

An investigation of agricultural use potential of dewatered sewage sludge

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Abstract

Background: One of the useful applications of Dewatered sludge (DWS) of municipal wastewater treatment plants (WWTPs) is its use as manure in agriculture; therefore, its quality characteristics should be specified. The aim of this research was to determine biological and physicochemical characteristics of DWS of Sari WWTP and compare them with standards, and also to investigate its potential use in agriculture.

Methods: Sludge samples were taken from the sewage sludge of Sari WWTP. Sampling and analysis of samples parameters including fecal coliform, salmonella, helminth ova, carbon, nitrogen, C/N, phosphorus, organic matter, potassium, moisture, electrical conductivity, and PH, were performed during four seasons with three replications based on the standard method.

Results: The fecal coliform, salmonella, and helminth ova of the DWS were $2.37 \times 10^6 \pm 1.06 \times 10^6$ MPN/1 g d.s weight, 47 ± 12.92 MPN/4 g d.s weight, and 466 ± 61.85 number/4 g d.s weight, respectively, therefore, the DWS of Sari WWTP was categorized in the class B of the EPA standard. The amounts of C/N, organic matter, carbon, nitrogen, phosphorus, potassium, moisture, electrical conductivity, and PH were obtained to be 12.7 ± 1.15 , $42.4 \pm 3.27\%$, $24.6 \pm 1.89\%$, $1.94 \pm 0.13\%$, $2.35 \pm 0.6\%$, $0.57 \pm 0.13\%$, $82 \pm 3.12\%$, 1.34 ± 0.21 ds/m, and 7.41 ± 0.45 , respectively.

Conclusion: The DWS of Sari WWTP has a good fertility value but it cannot be safely used in agriculture and should be improved for class A by the Processes to Further Reduce Pathogens (PFRP), especially by composting.

Keywords: Sewage sludge, Agricultural use, Fertilizer, Pollution control, Dewatered sludge

Citation: Aghili SM, Mehrdadi N, Aminzadeh B, Zazouli MA. An investigation of agricultural use potential of dewatered sewage sludge. Environmental Health Engineering and Management Journal 2019; 6(3): 179–184. doi: 10.15171/EHEM.2019.20.

Article History:

Received: 17 February 2019

Accepted: 24 June 2019

ePublished: 10 July 2019

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Introduction

Disposal of excess sludge from sewage treatment is an essential requirement for wastewater treatment plants (WWTPs). Dewatered sludge (DWS) generated from municipal wastewater treatments, has useful applications. One of the most appropriate useful applications of DWS is its use as manure in agriculture because DWS is known as a biological product compatible with the environment and full of reinforce nutrients for agricultural soil, and also, as a suitable alternative for chemical nitrogen and phosphorus manures (1-3). Given its enrichment in nutrients, such as nitrogen, phosphorus, and potassium, sludge can be used as soil conditioners and fertilizers to enhance agricultural products (4). But DWS contains many pollutants such as fecal coliform, salmonella, virus, helminth ova, and heavy metals that limit its use in agriculture (5,6). In the

provisions of 40 CFR part 503 of EPA, DWS is divided into two classes of B and A. The purpose of the sludge class B regulations is to reduce the fecal coliform to less than 2 million MPN/g d.s weight. Therefore, class B sludge is used only under strictly defined conditions and with strict agricultural constraints. The main purpose of the class A regulations is to reduce fecal coliform to less than 1000 MPN/g d.s weight, salmonella to less than 3 MPN/4 g d.s weight, the intestinal virus to less than 1 PFU/4 g d.s weight, and helminth ova to less than 1 ova/4 g d.s weight. Therefore, there is no limitation for the use of class A sludge in agriculture (7,8).

Sewage sludge may be stabilized by aerobic digestion such as composting, or anaerobic digestion (9,10). Literature review shows that sludge qualities are different in various WWTPs in the world and Iran, so that sludge quality of



domestic sewage treatment in the city of Franca in Brazil was in the standard class B (11); but evaluation of the quality of sewage sludge in the city of Sarkan in Hamedan and its comparison with environmental standards for reuse showed that the characteristics of sludge produced had a significant difference with those of the class A and class B (12); on the other hand, the sludge of Shosh's wastewater treatment was classified in none of the classes (13), while sludge quality in Isfahan WWTP was classified in class B (14).

WWTP of Sari in Mazandaran province of Iran has been designed for a population of 420,000 people in 4 modules by aerobic method. The capacity of each module is 24242 cubic meters per day (m^3/d), which is designed for 105,000 people. At present, the first module with a capacity of 19500 m^3/d is in operation and produces 1–3 tone DWS per day. By adding the next three modules, the amount of DWS produced will be significant. So, useful application of the DWS in agriculture, fertilizing the soil, and making money from creating manure by the compost of DWS are necessary.

The objective of this research was to determine the physicochemical and biological characteristics of DWS of Sari WWTP and compare them with standards, and also, to determine the fertility value and class of DWS of this plant and the potential for its use in agriculture.

Materials and Methods

This case study was conducted in Sari WWTP from April 2017 and lasted four seasons of the year. Since no qualitative study had been carried out on the DWS of Sari WWTP, it was necessary to test the sludge samples in the laboratory of the School of Health of Mazandaran University of Medical Sciences (MAZUMS) and provide the qualitative characteristics of the sludge to determine the class of the sludge. DWS samples were taken from the belt filter. Sterile containers were used for biological tests and to prevent the change of samples, they were kept at a temperature between 0 and 4°C until they were transferred to the laboratory. The biological parameters included fecal coliform, salmonella, and helminth ova. Fecal coliform was measured by MPN standard method 9221 E. The gas in the tubes containing Brilliant Green Agar culture medium in an autoclave at 44.5°C for 24 hours indicates that the test is positive. Salmonella was measured using counting in Xylose Lysine Deoxycholate (XLD) agar culture medium by standard method 9260 D (15). Helminth ova was measured according to EPA guideline (16).

The chemical parameters included C, N, C/N, phosphorus, organic matter (OM), and potassium. Total organic carbon (TOC) was measured by cold Walkley-Black method and the organic carbon of DWS was digested and oxidized by potassium dichromate in the presence of sulfuric acid. Total Kjeldahl nitrogen (TKN) was measured by the Kjeldahl method. The main purpose of this method is to convert nitrogen of DWS to ammonium

and determine the concentration of ammonia nitrogen. Sulfuric acid and salts are used to convert organic nitrogen to ammonium. Organic matter was measured by cold Walkley-Black. Phosphorus was measured by Olsen method and spectrophotometer at wavelength of 470 nm. 50 g of sodium bicarbonate was added to 2.5 g of DWS. After passing through the Whatman filter, 5 mL of the ammonium heptamolybdate vanadate solution was added to the solution, and then, the absorbance was measured by the spectrophotometer. Potassium was measured by the photometric method at wavelength of 598 nm. Moisture, the physical parameter, was measured by gravimetric method at temperature of 105°C for 24 hours. EC and PH, the physicochemical parameters, were measured by conductivity meter and SW-9045D potentiometric method, respectively (15). The medium and standard deviation of all parameters were obtained by SPSS version 24.

Results

Biological characteristics of DWS of Sari WWTP

The results of measurement of biological characteristics of DWS and standards are presented in Table 1.

Physicochemical characteristics of DWS of Sari WWTP

The results of measurement of physicochemical characteristics of DWS and standards are presented in Table 2.

Discussion

Fecal coliform

Fecal coliform is the main index of the determinant of sludge class based on the provisions of CFR 40 Section 503 of the EPA standard (8). For class B sludge, reaching to the Processes to Significantly Reduce Pathogens (PSRP) standard of sludge and reduction of fecal coliform to less than 2 million MPN/g d.s weights are considered. For class A sludge, reaching to the Processes to Further Reduce Pathogens (PFRP) standard of sludge and reduction of fecal coliform to less than 1000 MPN/g d.s weight are considered. In this research, the average fecal coliform of DWS of Sari WWTP in the four seasons of the year was 2.37×10^6 MPN/g d.s weight; therefore, it was categorized in class B, which is consistent with the results of the studies by Moretti et al (11) and Hait and Tare (7). Moretti et al investigated the sewage sludge of the domestic sewage treatment plant in the city of Franca (São Paulo, Brazil) and found that fecal coliform was 1.2×10^6 MPN/g d.s weight (11). Hait and Tare investigated the sewage sludge of the urban sewage treatment plant at Jajmau (Kanpur, India) and found that the fecal coliform was 4.5×10^7 MPN/g d.s weight (7). So, the DWS of Sari WWTP was categorized in the class B.

Salmonella

Another indicator of the sludge class, based on the EPA

Table 1. Biological characteristics of DWS of Sari WWTP and EPA standard

Biological Parameters	April-June 2017	July-September 2017	October-December 2017	January-March 2018	Yearly	Class B Standard EPA	Class A Standard EPA
Fecal Coliform (MPN/g d.s weight)	Min & Max	8.5×10 ⁵ - 1.1×10 ⁶	1.8×10 ⁶ - 3.18×10 ⁶	1.9×10 ⁶ - 3.78×10 ⁶	2.2×10 ⁶ - 3.48×10 ⁶	8.5×10 ⁵ -3.78×10 ⁶	
	Medium & Std. Deviation	9.6×10 ⁵ ±1.27×10 ⁵	2.53×10 ⁶ ±6.93×10 ⁵	2.88×10 ⁶ ±9.42×10 ⁵	3.11×10 ⁶ ±7.92×10 ⁵	2.37×10 ⁶ ±1.06×10 ⁶	1000
Salmonella (MPN/4 g d.s weight)	Min & Max	35-42	52-68	45-67	30-41	30-68	
	Medium & Std. Deviation	39±3.6	61±8.18	53±12.16	35±5.56	4712.92±	3
Helminth ova (OVA/4 g d.s weight)	Min & Max	364-451	493-560	458-510	387-489	364-560	
	Medium & Std. Deviation	400±5.39±	533±35.34	480±26.9	451±55.74	466±61.85	1

Table 2. Physicochemical characteristics of DWS of Sari WWTP and standards

Physicochemical Parameters	April-June 2017	July-September 2017	October-December 2017	January-March 2018	Yearly	10716 Standard of IRAN- Grade 2	10716 Standard of IRAN- Grade 1	WHO
Moisture (%)	78-85	76-83	80.1-86	83-86	76-86	35 maximum	15maximum	30-50
C (%)	Medium & Std. Deviation	81± 3.6	80±3.6	82.7±3.01	84.3±1.53	823.12±		
	Min & Max	22.3-24.2	21.8-23.5	24.1-26.7	26.1-27.3	21.8-27.3		
N (%)	Medium & Std. Deviation	23.5±1.04	22.6±0.85	25.7±1.4	26.6±0.62	24.61.89±	25 minimum	-
	Min & Max	1.84-1.96	1.77-2.03	1.93-2.15	1.81-2.12	1.77-2.15		
C/N	Medium & Std. Deviation	1.91±0.06	1.86±0.14	2.06±0.11	1.93±0.16	1.940.13±	1.25-1.66	0.4-1.5
	Min & Max	12.12-12.43	10.73-13.2	11.47-13.83	12.45-14.67	10.73-14.67		
Organic Matter (%)	Medium & Std. Deviation	12.3±0.16	12.21±1.3	12.51±1.2	13.84±1.21	12.71.15±	15-20	-
	Min & Max	38.44-41.72	37.58-40.51	41.54-46.03	44.99-47.06	38.44-47.06		
P (P2O5) (%)	Medium & Std. Deviation	40.51±1.8	38.96±1.47	44.3±2.41	45.85±1.07	42.43.27±	35 minimum	10-20
	Min & Max	1.6-2.6	2.2-2.8	1.2-3.1	1.9-2.7	1.2-3.1		
K (K2O) (%)	Medium & Std. Deviation	2±0.53	2.7±0.45	2.3±0.98	2.4±0.43	2.350.6±	1-3.8	0.2 – 3.8
	Min & Max	0.54-0.78	0.41-0.61	0.45-0.7	0.43-0.71	0.41-0.78		
PH	Medium & Std. Deviation	0.68±0.12	0.5±0.1	0.54±0.13	0.56±0.14	0.570.13±	0.5-1.8	0.1 – 2.8
	Min & Max	7.05-7.41	7.6-8.2	6.8-7.12	7.1-8.13	6.8-8.2		
EC (ds/m)	Medium & Std. Deviation	7.2±1.87	7.9±0.3	7.04±0.21	7.5±0.55	7.41±0.45	6-8	6-9
	Min & Max	1.12-1.38	1.23-1.48	1.15-1.74	1.05-1.63	1.05-1.74		
	Medium & Std. Deviation	1.28±0.14	1.41±0.15	1.38±0.31	1.31±0.29	1.340.21±	8 maximum	-

standard, is the reduction of salmonella to less than 3 MPN/4g d.s weight (7,8). In this study, the average salmonella of DWS in the four seasons was 47 MPN/4g d.s weight, which was much higher than the EPA standard, indicating that the DWS of Sari WWTP was in the class Bazrafshan et al investigated the DWS of Isfahan sewage treatment plant and found that the salmonella was 20.45 MPN/4g d.s weight (17). The average salmonella in a study by Dumontet et al was 24 MPN/4g d.s weight, therefore, it was categorized in the class B (18).

Helminth ova

The other indicator of the sludge class in accordance with the EPA standard, is the reduction of helminth ova to less than 1 ova/4g d.s weight (7,8). In this study, the average number of helminth ova of DWS in the four seasons was 466, which is consistent with the results reported by Navarro and Jimenez who reported that the amount of helminth ova for developing countries was 70-735 (19). So, the DWS of Sari WWTP was in the class B (19).

C/N

The C/N ratio is the main indicator of sludge stabilization (20). The ratio of 25 and 50 is suitable for aerobic composting. The optimum range for most organic wastes is from 20 to 25. This ratio for sludge should be in the range of 20-30 (21) or 25-30 (22). In lower ratios, ammonia is released and microbial activities are delayed and in higher ratios, nitrogen can be a limiting nutrient (23). The wastewater treatment sludge has a low C/N ratio. In this study, the C/N ratio of DWS was 12.7, which is less than those reported by Mokhtari et al, Alidadi et al, and Parvaresh et al, that were obtained to be 24, 29, and 20.38, respectively (24-26), but it was a little more than those reported by Nikaeen et al (27) and Zorpas and Loizidou (28), which were 13.7 and 10, respectively. So, it is necessary to compost DWS of Sari WWTP to add bulking agents for increasing the C/N ratio because the carbon of bulking agents is more than that of the DWS.

Phosphorus

Phosphorus is the essential mineral for plant growth. The shortage of phosphorus in the plant leads to its growth delay (29). In this research, the average phosphorus in the four seasons was 2.35%, which is consistent with those reported by Cai et al (30) and Zorpas and Loizidou (28). However, it is more than that reported by Rihani et al (31), which was 1.3 and less than the results reported by Yanez et al (32) and Roca-Perez et al (33) that was 4.85% and 3.6%, respectively, in the range of 1-3.8% of manure grade 1 of 10716 standard of Iran. So, DWS of Sari WWTP in terms of phosphorus is good for agriculture.

Organic matter

The organic matter is one of the stabilization indicators of DWS and it should be more than 25% so that it can

be suitable for soil enrichment (3,28). In this research, the average organic matter in DWS in the four seasons was 42.4%, which was consistent with those reported by Zorpas and Loizidou (28) and Nikaeen et al (27). However, it was less than the results reported by Roca-Perez et al and Ponsá et al that were 60% and 75%, respectively. Nevertheless, it was higher than the result reported by Rahmani et al, which was 37% (33-35), and higher than at least 35% of manure grade 1 of standard 10716 of Iran. So, DWS of Sari WWTP in terms of organic matter is good for agriculture.

Potassium

Potassium is another essential mineral for plant growth. In this research, the average potassium of DWS in the four seasons was 0.57%, which was a little less than the results reported by Rihani et al (31) and Yañez et al (32), and Zorpas and Loizidou (28), which were 0.69%, 0.83%, and 0.72%, respectively, and a little more than that reported by Roca-Perez et al (0.3%) (33), therefore, it was categorized in the range of 0.5%-1.8% of manure grade 1 of standard 10716. So, DWS the Sari WWTP in terms of potassium is good for agriculture.

Electrical conductivity and pH

Electrical conductivity represents the concentration of dissolved salts in the DWS. High electrical conductivity causes soil salinity, biological toxicity, and leads to delayed germination and longitudinal growth of roots. The average percentage of electrical conductivity of DWS in the four seasons was 1.34 d.s/m, which was consistent with the results reported by Zhang et al (36), indicating that it was in the range of manure grade 1 of standard 10716 of Iran. PH is one of the most important factors affecting microbial activity. The average PH of DWS in the four seasons was 7.41, which was consistent with the results of another study (37), it was in the range of manure grade 1 of standard 10716 of Iran. So, DWS of Sari WWTP in terms of Electrical Conductivity and PH is good for agriculture.

Moisture

Moisture carries dissolved nutrients into microorganisms and organic matter decomposition depends on the presence of moisture. Low moisture causes dehydration and slowing down the biological process. High humidity causes blockage of pores, disrupts aeration, and creates anaerobic conditions (38). The average percentage of moisture of DWS in the four seasons was 82%, which was consistent with those reported by Kulikowska and Sindrewicz (39) and was less than at maximum 35% of manure grade 2 of standard 10716 of Iran. So, at present, DWS of Sari WWTP in terms of moisture is not good for agriculture and its moisture should be reduced before the use.

Conclusion

According to the results, produced DWS in terms of phosphorus, potassium, EC, and pH is in the range of Grade 1 of Iran's manure 10716 standard. Also, the DWS in terms of C and C/N is in the range of Grade 2 of this standard, and in terms of N and organic matter, it is higher than the range of Grade 1 of this standard, but in terms of moisture is lower than the range of Grade 2 of this standard. Accordingly, it can be concluded that DWS of Sari WWTP has a good fertility value but it cannot be safely used in agriculture and should be improved for class A by composting. Also, due to the low C/N ratio of DWS, it is necessary to add bulking agents for increasing this ratio.

Acknowledgements

The authors would like to thank the Mazandaran Wastewater Company for supporting this study and Faculty of Health, Mazandaran University of Medical Sciences for collaboration in this research project.

Ethical issues

The authors hereby certify that all data collected during the research are as expressed in the manuscript, and no data from the study has been or will be published elsewhere separately.

Competing interests

The authors have declared that they have no conflict of interests.

Authors' contribution

All authors contributed in data collection, analysis, and interpretation. All authors reviewed, refined, and approved the manuscript.

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