Original Article

Investigation of sewage sludge quality for land application: A case study: Two Isfahan wastewater treatment plans

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ABSTRACT

Aims: The aim of this study was to investigate sewage sludge quality of Isfahan wastewater treatment plants (WWTPs) as a fertilizer in agricultural lands.

Materials and Methods: The samples were collected seasonally from two WWTPs, including North-Isfahan and Shahin-Shahr in 2012 and 2013, seasonally and biochemical parameters were measured for each site.

Results: The studied parameters were meet the Iranian standard level, including pH, nitrogen, phosphorous, potassium, calcium, total solids, organic matter, and moisture content except of magnesium. The carbon-nitrogen ratios was varied 7.41-9.45 and 8.7-9 in Shahin-Shahr and North-Isfahan WWTPs, respectively. The organic nitrogen was composed the highest percentage of the total nitrogen (about 78%) and inorganic nitrogen was in normal ranges. The electrical conductivity was varied 5-8.8 ds/m to 4.6-7.5 ds/m in Shahin-Shahr and North-Isfahan WWTPs, respectively. It may contribute to soil salinity in long term. Maximum nitrogen and phosphorous values were related to winter samples in both WWTPs. In Shahin-Shahr WWTP, minimum and maximum of potassium, calcium, and magnesium were measured in spring while they were the highest in spring in North-Isfahan WWTP.

Conclusion: Application of sewage sludge of Isfahan WWTP as a fertilizer could be useful regardless to its microbial contents because it provides essential nutrients for plants growth regardless to its fecal and total coliforms.

Key words: Agricultural land, fertilizer, pollution control, sewage sludge quality

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INTRODUCTION

Organic matters have important roles in soil properties such as preserving water and nutrients and preventing soil degradation. Since the dry land suffers from low organic matter, using of biological compounds is a common way to improve the soil composition (organic matter and nutrient). Using of sewage sludge could be positive through a good management policy by keeping international standard levels of physicochemical and microbial parameters. However the risks of the toxic matters should not be ignored. Therefore monitoring of these compounds and their environment fate is a critical

Access this article online

Quick Response Code:

Website:
www.ijehe.org

DOI:
10.4103/2277-9183.170703

This article may be cited as: Rahmani HR, Rezaei H, Amin MM, Kohanestani ZM. Investigation of sewage sludge quality for land application: A case study: Two Isfahan wastewater treatment plans. Int J Env Health Eng 2015;4:36.

issue to get comprehensive knowledge about its application benefits or limitations as agricultural fertilizer.

Sewage sludge or biosolids, are produced during the biological treatment of sewage, contains significant quantities of organic matter, moisture, nutrients and trace elements, that is why it is viewed as a source for agricultural application. An advantages of sludge treatment is transferring massive stinky sewage to neutral odorless compounds lost its moisture.[1,2] The methods using for sludge treatment depends on wastewater treatment plant (WWTP) characteristics such as location, type, size, number of active sections; sewage sludge properties (volume and composition) and disposal methods.[3]

In recent decades, the WWTPs are developing because of increasing wastewater generation, so managers have concerned about its environmental risks.[4] Previous studies reported that United States of America, European United Nations, Japan, Taiwan, and Korea produced annually 7, 8, 3.5, 0.2, and 2.43 million tons dried biosolids, respectively.[5-7]

Farzadkia reported nearly all of sewage disposed without any efficient treatment in four Tehran WWTPs.[8] While another approach on sludge quality of Isfahan WWTPs, showed aerobic digesters could supply standard criteria and microbial level was classified in class B of Environmental Protection Agency (EPA) standard.[9]

However, disposing of sewage sludge has being an environmental crisis in recent years, it consists of many nutrients such as nitrogen and phosphorous which effect on plant functions, biological and physicochemical properties of soil.[10-12]

Therefore, application of sewage sludge as a fertilizer in agricultural land acts as two side's effects (source of organic matters and risk of toxic matters) in order to disposing and potential use of the biosolids.[13] It is known that bioavailability of heavy metals in soil and ground waters depending on their concentrations in soil solutions. It effects on their plant uptake in response of their different distributions.[14,15] So, it could be used as nutrients for the soil and plant but, the pathogen microorganisms (bacteria and virus), heavy metal, and organic pollutants should be remain at their standard levels.

In Iran, 50 WWTPs established by 2002 and continued to increase to 75 by the end of 2003. Therefore the generation of wastewater increased significantly and there is a constant need to increase knowledge about suitable disposal solutions.[16]

Burning, disposing in sanitary sites and using in agricultural land are the most common disposal options.[2,8] Type of treatments, distance of WWTPs from the land and eco-social factors should be considered for land disposing management and decreasing the environmental risks.[17,18] There are limited data on Isfahan WWTPs sludge quality; therefore this study was carried to investigate the sewage sludge quality for land application as a fertilizer.

MATERIALS AND METHODS

This study was carried out from October 2012 to July 2013 in Isfahan WWTPs (case studies: North-Isfahan and Shahin-Shahr). The production capacities were 24.82×10^6 and 36.5×10^6 m^3/year for Shahin-Shahr and North-Isfahan WWTPs, respectively. The sewage sludge was produced through the two main routes including primary and secondary treatments.

Dried sewage samples were collected seasonally (with three replications) using sterilized bottles (containers) and then kept in refrigerator at 4°C to prevent any change in sludge conditions.[19,20] The sewage sludge were analyzed for basic physico-chemical properties using standard procedures:

Microbial and biochemical parameters were measured including total and fecal coliforms (counts), pH (glass electrode in 1 mol • L^{-1} KC1 [1:5 ratio]), total solid and organic matters (%) (wet dichromate oxidation with sulphuric acid), electrical conductivity (ds/m) (electrode conductivity meter), moisture content (%) (oven dry method, 24 h at 70°C), nitrogen (%), phosphorous (%), calcium (%) (by flame atomic absorption following ashed at 450°C and then residual was dissolved in 3 mol • L^{-1} HC1), magnesium (%), potassium (%), nitrate, ammonium and organic nitrogen (%) and carbon-nitrogen (C/N) ratio (%).[19,20]

Data were checked for normality distribution with the Kolmogorov–Smirnov test. Comparison the biochemical data and standard level (EPA) analyzed by using two tailed T-test, assuming a significant level of $\alpha = 0.05$ by SPSS 17 software package (SPSS, Richmond, Virginia, USA).

RESULTS

Selected properties of sewage sludge

The mean values and ranges for pH, total solids, organic matters and moisture were shown in Figure 1. Almost all of the parameters showed significant differences in two sites (Shahin-Shahr and North-Isfahan) except of organic matters. The maximum organic matters of Shahin-Shahr and North-Isfahan were 45.8 and 43.52, respectively. Total solids and moisture was approximately 60-40%. pH varied from 6.3 to 7 (mean = 6.7) and 6.8 to 7.2 (mean = 6.9) in Shahin-Shahr and North-Isfahan, respectively. It did not show vast variations and trend around the normal pH (pH = 7).

The parameters of each WWTP were comprised with standard levels reported by EPA.[17] According to the results, the values were in normal ranges in both WWTPs.

Sewage sludge quality as a fertilizer

The results of Shahin-Shahr sewage sludge components are given in Table 1. Seasonally variations of the Shahin-Shahr sludge showed that the minimum and maximum values of potassium, calcium and magnesium were in spring and summer, respectively. In this regards, both two studied WWTPs showed similar variations in different seasons. In spring, nearly all of components were the lowest.

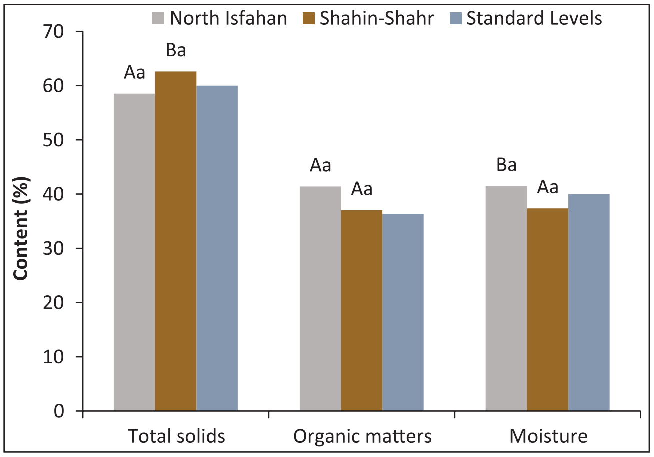

Figure 1: Physical parameters of sludge in Isfahan wastewater treatment plants. Similar capital and lowercase letter shows no significant differences between two sample sites and standard levels, respectively ($P > 0.05$)

Comparisons of the sludge quality parameters with standard levels showed that potassium, calcium and magnesium were lower than standard levels significantly ($P < 0.01$ and $P < 0.05$).[2,21]

Other parameters did not show any significantly differences with standards. Nearly all of quality parameters of sewage sludge were in the standard ranges. Therefore using Shahin-Shahr sewage sludge as a fertilizer is not restricted.

The mean values of nitrogen, phosphorous, potassium, classism, and magnesium of North-Isfahan sewage sludge are shown in Table 2. The minimum and maximum levels of nitrogen were in autumn and winter, respectively, whereas the phosphorous was in winter and spring. The maximum and minimum values of potassium and calcium were observed in summer and spring, respectively. However, the magnesium was the highest in spring [Table 2].

Table 1: Sewage sludge quality of Shahin-Shahr WWTP

Seasons	Parameters	*n* (mg/kg)	*P* (mg/kg)	Potassium (mg/kg)	Calcium (mg/kg)	Magnesium (mg/kg)
Spring	Mean	1.36	1.38	0.39	1.56	0.21
	Minimum–maximum	1.32-1.4	1.25-1.51	0.28-0.5	1.4-1.6	0.19-0.22
Summer	Mean	2	1.31	1.07	1.88	0.3
	Minimum–maximum	1.32-1.74	1.08-1.54	0.73-1.18	1.72-2.17	0.23-0.34
Autumn	Mean	2.97	1.36	0.53	1.86	0.27
	Minimum–maximum	2.41-3.81	1.15-1.7	0.4-0.6	1.6-1.95	0.25-0.28
Winter	Mean	3.02	1.53	0.6	1.57	0.27
	Minimum–maximum	1.93-3.81	1.24-1.75	0.55-0.65	1.3-1.65	0.26-0.28
Annually	Mean	2.16	1.33	0.58	1.7	0.27
	Minimum–maximum	1.32-3.81	1.08-1.75	0.28-1.18	1.3-2.17	0.19-0.34
EPA (1991)	Minimum–maximum	0.1-3.5	0.3-3.5	0.1-2.8	—	—
P		0.49^{ns}	0.137^{ns}	0.000**	—	—
Sullivan (1998)	Minimum–maximum	3-8	1.5-3	0.1-0.6	1-4	0.4-0.8
P		0.78^{ns}	0.918^{ns}	0.000**	0.015*	0.000**

*Significant difference at $\alpha = 0.05$, **Significant difference at $\alpha = 0.01$. ns: No significant difference, WWTP: Wastewater treatment plant, EPA: Environmental Protection Agency

Table 2: Sewage sludge quality of North-Isfahan WWTP

Seasons	Parameters	*n* (mg/kg)	*P* (mg/kg)	Potassium (mg/kg)	Calcium (mg/kg)	Magnesium (mg/kg)
Spring	Mean	1.4	1.65	0.62	2.5	0.34
	Minimum–maximum	1.3-1.45	1.6-1.68	0.6-0.63	2.5-2.54	0.32-0.35
Summer	Mean	0.98	1.13	0.21	2.08	0.28
	Minimum–maximum	0.95-1	1.13-1.14	0.2-0.22	2.05-2.1	0.28-0.29
Autumn	Mean	0.65	1.21	0.23	2.34	0.29
	Minimum–maximum	0.64-0.66	1.13-1.3	0.2-0.25	2.2-2.5	0.28-0.31
Winter	Mean	2.66	1.13	0.55	2.3	0.32
	Minimum–maximum	2.21-2.88	1.11-1.16	0.5-0.55	2.1-2.5	0.3-0.34
Annually	Mean	1.83	1.24	0.44	2.31	0.32
	Minimum–maximum	0.64-2.66	1.13-1.68	0.2-0.63	2.08-2.54	0.28-0.35
EPA (1991)	Minimum–maximum	0.1-3.5	0.3-3.5	0.1-2.8	—	—
P		0.962^{ns}	0.287^{ns}	0.004**	—	—
Sullivan (1998)	Minimum–maximum	3-8	1.5-3	0.1-0.6	1-4	0.4-0.8
P		0.000**	0.001**	0.687^{ns}	0.724^{ns}	0.002**

**Significant difference at $\alpha = 0.01$, ns: No significant difference, WWTP: Wastewater treatment plant, EPA: Environmental Protection Agency

Statistical analysis showed that potassium value was lower than EPA levels in 1991 while the nitrogen and phosphorous were in normal ranges ($P < 0.01$).[2,17]

Similar to EPA 1991 standard levels, comparison the quality parameters with Sullivan range showed that almost all of quality parameters were in the normal ranges or significantly lower than standard levels ($P < 0.01$).[17,21]

The sewage sludge quality of North-Isfahan and Shahin-Shahr WWTPs were compared. There were not significant differences in nitrogen, phosphorous, and potassium contents between two sample sits ($P > 0.05$). While calcium and magnesium were significantly higher in North-Isfahan ($P < 0.05$).

Electrical conductivity of Shahin-Shahr and North-Isfahan sludge varied from 5-8.8 to 4.6-7.5 (ds/m), respectively and it might contribute to soil salinity [Table 3].[22,23] Comparison of sewage sludge quality in two sites showed nearly all of quality parameters did not show any significant differences except of ammonium nitrogen and C/N ratio. They were significantly higher in North-Isfahan WWTP ($P < 0.05$).

Microbial properties of sewage sludge

The mean values of total and fecal coliforms are shown in Table 4. The minimum and maximum values were recorded in summer and winter, respectively. According to EPA levels, sewage sludge used as an agricultural fertilizer must have total coliform up to 10^3 (class A). Using the sewage classified in B class (10^3 - 2×10^6) is restricted and some limitations must be considered. However, the coli form count higher than 2×10^6 is not suitable as a fertilizer.

DISCUSSION

In general, the properties of sewage sludge depend on quality of the sewage sludge and prerequisite treatment processes. Percentage of total solid varies from 4% to 90% depending on different compounds produced along the treatment process from suspension sludge to solid one. The moisture also, is between 20% and 50% in solid sludge. In this study, the total solid and moisture were approximately 60–40%. It shows that the both Isfahan WWTPs are able to produce sludge with a high percentage of dry matters.

The maximum organic matters of Shahin-Shahr and North-Isfahan were 45.8 and 43.52, respectively. It reveals that anaerobic digestion and stabilization is followed weakly in both of WWTPs. The other reason for this fact is low pH values of sludge in the WWTPs.[24,25]

The pH could effect on plant and soil uptakes, so it changes the microbial populations in the soil. Since the low pH values (up to 6.5) results in more leaching and plant uptake of heavy metals, it can infer that the pH of sludge from Isfahan WWTPs has no risk for plant uptake of heavy metals.[22] Also, comparison of physical parameters with standard level confirmed that using of the sewage sludge as a fertilizer is not restricted from this point of view.

The results of sewage sludge quality confirm that North-Isfahan and Shahin-Shahr sewage sludges have a good potential for using as an agricultural fertilizer. According to previous studies, using sewage sludge (15-20 tons/ha) in Borkhar area, applying 15-20 ton sewage sludge adds nitrogen, phosphor, potassium, calcium, and magnesium to the soil up to 468, 280, 130, 344, and 52 kg/ha in Shahin-Shahr and 213,

Table 3: Some properties of sewage sludge as a fertilizer

Sample site	Parameter	C/N	EC (ds/m)	Ammonium nitrogen (%)	Nitrate nitrogen (%)	Organic nitrogen (%)	Carbon (%)
Shahin-Shahr	Minimum–maximum	6.8-9.43	5-8.8	0.088-0.36	0.01-0.098	1.74-3.81	13.2-26.6
	Average	8.24	6.55	0.2	0.038	2.43	21.53
	EPA (1991)	20	–	–	–	–	8-50
	Furr *et al*., 1976	–	–	0.65	0.05	–	–
	P	0.000**	–	0.000**	0.36ns	–	0.177ns
North-Isfahan	Minimum–maximum	8.7-9.9	4.6-7.5	0.315-0.329	0.006-0.013	0.32-2.32	21.9-25.3
	Average	9.14	6.1	0.324	0.0093	1.0867	24.07
	EPA(1991)	20	–	–	–	–	8-50
	Furr *et al*., 1976	–	–	0.65	0.05	–	–
	P	0.005**	–	0.028*	0.019*	–	0.592ns

*Significant difference at $\alpha = 0.05$, **Significant difference at $\alpha = 0.01$, ns: No significant difference, E/C: Electrical conductivity, C/N: Carbon-nitrogen ratio, EPA: Environmental Protection Agency

Table 4: Microbial properties of sewage sludge

Sample site	Parameter	Total coliforms (MPN/g) (dry weight)	Fecal coliforms (MPN/g)
Shahin-Shahr	Minimum–maximum	146.3×10^2-460×10^8	146.3×10^2-240×10^8
	Average	233×10^8	111×10^8
North-Isfahan	Minimum–maximum	188×10^4-240×10^8	85.3×10^2-93×10^8
	Average	80.9×10^8	31×10^8

MPN: Most probable number

193.5 60, 348, and 46.5 kg/ha in North-Isfahan. This data show the North-Isfahan and Shahin-Shahr sewage sludge are rich sources nutrient contents as a fertilizer except for magnesium and potassium.

The mean value of carbon in Shahin-Shahr and North-Isfahan sewage sludge were 21.5% (13.2-26.6) and 24.07% (21.9-25.3), respectively. Both of the WWTPs were in the normal ranges.[2] According to the standard level (8-50%), the carbon was relatively low in two sample sites. Also, the C/N of Shahin-Shahr and North-Isfahan were calculated 8.24 (7.41-9.45) and 9.14 (8.7-9.91), respectively which was lower than EPA levels. Totally, the lower C/N results in decreasing nitrogen uptake by microorganism and plant competition.[2,17]

Organic nitrogen, calculated by the difference between total and inorganic (nitrate and ammonium nitrogen), was the dominate form of nitrogen in the sludge (77-78%). The result was accordance with EPA.[22] Both of inorganic forms of nitrogen (nitrate and ammonium) were not restricted based on Sommers[26] and Furr *et al*.[27] The ammonium was higher than nitrate nitrogen (34 times in North-Isfahan and 5 times in Shahin-Shahr).

Generally inorganic and organic nitrogen depend on the sludge treatment and its usage.[22] The organic nitrogen does not change during drying process but the inorganic ones change. For example the ammonium nitrogen decreases because of evaporating during drying process or the nitrate nitrogen decreases during dewatering.[22]

Results of microbial properties of the sewage sludge, total coliforms were not in A and B classes (more than 2×10^6). It confirms that application of the sewage faced with some limits including:

a. The crops, not in contact with the fertilizer-induced soil, should not be harvested before 14 months after sewage application;
b. The crops, have underground production, should not be harvested before 20 months, if the sewage covered surface of the soil for more than 4 months;
c. The crops, have underground production, should not be harvested before 38 months, if the sewage covered surface of the soil for up to 4 months;
d. The other crops, do not any contacts with soil, should not be harvested before 30 days after sewage application and
e. Animals should not graze the grass before 30 days.[22]

Since in the microbial properties showed high value of coliforms counts (more than 2,000,000), WWTPs should employ selected technical methods to remove pathogens and it is suggested that the sewage sludge should not dispose into any place where have environmental conflicts. The result was accordance with Farzadkia; Ardali *et al*.; and Mesdaghinia *et al*.[8,28,29] Although Bina *et al*. and Takdastan *et al*. reported that the sewage sludge classified in B group at North-Isfahan and Shahin-Shahr, respectively.[2,9]

The treatment process for improving the microbial properties of the sewage sludge is suggested including:

a. Increasing the sewage retention time in driers or disposal place;
b. Considering the limiting fertilizers application, especially in crops contacted with fertilizer-induced soils directly and
c. Labors should be trained for sanitary points in sewage application at WWTPs and agricultural land.

Finally, we suggest monitor and analyze the crops produced in this fertilizer-induced soils to measure the effects of this fertilizer on crops quality and soil to understand its long term effects.

CONCLUSION

In summary, the sewage sludge is a rich source of nutrient matters (nitrogen, phosphor, potassium, calcium, magnesium, and organic matters), so its applications could support plant growth, increase organic matters of soil. Also, it improves the moisture and nutrients contents of the soil and its air and water infiltrations (physicochemical properties).

Results of sewage sludge quality showed the nitrogen, phosphor, potassium, nitrate, and organic nitrogen were higher in Shahin-Shahr WWTP, while the calcium, magnesium, and C/N ratio were higher in North-Isfahan. Both of the sites showed a good potential for applying them as agricultural fertilizer regardless to their microbial counts. Improving some treatment processes are suggested to eliminate the limitations.

Acknowledgments

We respect and honor Mr. Hossein Sharifi, Mr. Abdol Ali Amini, Mrs. Narjes Khodabakhsh and Mrs. Narges Moshgelgosha, the members of Soil and Water Institute of Isfahan who provided the necessary co-operations in supplying laboratory facilities of this research.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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