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Risk Assessment Classification of Mixed Sludge Produced from Different Sites of Menofyia Governorate, Egypt

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Abstract

Exposure to sewage sludge may cause different infectious diseases to human health, but the main reasons are direct contact of sewage sludge in agricultural lands by the farmers and consumption of fruits, grains, vegetables, etc., that are grown in sewage applied agricultural lands. Uses of the sludge in agricultural purposes after treatment may increase the soil fertility and act as alternatives sources in compare with chemical fertilizers. The result showed that the cultivated using the treated sludge in ratio with the soil, was safe and didn't act any hazardous to the human consumption. The study concluded that the quantity of sludge production depends on the type of wastewater treatment and the plant capacity, and the rate of biogas production depends on the ratio of sludge and agricultural solid waste and the mixing temperature of the digester. Due to the prominent levels of the element of Fe and Cd in the sludge, which may appear in the risk evaluation. The study showed that the uses of sludge produced from the wastewater treatment plant in biogas production may be environmentally safe and economical. The Risk Assessment Code (RAC) considers the percentage of heavy metals present in the mobile fraction (F1). The RAC was also used to assess the environmental risks posed by heavy metals. The RAC was used to assess soil contamination with heavy metals from sewage sludge and sewage sludge ashes. The observation showed that there were no associated risks with the soil mixed samples used in the study.
Keywords: Sludge; soil; heavy metals; Risk Assessment Code

1- Introduction

Reuse of waste products and fecal sludge is often practiced in several elements of the planet, because it generates sustenance opportunities, particularly in urban settings of low- and middle-income countries **(Drechsel et al., 2010)**. However, direct or indirect contact to waste products and fecal sludge are related to microorganisms and chemical hazards, which often lead to adverse health outcomes as mentioned in specific pointers issued by the planet Health Organization **(WHO) (WHO, 2006)**. Indeed, numerous morbific microorganism and microorganism strains will cause ill-health, like symptom, tract infections and skin problems **(WHO, 2006)**. Environmental contamination with parasitic worm eggs and larvae (e.g. Ascarislumbricoides, hookworm and Trichuristrichiura) and enteric protozoa cysts and oocysts (e.g. Entamoebahistolytica and mastigophoreentericis) will cause intestinal parasitic infections in animals and humans **(Becker et al., 2013; Strunz et al., 2014)**.

Toxic chemical compounds, like significant metals discharged in industrial effluents, will cause chronic malady and cancer (Ackah et al., 2013). Urbanization continues at a speedy pace, notably in low- and middle-income countries move challenges for the sanitation infrastructure with respect to operation and maintenance of the waste products and passageway sludge treatment plants (Rydin et al., 2012). In Menofyia Governorate in Egypt, square measure characterized by aging, overladen waste product treatment facilities serving a little proportion of the population, that is plus restricted fecal sludge assortment and treatment from on-site facilities. This is often a state of affairs the bulk of the population unremarkably should face in densely inhabited, unplanned, low-lying elements of such cities. As a

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result, water used for irrigation typically carries fecal and chemical contamination from avariety of sources, together with treatment plant effluent, run or hot discharge of fecal sludge, industrial biodegradable pollution and open excreting at intervals catchments.

Limiting this exposure needs a much better understanding of the sources of contamination and barriers which will be applied at numerous stages (WHO and UNICEF, 2014). Achieving targeted levels of service for the waste product and fecal sludge assortment and treatment is very difficult within the context of rising and restricted funding for capital investment, operation and maintenance. There's so a requirement for risk assessment and management approaches to spot and mitigate health risks particularly for the foremost vulnerable populations. This could be done by a mix of treatment and cost-efficient non-treatment measures and by mobilizing a large cluster of stakeholders to implement and monitor such risk assessment approaches (WHO, 2006).

Menofyia governorate has nineteen waste product treatment plants receive regarding 260.000 m^3/day and made 195 loads of dry solids /day. Sludge handling contains a nice importance in waste product treatment plants because of environmental, economic, social and legal factors. If handled properly, sludge is often a valuable resource for renewable energy production and a supply of nutrients for agriculture. The study aimed to investigate the different approaches to fecal sludge handling with specific attention to Sludge to-Energy option in Menofyia governorate.

2- Material & Methods

2.1 Sludge Sampling

Sludge samples were collected from six wastewater treatment plants in Menofyia governorate for the analysis of total metals and determination of physic-chemical characteristics of the sludge as shown in Figure 1.

For heavy metal analysis the samples were collected using plastic bags that were pretreated with diluted nitric acid and rinsed with distilled, de-ionized water. Therefore, separate samples of sludge from the fresh sludge pile have been collected in order to investigate the variation in metals contents as well as variation of sludge characteristics. Sludge samples, after collection, were dried at room temperature and there after stored in a refrigerator at 4 ^{0}C until they were analyzed.

2.2 Sample preparation

The dried sludge samples were first passed through a 2 mm sieve eliminating roots, stones, plastics, grass and other impurities. The samples were then powdered to fine sizes using mortar and pestle and thoroughly mixed to achieve homogeneity. The powdered sludge was then sieved mechanically to obtain fractions that are less than 63 μm samples were then sieved mechanically to obtain fractions that are less than 63 sludge samples after these steps were stored in plastic containers at 4 ^{0}C until they were analyzed.

Figure (1): Map of the WWTP in Menofyia Governorate

2.3 Determination of sludge Physic-chemical characteristics

A laboratory pH meter (OakTon Instruments pH/Ion 510 Bench pH/Ion/mV Meter) was used for determining the pH of the digestate before and after the digestion process. This meter was calibrated using commercial pH standards (pH 4.0, 7.0, and 10.0) following the instruction of APHA, (2017).

2. Heavy metals analysis

The total metal determination was done using a high-quality assurance purpose. The method used was inductively coupled plasma atomic emission spectrometry (ICP-OES). The analyzed metals include Zn, Cu, Cr, Pb, Ni, Cd, and Hg, As, Mo. Sample digestion was carried out according to METHOD3050B of the USEPA: Acid Digestion of Sediments, Sludge and Soils (USEPA, 2012; APHA, 2017).

For the digestion of sludge samples, 1 g. of prepared sludge was weighed using analytical 0.001 precision and transferred to heating mantles with reflux (vapor recovery±balance of device). Initially 10 ml of 1:1 HNO_3 was added and the samples were heated to 95 °C and refluxed for 10 to 15 minutes without boiling. After cooling, 5 ml of concentrated HNO_3 was then added to the samples and the samples were refluxed for 30 minutes and the procedure of adding 5 mL of concentrated HNO_3 was repeated until no brown fumes were generated indicating completion of reaction with HNO_3. The samples were then heated further for 2 hours at 95°C. After completion of the above steps and the samples have cooled, 2 mL of water and 3 mL of 30% H_2O_2 were added and the samples were slowly warmed to start the peroxide reaction. The H_2O_2 addition was continued in 1 mL aliquots to a maximum of 10 mL and the samples were heated for two hours at 95°C with a reflux. After completion of the peroxide digestion, the samples were cooled and 10 mL of concentrated HCl was added and the samples were slowly heated to 95°C and the heating continued for 15 minutes with a filter and the reflux. The digested samples, after cooling, were filtered through a 0.45 µm filtered digested samples were transferred to 100 mL volumetric flasks and filled to the 100 mL mark with distilled, deionized water. After this, the samples were split into two 50 mL volumes for analysis by the ICP-OES (USEPA, 2012; APHA, 2017).

All quality control measures have been observed throughout the sample preparation and analysis steps. Distilled-deionized water has been used for dilution and rinsing. All containers and glassware have been thoroughly washed and rinsed with 2% HNO_3 prior to use in the analysis. For each of the metals analyzed, stock solutions of analytical grade chemicals were used for preparation of primary and secondary standards. For determination of parameters describing sludge characteristics, analytical reagent grade chemicals have been used and the standard operating procedures as prescribed for the respective methods were followed. For the determination of method detection limits of metals, a number of blank samples containing distilled-deionized water were processed through the same steps as those of the samples and metal determinations were similarly made. Spike recovery analysis of each metal was made to determine the recovery due to matrix effects (USEPA, 2012; APHA, 2017).

2.4 Determination of Total Bacteria Count

1.0 mL of influent (raw) and effluent (treated) water of the serial dilution10-1, 10-2, 10-3 (which was prepared according to the standard methods for the examination of water and waste water) were transferred respectively after shaking several times with hand to sterile Petri-dishes, each dilution in duplicate 20 cm' of melted plate count agar at temperature 44 °C, were poured into the dishes. The contents were thoroughly mixed to facilitate distribution of the sample throughout the medium, then left to solidify and then incubated, inverted, at 37 °C ± 0.5°C for 48 hours. Total bacteria as colonies were counted and expressed as CFU/mL (APHA., 2017).

2.5 Parasite particles concentration

The wastewater samples were sieved through a polyester mesh of 40 (400 µm) to remove large particles. Raw wastewater samples were centrifuged (2100 × g,15 min, 4°C) in a 4 × 500 ml-capacity-swinging-bucketrotor of a refrigerated centrifuge (Beckman, GS-6RCentrifuge). The supernatant fluids were carefully aspirated by vacuum pump, without disturbing the sediment and about100 ml of supernatant was left on top of the sediment at the bottom of the canisters (Beckman Aerosolve®Cannisters). The residues were transferred to 50 ml conical centrifuge tubes and centrifuged as before.

A water-ether concentration procedure was performed with 30 ml deionized water and 9 ml diethyl ether (CC method). This concentration method was followed by flotation with zinc sulfate (ZnSO4· 7 H2O) (w/v) (specific gravity 1.364). The upper layer of the flotation solution was decanted into a container, and this solution was diluted with water to lower the specific gravity of the solution to below that of the protozoan (oocysts and helminths eggs, and then the (oocysts and eggs were collected in the sediment after centrifugation.

The other hand, treated samples were filtered by a cellulose-acetate membrane filter (pore size 0.8-µm, 50-mm diameter; Sartorius, Germany) to retain the particles. Sample elution is achieved by scraping the membranes with a smooth-edged plasticine molder and rinsing with PBS elution fluid (containing 0.1% Tween80 and 0.001% antifoam agent B). The eluate was collected in a clean glass petri-dish and transferred to a 50-ml centrifuge tube and centrifuged at 2100 × g for10 min.

Microscopic examination and enumeration of (oo)cysts and eggs were performed in a Thoma counting cell at 400× magnification for Giardia cysts and other protozoan (oo)cysts and in a McMaster counting cell (weberEngland) at 100× magnification for helminthic eggs.

Protozoan (oo) cysts and helminth eggs were identified by morphometric parasitological criteria including the size, which was measured by a calibrated microscope, and shape of eggs and (oo)cysts at 100×, 400× and1000× magnifications (APHA., 2017).

2.6 Determination of phenols

Phenol and chlorophenol (> 99%) were purchased from Sigma (Cairo). The standard mixtures of phenols were prepared by dissolving 10 mg of each compound in methanol in a 10-mL volumetric flask. The standard solution was stored at 4°C. Sodium chloride, hexane, tetrachloromethane, toluene, and xylene were all of analytical grade, and n-amyl acetate was of HPLC grade. The water used was purified by a WYQ sub-boiling distilling water purification system (Changsha, P.R. China).

The determination of phenolic compounds was carried out with a Hewlett Packard 5890 GC–FID (Palo Alto, CA). The separation was performed on a fused-silica capillary column (DB1701, 30 m × 0.25 mm × 0.25 μm). The carrier gas was nitrogen at a flow-rate of 1.5 mL/min. The injector and detector temperatures were 250°C and 300°C, respectively. The GC oven temperature was programmed as follows: initial temperature 130°C, held for 2 min; increased to 150°C at a rate of4°C/min and held for 1 min. The inlet was operated in split mode with a split ratio of 20:1. Peak identification was made by the comparison of retention time with the corresponding standard. An 85-2 magnetic stirrer was employed for stirring the sample during extraction (APHA, 2017).

3- Results & Discussion:

3.1 Sludge Uses and Soil Contamination

In the present study, the chemical and microbial characteristics of mixed soil with sludge were investigated, the soil samples mixed with sludge by the following mixed ratio 1, 2, 4 and 8% were investigated. The chemical and microbial data of mixed soil samples were compared with the control soil sample (non-mixed soil sample) as illustrated in Table (2).

The pH of mixed soil samples was slightly increased as mixed ratio of sludge increased. The same trend was observed with the have metals (Zn, Fe, Mn, Cd, Ni, As, Mo, Pb) and also with phenol and microbial parameters (Total bacterial count, and Helminth egg), as shown in Table (2) and Figures (2-7).

Disposal of sewage sludge presents a problem that touches a set of complex issues including health, environment, aesthetics and economics. The options available for sludge disposal are rather limited because of expressed objections to pollutants contained in sludge (Tezel, et al., 2011). Land application is simple and inexpensive but land is becoming scarce. Moreover, regulations and increasing environmental concern restrict the option for land disposal of sewage sludge (Wang et al., 2003). Incineration is expensive although the heat can be recovered as source energy.

Although sewage sludge is traditionally considered as waste, the recycling and reuse of valuable nutrients contained in the sludge are nowadays being considered as important resources for sustainable development (Cao, et al., 2012). In fact, the practice of applying sewage sludge to agricultural lands dates back to centuries (Mahendra et al., 2013). Treated sewage sludge can be recycled in various ways including its use as fertilizer with significant nutrient supplements improving plant growth. Sewage sludge is also used as a soil conditioner for improving the physical and chemical properties of soils in farmland, forests and home gardens (Wang et al., 2009).

Fear of toxic metals and pathogens are risks that are often cited against the use of sewage sludge for nutrient supplementation of soils. However, in addition to heavy metals and pathogens, other harmful and toxic pollutants such as pharmaceuticals, detergents, various salts, pesticides, toxic organics, flame retardants and hormone disruptors can also be present in sewage sludge. Sewage sludge can also inject in soils excessive amount of nutrients, pesticides and can increase soil salinity. Besides, raw sewage sludge has an objectionable odour and is not aesthetically accepted by farmers and as a result has to undergo extensive treatment before it is considered for agricultural application (Ukpong, et al., 2013).

Table (1): Soil mixing with sludge characteristics and soil contamination

Parameter	Unit	Control (Without sludge)	Sludge soil mixed (%)			
			1	2	4	8
pH	-	8.2	8.22	8.26	8.26	8.3
Zn	mg/kg	114	128	162	184	214
Fe		2844	2841	2860	2872	2877
Mn		1366	1358	1368	1379	1394
Cd		3.6	4.1	4.3	4.6	4.6
Ni		33.6	36.2	39.4	42.1	43.2
As		16.1	15.8	16.3	16.4	16.8
Mo		1.2	1.2	1.1	1.1	1.1
Pb		26.3	27.2	28.3	28.4	28.6
Phenol		0.1	0.3	0.3	0.4	0.4
Total bacterial count	CFU/g	3226	13600	18400	19800	24500
Helminths egg	U/g	1	3	8	8	12

Through the waste composting process, pathogens and organic pollutants in the sludge are reduced. The type of waste composting analyzed in this study is windrow composting. The process is known to destroy pathogens and produce waste that can be used as fertilizer. The waste is shredded and piled into windrows which are of an ideal shape for composting. Slow aeration and decomposition are continued until the waste is stabilized. The composted waste is transported to agricultural land to be spread out. The overall scheme of process is depicted in Figures (2-7).

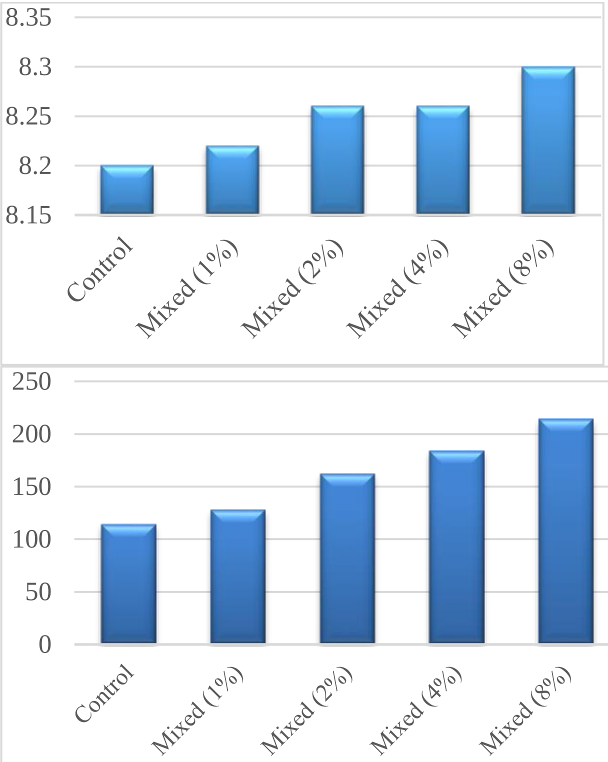

Figure (2): pH and Zinc (Zn) of mixed soil samples with treated sludge

3.2 Risk Assessment Code (RAC)

The RAC was also used to assess the environmental risks posed by heavy metals. The RAC was used to assess soil contamination with heavy metals from sewage sludge and sewage sludge ashes (Abdelrahman, et al., 2011). The risk assessment data were illustrated in Tables (5 and 6) and Figures (14, 15). The RAC takes into account the percentage of heavy metals present in the mobile fraction (F1). The risk level can be classified into 5 categories:

(<1)no risk; (1:10)low risk; (11:30)medium risk; (30:50)high risk; (>50)very high risk.

It is defined by the formula (Alkhamisi, et al., 2011):

$R_{ac} = F_1 / HM \cdot 100\%$.

Where: F_1—concentration of heavy metal in acid-soluble/free fraction, $mg \cdot kg^{-1}$; HM—total heavy metal concentration, $mg \cdot kg^{-1}$.

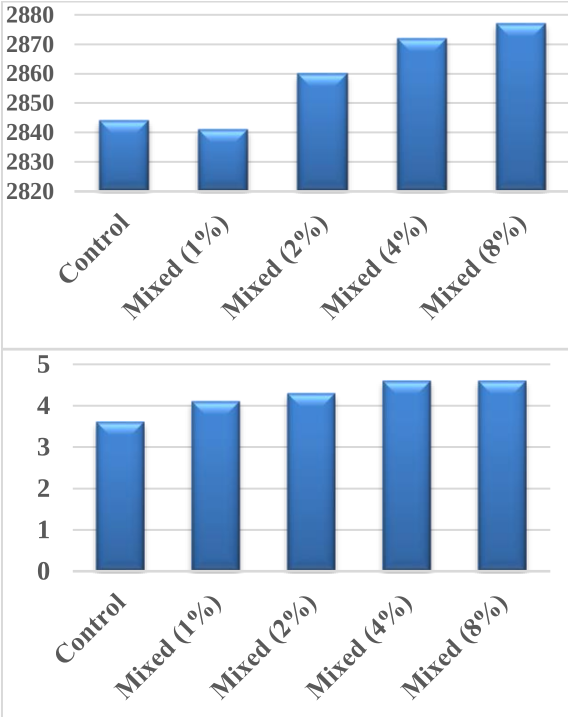

Figure (3): Iron (Fe) and Cadmium (Cd) of mixed soil samples with treated sludge

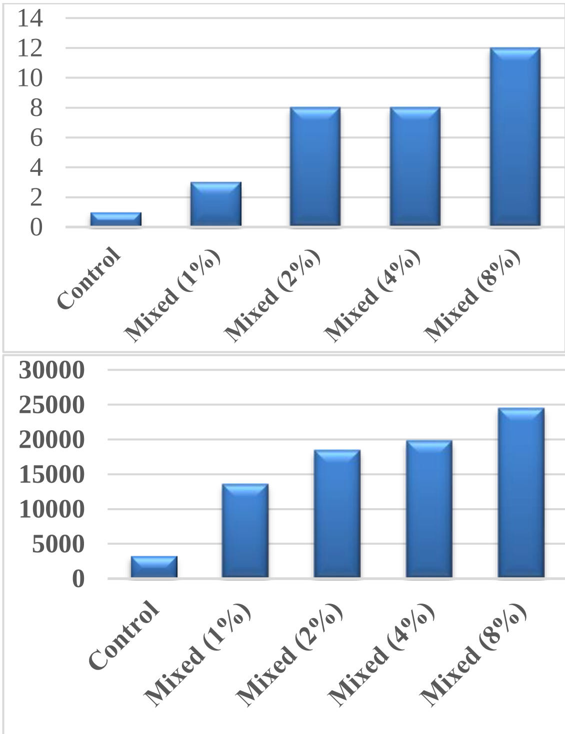

Figure (4): Helminths and Bacterial count of mixed soil samples with treated sludge

Potential Environmental Risk Index (PERI)

The potential environmental risk index (PERI) is a measure of the environmental risk of soil with heavy metals and is described in the following formulas:

$$C_f^i = \frac{C_D^i}{C_R^i}$$

where: C^i_f —pollution factor; C^i_D —concentration of the i-th element from the group of heavy metals present in the sewage sludge, mg/kg; C^i_R—concentration of the i-th element from the group of heavy metals in the soil, mg/kg (Alkhamisi, et al., 2011).

Table (2) Potential environmental risk index (PERI) indicator classification

PERI

PERI	**Potential Environmental Risk**
<150	**Low**
150-300	**Medium**
300-600	**High**
>600	**Very high**

Increased contents of heavy metals can produce adverse effects on soil biological properties while being toxic to plants. Most commonly, the background levels of heavy metals in soils are often lower than the heavy metals present in sludge. There is evidence that application of sewage sludge that contains heavy metals in excess concentrations not only affects the property of soils and soil microbial population in general, but also soil borne symbiotic microorganisms such as rhizobacteria and arbuscular mycorrhizal fungi. Such symbiotic microorganisms contribute to nutrient acquisition by plants which are important for reducing fertilizer inputs in sustainable plant production systems. Above the admissible level, toxic metals significantly reduce soil fertility. Metals also inhibit enzyme activity in the soil and alter soil acidity. The mechanisms of harmful reactions of metals are diversified. Metals inactivate enzyme systems thus leading to physiological changes which in the most extreme cases can cause tissue and cell necrosis (Ahmed, et al., 2003).

Table (3): Risk Assessment Code and heavy metals level of sludge of the wastewater plants

Parameter	Unit	MDL	Control (Without sludge)	Sludge soil mixed (%)			
				1	4	8	12
Zn	mg/kg	0.001	2.9	3.7	5.1	6.8	7.2
Fe		0.001	64.5	66.8	71.2	73.4	77.2
Mn		0.001	30.8	31.5	34.6	38.4	41.2
Cd		0.001	0.1	0.1	0.12	0.12	0.13
Ni		0.001	0.8	0.9	1.1	1.2	1.4
As		0.001	0.4	0.4	0.42	0.46	0.48
Mo		0.001	0.0	0.0	0.0	0.0	0.0
Pb		0.001	0.6	0.61	0.64	0.65	0.69
RAC	-	-	0.94 (No risk)	3.6 (Low risk)	11.2 (Medium risk)	17.2 (Medium risk)	33..4 (High risk)

MDL: Minimum detection limit

Table (4): PERI values for the sludge of wastewater treatment plants

Parameter	Unit	MDL	Control (Without sludge)	Wastewater treatment plant			
				Quesna WWTP	Ashmoun WWTP	Menouf WWTP	Istanha WWTP
Zn	mg/kg	0.001	2.9	1012	612	915	844
Cu		0.001	64.5	288	186	264	246
Cr		0.001	30.8	30.2	26.1	29.6	26.6
Pb		0.001	0.1	46	41	44	41
Ni		0.001	0.8	112	96	94	96
Cd		0.001	0.4	3.1	2.2	2.8	2.8
Hg		0.001	0.0	1.1	0.9	1.2	1.2
As		0.001	0.6	0.3	0.2	0.2	0.2
PERI	-	-	-	13.98 (Low risk)	9.07 (Low risk)	12.67 (Low risk)	11.80 (Low risk)

MDL: Minimum detection limit

Sludge application rate is an important parameter that determines the extent of accumulation of heavy metals in soils and their absorption by plants. Increased concentrations of lead, cadmium, nickel and chromium have been observed in plant seeds as a result of increased application of sludge. The level of plant uptake, bio-accumulation and tolerance of plants to heavy metals varies among different crops at different rates of application of sewage sludge. Some plants can continue storing toxic heavy metal elements, and with increased rate of application of sludge, this leads to bioaccumulation of heavy metals and increased level of toxicity along the food chain (Al-Haddabi, et al., 2004).

The results showed that, the mixed sludge ratio with soil of 8% didn`t causes any risks to the consumers and make the soil to be fertile

4- Conclusion & Recommendation:

4.1 The present study concluded the following:

- The quantity of sludge production depends on the type of wastewater treatment and the plant capacity.
- Due to the high levels of the element of Fe, Cd, Pb and Mn in the sludge, that may be appear in the risk evaluation but actually the two elements could be present in high levels due to the drinking water that depend on the ground water abstraction.
- Uses of the sludge in agricultural purposes after treatment may be increase the soil fertility and act as alternatives sources in compare with chemical fertilizers.
- The study concluded that, the cultivated tomato by using the treated sludge in ratio with the soil, was safe and didn`t act any hazardous to human consumption.
- The study showed that the uses of sludge produced from the wastewater treatment plant in biogas production may be environmentally safe and economical.
- The PERI index showed low risk for the analyzed sewage sludge, which was due to low contamination risk values for Fe, Cd, Pb and Mn, while the other heavy metals showed low risk levels.

4.2 The study recommended the following:

- The best way to towards sustainable biogas production at WWTPs is the establishment of a monitoring system. It is recommended that each plant should regularly evaluate its processes and publish the results in an annual report, illustrating good and deficient performances, as well as optimization possibilities.
- Good awareness of each stage of the process and the possibilities for improvement is one of the most important steps in the optimization process. The annual report can also serve as a communication tool in order to attract attention of the local population and politicians when investments are required. It is further important to remain attentive to developments and regularly investigate new possibilities. It is sometimes beneficial to replace an old system, even though still functional, by a new, more efficient one. Or, as the industrial neighborhood of a plant changes, new possibilities for synergies should be examined. However, plant optimization is a continuous process, which requires a committed, innovative and dynamic operating team. Continuous education and experience exchange is an effective way to keep up with the best practices and the newest technological developments.

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