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ORIGINAL RESEARCH

Utilization of drying beds to produce safe agricultural fertilizer from sewage sludge

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Abstract

Purpose: Sludge treatment and reuse as a fertilizer is of great significance in Gaza Strip. This study aimed to treat sludge generated at North Gaza WWTP, to produce rich nutrients fertilizer, to apply it in a greenhouse, and to compare its performance with different fertilizers.

Method: The concept of drying beds was applied to 1500 kg of sludge, which was exposed to the sun for 75 days; it was tested every 15 days to measure quality parameters.

Results: After 45 days, complete removal of F.C., *E-Coli*, *salmonella,* and helminths was achieved. The treated sludge had NPK of 3.3, 14 and 1.4% respectively. The treated sludge showed to be a good competitor to the commercial fertilizer that had NPK of 3.2, 1.9, 2.3 % respectively. The treated sludge and commercial fertilizer were tested for heavy metals; concentrations of Cd, Pb, Cu, Hg, Cr, Ni, and Zn in the treated sludge were 1.4, 110, 0, 0, 80.5, 26.4 and 1369.7 mg.kg-1; while for the commercial fertilizer they were 1.67, 141.3, 142, <0.001, 144.2, 13.45, and 437.5 mg.kg-1 respectively.

Conclusion: Heavy metals' concentrations were in line with Palestinian, Jordanian, Iraqi, and most European Countries' standards. The treated sludge, local fertilizers, and mixtures were applied in a greenhouse, and development of selected crops was monitored. The seedlings' best development occurred when being fertilized with the treated sludge followed by commercial fertilizer. Crops fertilized by treated sludge were free from F.C. and *E-Coli*. The study recommended further investigating efficient treatment techniques to shorten the treatment period.

Keywords: Sludge, Bio solids, Fertilizer, Nutrients, Heavy metals, Drying beds

Introduction

Municipal wastewater contains a wide variety of contaminants, including microorganisms, inorganic and organic contaminants, suspended solids, dissolved solids, turbidity-causing solids, organic and inorganic material, algae, microscopic organisms, colloids and precipitated solids from the original water (Anjithan 2015; Crittenden et al. 2012; USEPA 2011). Wastewater treatment generates residual products such as liquid, solid, semisolid, and gaseous byproducts. Solid residual, known as sludge, is the final product of wastewater treatment. As outlined in Fig. 1, the

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main sources of sludge are primary sedimentation basins and secondary clarifiers (Riffat and Husnain 2022). A small amount of sludge comes from chemical precipitation, screening, and grinder and filtration devices (Ghannam 2016). In the past, wastewater treatment plants (WWTP) sludge used to be discharged into the nearest open areas adjacent to the treatment plant with little or no treatment. Nowadays, and due to stringent effluent discharge standards, this sludge can't be disposed of randomly in open spaces (Anjithan 2015; Dharmappa et al. 1997).

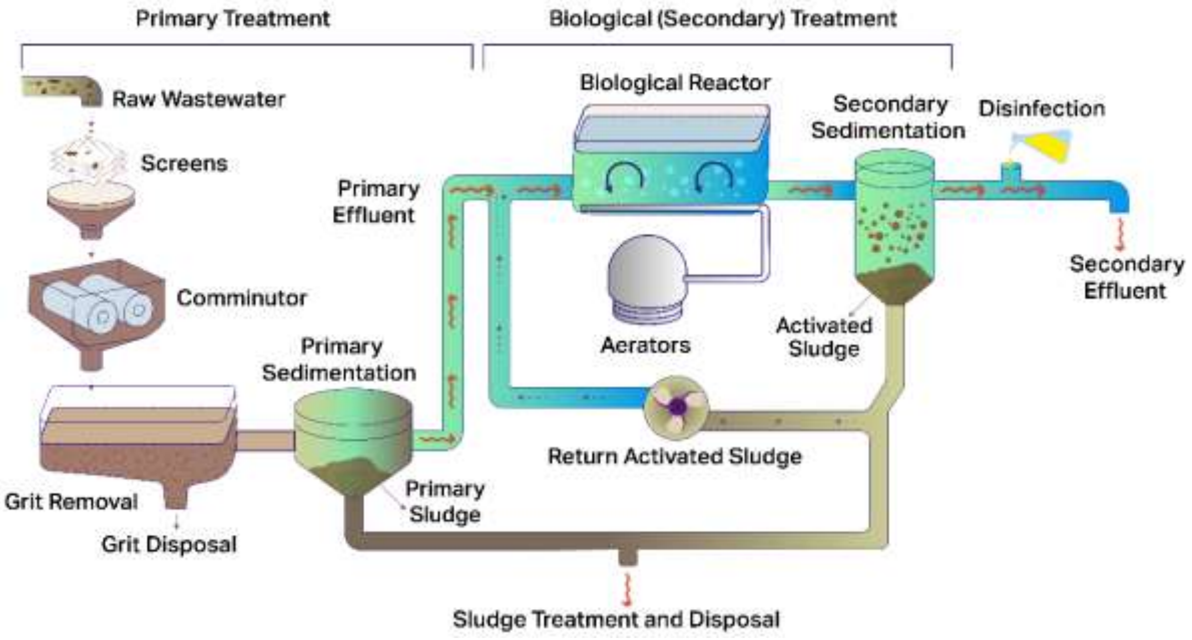


Fig. 1 Different sources of sludge at WWTPs

Due to population growth, diminishing of world natural resources and energy crisis, the importance and need of developing a sustainable approach toward environmentally acceptable sludge management can't be ignored (Pappu et al. 2007). There is also considerable pressure on the wastewater authorities for the safe treatment and disposal of sludge. It is crucial to choose a suitable sludge treatment and disposal system, which is both economically and technically feasible (Anjithan 2015; Crittenden et al. 2012; Ippolito et al. 2011). In general, a potential waste management depends on several tiers like disposal, recovery, recycle, reuse and prevention; this hierarchy is also suitable for managing bio solids (Delibacak et al. 2020). The two main disposal strategies for municipal sewage sludge management are reuse, including agriculture or landscaping and final disposal (Grobelak et al. 2019).

Drying beds are a popular method for dewatering digested bio solids and un-thickened primary and waste-activated sludge. Advantages of this method are low cost, low maintenance, the high solids content in the dried cake, less transport cost to the final disposal site, and the possibility of use in agriculture. Disadvantages include large land requirements, odor problems, rodents, and labor-intensive dried product removal. Types of drying beds include conventional sand beds, paved beds, artificial media beds, solar drying beds, and vacuum-assisted beds (Manfio et al. 2018; Riffat R, Husnain 2022).

The performance of drying beds depends on solar energy in terms of sun radiations, amount of water discharged into the underlying pipes and rate of evaporation. To raise the performance of drying beds, various techniques were investigated; those included the use of paved drying beds. In this technique, sludge dewatering time is shorter and has less operating cost. Despite the advantages of paved drying beds, they have limited use since the 1950s (Gohary et al. 2022). It is recommended to dewater digested or otherwise stabilized sludge in the paved drying beds to avoid odor complaints and to satisfy regulatory requirements for final sludge disposal (Elbaz et al. 2020).

According to the hierarchy principles of waste management, bio solids' agricultural recycling will be a more environmentally preferred option over the traditional disposal methods. Utilizing bio solids as valuable plant nutrients and as an effective soil amendment will help in sustainable management of this waste and minimizing the negatives associated with its traditional disposal (Delibacak et al. 2020).

Although several organic and mineral constituents in the sludge may have fertilizing characteristics, others may not be desirable. These undesirable constituents can generally be grouped into metals, trace organic contaminants and pathogenic organisms. Domestic wastewater sludge has low heavy metals content, usually presenting no environmental hazard. Most chemical contaminants in the sludge resulted from the discharge of industrial effluents into the sewerage system (Andreoli et al. 2007).

Conversion of sewage sludge to a soil amendment can be performed by a broad spectrum of methods, which significantly differ by substrate/amendment composition, treatment time, and physicochemical conditions (Muter et al. 2022). This is because sewage sludge is an essential type of organic waste among the various categories of solid waste (Singh et al. 2014). Using sludge on agricultural land is the best way to recycle the nutrients it contains, thus making sludge a vital biological resource for sustainable agriculture (Collivignarelli et al. 2019; Kecskésová et al. 2020). On the other hand, excessive concentrations of plant nutrients, mainly nitrogen and phosphorus, can also harm the environment, especially inland waters (Muter et al. 2022). From an agronomic point of view, sludge has nutrients essential to plants, and their presence in sludge depends on the influent sewage quality and wastewater and sludge treatment processes used. Nitrogen and phosphorus are found in large quantities, and potassium appears in deficient concentration, so chemical fertilizers usually supplemented it (Andreoli et al. 2007).

Sludge application on agricultural land can represent an interesting strategy to improve crops productivity by increasing soil organic matter (SOM) content, fertility, and nutrient presence; moreover, sludge can also improve soil physical properties, especially in cases of heavy textured and poorly structured soils (Alvarenga et al. 2015; Castán et al. 2016; Neczaj and Grosser 2018). Furthermore, spreading sludge on agricultural land reduces the effect of organic matter loss in the soil, where the depletion of SOM is one of the most severe processes of soil degradation (Lal 2015). Land application of sludge has a great incentive in view of its fertility and soil conditioning properties unless it contains toxic substances. The heterogeneous nature of sludge produced at different treatment plants and the variations between seasons necessitates knowledge of its chemical composition prior to the land application (Kulling et al. 2001).

According to Mercl et al. 2018, a high rate of sludge composts applied once (60 Mg.ha^{-1} compost in seedbed) is not recommended since high nitrate concentration is not taken up by maize and increases the leaching risk. Furthermore, sludge commonly contains high amounts of human pathogenic bacteria, so, sludge should be appropriately hygienized before land application (Mercl et al. 2018). Land application of sludge became more popular due to the possibility of recycling valuable components such as organic matter, N, P and other plant nutrients. Its application to soil enables the recycling of nutrients and may eliminate the need for commercial fertilizers in cropland (Martinez et al. 2002).

The main problems related to sludge reuse included the presence of heavy metals, organic contaminants, and/or pathogens (Bradley and Smith 2011; Islam et al. 2013). In the scientific literature, no agreement could be found about the adverse effects caused by the land application of sludge. The following aspects could be reported: (i) raising the levels of persistent toxins in soil and vegetation (ii) potentially slow and long-termed biodiversity reduction through the fertilizing nutrient pollution operating on the vegetation, (iii) greenhouse gas emissions (e.g., CH_4 and N_2O), and (iv) the release of odorous compounds (Ashekuzzaman et al. 2020; Lleó et al. 2013; Manzetti and Spoel 2015).

For the case of Gaza Strip, there is an urgent need for sludge treatment and reuse as a fertilizer. This is because of the real and crucial need to find a suitable and economic source of fertilizer to the farmers to support their production, to enhance their resilience, and to increase the fertility of their lands. Additionally, the economic ability of the farmers to fertilize their lands with the imported fertilizer has rapidly declined; this is due to the current deteriorated economic situation. Therefore, providing a low-price fertilizer will be an encouraging and supporting option to them. Moreover, the high expense of transporting and final disposal of sludge compromises the largest portion of sludge management expenses; therefore, the option of sludge reuse will minimize its quantity being finally disposed of. Finally, the improper treatment and handling of sludge in Gaza Strip may have many health and environmental impacts that require immediate intervention to ensure its compliance with regulations and standards. Based on that, it is recognized that the most suitable option is to reuse sludge and to utilize it as agricultural fertilizer; this will provide a sustainable and reasonable fertilizer that have many positive economic and environmental benefits.

The aims of this research were to utilize drying beds for sludge treatment, to determine the suitability of the treated sludge usage as a fertilizer, and to determine its performance in comparison to other local and commercial fertilizers available in Gaza Strip. This research applied the concept of drying beds to the partially treated sludge. The sludge was dewatered by evaporation via direct exposure to the sun. The treated sludge underwent an intensive testing program until fecal coliform (C.F.) and *E-Coli* were removed. In addition to other fertilizers, treated sludge was tested and applied as fertilizer on different crops inside a greenhouse. The development and yield of the crops was monitored and compared. On the other hand, laboratory testing for the harvested crops was conducted to measure the level of possible biological contamination due to the application of different types of fertilizers.

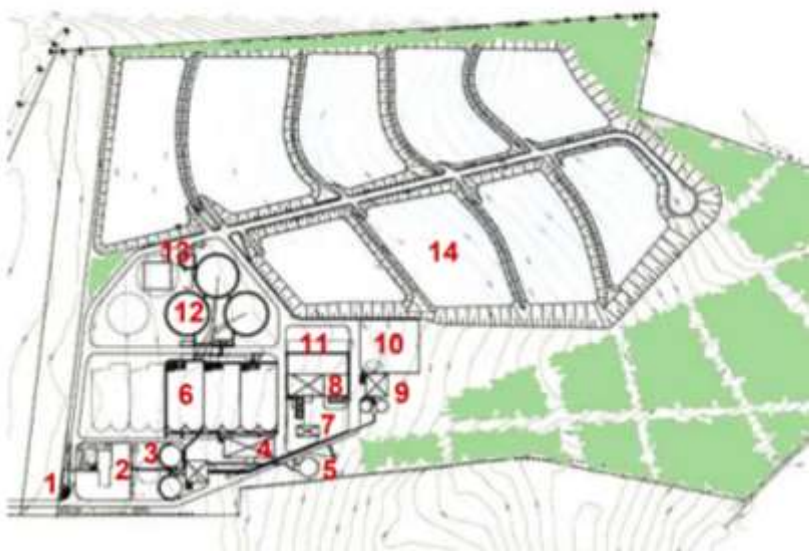
Materials and Methods

Source of sludge samples

The North Gaza Emergency Sewage Treatment Project (NGEST) was launched to respond to the critical environmental and human health risk caused by severe overloading of the outdated Beit Lahia WWTP (Rehan 2014). NGEST is a multiple phase project; the first phase was the establishment of the North Gaza Wastewater Treatment Plant (NGWWTP), while the second phase intended to increase the plant's treatment capacity to 69,000 $m^3.d^{-1}$ (Miller et al. 2006). The current capacity of the NGWWTP is 36,000 $m^3.d^{-1}$ and now receiving about 34,400 $m^3.d^{-1}$. The anticipated average daily flows increased in 2021 to reach the design capacity of 36,000 $m^3.d^{-1}$ (Rabah 2020). The plant treated wastewater based on an activated sludge system; it served more than 350,000 citizens living in the Northern Governorate of Gaza Strip (PWA 2017).

Nine infiltration basins with an infiltration capacity of 35,600 $m^3.d^{-1}$ were constructed to recharge the treated effluent into the aquifer (Miller et al. 2006; Rehan 2014). Recovery of the recharged water was made through 28 recovery wells to be used in irrigation (Rabah 2020). The treatment plant included preliminary treatment, primary treatment, secondary biological treatment, and sludge treatment (thickening, digestion, dewatering, drying and storage) (Rehan 2014), a general layout for NGWWTP is presented in Fig. 2.

Sludge undergoes a series of treatment stages at NGWWTP. 1) Thickening: Thickening took place through a centrifugation thickener. The primary sludge is pumped to a sludge silo while the secondary sludge is mechanically thickened in two thickeners with the addition of polymer. The Thickened primary and secondary sludge are pumped to the anaerobic digestion with total dry solids of 5%. 2) Anaerobic Digestion: It consists of two digesters where a 35% reduction of sludge can be achieved. 3) Dewatering: The digested primary sludge and thickened secondary sludge are dewatered in a centrifuge equipped with a polyelectrolyte unit. The centrifuges are designed to operate on an average of 25% solids by weight in the cake. Polyelectrolyte make-up and dosing units support the centrifuges to condition the digested sludge before dewatering. The maximum polyelectrolyte dosage is 8 kg/ton solid. 4) Sludge Storage: 40 $m^3.d^{-1}$ of dewatered sludge is pumped to the sludge storage with a retention time of 100 days (Hamdan 2020).



1. Entrance	2. Administration Building	3. Digesters
4. Energy Building	5. Gas Holder	6. Activated Sludge
7. Odor Treatment	8. Primary Settling	9. Sludge Dewatering
10. Sludge Storage	11. Preliminary Screening	12. Final Clarifiers
13. Pump Station	14. Infiltration Basins	

Fig. 2 General layout for NGWWTP

Climatic data

Weather data of the treatment location were registered throughout the treatment period extending from August to October 2020. The relative humidity ranged from 42 to 91%; the wind speed ranged from 10 to 22 $km.hr^{-1}$, the maximum temperature ranged from 22 to 36°C, and the minimum temperature ranged from 14 to 24°C, while the sun shining hours ranged from 10.98 to 13.33 hours. A recent study conducted by El-Hallaq, 2019 stated that the annual evaporation rate exceeds 1600 mm (EL-Hallaq 2019). The treatment location was considered a semi-arid region, there was a negligible variation in the temperature from day to day.

Drying beds technique for sludge treatment

In this work, sludge was treated according to the drying beds principle. A suitable area at the University College of Applied Sciences (UCAS) was prepared to receive about 1500 kg of sludge. Sludge treatment took place via spreading the sludge with a thickness of about 15 cm and exposing it to the direct sun. Sludge was flipped three times a week to ensure direct exposure to the sun; sampling and testing of sludge were kept every 15 days and continued up to 75 days.

Results and discussion

Physical, chemical and biological testing of raw and treated sludge

The heterogeneous nature of sewage sludge produced at wastewater treatment plants and the variations between seasons necessitates knowledge of the physical, chemical and biological constituents of sewage sludge prior to the land application. Characteristics of sewage sludge depend on the waste water treatment processes and sludge treatment (Kulling et al. 2001). Laboratory testing of the raw sludge samples was conducted at the Islamic University and Coastal Municipalities Water Utility Laboratories. The procedure for physical, chemical and biological testing were conducted according to the standard methods as described by (Rodger et al. 2017) in “Standard Methods for the Examination of Water and Wastewater”, 23rd Edition. For the treated sludge, testing was conducted every 15 days to monitor the efficiency of the treatment process. The conducted tests included nitrogen, organic matter content, water content, phosphorous, pH, temperature, carbon-to-nitrogen ratio (C/N), sand, sodium adsorption ratio (SAR), *E-Coli*, F.C., helminth, eggs, potassium, and some heavy metals. Description of the testing methods conducted in this research will be presented in the following paragraphs.

Nitrogen: It is the sum of the oxidized nitrogen (nitrate and nitrite), and Total kjeldahl nitrogen. The oxidized nitrogen in solid samples is extracted in reagent water, filtered, and passed through a cadmium-copper reduction column prior to analysis. The cadmium-copper reduction column converts any nitrate present in the samples to nitrite. The nitrite concentration of samples (nitrite originally present plus reduced nitrate) is determined by diazotizing with sulfanilimide and coupling with N-(1-naphthyl) ethylenediamine dihydrochloride to form a highly colored azo dye, which is measured colorimetrically. Total kjeldahl nitrogen (TKN) in the sample is first converted to ammonia by metal-catalyzed acid digestion. The resulting ammonia is then separated from the sample by distillation and captured in a boric acid solution. The sample is titrated using diluted HCL.

Organic Matter and organic carbon: The method is based on the gravimetric weight change associated with the high-temperature oxidation of organic matter. After initial oven drying at 105°C, the samples are burnt in a muffled oven for 4 hours at 550°C. Percent weight loss during the ignition step as organic matter (weight % loss) with a detection limit of 0.05%. The organic carbon calculation is based on the assumption that organic matter contains 58% carbon.

Carbon/Nitrogen: The ratio between organic carbon and total nitrogen

Water Content: Gravimetric soil water content (%) = [(mass of moist sample − mass of oven-dried sample)/mass of oven-dried soil] × 100%

Phosphorus: In a dilute orthophosphate solution, orthophosphates react with ammonium heptamolybdate to form a phosphomolybdic acid. This complex is reduced by ascorbic acid in the presence of potassium antimony tartrate to form molybdenum blue. The intensity of blue color is proportional to phosphate concentration and the absorbance of the complex is measured at 880 nm. Sodium Adsorption Ratio (SAR): The formula used to calculate SAR is:

$$SAR = \frac{Na^{+}}{\sqrt{1/2(Ca^{+2}+Mg^{+2})}},$$

Where sodium, calcium, and magnesium concentrations are expressed in milliequivalents/liter. Sodium and potassium are calculated by flame photometric method. Sodium and potassium in extracted solution are atomized into an oxyhydrogen or oxyacetylene flame. The flame excites atoms of sodium and potassium causing them to emit radiation at specific wavelengths. The amount of radiation emitted is measured on a spectrophotometer. Under standard conditions, it is proportional to the concentration of sodium or potassium in the solution. Calcium is calculated by using EDTA as a titrant solution for an appropriate volume of the extracted sample in the presence of meroxide as an indicator, and the color change from pink to dark pink is the end of the reaction.

E-Coli: Verify at least 5% of MUG-positive and MUG-negative results. Pick from well-isolated sheen colonies that fluoresce on nutrient agar with MUG (NA MUG), taking care not to pick up medium, which can cause a false positive response. Also, verify non-sheen colonies that fluoresce. Verify by performing the citrate test and the indole test, but incubate indole test at 44.5°C. *E-Coli* is indole-positive and yields no growth on citrate.

Fecal coliform (FC): 25 g of sludge was weighed and placed in 225 ml (peptone water), and were sub culture on Petri dishes containing M-FC media, the sample was placed in incubation at 44 °C for 18-24 hours.

Salmonella: 25 g of sludge was weighed and placed in 225 ml (peptone water), and were sub culture on Petri dishes containing XLD or ss agar media, the sample was incubated at 37 °C for 18-24 hours.

pH, Electrometric titrator: Use any commercial pH meter or electrically operated titrator that uses a glass electrode and can be read to 0.05 pH unit. Standardize and calibrate according to the manufacturer's instructions. Pay special attention to temperature compensation and electrode care. If automatic temperature compensation is not provided, titrate at 25 ± 5°C.

Electrical Conductivity measurement: Thoroughly rinse the conductivity cell with one or more portions of sample. Adjust temperature of a final portion to about 25°C. Measure sample resistance or conductivity and note temperature to ±0.1°C.

Total Dissolved Solids: A well-mixed sample is filtered through a standard glass fiber filter, and the filtrate is evaporated to dryness in a weighed dish and dried in an oven at 103 to 105°C to constant weight. The increase in dish weight represents the total dissolved solids. For each test conducted for either the raw or the treated sludge, three samples were taken and tested; the results reflected the average value of the three samples. Testing results of the raw sludge were outlined in Table 1.

Table 1 Testing results of raw sludge sample

Parameter	Unit	Value
Electrical Conductivity	µs/cm	1800
Total Dissolved Solids	$mg.kg^{-1}$	950
pH	-	6.50
Nitrogen	%	1.15
Potassium	%	0.90
Sodium	%	0.88
Organic Matter	%	58
Water Content	%	50
Sand Content	%	3.60
Phosphorus	%	13.5
Sodium Adsorption Ratio	-	3.60
Fecal Coliform	cfu/g	96
Escherichia Coli	cfu/g	68
Helminthes	Count	Null
Intestinal helminths eggs	Count/g	600
Carbon/Nitrogen	-	50.4

Physical, chemical and biological testing results for the treated sludge were outlined in Figs 3, 4, 5 respectively.

The standard deviation for each tested parameter was obtained and graphically outlined as an error bar on Figs 3, 4,5. It was noticed from Figs 5.A, 5.B that F.C. and *E-Coli* completely disappeared from sludge after 45 days; however, the treatment process continued for 75 days for safety measures.

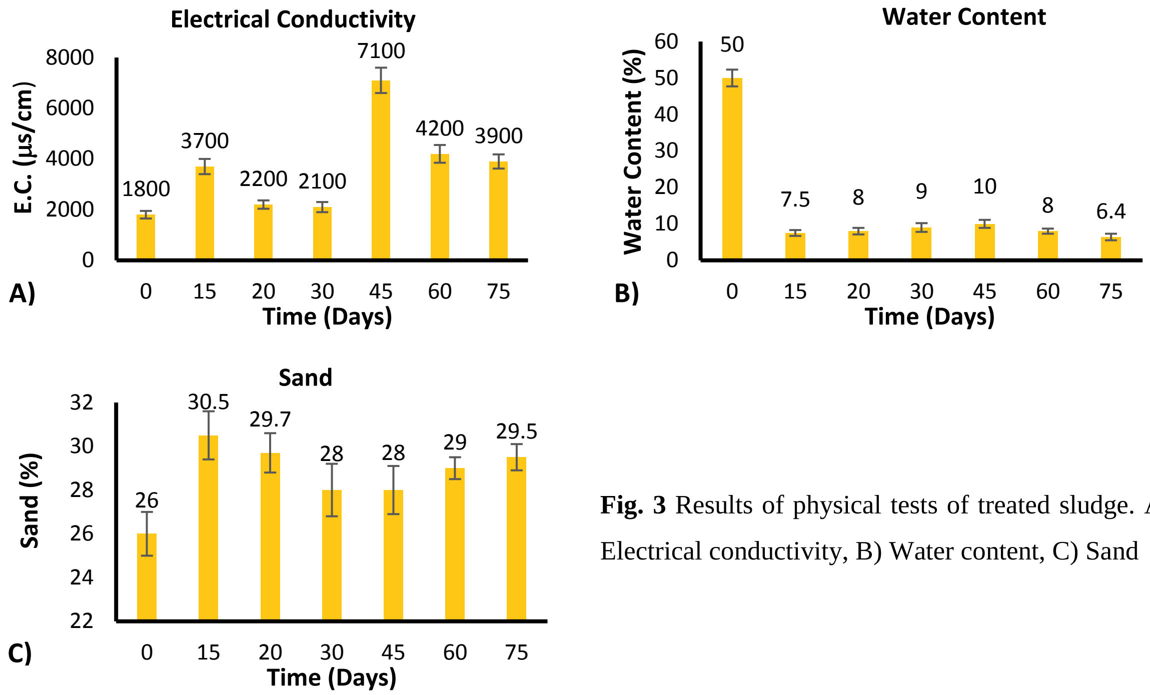


Fig. 3 Results of physical tests of treated sludge. A) Electrical conductivity, B) Water content, C) Sand

Heavy metals testing results

Determination of levels of some heavy metals in sludge is necessary prior to its application as a fertilizer; this is due to the inherent risk of heavy metal toxicity to the soil, plants, and humans. Based on relative toxicity to plants and animals, two groups of heavy metals can be identified. The first group comprising cadmium, mercury and lead are highly toxic to humans and animals but are less toxic to plants. The second group comprising zinc, nickel and copper are, when present in excess concentration, more damaging to plants than to humans and animals (Tirunah et al. 2014). Testing results of heavy metals for the treated sludge and the commonly used commercial fertilizer in the Gaza Strip – known as organic fertilizer vigrow-Israel non-hazardous product –, which was produced by Romana Organic Industries, were presented in Table 2. The regulatory limits of heavy metals in treated sludge for some countries were also outlined in Table 2. This will help judge the treated sludge's suitability for use in agricultural applications. The testing procedure for heavy metals were conducted according to the standard methods as described by (Rodger et al. 2017) in "Standard Methods for the Examination of Water and Wastewater", 23rd Edition. A brief description of the conducted tests is presented below:

Cadmium (Cd), 3500-Cd B. Atomic Absorption Spectrometric Method: Graphite furnace atomic absorption (GFAA) spectroscopy was used to measure the amount of cadmium (Cd), lead (Pb), copper (Cu), mercury (Hg), chromium (Cr), nickel (Ni), and zinc (Zn) in the sludge after digestion with acid. The quantification is based on the amount of light absorbed by a carefully measured volume of solution is directly proportional to the concentration of the heavy metal being tested in that sample. In GFAA spectroscopy, light coming from an external lamp source is directed inside a graphite tube into a small volume of sample. Using the calibration curve, the concentration of the heavy metal being tested (µg.kg-1) in sludge was estimated (Rodger et al. 2017).

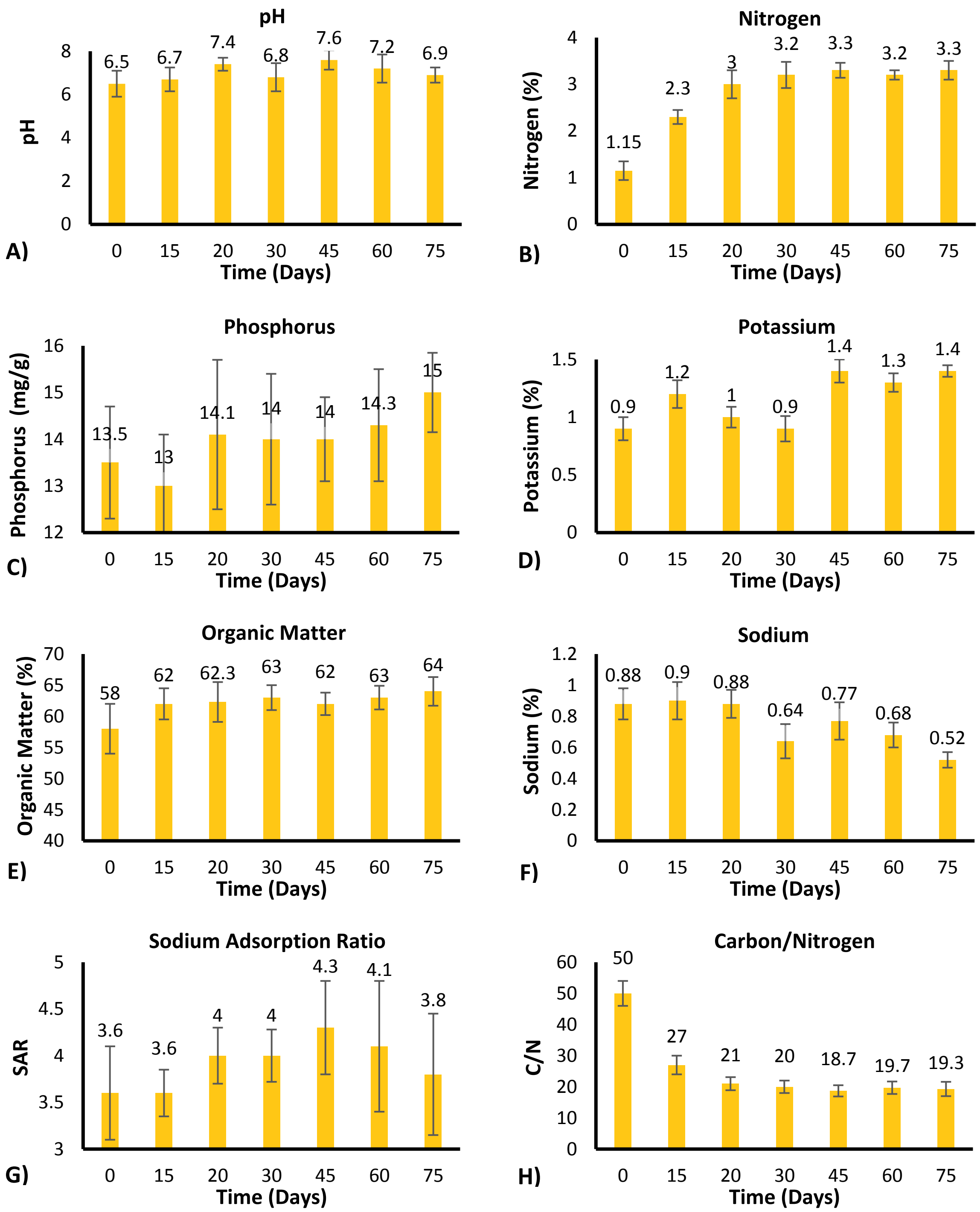


Fig.4 Results of chemical tests of treated sludge. A) pH, B) Nitrogen, C) Phosphorous, D) Potassium, E) Organic matter, F) Sodium, G) SAR, H) C/N Ratio

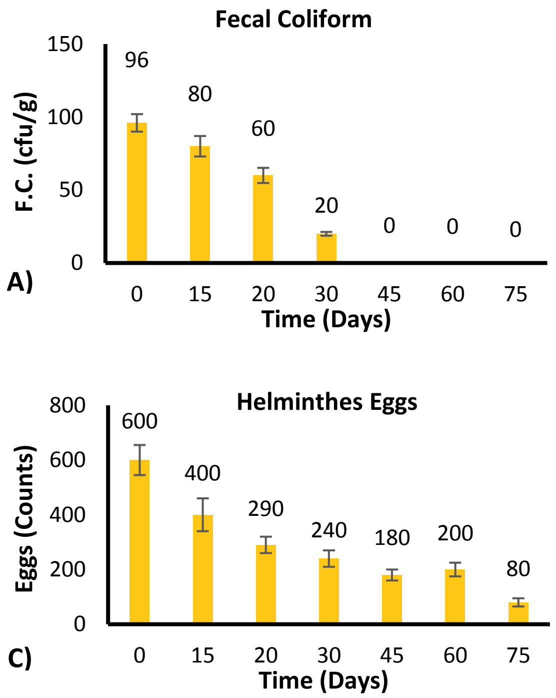


Fig. 5 Results of biological tests of treated sludge. A) Fecal coliform, B) E-Coli, C) Helminthes eggs

Testing results of the available local fertilizers

It is worth comparing the concentration of some parameters in the treated sludge with the available commercial and local fertilizers used in the Gaza Strip. This comparison will help to investigate the possibility of applying the treated sludge as a fertilizer and assess its effect on the growth and yield of different crops. Different types of fertilizers including the commercial fertilizer, cow manure, and chicken manure were obtained as shown in Figs 6, 7, 8, 9.

Fig. 6 Treated sludge

Fig. 7 Commercial fertilizer

Fig. 8 Cow manure

Fig. 9 Chicken manure

The above-mentioned fertilizers were tested for the parameters previously mentioned in the manuscript. Three samples for each type were taken and tested, the average values of the testing results were outlined in Figs 10, 11, 12. The standard deviation for each tested parameter was obtained and graphically outlined as an error bar on Figs 10, 11, 12.

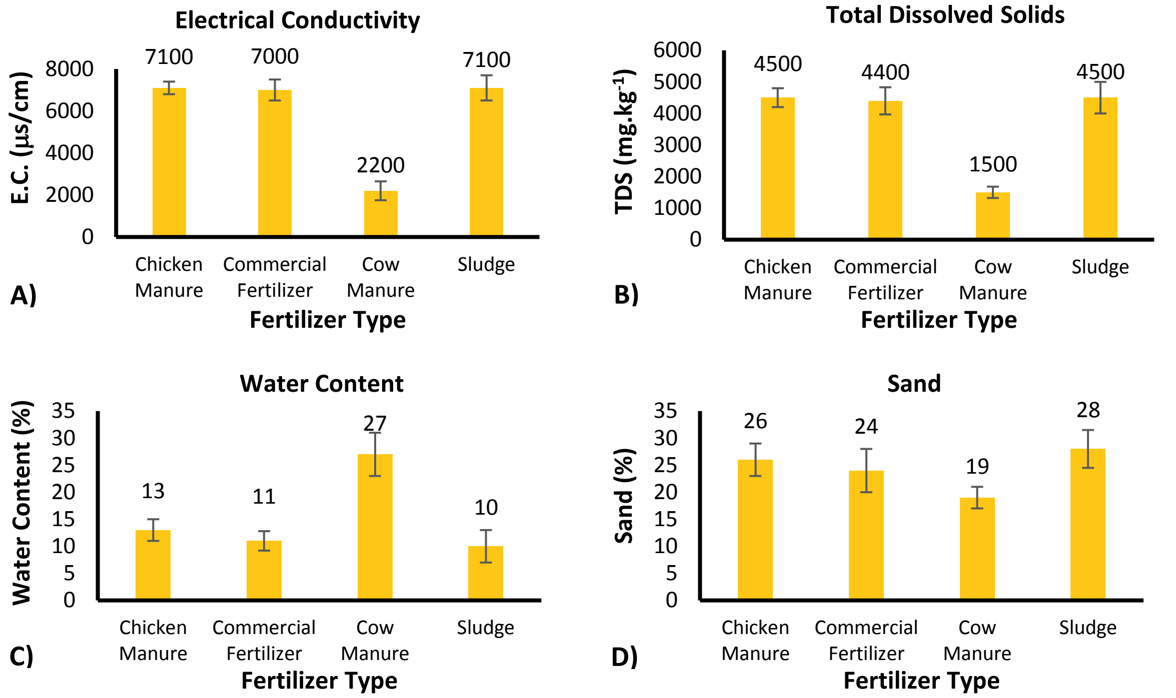


Fig. 10 Results of physical tests of treated sludge. A) Electrical conductivity, B) Water content, C) Sand, D) Total dissolved solids

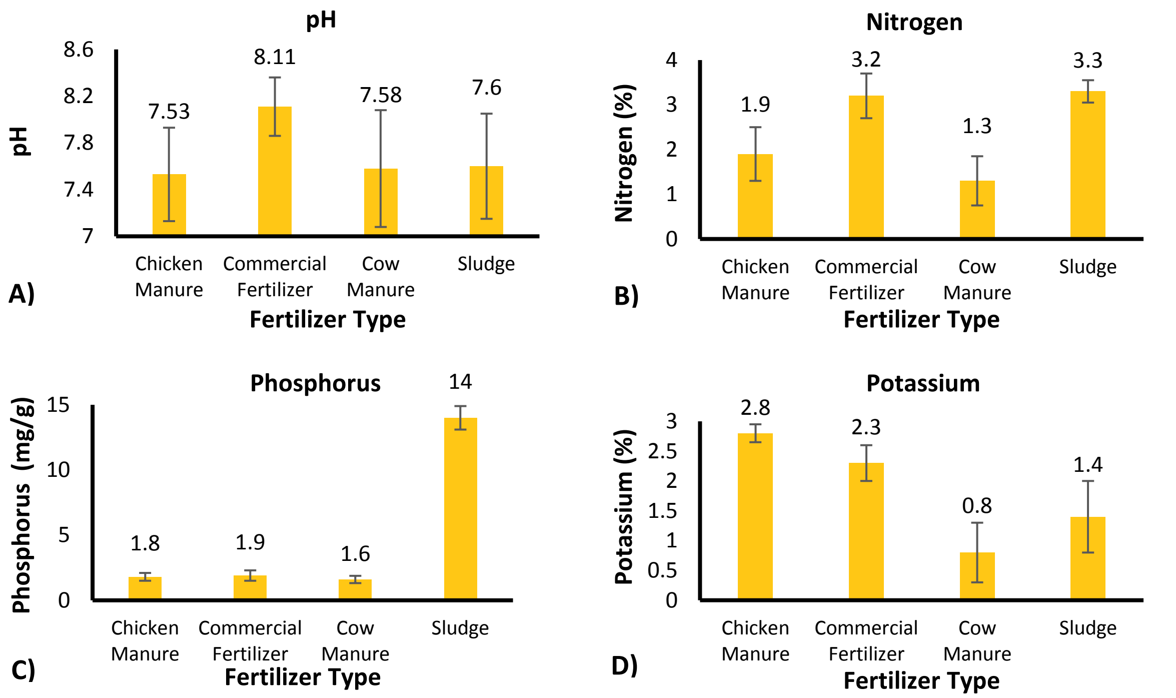
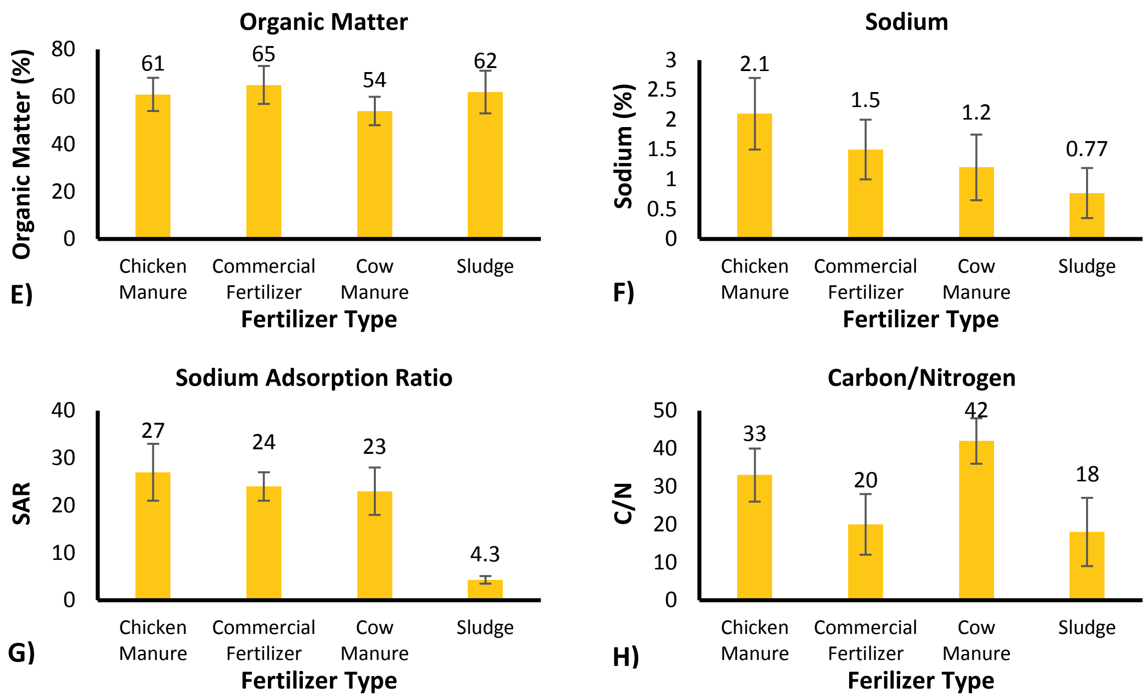


Fig. 11 Results of chemical tests of treated sludge. A) pH, B) Nitrogen, C) Phosphorous, D) Potassium, E) Organic Matter, F) Sodium, G) SAR, H) C/N Ratio



Continued Fig. 11 Results of chemical tests of treated sludge. A) pH, B) Nitrogen, C) Phosphorous, D) Potassium, E) Organic Matter, F) Sodium, G) SAR, H) C/N Ratio

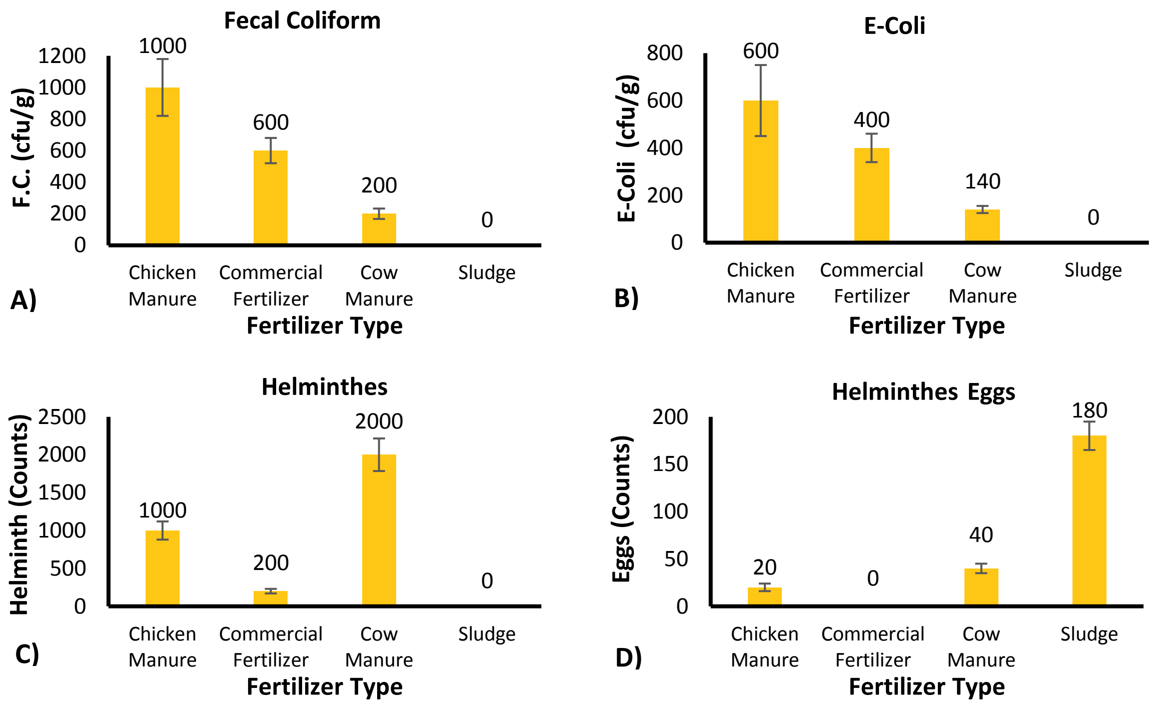


Fig. 12 Results of biological tests of treated sludge. A) Fecal coliform, B) *E-Coli*, C) Helminthes eggs, D) Helminthes

Table 2 Testing results for heavy metals and standard concentration for some countries

		Heavy Metal Concentration (mg.kg^{-1})							
		Cadmium	Lead	Copper	Mercury	Chromium	Nickel	Zinc	Reference
Fertilizer Type	Treated Sludge	1.4	110	0	0	80.5	26.4	1369.7	-
	Commercial	1.67	141.1	142	<0.001	144.2	13.45	431.5	-
Country	Palestine	20	750	1000	16	400	300	2500	(SoP 2015)
	Jordan	40	300	1500	17	900	300	2800	(HKoJ 2007)
	Iraq	39	300	1500	17	1200	420	2800	(RoI 2016)
	Germany	10	900	800	8	900	200	4000	(GoG 2017)
	Spain	40	1200	1750	25	1500	400	4000	(GoSp 1990)
	France	20	800	1000	10	1000	200	3000	(GoFr 1998)
	Italy	20	750	1000	10	200	300	2500	(GoIt 1992)
	Netherlands	1.25	100	75	0.75	75	30	300	(GoN 1998)
	Austria	10	500	500	10	500	100	2000	(LoLA 2019)
	Sweden	0.75	25	300	1.5	40	25	600	(GoSw 1994)
	Portugal	20	750	1000	16	1000	300	2500	(GoPr 2009)
	Finland	1.5	100	600	1	300	100	1500	(GoF 1994)
	Denmark	0.8	120	1000	0.8	100	30	4000	(GoD 1994; GoD 2018)
	Ireland	20	750	1000	16	-	300	2500	(GoIr 1998)
	Greece	40	1200	1750	25	500	400	4000	(GoGr n.d.)
	Belgium	10	500	800	1.6	150	100	2000	Collivignarelli et al. 2019
	Luxemburg	2.5	200	700	1.6	100	80	3000	(GoLu 2014)
	Poland	20	750	1000	16	500	300	2500	(GoPl 2015)
	Hungary	10	750	1000	10	1000	200	2500	(GoH 2001)
	Czech	5	200	500	4	200	100	2500	(GoCR 2001; GoCR 2016)
	Romania	10	300	500	5	500	100	2000	(GoR 2004)
	Lithuania	20	750	1000	8	400	300	2500	(GoLi 2006)
	Slovakia	10	750	1000	10	1000	300	2500	(GoSl 2001)
	Bulgaria	30	800	1600	16	500	350	3000	(GoB 2016)
	Estonia	20	750	1000	16	1000	300	2500	(GoE 2002)
	Cyprus	40	1200	1750	25	-	400	4000	(GoCy 2002)
	Latvia	10	500	800	10	600	200	2500	(GoLa 2006)
	Slovenia	1.5	250	300	1.5	200	75	1200	(GoSlov 2008)
	Malta	5	500	800	5	800	200	2000	(GoM 2002)
	Croatia	5	500	600	5	500	80	2000	(GoCr 2008)

Application of sludge as a fertilizer

The application of sludge to soil is of great importance regarding the supply of organic matter and nutrients, especially nitrogen and phosphorus (Tirunah et al. 2014), as well as conditioning soil properties, unless it contains toxic substances (Kulling et al. 2001). The increase of organic matter can improve soil's physical, chemical, and biological properties, which are necessary for long-term soil fertility and nutrient availability due to the aliphatic compounds with a low molecular weight that strongly interact with soil minerals. The higher availability of organic matter and nutrients also increases the activity of soil enzymes, soil microbial activity and soil microbial biomass growth (Hudcová et al. 2019). Application of sludge resulted in a reduced bulk density that led to an increased soil porosity and soil-air recirculation, improved soil structure and water holding capacity, and increased soil humus concentration (Muter et al. 2022).

The treated sludge and the locally available commercial and municipal fertilizers (animal manure) were applied to different crops. For this sake, several crops and vegetables were planted and fertilized with different fertilizers, and the development and growth of these crops were monitored and compared to each other to determine each fertilizer type's efficiency. The applied fertilizers included commercial fertilizer, cow manure, chicken manure, treated sludge, and different mixtures. A greenhouse of 300 m^2 area was prepared at UCAS campus. Representative soil and water samples were collected and tested according to the standard methods outlined in "Standard Methods for the Examination of Water and Wastewater", 23rd Edition, and testing results were summarized in Table 3. The land was divided into 8 portions; the distance separating portions was 1m, each portion was labeled according to the crop type and the applied fertilizer. The irrigation technique adopted was the drip irrigation system. The crops included lettuce, squash, eggplant, cucumber, tomato, and rocca as shown in Figs 13, 14, 15, 16, 17, 18. These crops were selected because of the high possibility of being contaminated once fertilizers were applied to them as they were close to the ground and may be in contact with the fertilizers. The obtained results reflected the riskiest scenario that might happen as part of the products could be eaten either raw or cooked. The selection of the crops was also endorsed by a workshop gathering some experts in the agricultural sector as well as sludge treatment and management.

Fig. 13 Lettuce seedlings

Fig. 14 Squash seedlings

Fig. 15 Eggplant seedlings

Fig. 16 Cucumber seedlings

Fig. 17 Tomatoes seedlings

Fig. 18 Rocca seedlings

Table 3 Chemical and biological testing results of soil and water

Parameter	Unit	Soil Result	Water Result
pH	-	6.8	7.9
Electrical Conductivity	µs/cm	3600	2800
Total Dissolve Solids	$mg.Kg^{-1}$	1800	1500
Sodium Adsorption Ratio	-	0.19	1.4
Nitrogen	$mg.Kg^{-1}$	4.8	
Potassium	$mg.Kg^{-1}$	1.4	
Phosphorus	$mg.Kg^{-1}$	5.4	
Fecal Coliform	cfu/g	Null	
Escherichia Coli	cfu/g	Null	
Helminthes	count	Null	
Organic Matter	%	0.24	
Intestinal Helminths Eggs	Count/g	8	
Cadmium	$mg.Kg^{-1}$	1.23	
Lead	$mg.Kg^{-1}$	3.10	
Copper	$mg.Kg^{-1}$	214	
Mercury	$mg.Kg^{-1}$	<0.001	
Chromium	$mg.Kg^{-1}$	6.70	
Nickel	$mg.Kg^{-1}$	2.82	
Zinc	$mg.Kg^{-1}$	15.37	
Boron	$mg.Kg^{-1}$	8.65	
Chloride	$mg.Kg^{-1}$		540
Ammonium	$mg.Kg^{-1}$		0.01
Total Hardness	mg/l as $CaCO_3$		390
Calcium Hardness	mg/l as $CaCO_3$		240
Calcium	$mg.Kg^{-1}$		96
Magnesium	$mg.Kg^{-1}$		36
Sulfate	$mg.Kg^{-1}$		14
Sodium	$mg.Kg^{-1}$		64
Potassium	$mg.Kg^{-1}$		1.9
Carbonate	mg/l as $CaCO_3$		0.0
Bicarbonate	mg/l as $CaCO_3$		14.2
Nitrate	$mg.Kg^{-1}$		75
Nitrite	$mg.Kg^{-1}$		0.001

The applied fertilizers included treated sludge, commercial fertilizer, cow manure, chicken manure, 50% sludge + 50% commercial fertilizer, 50% cow manure + 50% sludge, and 50% chicken manure + 50% sludge. A blank soil without any fertilizer was considered a control. The applied fertilizer quantity was estimated according to the fertility content of each fertilizer in terms of nitrogen, phosphorous and potassium (NPK), and according to the requirements of each crop to these three elements. Intensive site visits were kept at fixed intervals to monitor the development and progress of the crops in terms of plant length, leaf length; width; color; number, growth status, and visual damages. Monitoring results for different crops were summarized in Table 4. It was clearly noticed from the on-site-monitoring program that the treated sludge and commercial fertilizer demonstrated an impressive increase in yield in terms of quantity and size. They also encouraged healthy plant development and growth, improved the quality of crops, enhanced water retention capacity of the soil, and encouraged root system development. When plants yielded products, as shown in Figs 19, 20, 21, 22, 23, 24, crops were harvested and sent to the laboratory for biological testing. The conducted tests aimed to investigate the possibility of any biological contamination of the harvested crops; the tests included F.C. and *Escherichia Coli*. Testing results of different crops were outlined in Table 5.

Fig. 19 Developed Lettuce seedlings

Fig. 20 Developed Squash seedlings

Fig. 21 Developed Eggplant seedlings

Fig. 22 Developed Cucumber seedlings

Fig. 23 Developed Tomatoes seedlings

Fig. 24 Developed Rocca seedlings

By referring to Table 4, one can observe that the best crop development occurred when the treated sludge was applied, followed by the commercial fertilizer. A mixture including treated sludge and commercial fertilizer was ranked as the third best fertilizer, and cow manure and chicken manure were ranked in fourth place. Treated sludge and chicken manure mixture were in sixth place, while the mixture containing treated sludge and cow manure was ranked last. It can be also observed from Table 5 that crops fertilized by the treated sludge were free from biological contamination indicators including F.C. and *E-Coli,* which was a good indicator of the safe application of treated sludge as a fertilizer. The presence of F.C. and *E-Coli* was noticed in crops fertilized with cow manure, chicken manure and commercial fertilizer. Worth to mention that the testing results for these indicators in cow manure, chicken manure and commercial fertilizer were positive. These results supported the possibility of utilizing treated sludge as a fertilizer, either alone or in conjunction with other local fertilizers, without any adverse health impacts. For the case of the control sample, crops were free from fecal coliform and *Escherichia Coli*, and this was due to the absence of these indicators from the original soil.

Analysis of results and comparison with standards

Physical parameters

Electrical conductivity (E.C.) is an index of salt concentration and an indicator of electrolyte concentration of the solution (Gartley 2016). It is proportional to the total amount of fertilizer salts present in a solution (Nemali 2018). It is a measure of water quality, soil salinity and fertilizer concentration. Knowing E.C. levels can help plant production and lead to the more cost-effective use of plant inputs and less shrinkage. The presence of high salt levels is a sign that adjustments are needed before the damage shows up in plants (Thurow 2022a). The first exterior sign of distress caused by excess nutrients is wilting leaves. Foliage growth can become harder, darker, and brittle. Plants stop growing, staying shorter with smaller leaves. Brittle leaves are the product of a high E.C. On the other hand, low nutrient concentration forces more water uptake from the roots. As a result, the foliage becomes weak and soft, often lighter green or pale. A low E.C. condition is more easily rebalanced than a high concentration of nutrients already flowing in the system. Figs 10.A and 10.B showed that sludge had nearly the same E.C. and TDS of commercial fertilizer and chicken manure, indicating that the treated sludge could be considered as a good competitor fertilizer.

Water content measurement is important for several reasons, including product quality, economical, legal, and labeling requirements (IFA 2014). If the water content is too low, it will be difficult to form balls and the output will be low. If the water content is too much, there will be many large balls, and the surface of the balls will be sticky, which is easy to block the screen surface (PFMS 2022). As outlined in Fig 10.C, the treated sludge and the commercial fertilizer had the lowest water content of 10% - 11%, indicating a good quality fertilizer. Chicken manure had a water content of 13%, but cow manure had the highest value of 27%. To get the highest benefit from the treated sludge once applied as a fertilizer, it is preferable to be applied in the wetting area for optimal dissolution.

It was expected to have high sand content in the locally available fertilizers such as cow and chicken manure. This is due to the practices followed by the breeders of cows and chicken in the Gaza Strip. They used to spread sand on ground to help absorb animals' liquid waste. As outlined in Fig. 10.D, the testing results indicated that the sand content in sludge is a little bit higher than that of cow and chicken manure. This may require a better grit removal process in the WWTP. For the case of commercial fertilizer, sand content was the lowest indicating good control of sand in the manufacturing process.

Table 4 Monitoring results for the development of different seedlings

Crop Type	Parameter	**Fertilizer Type**							
		Control Sample	Treated Sludge	Cow Manure	Chicken Manure	Commercial Fertilizer	50% Sludge, 50% Cow	50% Sludge, 50% Chicken	50% Sludge, 50% Commercial
Lettuce	Leaf Length	+	+ + + + + +	+ +	+ + + +	+ + + + +	+ + + + + + +	+ + +	+ + + + + + + +
	Leaf width	+	+ + + + + + +	+ +	+ + + +	+ + + + +	+ + +	+ + + + + + + +	+ + + + + +
	Leaf Number	+	+ + + + + + + +	+ +	+ + +	+ + + + + + +	+ + + + +	+ + + +	+ + + + + +
Squash	Leaf Length	+	+ + + + + +	+ + +	+ + + + + + + +	+ + + +	+ +	+ + + + +	+ + + + + + +
	Leaf width	+	+ + + +	+ + +	+ + + + + + + +	+ + + + +	+ +	+ + + + + +	+ + + + + + +
	Leaf Number	+	+ + + + + + + +	+ + + + + + +	+ + + + +	+ + + + + +	+ +	+ + + +	+ + +
	Plant Length	+	+ + + + + + + +	+ + + + +	+ + + + + +	+ + + + + + +	+ + +	+ +	+ + + +
Egg-plant	Leaf Length	+	+ + + + + + +	+ + + +	+ + + + + +	+ + + + + + + +	+ + +	+ +	+ + + + +
	Leaf width	+	+ + + + + +	+ + + + +	+ + + + + + + +	+ + + + + + +	+ + +	+ +	+ + + +
	Leaf Number	+	+ + + + + +	+ + + + + + +	+ + + + +	+ + + + + + + +	+ + +	+ +	+ + + +
	Plant Length	+ + +	+ + + + + +	+ + + + +	+ + + + + + + +	+ + + + + + +	+ + + +	+	+ +
Cucumber	Leaf Length	+ + + + + + + +	+ + + + + + +	+ + +	+	+ + + + + +	+ +	+ + + +	+ + + + +
	Leaf width	+ + + +	+ + + + + + +	+ +	+	+ + + + +	+ + +	+ + + + + + + +	+ + + + + +
	Leaf Number	+ + + +	+ + + + + +	+	+ +	+ + + + + + +	+ + + + +	+ + + + + + + +	+ + +
	Plant Length	+ + + + +	+ + + + + + +	+ + + + + +	+ + +	+ + + + + + + +	+	+ +	+ + + +
Tomato	Leaf Length	+	+ + + + + +	+ +	+ + + +	+ + + + +	+ + + + + + +	+ + +	+ + + + + + + +
	Leaf width	+	+ + + + + +	+ + + + + + +	+ + +	+ + + +	+ + + + +	+ +	+ + + + + + + +
	Leaf Number	+	+ + + + +	+ + + + + +	+ + + + + + +	+ + + + + + + +	+ + +	+ +	+ + + +
	Plant Length	+	+ + + + + + +	+ + + +	+ +	+ + + + + + + +	+ + + + +	+ + +	+ + + + + +

Table 5 Biological testing results for different crops

Crop Type	Biological Indicator (cfu)	Fertilizer Type							
		Control Sample	Treated Sludge	Cow Manure	Chicken Manure	Commercial Fertilizer	50% Sludge, 50% Cow	50% Sludge, 50% Chicken	50% Sludge, 50% Commercial
Lettuce	F.C.	Null	Null	Null	210	Null	Null	Null	Null
	E-Coli	Null	Null	Null	Null	Null	Null	Null	Null
Squash	F.C.	Null	Null	Null	Null	Null	Null	Null	Null
	E-Coli	Null	Null	Null	Null	Null	Null	Null	Null
Eggplant	F.C.	Null	Null	1000	20	Null	Null	Null	Null
	E-Coli	Null	Null	500	100	Null	Null	Null	Null
Cucumber	F.C.	Null	Null	Null	200	480	Null	Null	Null
	E-Coli	Null	Null	Null	Null	Null	Null	Null	Null
Tomato	F.C.	Null	Null	Null	Null	Null	Null	Null	Null
	E-Coli	Null	Null	Null	Null	Null	Null	Null	Null
Rocca	F.C.	Null	Null	Null	20	Null	Null	Null	Null
	E-Coli	Null	Null	Null	Null	Null	Null	Null	Null

Chemical parameters

Levels of pH are essential in soils, irrigation water and spray tank solutions. Soil and water pH is the most important aspect in determining nutrient availability to crops. The pH levels in spray tanks determine the effectiveness of pesticides (Thurow 2022b). According to the testing results shown in Fig. 11. A, sludge tends to be alkaline as well as other fertilizers, with approximately equal values for the pH.

Plants in large amounts require nitrogen (N) since it plays essential functions and can be the limiting factor in plant production and proper crop development. It is an essential element of all the amino acids in plants, important in the growth and development of plant tissues, cell membranes and chlorophyll. It is a component of nucleic acid that forms DNA, a genetic material significant in transferring certain crop traits and characteristics that aid in plant survival. Plants with sufficient nitrogen will experience high rates of photosynthesis and typically exhibit vigorous plant growth and development (Tajer 2016c). As outlined in Fig. 11. B, nitrogen content in the treated sludge was the highest; 3.3%, nearly equal to that of the commercial fertilizer; 3.2%. However, cow manure had the lowest content of 1.3%, and chicken manure had 1.9%.

Plant growth is boosted by phosphorous whose lack leads to weak plants that fail to produce as expected. It stimulates root development, and it is required for photosynthesis and in the storage and transportation of nutrients throughout the plant. Plants are expected to produce fruit after a given time if all the circumstances are correct, and legumes help fix nitrogen in the soil through their roots. Plants with access to enough phosphorous can resist diseases because all their parts are well developed and grow quickly (Tajer 2016b). As shown in Fig. 11.C, phosphorous concentration was the highest in the treated sludge at 14%, while other fertilizers contained a slim ratio between 1.6 - 1.9%.

Potassium is an essential plant nutrient, is required in large amounts for the proper growth and reproduction of plants and is considered second only to nitrogen (Tajer 2016a). It affects plant shape, size, color, taste, and other measurements attributed to healthy produce. In photosynthesis, potassium regulates the opening and closing of stomata, and therefore regulates CO_2 uptake. Potassium plays a significant role in regulating water in plants; both uptake of water through plant roots and its loss through the stomata are affected by potassium, improving drought resistance (Dotaniya et al. 2020). As shown in Fig 11.D, potassium concentration in chicken manure was the highest at 2.8%, followed by commercial fertilizer at 2.3%. For the case of cow manure, potassium concentration was the lowest at 0.8%, while for the treated sludge; it was 1.4%.

Organic matter (O.M) resources in soils are stable, relatively low and frequently require replenishment. Usually about 5% of O.M from soil decomposes yearly; that rate increases if conditions become favorable for decomposition, which often occurs with excessive tillage. Therefore, the use of sewage sludge in agriculture is a desirable method of their utilization. The addition of sewage sludge to soils may thus be an inexpensive and effective alternative to the methods applied currently. O.M. is a reservoir of nutrients that can be released into the soil, the water-holding capacity of O.M. behaves somewhat like a sponge, with the ability to absorb and hold up to 90% of its weight in water, soil structure aggregation that O.M. causes soil to clump and form soil aggregates, which improves soil structure. Increasing soil O.M. from 1 – 3% can reduce erosion by 20 – 33% because of increased water infiltration and stable soil aggregate formation caused by O.M. (Delibacak et al. 2020, Funderburg 2001). As outlined in Fig. 11.E, all fertilizers had an O.M. content between 55 – 65% which indicates their quality. Once the soil is poor, the organic manure is very useful for improving the soil and increasing its fertility. The added organic matter improves crop yields and yield quality.

Sodium adsorption ratio (SAR) describes the tendency for sodium cations to be adsorbed at cation- exchange sites in the soil at the expense of other cations (Malik 2017). As shown in Fig. 11.G, the treated sludge had a SAR of 4.3 compared to other fertilizers; SAR values for commercial fertilizer, chicken manure, and cow manure were 24, 27, 23, respectively, indicating that the treated sludge was the best in terms of SAR.

Fertilizer with C/N ratio under 20:1 is considered ideal for crop production. When there is insufficient nitrogen in the organic material to break down the carbon, the microorganisms utilize nitrogen from the soil. When C/N ratios > 25 to 30:1, it could result in nitrogen deficiency of a crop that relies on soil nitrogen (Brown 2015). As outlined in Fig. 11.H, the treated sludge and commercial fertilizer had C/N ratios of 18 and 20, respectively, which was very close to the ideal ratio. For the case of chicken and cow manures, C/N ratio exceeded 30:1 which might result in nitrogen deficiency.

Biological parameters

Fecal coliform (F.C.) is an indicator of fecal contamination. Coliform bacteria generally originate in the intestines of warm-blooded animals. Testing results shown in Figs 5.A and 12.A outlined that treating sludge in drying beds reduced F.C. from 96 cfu/g to zero in 45 days which was a good achievement. The results showed that other fertilizers contain F.C. with different concentrations; 100, 600 and 200 cfu/g for chicken manure, commercial fertilizer, and cow manure respectively.

E-Coli is a bacterium commonly found in the gut of warm-blooded organisms. Most strains of *E-Coli* are harmless but are part of the beneficial bacterial flora in the human gut. However, some types can cause illness in humans, including diarrhea, abdominal pain, fever, and sometimes vomiting. By referring to Figs 5.B and 12.B, it was noticed that *E-Coli* decreased from 68 to zero in 45 days. Testing results outlined that *E-Coli* in chicken manure, commercial fertilizer, and cow manure were 600, 400, and 140 cfu/g, respectively. It was a significant advantage that the treated sludge was free from pathogens indicated by zero concentrations of F.C. and *E-Coli*.

Helminthes are the most common parasites infecting humans (Saunders et al. 2012), they can infect every organ and organ system. Prevalent in the intestines, they are found in the liver, lungs, blood, brain, and other organs (Cohen et al. 2017). Helminth's count was zero in the raw sludge sample, while their eggs were 600 eggs. After sludge treatment, the number of eggs decreased from 600 to 180 in 45 days and to 80 in 75 days, see Fig. 5.C. For other fertilizers shown in Fig. 12.C, helminth counts were 1000, 2000, and 200 in chicken manure, cow manure and commercial fertilizer, respectively. Fig. 12.D showed the testing results for helminths eggs counts were 20, 40 and 0 in chicken manure, cow manure and commercial fertilizer, respectively. *Salmonella* was tested at 45-day of the treated sludge sample and the testing results were null.

The encouraging results of the different biological tests assisted in reducing the strength of the barriers put by different authorities to protect the public health and the environment. Such results – when compared to other local fertilizers – will also enhance the manual application of the treated sludge, as the health impacts will be minimal.

Heavy metals

Heavy metals can be divided according to their need for different organisms. There are those, which are doubtless essential, and those, which are not recognized as essential. Copper (Cu) and zinc (Zn) are essential to plants, animals and humans. Chromium (Cr) and nickel (Ni) are essential to humans and plants, respectively. In contrast, cadmium (Cd), lead (Pb) and mercury (Hg) are not essential to any of these organisms (Silva and Camilotti 2014). However, essential or not essential metals may be toxic. For example; Cd, Pb and mercury (Hg) are not essential to humans but in excess can also cause toxicity.

The 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 (Del val et al. 1999, Jacuote et al. 2000, Kelly et al. 1999, Sauerbeck 1987, Wetzel and Werner 1995). Such symbiotic microorganisms contribute to nutrient acquisition by plants, which are important for reducing fertilizer inputs in sustainable plant production systems. Above the acceptable levels, toxic metals significantly reduce soil fertility. Metals also inhibit enzyme activity in the soil and alter soil acidity (Gawdzik and Gawdizik 2012). Heavy metals toxicity was also known to affect plant photosynthesis processes (Ouzounidou and Ilias 2005; Wang et al. 2009). The presence of excess concentration of metals in plants can directly inhibit photosynthetic electron transport as well as photosynthetic metabolism (Burzyhski and Zurek 2007). In the following paragraphs, the concentrations of the already tested heavy metals will be compared with different local, regional and international standards.

Cadmium concentration was 1.4 $mg.Kg^{-1}$ in the treated sludge and was 1.67 $mg.Kg^{-1}$ in the commercial fertilizer, while the permissible concentration indicated by the Palestinian Standards was 20 $mg.Kg^{-1}$. Cadmium concentration in the treated sludge was within the limits of Jordan, Iraq and most of the European countries excluding the Netherlands, Sweden, and Denmark. The treated sludge was suitable for plants because plants grown in soil containing high levels of cadmium showed visible symptoms of injury reflected in terms of chlorosis, growth inhibition, browning of root tips, and death (Asati et al. 2016).

Lead is known for its immobility and limited translocation in plants. Lead concentrations in the treated sludge and commercial fertilizer were 110 $mg.Kg^{-1}$, and 141.1 $mg.Kg^{-1}$ respectively, which were within the Palestinian, Jordanian, Iraqi and most of the European countries Standards excluding the Netherlands and Sweden. Lead concentration in sludge would vary widely depending on traffic density, industrial emissions, and climatic factors. Lead sources include batteries, pigments, solder, roofing, cable covering, lead jointed waste and PVC pipes, ammunition, chimney cases, and fishing weights (Tiruneh et al. 2014). High levels of lead affected plant chlorosis, root system darkening, stunted plant growth and increased oxidative stress (Silva and Camilotti 2014).

Copper is an essential metal for average plant growth and development, although it is also potentially toxic (Asati et al. 2016). Copper may be derived from cleaning products, cosmetics and shampoos, fuels, inks, medicines and ointments, food products, oils and lubricants, paints and pigments, polish and wood preservatives, electronics, plating, paper, textile, rubber, fungicides, printing, plastic, and brass and other alloy industries. It can also be emitted from various small commercial activities and warehouses, as well as buildings with commercial heating systems (Tiruneh et al. 2014). Copper concentration in the treated sludge was zero, while its concentration was 142 $mg.Kg^{-1}$ in the commercial fertilizer. Excess copper concentration can affect plants interveinal chlorosis in younger leaves, reduce branching, thickening, darkening of rootlets and reduce plant growth (Silva and Camilotti 2014).

Mercury is not essential for plant growth. Contamination of soils by mercury is often due to the addition of this heavy metal as part of fertilizers, lime, sludges, and manures (Asati et al. 2016). Its concentration in the treated sludge was zero while it was < 0.001 $mg.Kg^{-1}$ in the commercial fertilizer. High mercury concentrations can affect a plant's hypertrophic root, retard plant growth, and increase oxidative stress (Silva and Camilotti 2014).

Chromium is a toxic metal that can cause severe damage to plants and animals and induces oxidative stress that causes severe damage to cell membranes. Sources of chromium include alloys, preservatives, dying, and tanning activities, paint and plating baths, tannery industries that use chrome tanning, metal industries, cleaning products, oil and lubricants, photographing and pesticide products (Tiruneh et al. 2014). High chromium concentration can disturb the chloroplast ultrastructure there by disturbing the photosynthetic process (Asati et al. 2016). According to Palestinian standards, the allowable limit of chromium was 400 $mg.Kg^{-1}$. In comparison, its concentrations in the treated sludge and commercial fertilizer were 80.5 and 144.2 $mg.Kg^{-1}$, respectively, which were within the acceptable Palestinian, Jordanian, Iraqi, and most European countries standards except the Netherland and Sweden.

Nickel is an essential nutrient for plants; the amount of nickel required for average growth of plants is meager. Wastewater containing nickel originate from cosmetics, paints and pigments, production of alloys, electroplating, catalysts and nickel-cadmium batteries, corrosion of equipment from launderettes, jewelry shops, metal processing industries, motor vehicle and aircraft industries, printing and chemical industries (Tiruneh et al. 2014). High concentrations may adversely affect plants, including increased oxidative stress, germination retardation, stunting of root growth, chlorosis, inhibition of plant growth and reduced yield (Silva and Camilotti 2014). The treated sludge had a nickel concentration of 26.4 $mg.Kg^{-1}$, which was acceptable according to Palestinian, Jordanian, Iraqi, and European standards except for Sweden. In the case of commercial fertilizer, its concentration was 13.45 $mg.Kg^{-1}$.

Zinc can be derived from both natural, domestic and industrial sources. Domestic sources include cosmetics and shampoos, lubricants, medicines and ointments, paints, oil and lubricants, polish and washing powders, galvanization processes, brass and bronze alloy production, tires, batteries, plastics, rubber, fungicides, paper, textiles, taxidermy (zinc chloride), embalming fluid (zinc chloride), building materials and special cements (zinc oxide, zinc fluorosilicate), dentistry (zinc oxide), and also in cosmetics and pharmaceuticals. Industrial sources of zinc could be wastewater streams from steel works, fiber manufacture, and wood-pulp production (Tiruneh et al. 2014). Zinc helps plants produce chlorophyll; leaves are discolored when the soil is deficient in zinc, and plant growth is stunted. High concentrations can have adverse effects on plants, including chlorosis, stunted plant growth and reduced yield (Silva and Camilotti 2014). The zinc concentration in the treated sludge and commercial fertilizer were 1369.66 mg.Kg^{-1} and 431.54 mg.Kg^{-1} respectively, which were within the Palestinian, Jordanian, Iraqi, and European Countries standards except the Netherlands, Sweden, and Slovenia.

Conclusion

Sludge treatment via drying beds is a suitable technique for the Gaza Strip as it is located in a semi-arid region and is characterized by plenty of sunshine hours. At Gaza Strip climatic conditions, 45 days of exposure to the sun were sufficient to remove F.C., *E-coli*, and *salmonella* from sludge samples. Nitrogen, phosphorous and potassium (NPK) content in the treated sludge, commercial fertilizer, chicken manure and cow manure were 3.3, 14, 1.4; 3.2, 1.9, 2.3; 1.9, 1.8, 2.8; and 1.3, 1.6, 0.8 respectively. Cow manure had the lowest fertility content in terms of NPK; the treated sludge was the richest fertilizer in terms of nitrogen and potassium, while the chicken manure was the richest in potassium followed by the commercial fertilizer and treated sludge. The treated sludge had a C/N ratio of 18:1 which is very close to the ideal ratio (20:1), while was ideal for the case of the commercial fertilizer. For the case of chicken and cow manures, the ratios were 33:1 and 42:1 respectively, which exceeded the ideal ratio; this could result in nitrogen deficiency. The SAR values for the treated sludge, cow manure, commercial fertilizer, and chicken manure were 4.3, 23, 24, and 27 respectively. This indicated that the tendency for sodium cations to be adsorbed at cation- exchange sites in the soil at the expense of other cations was the least for the treated sludge followed by cow manure, commercial sludge and chicken manure respectively. The results of heavy metals testing indicated that sludge carried no risk with respect to heavy metals toxicity. The study concluded that treating the sludge by drying beds was an economic solution that would produce a reliable, rich nutrient, economic and sustainable fertilizer. The application of this fertilizer alternative would reduce the input cost paid by farmers to fertilize their crops and vegetables; it would also produce crops free from biological contamination (fecal coliform, *E-Coli*, helminths, and *salmonella*) rendering the treated sludge to be a good competitor to other fertilizers. The high cost of transporting and disposing sludge would also be lowered, as the amount being transferred from the WWTP to the final disposal site would be reduced. Proper treatment of sludge would provide a sustainable and reasonable fertilizer that has many positive economic and environmental benefits. The results of the experimental program showed that the treated sludge is an optimal solution for increasing soil fertility, improving the retention of water and nutrients, releasing essential nutrients to the plant, and improving their uptake by the plant. Using the treated sludge as fertilizer should not raise any concerns regarding heavy metals concentrations including cadmium, lead, copper, mercury, chromium, nickel and zinc as they fell within the acceptable limits of the Palestinian, Jordanian, Iraqi, and almost all the European Countries standards. The study revealed that the treatment period for sludge was relatively long (45 days), therefore it was recommended to conduct further research to shorten this period. It was also recommended to complement drying beds by another technique to destroy helminths eggs and to investigate boron concentration in the treated sludge, compare it with the allowable limits, investigate its treatment options, and study its impacts.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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