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Characterization of Sewage Sludge for Quality Assessment and Its Safe Utilization in Agriculture

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The current investigation was undertaken to explore the physico-biochemical properties of sewage sludge (SS) and its feasible application in agricultural field as an organic manure as source of nutrients with to solve the environmental concern. Sewage sludge samples were collected from sewage treatment plants (STP), Bhagwanpur, Varanasi, Uttar Pradesh, India and passed through a 2 mm sieve for further analysis of different physical, chemical and biological parameters. The treated sewage sludge consists of both major and micro nutrients along with a good amount of organic matter. Application of this sewage sludge has the ability to enhance the physical, chemical and biological properties of soil which is beneficial for plant growth and development sustainable soil environment. However, it also contains some amount of toxic heavy metals and organic pollutants that can adversely affect soil environment depending on the origin source of sewage sludge, and treatment process of sewage sludge. Furthermore, the toxic elements go through the

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food chain due to its uptake and accumulation by crops posing a possible threat to human health. Sewage sludge application in soil offers essential nutrients particularly for plant growth, maintains the organic carbon in soil and decreases environmental concern with economic factors that restrict landfill or incineration disposal of sewage sludge. However, a careful assessment of the characteristics of sewage sludge is required prior to its soil application to improve the soil health without causing environmental hazard. The SS analyzed in the present study had heavy metals content but was within permissible limits as resulted its suitable for soil application as source of nutrients.

Keywords: Heavy metals; major nutrient; micronutrients; sewage sludge; soil health; sewage treatment plants.

1. INTRODUCTION

The world human population of 7.7 billion in 2019 is predicted to touch 8.5 billion by 2030, 9.7 billion in 2050, and 10.9 billion in 2100 as per the medium-variant projection [1]. At present, India has to produce 300 million ton (Mt) of food grains in 2020 to feed the growing population. The net cultivated land of India which is 142.5 million hectares (Mha), is limited and has continuous pressure due to the production of food grains for the increasing population [2]. Near about 45 Mt of nutrients are required, out of which 35 Mt is estimated to be supplied by chemical fertilizer and the remaining by organic sources [3].

Rapid urbanization and rising living standards would result in the generation of a higher amount of wastewater due to intensified daily human activities. [4] The estimated generation of wastewater from city centres may cross 120,000 millilitre per day (MLD) by 2051 and rural India will also generate not less than 50,000 MLD of wastewater [5]. The urban area generates large amount SS wastes that can be used as an organic manure for carbon stabilization in soil with the advantage to reduce the environmental concern. Sewage sludge (SS) is rich source of nitrogen (N), phosphorus (P), sulphur (S), calcium (Ca), micronutrient and heavy metal [6]. The agricultural application of sludge for crop production provides a feasible and cost effective disposal alternative.

The production of SS in India is increasing at a faster rate for which the wastewater treatment facilities are being developed [7]. The solid material remaining after sewage treatment is referred to as bio-solids or sewage sludge. Often these materials can be obtained at little or no cost by farmers or landowners [8]. The utilization of SS in agriculture is gaining popularity as a source of waste disposal. It has been widely used in many countries around the world in Europe, where each year, more than ten million tons of SS is generated, of which, around 37% are used for crop production [9]. In the European Union (EU), more than half of the 27 EU affiliated countries recycle >50% of SS to agricultural land either straight or after preparation of compost [10]. Sludge generated in Italy and Spain is recycled through agricultural soils by 31% and 65% per year, respectively [11,12]. However, SS contains some amount of heavy metals and that can adversely affect soil micro-organisms [13,14]. Furthermore, the toxic elements go through the food chain due to its uptake and accumulation by crops posing a possible threat to human health [3,15].

Most of the sewage treatment plants (STPs) are designed in India for treating wastewater emanating from the domestic sector and provide only primary and secondary treatment to wastewater functioning on activated sludge process technology. There is no provision for the advance treatment of wastewater. At Varanasi, Uttar Pradesh, India more than seven thousand houses, small and medium scale industries are located in and around the city. The majority of these industries are devoid of effluent treatment facilities and ultimately discharge their effluents laden with toxic metals directly into the city sewage, which eventually drains into the river Ganga that serves the population of northern India.

The management and disposal of SS in an economically and environmentally acceptable manner is one of the most persistent problems of society. The study showed that the dose of SS > 45 ton ha^{-1} there could be a chance for build-up of heavy metals [7]. Seeking its suitability for agriculture purpose to buildup soil fertility, the Bhagwanpur STPs sewage sludge was analyzed to know the nutrient status. The physical, chemical and biological analysis of Bhagwanpur sewage sludge has been done to find out its suitability for agricultural purposes.

2. MATERIALS AND METHODS

The Bhagwanpur STP is located in Varanasi, Uttar Pradesh, India having importance to treat the wastewater coming from the mainly urban city area of Varanasi. The sample of SS was collected from Bhagwanpur STPs during the summer season of 2017 directly from the drying tank where sludge was collected for solidification. The sludge was collected in a plastic bag and kept moist for enzyme and microbial analysis in freezing temperature up to 4°C. The remaining portion of sludge was dried under shade condition and finally passed through a 2 mm sieve. The collected sludge was further analyzed for different physical, chemical and biological properties. The bulk density (BD) of SS was determined using a method outlined by [16]. The water holding capacity (WHC) of sludge was determined by keen box by setting a filter paper of the same diameter inside the keen box [16]. The moisture percentage in sewage sludge was measured using the moisture box formula given below.

$$W = \frac{M2 - M3}{M3 - M1} \times 100$$

Where W= Moisture Percentage
M_1= Mass of empty container with lid,
M_2= Mass of the container with wet soil and lid,
M_3= Mass of the container with dry soil and lid.

The pH and EC of sewage sludge were determined in 1:2.5 soil:water suspension [17] and Organic carbon [18]. The available nitrogen (N) content in SS has been determined by the 0.32% alkaline $KMnO_4$ method [19]. The available phosphorus (P) content in SS has been determined by the ascorbic acid method given by [20]. The available potassium (K) content in SS has been determined by the 1N neutral ammonium acetate method [21]. The available sulphur (S) content in SS was determined by the turbidimetric method outlined by [22]. The total micronutrients and heavy metals were analyzed by the aqua regia digestion mixture. The conventional aqua regia digestion procedure consists of digesting soil samples on a hot plate with a 3:1 mixture of HCl and HNO_3 [23]. The micronutrients (Fe, Cu, Mn and Zn) and heavy metal (Cd, Cr, Ni and Pb) contents were measured by Absorption Spectrophotometer (Agilent FS-240) [24]. The population of bacteria, fungi and actinomycetes in sludge were determined by serial dilution and plating technique using Asparagine-Mannitol agar medium [25], Rose Bengal streptomycin agar medium [26] and Ken Knight and Munaier's medium [27], respectively by pour plate method. Urease activity in sludge was estimated as the amount of urea hydrolyzed after the incubation period [28]. Alkaline phosphatase enzyme activity in SS was measured by method outlined by [29]. Dehydrogenase activity in sewage sludge was determined by triphenyl tetrazolium chloride (TTC) method [30]. The three samples were run for analysis and the mean of three samples were presented in tables and figures.

3. RESULTS AND DISCUSSION

Sewage sludge is the outcome of the wastewater treatment process after the solidification of treated waste which generally settles down. The present collected sludge had an ample amount of nutrients which might be helpful to improve the fertility of the soil. The sludge may not only have a good amount of nutrients but also might be a good activator for the different enzymes and microbes.

The data of the physical properties of SS has been depicted in Table 1 which clearly shows that the Bhagwanpur STPs SS had good physical properties which might be helpful to improve the soil's physical condition. The BD (Mg m^{-3}) of sludge was reported 1.19, which is helpful to improve the soil BD after sludge incorporation in the soil [31]. The sludge also had good WHC of 52.44% which is a good water indicator for the soil as it might be helpful in improving the soil's physical properties. The WHC is generally dependent upon the BD of the sludge [7,31]. The sludge had a moisture content of 19.8% which could help to activate the different microbes into the soil. The data of the physical properties of sludge clearly indicated that this sludge can be a good amendment to improve the soil BD. [7,3,32] Some studies reported that SS has good physical properties that can improve the soil physical properties. The improvement in the soil's physical properties will be helpful to the proper aeration in the soil which will result in better root growth.

Table 1. Physical properties of sewage sludge of Bhagwanpur STPs

S. No.	Parameter	Sewage sludge
1.	Bulk Density (Mg m^{-3})	1.19
2.	Water Holding Capacity (%)	52.44
3.	Moisture (%)	19.8

Data represent mean of three samples

The SS was also further studied for chemical properties and has been presented in Table 2. The analysis of SS of Bhagwanpur STPs had the pH 7.02, EC 3.25 dS m^{-1} and organic carbon 7.98 %. The sludge had available N 144.55, P 70.23, K 170.22 and S 46.31 mg kg^{-1} respectively. Whereas, the total N, P, K and S contents were 1.85, 1.40, 1.20 and 1.21% respectively (Table 2). The SS is also analyzed for DTPA extractable available trace elements which can be available for plant growth if applied in the soil represented in Table 2 and Fig. 1. The DTPA extractable iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn) contents of sludge were 90.56, 31.23, 40.23 and 32.03 mg kg^{-1} respectively. The DTPA extractable amounts Cd, Cr, Ni and Pb in SS were 5.66, 9.30, 2.30 and 12.23 mg kg^{-1} respectively. The trace metal content which is critically important to apply the SS in agriculture was also analyzed for the safe usage of sludge in agriculture. However, the total Trace metal represented in Fig. 2 and Table 2.

According to [33,34] the permissible levels for potentially toxic elements e.g., Zn, Cu, Cd, Pb, Ni and Cr in sludge to be used in agricultural soils are 2500-4000, 1000-1750, 20-40, 750-1200, 300-400 and 750-1200 mg kg^{-1} respectively. The trace metal (heavy metals and micronutrients) were below the permissible limit. However, in comparison with [34], the heavy metal content within the permissible limit in which ceiling limits in sludge are 85 mg Cd kg^{-1} and 7500mg Zn kg^{-1}, and exceptional quality sludge contains a maximum concentration of 41 mg Cd kg^{-1} and 2800 mg Zn kg^{-1} sludge. The EU sludge directive limits agricultural use of sludge with < 40 mg Cd kg^{-1} and <4000 mg Zn kg^{-1} [35]. Further, it has been found that SS which is treated by the STPs could be used for agriculture purposes with precautionary measures. The studies conducted by researchers on SS clearly show that present sludge could be used for agricultural purposes to enhance soil fertility and also the safety measures to be followed. Although sludge has a good nutrient value but continuous use of sludge might be responsible for the buildup of heavy metals in the soil that should be kept in view during the soil application [7,3,36,37,38].

The study revealed that SS has a higher population of microorganisms i.e., bacteria, fungi and actinomycetes. Regarding the biological properties of sludge which has the bacteria population 42.44×10^{-6} cfu g^{-1} soil, fungi population 30.41×10^{-4} cfu g^{-1} soil and actinomycetes population 39.20×10^{-5} cfu g^{-1} soil.

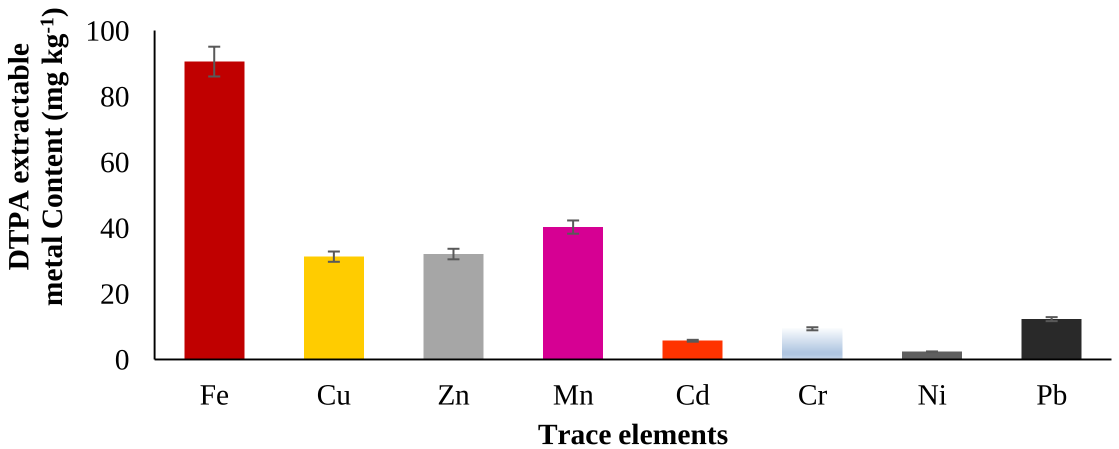

Fig. 1. DTPA extractable trace elements content (mg kg^{-1}) in sewage sludge of Bhagwanpur sewage treatment plants (STPs)

Table 2. Chemical properties of sewage sludge of Bhagwanpur

S. No.	Parameter	Sewage sludge	Permissible limit*#
1.	pH (soil:water, 1:2.5)	7.02	
2.	EC (dS m^{-1})	3.25	
3.	Organic Carbon (%)	7.98	
Available content (mg kg^{-1})			
4.	N (Nitrogen)	144.55	
5.	P (Phosphorus)	70.23	
6.	K (Potassium)	178.22	
7.	S (Sulphur)	46.31	
Total content (%)			
8.	N (Nitrogen)	1.85	
9.	P (Phosphorus)	1.40	
10.	K (Potassium)	1.20	
11.	S (Sulphur)	1.21	
DTPA extractable trace elements (mg kg^{-1})			
12.	Fe (Iron)	90.56	
13.	Cu (Cupper)	31.23	
14.	Zn (Zinc)	32.03	
15.	Mn (Manganese)	40.23	
16.	Cd (Cadmium)	5.66	
17.	Cr (Chromium)	9.30	
18.	Ni (Nickel)	2.30	
19.	Pb (Lead)	12.23	
Total trace elements (mg kg^{-1})			
20.	Fe (Iron)	500.32	
21.	Cu (Cupper)	246.87	1000-1750
22.	Zn (Zinc)	200.25	2500-4000
23.	Mn (Manganese)	258.45	-
24.	Cd (Cadmium)	8.25	20-40
25.	Cr (Chromium)	44.31	750-1200
26.	Ni (Nickel)	17.23	300-400
27.	Pb (Lead)	52.13	750-1250

** Council of the European Communities, 1986.# [39]*

Table 3. Microbial and enzymatic properties of treated sewage sludge of Bhagwanpur Sewage STPs

S. No.	Parameter	Sewage sludge
1.	Bacteria (10^{-6} cfu g^{-1} soil)	42.44
2.	Fungi (10^{-4} cfu g^{-1} soil)	30.32
3.	Actinomycetes (10^{-5} cfu g^{-1} soil)	40.41
4.	Dehydrogenase (µg TPF released g^{-1} soil day^{-1})	77.23
5.	Urease (µg urea hydrolysed g^{-1} soil h^{-1})	300.00
6.	Phosphatase (µg PNP formed g^{-1} soil day^{-1})	220.00

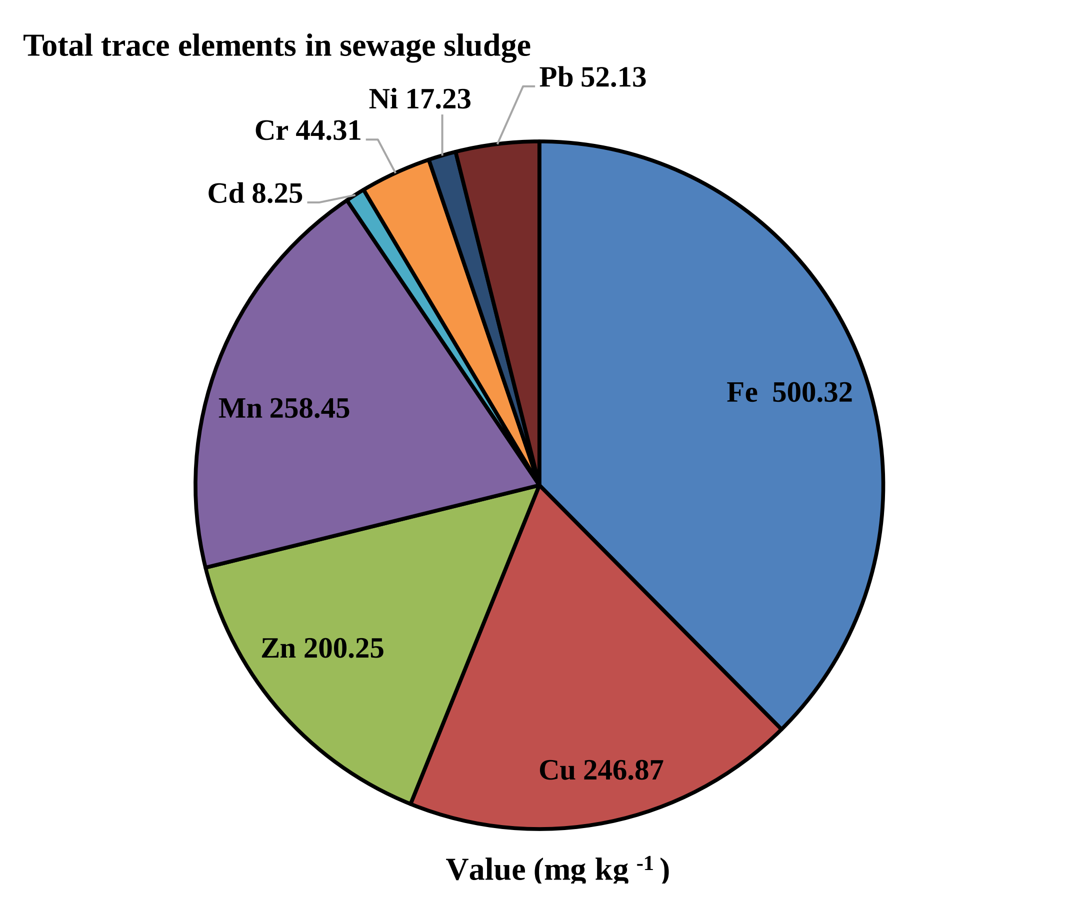

Fig. 2. Total trace elements content (mg kg^{-1}) in sewage sludge of Bhagwanpur sewage treatment plants (STPs)

The study revealed that SS has a higher population of microorganisms i.e., bacteria, fungi and actinomycetes. Regarding the biological properties of sludge which has the bacteria population 42.44×10^{-6} cfu g^{-1} soil, fungi population 30.41×10^{-4} cfu g^{-1} soil and actinomycetes population 39.20×10^{-5} cfu g^{-1} soil. The enzyme activity of sludge revealed that dehydrogenase activity was 77.23 µg TPF released g^{-1} soil day^{-1}, urease activity 300 µg urea hydrolyzed g^{-1} soil h^{-1} and phosphatase activity 220 µg PNP formed g^{-1} soil day^{-1} respectively (Table 3). It is clearly evident that the applications of SS in the soil is not only helpful in improving the microbial population but also the enzymatic activity of soil. The study of SS shows that the Bhagwanpur STPs could be used for improvement in soil health, and our findings are in line with the findings of [40]. The based of chemical composition, physical and biological sewage sludge is appropriate for application in agriculture in short term.

4. CONCLUSION

Bhagwanpur SS is rich source of nutrient with organic matter. Therefore, it could be a good source of nutrients for soil health. However, it should be used safely and continuous use of SS in the field should be avoided. The present sludge could be an option as an organic source for a nutrient that can be applied where humans generally do not prefer direct consumption. Proper soil testing and sludge testing should be done for proper risk management of sludge application in the soil.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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