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Study of sludge from the largest wastewater treatment plant in the Middle East (Southern Tehran, Iran) based on chemical and microbiological parameters for use in agriculture

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ABSTRACT

Sludge (if not well-stabilized) used for improving the soil quality of agricultural lands might lead to soil contamination, and has caused many concerns in recent years. Therefore, the quality assessment of the sludge produced in wastewater treatment plants is essential prior to its application for the improvement of agricultural lands. This study is aimed to determine the quality of the sludge disposed from Southern Tehran Wastewater Treatment Plant. The microbial and physicochemical quality and concentration of sludge heavy metals resulting from anaerobic digesters and the sludge drying bed obtained from South Tehran Wastewater Treatment Plant were evaluated during spring and summer. The amount of volatile solids in sludge from digesters and sludge drying bed were between 62 and 68%, which showed the high level of organic matters in the sludge as well as poor anaerobic digestion and stabilization. Furthermore, the amount of heavy metals in the spring and summer in the sludge obtained from digestions and sludge drying bed was less than the EPA standard level. The present study showed that the sludge of South Tehran Wastewater Treatment Plant was often in class B, and the sludge should be used by taking into account certain considerations to improve the soil quality and to increase fertility, but it was in favorable conditions considering the concentration of heavy metals.

Keywords: Sludge; Microbial; Physicochemical; Heavy metals; Southern Tehran Wastewater treatment plant

1. Introduction

Rapid urbanization and industrialization has resulted in a dramatic increase in the volume of municipal wastewater produced globally [1–3]. This wastewater contains all the materials that enter in human metabolism, such as food, beverages, pharmaceuticals, a numerous household chemicals and the materials discharged from residential homes, commercial, institutional and industrial facilities to the sewer system [4–7]. Biological treatment is one of the most

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important wastewater treatment processes [8]. Activated sludge process is used as a biological technology for the treatment many types of wastewater [9–11]. During this process, a large volume of sludge is produced, a part of which is removed to adjust the concentration of microbial mass in the aeration tank [8,12]. The amount of sludge produced in wastewater treatment plants is about 1% of the treated wastewater that is approximately equal to 50 g per day per person and can be used as a source of energy. The US Environmental Protection Agency (EPA) has estimated that the publicly owned wastewater treatment works (POTW) produce above 8 million ton (dry weight) of sewage sludge annually [5,13,14]. The excess sludge produced in biological treatment processes is among the secondary solid wastes that should be disposed of safely and properly [15]. Treatment sludge is a solid material that is obtained from various treatment methods to remove the suspended and dissolved pollutants of the wastewater through the separation of solids from the liquid. In fact, it is an important sub-product in the treatment process [16]. The purpose of sludge treatment is to convert the raw and odorous sludge into neutral and odorless substances, which could easily lose water [17,18]. The methods used for sludge treatment depend on the size, type, and position of treatment plants, operation of units, properties and amounts of solids, and ultimately, the final disposal of sludge [19]. Sewage sludge contains organic matters and inorganic elements [20]. Soil modification with sewage sludge will improve soil characteristics such as organic matters, nutrients, porosity, water conservation, and density and it is economically affordable [21]. However, the use of sludge (if not well-stabilized) for improving soil quality of agricultural lands might lead to soil contamination with heavy metals, aromatic hydrocarbons, and microbial agents, which has caused numerous concerns in recent years [22]. Sludge might be used as spread on the ground in pastures and grasslands, on the surface of the earth, or through injection under the soil surface, but the important point for the sludge used for soil fertility is its control in accordance with the U.S. Environmental Protection Agency's (EPA's) Law 503 include three parameters of heavy metals (such as arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc), pathogenic agents (such as bacteria, viruses, and parasites), and absorption potential for the carriers of pathogenic agents (such as mice, insects, and mosquitoes) [23]. Therefore, a qualitative assessment of the sludge produced in wastewater treatment plants is essential prior to their application for the improvement and strengthening of the agricultural lands. Moreover, sludge management of wastewater treatment plants is one of the most important and expensive issues in wastewater engineering; it accounts for 50–60% of initial investment and up to 50% of management costs of wastewater treatment plants [24]. Besides, the problems caused by sludge disposal induce irreparable damage to the environment and humans. Therefore, the proper management of the sludge disposal caused by wastewater treatment has become one of the challenges of the present century. This study is focused on the sludge quality of Southern Tehran Wastewater Treatment Plant, with regard to the recent construction of this treatment plant, lack of studies in this field, and importance of this wastewater treatment plant as the largest one in the Middle East. The measurable items include fecal coliform and salmonella, pH, determination of total solids, determination of fixed and volatile solids, determination of phosphorus, Kjeldahl nitrogen, and heavy metals.

2. Materials and methods

2.1. Description of study area

Southern Tehran Wastewater treatment plant is designed for the wastewater treatment of four million people and a wastewater flow of 450,000 cubic meter per day. This plant is located in the south western part of Rey city in south of Tehran megacity. It covers an area of 110 ha. After treatment, the effluent of this plant is used for the irrigation of 50,000 ha of farmlands of Varamin plain. The produced sludge in the plant is also used as a soil fertilizer and conditioner for the farmlands in the area. A scheme of this plant shown in Fig. 1.

2.2. Sampling

This study was conducted for 6 months in the spring and summer of 2016 on the sludge of Southern Tehran Wastewater Treatment Plant. In order to determine the physical, chemical, and biological properties of sludge, the homogenized sampling was conducted on five digestions; also, four sample was taken from the belt filter press and 4 samples were taken from the sludge drying bed; in total, 44 samples including 20 samples of digester sludge and 20 samples of sludge drying bed were collected. Belt filter presses are applied widely in many wastewater treatment plants to remove water from liquid wastewater residuals and generate a non-liquid material expressed as cake [25,26]. The samples were taken in spring and summer (in each season two samples were taken from each point). For sampling from digesters, the discharge outlets were cleaned and then the samples were taken from the outlets. 0.5 in^3 in sampling bottles were considered for possible gas accumulation. For homogenized sampling from sludge drying bed, 6 in of surface sludge was taken away to remove suspended solids and foams, the sludge was divided into 4 parts and a sample was taken from each part and finally all the samples were mixed to obtain representative sample. For the sampling from belt filter press, the samples were directly taken from the belts.

Fig. 1. Aerial view of Southern Tehran Wastewater treatment plant.

The samples were immediately transferred to laboratory, and analyzed maximum 6 h. Fig. 2 shows sampling points in the Southern Tehran Wastewater treatment plant.

2.3. Microbial experiments

Based on the EPA standards, for the application of sludge in agricultural lands, if the number of coliforms is below 1000, there is no limitation on the use of the sludge (Group A), but if the number of sludge coliforms is between 1000 and 2000000 (group B), there is limit to its use. If the number of coliforms in the sludge exceeds 2000000, the produced sludge with this number of coliforms cannot be used in agricultural lands. For examining the microbial quality of the disposed sludge, the indicators of the fecal coliform (FC) are determined by multi-tube fermentation using A1-medium and salmonella experiment in the MSRV media. The analysis of the selected indicators is described in detail in the assessment of the microbial quality of the sludge in EPA 1681 and 1682 [27,28].

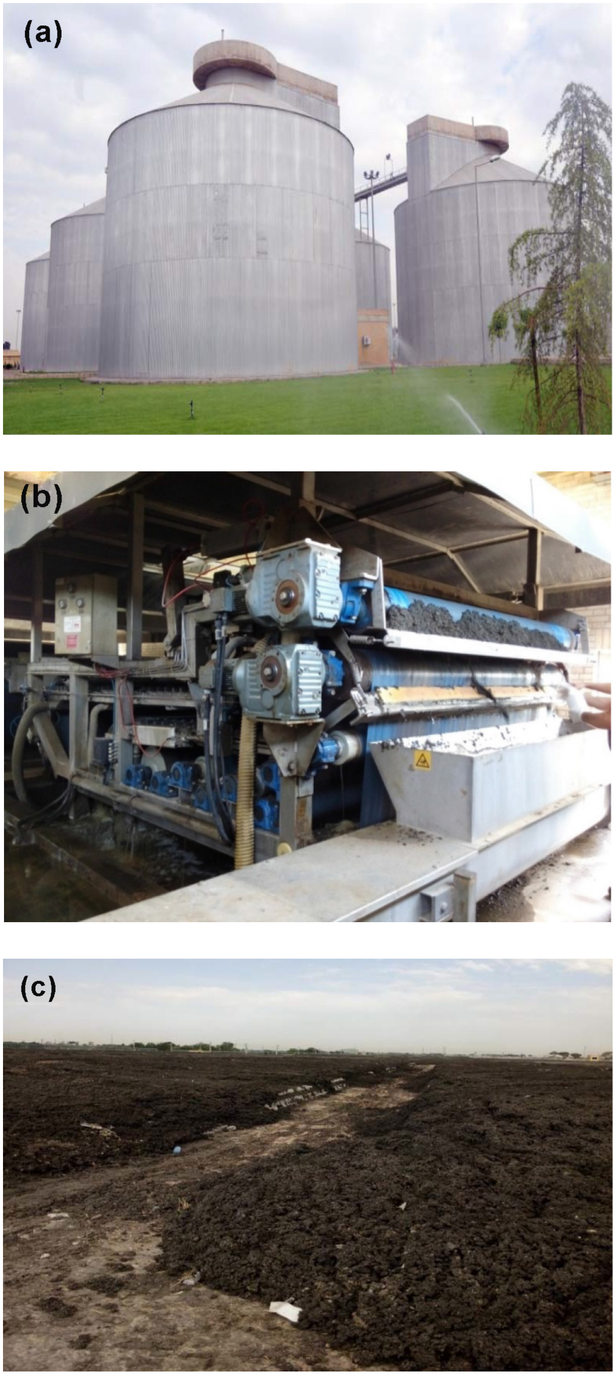

Fig. 2. Sampling points, (a) Sludge digesters, (b) Belt filter press and, (c) Sludge drying bed.

2.4. Physicochemical experiments

To determine physicochemical experiments, the parameters including pH, total solids, fixed and volatile solids, phosphorus, and Kjeldahl nitrogen were studied and compared with the standard. Total fixed and volatile solids were measured in sludge samples using gravimetric method. Available nitrogen was measured using the alkaline-permanganate technique. The amount of phosphorous was measured using the Bray and Kurtz method [3]. All the experiments were carried out based on the guidelines in the Standard Methods for the Examination of Water and Wastewater.

2.5. Heavy metal experiments

In this research, the concentrations of heavy metals such cadmium, arsenic, molybdenum, cobalt, lead, nickel, chromium, copper, zinc, manganese, and iron were determined. The concentration of heavy metals was examined based on EPA 3050 after extraction by hydrochloric acid and nitric acid using ICP-OES (Spectro Arcos Germany). Statistical analysis was performed using Microsoft Excel 2016.

3. Results

3.1. Microbial results

The average population of fecal coliform and salmonella in the spring and summer is given in Table 1.

In comparing the results with the EPA limits, the number of fecal coliform in the digesters in the spring and summer was in class A and B, respectively. But it was in B in the drying bed sludge in the spring and summer. The number of Salmonella in the digesters in the spring and summer was in class A and B, respectively and in drying beds, it was in class B. As is clear, the average number of fecal coliform and salmonella in the summer was higher than the spring.

3.2. Physicochemical results

The values of pH, dry weight, moisture, total solids, volatile solids, fixed solids, nitrogen, and phosphorus in the spring and summer for the sludge obtained from anaerobic digestions and sludge drying bed of Southern

Table 1
Comparison of average microbial results of the sludge drying beds and digesters in the spring and summer

Sampling location	Season	Number of samples	Fecal coliform (MPN/g)	Salmonella (MPN/4 g)
Digester sludge	Spring	10	779	0
	Summer	10	11453	5
Drying bed sludge	Spring	10	190174	4
	Summer	10	190174	23
Average	–	–	98145	8

Table 2
Results of physicochemical experiments of the digesters sludge in Southern Tehran Wastewater treatment plant in the spring and summer

Sampling point	Season	pH	Dry weight (% TS*)	Moisture (%)	VS * (%)	FS* (%)	N* (% TS)	P* (g/100 g)
Digester A	Spring	7.80	2.60	97	69.50	30.50	3.82	1.47
	Summer	7.54	2.67	97.33	67.29	32.71	3.82	0.46
Digester B	Spring	7.75	3	96.60	68.22	31.78	3.14	1.68
	Summer	7.51	2.66	97.34	69.95	30.05	4.23	0.3
Digester C	Spring	7.81	3	96.40	67.46	32.54	4	1.02
	Summer	7.65	2.63	97.37	64.50	35.50	4.51	0.86
Digester E	Spring	7.63	2.40	97.50	66.70	33.30	2.18	0.40
	Summer	7.51	2.75	97.25	65.91	34.09	3.35	0.21
Digester F	Spring	7.67	3	96.90	68.13	31.87	2.60	0.80
	Summer	7.67	2.38	97.62	68.20	31.80	5.10	1.11
Average	Spring	7.73	2.80	96.88	68	32	3.15	1.07
	Summer	7.58	2.62	97.38	67.17	32.83	4.20	0.59
Standard deviation	Spring	7.73 ± 0.079	2.80 ± 0.283	96.88 ± 0.421	68 ± 1.036	32 ± 0.036	5.10 ± 0.777	1.11 ± 0.514
	Summer	7.58 ± 0.078	2.62 ± 0.140	97.38 ± 0.140	67.17 ± 2.093	32.83 ± 0.093	4.20 ± 0.666	0. 59 ± 0.384

*TS = solids, VS = volatile solids, FS = fixed solids, N = nitrogen, P = phosphorous

Tehran Wastewater treatment plant are shown in Tables 2 and 3. The values of pH in the sludge samples obtained from digesters and sludge drying bed were in range 7.5–7.8. Therefore, the values of pH in this study was appropriate and did not lead to the leaching of heavy metals. No standard has been defined for the level of total, volatile, and fixed solids. The average amount of total solids in the sludge drying bed in the spring was more than the summer, which is due to the longer retention time of the sludge in the outdoor in the spring. The amounts of volatile solids in sludge from digesters and sludge drying bed were in range 62–68%, and the amount of fixed solids in the sludge obtained from the digesters and sludge drying bed was 32–37%, which could indicate the high levels of organic matters in sludge and poor anaerobic digestion and stabilization. The total nitrogen in the summer was more than the spring. The amount of phosphorus in the summer was less than spring. It should be noted that the amount of phosphorus and nitrogen in the sludge depend on the existing methods for the removal of phosphorus and nitrogen from wastewater and the outlet effluent standards from wastewater treatment plant. Besides, there was no specific standard on the amount of nitrogen and phosphorus in the samples defined in this study.

3.3. Heavy metals concentrations

The average and standard deviation of absorbable concentration of studied heavy metals is presented in Table 5.

4. Discussion

Urban wastewater treatment leads to the production of large amounts of sewage sludge, which requires proper and environmental management prior to final disposal [31]. In this study sludge from the largest wastewater treatment plant in the Middle East (Southern Tehran, Iran) was studied based on chemical and microbiological parameters for use in agriculture.

4.1. Microbial evaluation of the sludge

In comparing the results with the EPA limits, the number of fecal coliform in the digesters in the spring and summer was in class A and B, respectively. But it was in B in the drying bed sludge in the spring and summer, respectively. The number of Salmonella in the digesters in the spring and summer was in class A and B, respec-

Table 3
Results of physicochemical experiments of the sludge drying beds in South Tehran Wastewater treatment plant in the spring and summer

Sampling point	Season	Dry weight (% TS*)	Moisture (%)	VS*	FS*	pH	N* (% TS)	P* (g/100 g)
Drying bed 1	Spring	17.40	82.50	65.35	31.65	8	1.50	0.47
	Summer	17.20	82.80	68.65	31.35	7.60	2.17	0.16
Drying bed 2	Spring	31.50	68.40	69.75	30/25	7.80	1.12	1.11
	Summer	16.68	83.14	66.10	33.90	7.80	2.31	0.23
Drying bed 3	Spring	15.30	84.60	67.80	32.20	7.30	1.62	0.24
	Summer	16.04	83.96	64.38	35.62	7.58	0.84	0.25
Drying bed 4	Spring	15.80	84	68.07	31.93	7.60	1.51	1.34
	Summer	16.03	83.97	66.19	33.81	7.68	1.61	0.53
Drying bed 5	Spring	89.90	10	48.16	51.84	8	0.76	1.04
	Summer	23.79	76.21	45.31	54.69	7.80	1.47	0.81
Average	Spring	33.98	65.90	64.42	35.58	7.74	1.30	0.84
	Summer	17.98	82.02	62.13	37.87	7.69	1.68	0.39
Standard deviation	Spring	33.98 ± 31.96	65.90 ± 31.925	64.42 ±9.124	35.58 ± 9.124	7.74 ± 0.29	1.30 ± 0.776	0.84 ± 139.437
	Summer	17.98 ± 3.285	82.02 ± 3.285	62.13 ± 9.521	37.87 ± 9.521	7.69 ± 0.105	1.68 ± 0.589	0.39 ± 53/621

*TS = solids, VS = volatile solids, FS = fixed solids, N = nitrogen, P = phosphorous

Table 4
Limit values for metal concentrations in sludge for use in agriculture in mg/kg [29,30]

Country	Cd	As	Mo	Co	Pb	Ni	Cr	Cu	Zn	Mn	Fe
China	5–20	75	–	–	300–1000	100–200	–	800–1500	2000–3000	–	–
Japan	5	50	–	–	100	300	500	–	–	–	–
EU	20–40	–	–	–	750–1200	300–400	–	1000–1750	2500–4000	–	–
Russia	15	10	–	–	250	200	500	750	170	–	–
US (EPA)	39–85	41–75	75	–	300–840	420	–	1500–3400	2800–7500	–	–

Table 5
Concentration of heavy metals in the spring and summer for sludge obtained from anaerobic digesters and sludge drying bed in Southern Tehran Wastewater treatment plant

Metal (mg/kg)	Average and standard deviation (drying bed sludge in spring)	Average and standard deviation (drying bed sludge in summer)	Average and standard deviation (digester in spring)	Average and standard deviation (digester in summer)
Cd	0.61±0.262	0.38±0.114	0.54±0.183	0.55±0.103
As	1.48±0.467	1.13±0.291	1.14±0.468	1.43±0.167
Mo	1.38±0.476	1.05±0.092	1.42±0.375	1.31±0.175
Co	1.32±0.132	1.17±0.128	1.33±0.389	1.42±0.135
Pb	41.36± 10/108	30.26±30.26	40±10.192	37.21±4.629
Ni	32.57±9.677	23.19±2.181	33.3±9.670	30.84±4.864
Cr	25.8±10.984	16.62±2.181	26.18±8.249	22.01±3.603
Co	205.45±56.499	148.82±9.692	196.92±59.959	191.01±26.970
Zn	873.23±191.594	593.18±88.625	857.91±223.873	789.74±138.190
Mn	89.16±18.424	80.7±15.126	78±22.393	87.6±6.017
Fe	2504.9±56.208	2420.16±584.126	2313.72±607.632	2517.2±225.047

tively and in drying beds, it was in class B. As is clear, the average number of fecal coliform and salmonella in the summer was higher than the spring. Therefore, in accordance with the recommendations the EPA, class A sludge can be applied for agriculture. A study by Qureshi et al. [32] showed that the number of thermoduric coliform bacteria of the sludge from all the standard wastewater treatment plants met the requirements of class B, except for wastewater treatment plants in cities of Ahar and Sarab that were in class A. Except in Bostanabad Wastewater treatment plant, the other studied wastewater treatment plants did not meet the requirements of standard A for salmonella bacteria, which was consistent with the findings of this study [32]. The study by Rahmani et al. [33] showed that the average population of fecal coliform in the evaluated seasons exceeded 2,000,000 that was not in any group of the EPA standards, which was not consistent with the results of this study. The study of Asadi et al. [34] showed that the biological sludge produced in all the three wastewater treatment plants in the winter after drying under normal conditions was in EPA class B, meanwhile, the microbial quality of sludge in the summer was below EPA class B; therefore, it cannot be used in agriculture. The mountainous region, cold weather in the winter, and hot days in the summer were reported as the main causes of different results in two seasons, which was consistent with the results of this study. A variety of sludge treatment technologies are used in European Union (EU) countries. It seems that the anaerobic and aerobic digestion is the most popular stabilization ponds [31]. The strategic approach of sludge treatment process can be considered as an effective factor in reducing bacteria. In a study by Lloret et al. [35] in Spain, the average heat-resistant bacteria in raw sludge was reported CFU, which was reduced to less than 15 after treatment using auto thermal thermophilic aerobic digestion (ATAD) process. In another study carried out by Wong et al. [36] in Michigan, the certain pathogens of thermoduric coliform were studied in the outlet sludge of the mesophilic anaerobic digesters and sludge dehydrated in 4 wastewater treatment plants; the results showed that amount of these bacteria in the samples from anaerobic digester was equal to 10^4 MPN. These indicators were higher than those in the dehydrated samples. The results of other studies have indicated that the use of sludge for soil modification can change the physical, chemical, and microbial quality of the soil and, in terms of microbial conditions, this change increased the number of bacteria in the soil [37]. In the present study, the number of salmonella in sludge was examined by EPA 162 to determine the class of sludge. According to the EPA, if the number of salmonella in the sludge is less than 3 in 4 g of total solids, it could be categorized in class A sludge. In case the sludge is used to improve the soil condition, the treatment plant units efficiency must be enhanced.

4.2. Physicochemical evaluation of sludge quality

As observed, the values of pH in the sludge samples of the digesters and sludge drying bed were in range of 7.5–8.5. The pH of the sludge with an impact on pH of soil was effective in the absorption of the elements in the soil and plant, affecting the microbial population of the soil. The pH below 6.5 was effective in the leaching of heavy metals and absorbance by the plant [38]. Therefore, the value of pH was appropriate in this study and did not result in the leaching of heavy metals and absorbance by the plant. The sludge properties vary depending on wastewater effluent properties, treatment processes, and sludge preparation. The produced sludge can be a suspension of liquid sludge or total solids of 0.04 to a solid compound or 90% varied total solids. Also, the moisture content was 20–50 in solid sludge conditions [38]. The high amounts of organic matter in sludge indicated high levels of organic matter and poor anaerobic digestion and stabilization. Furthermore, low content of organic matter decrease the number of insects and carriers. No standard has been set for the amounts of total, volatile, and fixed solids in sludge. The average amount of total solids in the sludge drying bed in the spring was more than the summer, which was due to the longer retention time of the sludge in the outdoors in the spring. The average amount of total solids in the sludge obtained from digesters in the spring and summer had no significant difference. The amount of volatile solids in sludge obtained from digesters and sludge drying bed was in range of 62–68%, and the amount of fixed solids in the sludge obtained from the digesters and sludge drying bed was 32–37%, which indicated the high levels of organic matter of sludge and poor anaerobic digestion and stabilization. Moreover, the high content of organic matter attracted insects and carriers in Southern Tehran Wastewater Treatment Plant, which was clearly visible when sampling the sludge. If the organic matter is relatively high in the wastewater, it indicates the inefficiency of the anaerobic digester system in the treatment plants and the stabilization of sludge. However, the important point that should be noticed is that, in each treatment plant, with the increase in the retention time of sludge in the bed, a relatively increasing trend in pH as well as a completely decreasing trend in moisture and organic matter can be seen, but there is inconsistency in these increasing or decreasing trends.

4.3. Evaluating quality of sewage sludge for heavy metals

In comparing the amount of heavy metals with the EPA limits (Table 4), it was found that the studied heavy metals had a less concentration than the limit and the sludge had no limitation in this regard. The most important toxic mineral chemicals in sewage sludge, which are capable of causing acute or chronic diseases in humans with harmful effects on plants and animals, are mostly the elements measured and presented in Table 4. The major part of heavy metals is treated as oxide or hydroxide during wastewater treatment; if the resulting sludge is used for soil modification, some of the heavy metals could be released and absorbed by plants. In this regard, it is important to note that these elements generally have an accumulative property and more attention is required in the application of this sludge in a particular soil, in each turn, throughout the year, and in the successive years. A study by Alvarez et al. [39] showed that the amount of organic matter in the compost was less than the digested and dehydrated sludge, which was consistent with the above study. In a study by Rahmani et al. [33] on some qualitative characteristics and concentrations of heavy elements in dried sewage sludge of Shahinshahr Wastewater Treatment Plant, the pH values, total solids, organic matter, and moisture were in the range of common values and the content of organic matter in these samples was less than our study, which indicates better stabilization of Shahinshahr Wastewater treatment plant than Southern Tehran Wastewater treatment plant.

Plants require some nutrients for growth. These nutrients are classified as macro nutrients such as nitrogen, phosphorus, potassium, and calcium and micro nutrients such as zinc, manganese, and iron. Sewage sludge, as an organic waste, improves the physicochemical properties and also increases concentration of high and low consumed nutritional elements for plant growth. In recent years, the use of sewage sludge has been considered in agricultural lands, given that it is an organic fertilizer full of various nutrients such as nitrogen and phosphorus. According to the results, the amount of total nitrogen in the summer was more than the spring. The amount of phosphorus in the summer was also less than the spring. It is interesting to note that the amount of phosphorus and nitrogen in sludge depends on the standards of outlet effluent from the treatment plant and the existing methods for removing phosphorus and nitrogen from the wastewater. Besides, there was no specific standard for the amounts of nitrogen and phosphorus in the samples defined in this study. Rahmani et al. [33] conducted a study on the dried sewage sludge in Shahinshar Wastewater Plant, Isfahan. The results of this study showed that all the elements studied in the sludge and their annual load, except for arsenic, had a concentration below the limit. Results of this research were consistent with those of this study. Da Silva Oliveira et al. [40] conducted a study on the urban wastewater and treated and untreated sludge from the units of biological wastewater treatment. Their study showed that the concentration of heavy metals for the treatment of sewage and sludge was at maximum limit proposed by the Sao Paulo State Environmental Protection Agency (CETESB); thus, there was an urgent need for the authorities to reduce As, Be, Hg, Sn, Ti, and V metals to a safe level, which was not consistent with the results of this study. Mtshali et al. characterized sewage sludge quality produced from seven wastewater treatment plants in Swaziland for agricultural uses. Despite the variations in sludge processing and sludge storage times, the sludge samples showed high concentrations of organic matter, nutrients and heavy metals required for plant growth. But the concentrations were found to be within acceptable limits with respect to agricultural uses [3]. These results are in consistent with our results in this study. Measured levels of metal concentrations in sludge for use in agriculture in different countries are given in Table 6.

5. Conclusions

This study was aimed to evaluate the quality of sludge in Southern Tehran Wastewater treatment plant. Results of the study and a comparison with the standards of the USEPA showed that the sludge of this treatment plant was in class B in most cases, which had limitations for agriculture, and the required considerations should be taken into account for use. Micro biologically and biologically, this sludge is not appropriate for use in grassy playgrounds, home gardens, flowerpots, and packaging for sale. Besides, results of sludge physicochemical experiments showed that stabilization was not done properly in anaerobic digestions, which led to the attraction of insects and carriers around the sludge drying bed and was also due to the high amount of moisture and organic matter of the sludge in the treatment plant, requiring a change in sludge treatment systems. As for the amount of heavy metals, however, it was in good conditions in comparison with the standards of the USEPA; this sludge could be used for all the sludge uses and caution is only required for agricultural use due to the accumulation capability of these elements.

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Conflict of Interest

The authors of this article declare that they have no conflict of interests.

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Table 6
Measured levels of metal concentrations in sludge for use in agriculture in different countries in mg/kg [29]

	Cd	As	Mo	Co	Pb	Ni	Cr	Cu	Zn	Mn	Fe
Brazil	11	15	113	–	80	42	144	255	689	–	–
Los Angeles (USA)	76	6	18	–	39	51	84	1060	1180	–	–
Ottawa (Canada)	1	1	–	–	51	16	50	460	593	–	–
Finland	1	–	–	–	9	30	18	244	339	–	–
Germany	2	–	–	–	62	32	61	380	956	–	–
Italy	2	–	–	–	76	16	22	261	577	–	–
Turkey	1	–	–	–	34	62	34	70	300	–	–
Suzu (Japan)	2	8	–	–	5	32	20	–	–	–	–
Moscow (Russia)	–	0-24	–	–	0.8–1070	1.4–306	18–1280	0.9–1200	3–3820	–	–

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