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Heavy metal contaminated sewage sludge and agriculture: An environmental concern

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Abstract

Heavy metals enter the environment through various activities which affect the soil fertility, microbial activity and plant growth. To monitor the heavy metal pollution in soil, a number of parameters including microbial biomass, basal respiration and enzyme activities are used as indicators. Significance and drawbacks associated with long and short term application of sewage sludge on soil properties and crop health under variable environmental conditions are main aspects of this article.

Keywords: Heavy metal, Sewage sludge, Crop health

Introduction

A lot of waste water is generated in day to day activities. Treatment of this waste involves primary treatment for removal of suspended material by sedimentation resulting in production of primary sludge, while secondary treatment involves biological (both aerobic and anaerobic) treatment and formation of secondary sludge. These processes are affected by various environmental conditions i.e. temperature, pH, nutrients, trace elements etc. Thus sludge consist of waste slurry (upto 95% moisture) containing large amount of suspended solids (Pathak *et al.*, 2009). These solids include both original suspended solids and newly formed suspended solids from dissolved solids during treatment process. Sludge can be subjected to various treatments. The water content is decreased followed by stabilization so as to return to nature with minimum environmental problems. As per report on "Environmental, economic and social impacts of the use of sewage sludge on land" prepared for the European Commission in 2008, the total quantities of sludge production in the 27 countries of EU (EU27) are presently estimated at 10.13 million tons (dry solids), which is likely to increase to 13.0 million tons in 2020. The total solid content of the sludge varies from 0.83-12.0 %, while volatile solids constitute 30-88% of total solids. In addition, phosphorous (0.8-11%), potassium (0.4-3.0%), silica (10-20%) and protein (15-41%) of total solids, are constituent of sludge. Organic matter is present at concentration of 200-2000 mg/litre HAc. Calcium, magnesium and sulphur are present, but to lesser extent. The microbial load consists of coliforms, *Streptococci*, *Salmomella* and other microbes (Rulkens, 2003). As sludge is rich in nitrogen (26000-38700 mg/kg of dry sludge solids), phosphorous (13400-14400 mg/kg of dry sludge solids) and other useful organic matter finds its application in agriculture (Nandakumar *et al.*, 1998; Pathak *et al.*, 2008). In addition to this, two major groups of pollutants are present in sludge; organic pollutants including PAH, PCNB, dioxins etc., while metal toxic elements includes Cadmium (Cd), Copper (Cu), Nickle (Ni), Lead (Pb), Zinc (Zn), Mecury (Hg) *etc*. The sources of various pollutants in the waste water are represented in Figure 1.

Table 1 describes the various methods of disposal of sludge. In European union, nearly 40% of total sludge is estimated to be spread on land for agricultural use.

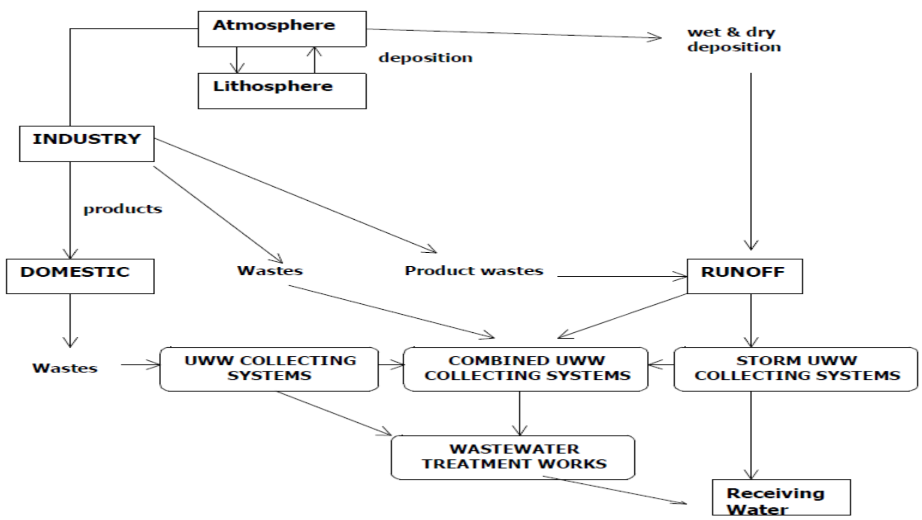

Figure 1: Sources of pollutants in wastewater (after Lester, 1987).
(*Source: http://ec.europa.eu/environment/waste/sludge/pdf/sludge_pollutants_xsum.pdf*).

Table 1 Disposal of sewage sludge.

Sr No.	Application	Significance	Drawbacks	Reference
1	Incineration	Reduced volume, detoxification	• Air discharge, (particles, greenhouse gases, heavy metals • Problem of odour	Petersen *et al.*, 2003
2	Landfilling	mono-deposits/ mixed-deposits	• Operational requirements, • Emission of green house gases, carbon dioxide etc. • Odour problem	Rovira *et al.*, 2011
3	Land spreading	Agricultural benefits	• Concentration of heavy metals or other toxic matters • Pathogen risk to human, animals and plants	Rauch and Becker, 2000

Heavy metals composition in sewage sludge and its toxicity

Heavy metal is group of metals/metalloids with high specific weight and is natural components of the earth's crust (Hashima *et al.*, 2011). Most common heavy metals occur in sewage sludge are arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn), and the metal concentrations depends on the type and intensity of the industrial activity, and type of process employed during the sewage sludge treatment (Basta *et al.*, 2005; Alvarez *et al.*, 2008). The concentration of heavy metals in the sludge is approximately 0.5-2% on dry weight basis, however higher levels (6%) were observed in some cases (Lester *et al.*, 1983). Level of heavy metals in sewage sludge and regulatory limits in soil are compiled in Table 2 and 3. Toxicity of metals may depend on synergistic or antagonistic interactions. For example, Zn and Cd may have different effects based on their concentrations and investigated target (Adriano, 2001).

Table 2: Heavy metals in sewage sludge in India.

Sr No.	Metal	Concentration (mg/kg of dry sludge solids)
1	Cu	280-543
2	Ni	192-293
3	Zn	870-1510
4	Cr	102-8110
5	Cd	41-54
6	Pb	91-129

(Reference: Singh et al., 2004. Pathak et al., 2008)

Metals in combination have more adverse effect on soil microbial biomass and activity (Chander *et al.*, 1995; Khan and Scullion, 1999) as compare to single metals at high concentrations.

Table 3: Soil concentration ranges and regulatory guidelines for some heavy metals.

Sr No.	Metal	Soil Concentration Range (mg/kg)	Regulatory limits (mg/kg)
1	Pb	1.00-69000	600
2	Cd	0.10-345	100
3	Cr	0.05-3950	100
4	Hg	<0.01-1800	270
5	Zn	150-5000	1500

(References: Riley et al., 1992; NJDEP, 1996)

Long-term field studies have demonstrated consistent evidence that sewage sludge application increases heavy metal concentrations in soil (Udom *et al.*, 2004; de Melo *et al.*, 2007; Nogueira *et al.*, 2008, 2010). The levels of heavy metal in tropical soils may increase considerably even in a short-time after sewage sludge application (Oliveira and Matiazzo, 2001; Marques *et al.*, 2007). Heavy metals availability and their transfer to plants, animals and humans depend on the sewage sludge quality (Katsoyiannis and Samara, 2007), amount of metal sludge, soil physico-chemical properties, the strength of element binding in the soil and the ability of a plant to regulate its uptake. Toxicity of metals from sludge in soil depends on its bioavailability, which in turns determines the suitability of sludge in soil. Metals could be present in sludge as oxides, sulphides, hydroxides and silicates or bound to organic material depending on the type of sludge, type of metal, and various treatment procedures applied. More than 90% of Zn and 40% of Cr is present in oxidizable fraction of sewage sludge, while Ni, Pb and Zn are present in reducible fraction (Fuentes *et al.*, 2004; Wang *et al.*, 2005, 2006). Decontamination of sludge from metals is reportedly carried out by various extraction processes (Fuentis *et al.,* 2004; Babel and Dacera, 2006). Cu and Zn are more strongly and effectively sorbed in soil and plants. Metals can become toxic as high volumes of sewage sludge are applied (Fjällborg and Dave, 2003). Heavy metal uptake by plants depends on the nature of the soil and plant. Most of vegetative parts of plants, especially leaves, have higher accumulation of heavy metals as compared to seeds, nuts and fruits. Accumulation of heavy metals more harmful in cereals and vegetables as these are consumed by humans and animals.

Application of sewage sludge in agriculture

1. Short term exposure

Addition of sludge in soil helps in the improvement of physical, chemical and biological properties of the soil (Speir *et al.,* 2004; Griffith *et al.,* 2005). Improvement in soil texture and water holding capacity of the soil which is favourable for the growth of the plant roots and also responsible for drought tolerance by the plants (Macdonald *et al.,* 2011). Study (Bertoncini *et al.,* 2008)) has shown the enhancement of soil biomass, soil organic matter (2.38%), nitrogen (0.20%), moisture (5%) and porosity (11%) and cation exchange capacity of soil. Significant increase in microbial biomass carbon, basal respiration and soil enzymatic activity is also observed (Banerjee *et al.,* 1997). Further addition of sludge may affect microbial composition of soil which in turns affect the nutrient-recycling and ecosystem functioning. Over the short term, sewage sludge application improves the soil physical (Sort and Alcaniz, 1999, Griffiths *et al.,* 2005) and chemical (Speir *et al.,* 2004) condition and promotes microbial growth and activity (Debosz *et al.,* 2002, Garcia-Gil *et al.,* 2004). This significance may overcome the negative effect of heavy metals and other organic pollutants. Kizilkaya and Bayrakli (2005) studied the effect of sewage sludge adding different doses (0-300 t/ha) and C:N (3:1-9:1) on enzyme activities in a clay loam soil and found a rapid increase in these parameters. Sewage sludge also significantly increased the available heavy metal contents in soil. However the presence of available metals due to the addition of sludge at all doses and C :N ratios negatively affected all enzymatic activities in soil. Knight *et al.,* (1997) observed a decrease of soil microbial biomass and enzymatic activities as sewage sludge was added. Sastre *et al.,* (1996) and Banerjee *et al.,* (1997) also observed increased microbial activity, soil respiration and enzyme activity with sewage amended soil. Tarrason *et al.,* (2010) carried out field study on degraded Mediterranean soils to determine the effect of different types of sludge on soil microbial properties for one year duration. Both loam sand and loam soils amended with thermally dried sewage sludge showed the highest microbial basal respiration and carbon mineralization coefficient. Addition of sludge caused transient non-equilibrium in all soil microbial properties. Effect of application rates of sewage sludge and mineral nitrogen and phosphate fertilizers on As, Ba, Cd, Cr, Cu, Ni, Pb, Se, and Zn in soil and cane plant during the field study carried out by Nogueria *et al.,* (2013). The results indicated that sewage sludge addition in a tropical soil did not cause heavy metal contamination in soil and sugarcane within a short duration. It was suggested by authors that an application of sewage sludge to medium fertility tropical soil may provide beneficial quantities of plant nutrients with low risks of heavy metals. Mardomingo *et al.,* (2013) investigated application of a single high dose (160 Mg ha^{-1} dry mass) of three organic amendments namely municipal solid waste compost (MSWC), and aerobically (AES) and anaerobically digested (ANS) sewage sludge on soil microbial activity under field conditions over a one-year period. Change in microbial biomass carbon (MBC), basal respiration (BR) and metabolic quotient (MQ), and enzymatic activities was evaluated. These organic amendments produced different effects on soil microbial activity depending on the treatment and stabilization processes of the organic wastes. MSWC significantly increased the MBC, with the highest content observed in summer season. Soil microbial activity (BR, CA, DA and hydrolase activity) remained stable during the experiment duration of one-year. In soils amended with sewage sludges, the content of MBC did not increase, although significant rise was observed for BR and MQ shortly after application. The highest BR values were 23.88±13.2 and 9.28 ± 0.81 μg O2 g^{-1} h^{-1} for AES and ANS, respectively. AES and ANS treatments led to varied patterns in soil enzyme activity. In the short-term, both treatments increased the oxidoreductase enzyme activity, with maximum of CA in AES. Further application of aerobic (AES) and anaerobic (ANS) sewage sludge did not increase the microbial biomass, although it reduced the proportion of total organic carbon in soil. However, over the same period, an increase in soil basal respiration and metabolic quotient was observed thus indicating a higher activity to maintain increased energy requirement. In contrast, the application of the municipal solid waste compost (MSWC) promoted an increase in soil microbial biomass and had a positive effect on soil microbial activity throughout the experiment. This was due to the improvement of various soil properties (soil aggregation and water holding capacity).

Xue and Huang (2013) assessed the suitability of sludge compost application (0-75%) for tree peony (*Paeonia suffruticosa*)-soil ecosystems. Increase in soil microbial biomass carbon, basal respiration and enzyme activities, plant height, flower diameter, and flower numbers per plant of tree peony was observed with addition of sludge compost as compared to control. Concentration beyond 45% showed decreased or negative trend in soil properties although soil organic C, total Kjeldahl N, and total P increased with the sludge compost amendment. Soil metabolic quotient initially decreased with the increasing sludge compost application (15–45%), followed by increasing trend at compost concentration of 45–75%. With the increasing sludge compost application dosage, soil organic C, total N and P increased significantly. On the other hand, sludge compost had high EC and heavy metals, which lead to the decline of microbial biomass and activity and the inhibition of tree peony growth.

2. Long term exposure

Long term application of sewage sludge lead to accumulation of potentially toxic heavy metals through repeated sludge additions, which in turn could have a detrimental influence on soil microbial communities and their functions thereby putting question on the long term viability of sludge application on land. Long term effect of sewage sludge on soil microbial biomass is varied (DEFRA, 2005; Speir *et al.,* 2007). Microbial community composition is an important consideration as changes may alter the physiological and functional capacity of the community (Waldrop *et al.,* 2000), which could be reflected in nutrient cycling and ecosystem functioning. Long term soil metal stress reduced utilization efficiency of organic C, and inhibited nitrification and organic P mineralization, potentially causing available nutrient imbalance and soil quality degradation.

Macdonald *et al.,* (2011) studied the long term impacts of Zn and Cu enriched sewage sludge on bacterial, fungal and archaeal communities in arable and grassland soils and observed a small, but significant effect of Zn and Cu on bacteria, archaea and fungi. Although the metal effects were comparatively weak as compared to effect of site. Microbial communities demonstrated dose related effects implying a progressive change in community structure in response to increasing metal concentrations as reported by other workers (Frostegard *et al.,* 1993; Macdonald *et al.,* 2008). Earlier Giller *et al.,* (1998) reported a decrease in soil microbial biomass C as a result of long term exposure of heavy metals, whereas other studies indicated that microbial biomass carbon may not be a reliable indicator of metal stress (Vig *et al.,* 2003; Gil-Sotres *et al.,* 2005). In Li *et al.,* (2009) experiment of long term acid metal contaminated soils, microbial biomass was very low compared to unpolluted acid soils in China suggesting microbes had been inhibited. Toxic metals can cause protein denaturation or damage to the integrity of microbial cell membranes, consequently influence their growth, morphology and metabolism (Leita *et al.,* 1995). Poulsen *et al.,* (2013) established a long-term field trial and found significant affect on the soil organic matter (SOM) C content, basal CO_2 respiration and soil microbial biomass (MB) C. All soils with organic fertilizer had higher MBC than those with no added fertilizer (unfertilized and unfertilized) and inorganic fertilizer. Treatments with increased levels of household waste and sewage sludge had the highest number of heterotrophic bacteria. Sole carbon source utilization indicated a strong microbial community in the treatments. Cumulative input of heavy metals to be less than eco-toxicological limits. This study indicated the possible use organic urban waste for an extended period on a given site. In an another study, microbial biomass was not increased for sludge addition as compared to control (Odlare *et al.,* 2008), while an increase was observed for manure and sludge in a field study with amendment for 30 years (Marschner *et al.,* 2003) and also in a long term study compost and manure (Garcia-Gil *et al.*, 2000). Studies have also indicated beneficial short to medium term effects on the microbial communities. Roig *et al.*, (2013) observed the systematic and periodical use of anaerobically digested sewage sludge for 16 years. The results showed that the input of sludge enhanced soil properties were dependent on application doses and frequency. However, beyond a maximum dose (40 Mg ha^{-1} $year^{-1}$), soil properties showed no improvement The studies showed an increase acidity of the soil exchange complex, better soil organic matter (C and N) and microbial activity and nitrogen mineralization. Some Cd toxicity was observed in the phyto-toxicity test. Sewage sludge amendment (40 or 80 Mg ha^{-1} $year^{-1}$) was not toxic for C mineralization microorganisms. The results indicated that adding addition of sewage in small doses along time is better than single applications. It increased soil fertility and minimized the negative environmental impacts.

Conclusion

Studies have concluded the significant and harmful effect of the metal contaminated sewage sludge depending upon various factors. There is need for decreasing metal content in waste which could be done by low domestic discharge of metals, public awareness and proper waste disposal methods. Future research should be concentrated on identifying specific sources of toxicity and identifying specific group of microbes affecting soil properties and activities. New methods should be developed to monitor soil metal pollution and bioremediation.

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