricity consumption (248.38%), chlorine consumption (115.67%), treatment plant effluent (105.31%), effluent nitrogen (29.42%), and effluent phosphorus (1.16%) had the most adverse effects on the environment, respectively.

Comparing the results of the first and second six months by IMPACT 2002+ also indicated that the environmental impacts of the treatment plant effluent in the first six months were more than those of the second six months. Also, the results of environmental impacts per m^3 of activated sludge treatment plant effluent in the first and second six months by ESM indicated that, in the impact categories of emissions to the air, emissions to groundwater, and natural resources, the treatment plant effluent in the first six months had a more environmental impact than the second half. However, in the impact categories of emissions to surface water and energy resources, the treatment plant effluent had a more adverse environmental effect in the second half than the first one. In general, the environmental impact of the activated sludge treatment plant effluent had no significant difference between the first and second halves of the year. Tabesh et al. [23] evaluated the life cycle of wastewater treatment plants using LCA and SimaPro software in Tehran, Iran. The results showed that using biogas, instead of natural gas, can significantly reduce the environmental impacts of WWTPs, for example, it can alleviate the negative impacts of fossil fuels that consequently reduces the adverse effects on water resources, which was consistent with the results of our study. Polruang et al. [24] studied the environmental impacts of seven WWTPs in Thailand using three power schemes, including the current power generation and the next 5 and 20 y power generation plans, and three effluent management programs by LCA method. The results indicated that power generation in the next 5 and 20 y would reduce dependence on fossil fuels and increase using renewable energies. It was also found that the consumption of electric power and energy resource had the most adverse impact on almost all the environmental aspects, except for abiotic depletion and eutrophication.

5. Conclusion

Although assessing the performance of the studied activated sludge treatment plant effluent using IMPACT 2002+ and ESM showed a difference in the environmental pollution of effluent in the first and second six months of the year, it was not significant.

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