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Detoxification of Sewage Sludge by Natural Attenuation and its Application as a Fertilizer-A Review

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A B S T R A C T

Sewage sludge generated from the waste-water treatment systems can play an essential role as fertilizers in the agriculture system. Sewage sludges have hazardous toxic materials; therefore, their application is minimal. Proper dumping of sludge produced via waste-water treatment plants (WWTP) has been categorized as severe ecological trouble and a feasible option to be used in farming formerly sewage sludge is affluent in natural substance and nutrients. On the other hand, sewage sludge contains various toxic agents therefore special attention is required for its application in farming to evade any harm to the organisms as well as to the environment. Controlled and well monitored process of natural attenuation (biological, physical, and chemical processes) which is a part of the environment can detoxify the toxic substances present in the sewage sludges. This review will lead the readers towards the assessment of different processes used for the decontaminating sewage sludge naturally.

Introduction

Sewage sludge

Industrial/municipal waste-water treatment process generates a semi-solid byproduct known as sewage sludge/septage. The sludge from simple waste-water treatment called "septage" generally combined with sanitation system within the set up. In this process of on-the-spot sanitation, 50-55% of suspended solids are primarily removed in the settling tank within one hour. The solid waste material that are collected at this stage are termed as "fresh" until they are treated anaerobically. The sludge will turn into putrescent within little period by anaerobic bacteria and should be eliminated from the sedimentation tank prior to this process.

The on-site sanitation process constitutes of two major steps. Firstly, constant removal of sludge from the base of tank with the help of mechanical scraper and secondly, digestion using highly active anaerobic microbes that initiates process of liquefaction and condensing of the sludge. The Imhoff tank and lower digestion chamber are connected together wherein the settled sludge moves and get degraded with the help of anaerobic microbes. Primary settling step is followed by secondary treatment where sludge is usually exposed to both aerobic and anaerobic microorganism at room and high temperature. After that, the result is called "digested" sludge for an extended period and could be disposed of by drying and then landfilling.

Amount release

The total sewage sludge generated is equal to the quantity of treated waste-water, which depends upon method implemented for waste-water treatment and its quantity is calculated and expressed as kg/m^3 of total waste-water treated. Total quantity of sludge from waste water treatment plant is evaluated by summarizing sludge from primary settling tanks plus surplus sludge expelled out from the biological treatment process.

Contaminations

Wastewater comprises of very broad-ranging contaminants including complex organic matter, N-rich compounds, P-rich compounds, and pathogenic microbes like protozoa, bacteria and viruses. These contaminants may even include pollutants like Synthetic organic compounds, inorganic compounds, microplastics, sediments, radioactive substances, oil etc. The categories that broadly defines the pollutant components are physical, chemical, and biological. The load and concentration of particular pollutants majorly depends on the actual source of wastewater. Some common pollutants are described in this section.

Pathogens

Three broad categories of microbes that are part of the waste water treatment process comprises of Aerobic, anaerobic and facultative microbes. The microbes that are associated with waste water possess high risk of pathogenicity for humans. Apart from bacterial species, other common pathogens include viruses, parasitic protozoans, and helmints (Cai and Zhang, 2013).

Sources of Pathogens in wastewater may include:

Microbe type - Common source

Faecal pathogens - Human/animal fecal wastes

Enteric pathogens - Household waste like bathing and laundry (Gerardi *et al.*, 2010)

Zoonotic enteric pathogens - Livestock and poultry waste (Gerardi *et al.*, 2010)

The table below highlights list of some common pathogens and their ill effect on human health **(**Ashbolt, 2004; Gerba and Smith, 2005)

The microbial contaminants raise issue in this process when certain microbes of class A sludge products re-grow in certain favorable ecological

conditions (Keller *et al.*, 2002). Their presence may sometime remain unnoticed in raw sewage sludge (Lewis and Gattie, 2002). The problem is minor and harmless for human health if process is highly efficient and regular monitoring of potential regions are carried out (Harrison and Oakes, 2003).

Micro-pollutants

Micro-pollutants are composites that are usually present at very low level expressed as µg/L and mg/Kg in the water and soil system, which causes serious ecological problems. They can turn into more concentrated sewage sludge. These removal decisions with several perspectives established some human health and ecological problems. Several workers reported that endocrine-disrupting compounds, pharmaceuticals, and per-fluorinated organic micro-pollutant compounds are found in sewage sludge samples worldwide at the level ranging up to hundreds of mg/Kg of dehydrated sludge (Arvaniti and Stasinakis, 2015). Sterols and other hormones have also been observed.

Heavy metals

Several workers reported that sewage sludge contain high concentration of heavy metal (lead, thallium, arsenic, cadmium, etc.) after treatment process. Various chemical methods like leaching can cut the metal level and get the permissible limit (Turek *et al.*, 2005).

Other toxic materials

The sources that dispose their waste in sewage treatment plants varies from domestic waste to hospital waste including nursing homes and effluents from industries. There are certain compounds like Polychlorinated Biphenyls (PCBs), dioxin, and brominated flame retardants that have their trace left even post treatment. A large proportion of active compounds originating from public places remain overlooked due to their little content but are toxic in nature for our environmental surroundings. Polybrominated Diphenyle Ethers (PBDEs), plasticizers, and other human evolved contaminants, medicines and personal care products are the active part of the sludge. In treated sewage sludge synthetic fiber residues and bio-solids treated soils may act as an indicator of past bio-solids application (Zubris and Richards, 2005).

The permissible limit of pollutants

The governing body that defines the permissible limit of contaminants of sludge is Environmental Protection Agency Act 1992 (EPA). Sludge pollutant are composed of organic matter and inorganic matter as well as their mixture, also it may contain pathogenic organism.EPA reports have underlined the major reasons of health issues like abnormal behavior, tumor, gene mutation, different kind of diseases, faults in reproduction system, physical and physiological and malformation, effect on offspring and sometimes even death.

Treatment of Sewage sludge

Sewage sludge treatment is a process of removal of sludge and monitor it at regular intervals to control the amount of sludge produced through the treatment plant. The major constituents of sewage are water with small proportion of solid particulates. Primary sludge comprises settleable solids eliminated during immediate treatment process in primary clarifiers. Treated sewage sludge from the secondary treatment bioreactors is separated in the secondary clarifiers (fig.1). Oxification and treatment of sludge is paying attention to dropping sludge mass and volume to decrease removal expenditure and on falling possible health threats of discarding alternatives. The primary effort in sludge treatment is to reduce the volume of water and remove the pathogens from it.

Pathogen removal is commonly achieved by warming in thermophilic digestion, composting, or incineration. The selection of a sludge treatment is varied due to sludge volume produced and the assessment of treatment overheads essential for accessible removal alternatives. In rural areas air-

drying and composting is very promising and attractive event for the sludge treatment. Simultaneously, inadequate land accessibility may compose aerobic digestion and mechanical dewatering appropriate for urban, and economies of scale may promote energy recovery choices in urban regions.

During anaerobic digestion process, methane gas is generated due to which energy production process is elevated but the energy is yet not enough to promote water evaporation from sludge. Neither it is adequate for processes like running power blowers, pumps, or centrifuges used for dewatering.

The particulate matter collected in the primary and secondary sludge may contain some harmful substances. These substances get accumulated in clarifier by sorption of all toxic material from liquid on the solid surface. These substances tend to be recovered in the sludge in attempts to reduce volume of sludge.

Treatment methods

Thickening

Sludge treatment process is initiated by process of thickening. After primary or secondary treatment sludge may be moved to larger region for rapid settlement process. The thickness of the primary sludge maintained on 8-10% solids, though secondary sludge may be condensed upto 4-5%.

Thickeners are frequently similar to a clarifier due to stirring mechanism. Thickened sludge having10% solids May get further sludge treatment though liquor thickener spill over is go back to the sewage treatment process.

Dewatering

By using the centrifugation, filtration, and evaporation process the water content of the sludge can be minimized. These methods minimize transportation overheads of removal and improve composting process. Centrifugation might be the first step to decrease volume of sludge, followed by filtration and evaporation. Sand drying bed and belt filter press (mechanical process) methods are used for filtration. After filtration, the filtered material and cent rate are further undergo for sewage treatment. In dewatering proceed the sludge is became solid having 50-75% water content.

Sidestream treatment technologies

After thickening and dewatering process two products are generated. One is thickened/dewatered sludge and other is liquid fraction. This liquid needs additional treatment because it contained higher amount of nitrogen and phosphorus when sludge is treated an-aerobically in the sewage treatment plant or as a separate procedure.

Phosphorus recovery

Dewatering streams is also applied for phosphorus recovery process. One more advantage of sewage treatment is that it decreases disruptive struvite scales in pipes, pumps, and valves. These hindrances could be a repair problem mainly for natural nutrient elimination plants where the P-content is high.

Several measures have been implemented to prevent phosphorus's chemical precipitation in the fluidized bed reactor. This helps to recuperate the pellets rich in phosphorus in crystalline form during dewatering step of sludge. This products termed as “Crystal Green” are used for various purposes like in agriculture, as ornamental plant farm as fertilizer.

Digestion

Sludges treated by several digestion methods to decrease the quantity of organic matter and pathogenic microbes of the solids. The three most common treatment methods include anaerobic and aerobic digestion, composting. Sludge digestion recommends considerable expenditure compensation via falling sludge mass upto 50% and producing biogas as a precious energy resource.

Anaerobic digestion

In this process, thermophilic and mesophilic anaerobic bacteria are used at higher temperature. In thermophilic digestion, the sludge is fermented in tanks at 55°C, and in mesophilic, the temperature is around 36°C for shot incubation time. Digestion at higher temperature is more costly due to high consumption of heat for warming the sludge. In Mesophilic Anaerobic Digestion (MAD), sludge is fed into big container and detained for approx. two weeks to set aside the digestion process. Four different stages like hydrolysis, acidogenesis, acetogenesis, and methanogenesis are essential to digest the sludge. After complete digestion, the complex proteins and sugars are converted into simple H_2O, CO_2, and CH_4 compounds.

Methane gas produced during anaerobic digestion is one of the most beneficial processes as the energy generated from methane is applied for several processes like heating of tank, running of engines and micro-turbines. Some of its disadvantages includes its long time period requirement which is upto 30 days and cost-competitive. Larger areas consume the biogas for combined heat and power, using the generators' cooling water to keep the digestion plant's temperature essential 35 ± 3°C. Enough energy can be produced in this method to generate more electricity than the machines involved.

Aerobic digestion

Aerobic digestion involves aerobic bacterial system for this purpose. Bacterial cultures are quickly degraded organic compounds into simple CO_2 compounds in the presence of oxygen. During this process endogenous respiration occur when organic matter is depleted and some bacterial culture become die which utilized as nutrients by other bacteria. Solids matter of sludge decline in this stage. Aerobic digestion is a cost-effective process because it consumes less time when compared with anaerobic digestion. But the compensation of time is compromised by the expense required for running of blowers, pumps, and motors additionally to supply oxygen for the process. Thus, making the operating charges of aerobic digestion more than anaerobic digestion. Although, this issue has been resolved with introduction of non-electric aerated filter systems that utilize natural air currents, hence electrically operated system is omitted.

Composting

Composting is process of sewage sludge where biological agents like bacteria are used in combination to some very common agricultural wastes viz., sawdust, straw, wood chips, corn cobs, nutshells, shredded tree-pruning waste, or bark from lumber or paper mills. Bacterial cultures degrade the sludge under aerobic conditions, where the heat produced during the process also eliminates all kind of pathogenic microbes and parasites. Throughout the process, oxygen level is maintained between range of 10-15%. The temperature of chamber is maintained by using an insulating blanket of earlier composted sludge over aerated composting piles.The compost pile temperature is crucial for proper functioning of microbes, changes in the composition of microbes in compost pile vary as the temperature rises to mesophilic phase then to thermophilic phases and then temperature gradually falls completing the process of composting. Most of the microorganisms are destroyed during the thermophilic phase. The microorganism composition changes in the compost pile and therefore their requirement of oxygen level and moisture content also changes. The parameters, compost moisture content, O2 and CO2 level in the compost pile and temperature of compost pile are all interrelated and therefore regulated accordingly. Variation in any one of them causes variation in all. Air supplied for oxygen level is at a rate such that it fulfils the moisture content requirement. Higher moisture level requirements need high rate of air. Air supply also causes heat loss that result in a temperature reduction within the compost pile. This in turn lowers the rate of microbes functioning. A proper monitoring of oxygen, carbon dioxide and air is needed for efficient functioning of the plant. It is

preferred to have automated system of air regulation where air supply starts if CO2 drops below 8%.

Drying beds

Drying is the final stage of the process and requisite of this step are not clearly defined; therefore, some developing countries implement cost effective method. A simple drying bed is used where no provisions are made to drain excess water or turn over the residues. While a more sophisticated systems are available with mechanical devices to turn over the sludge when they are too wet and also water draining facility. Drying beds are constitutes of four layers with gravel and sand. Top layer of the bed is 15-20 cm thick and made up of coarse gravel. Followed by 10 cm thick layer of fine stone, then is a sand layer that acts to filter the sludge from gravel layer. This sand layer has a thickness of 10-15 cm. On the drying bed, the sludge dries up as water keeps percolating at each stage and drained off from the pipes beneath all the layers.

Emerging technologies

One of the most promising roles of a byproduct of sewage treatment plants are Phosphorus rich fertilizers. Countries like Sweden, Germany and Canada are producing reasonably good amount of phosphorus rich fertilizers from sewage plants and are supplying it worldwide. The process of phosphorus extraction from sludge or waste water depends upon type of sludge and also on the process employed like precipitation method, wet-chemical method or thermal treatment. One example of advancement in this area is Omni Processor. A method which is yet to be developed completely, here, sewage sludge can be used to produce good amount of electricity. One pre-requisite of the method is that the sludge must have attained appropriate stage of dryness. Another example is production of hydrocarbons by thermal de-polymerization process where sludge is heated to 250 ℃ and then compressed to 40 Mpa. This process comprises of two steps, firstly, high-pressure boiling and secondly rapid decompression. Sludges of this method are then sterilized which raises the biodegradable activity by killing the pathogens. Sludges can then be used for agricultural processes. Europe, China and America are some countries which use sludges for producing electric power.

Natural attenuation

Bioremediation is a process where microbes residing in an environment are used to degrade the toxic pollutants and clean the environment by a natural process. This process is also called "Natural attenuation". The location for natural attenuation depends first a quick assessment of the location and marking their endpoint. It is a two-step process, firstly Bio stimulation is carried out where synthetic nutritive material and growth promoting chemicals are added to enhance the native microbial growth. Secondly, Bio-augmentation process is carried out in which exogeneous microorganisms are added to enhance the degradation process. Bioremediation process promotes growth of native microorganisms and gradually growth explosion of stimulated as well as inoculated microorganisms.

Advancements in recent techniques of Molecular biology, study on gene responsible for degradation of pollutants, metagenomics have opened new ways in exploring the bioremediation process. Sewage sludge (SS) is a type of semi-solid material that are resultant of sewage treatment from industrial waste. Its composition is varied depending on the source, it may consist of organic material, Nitrogen, Phosphorus, Potassium, Calcium and magnesium. Since, they are very rich in essential elements, they are extensively used in agriculture as fertilizers. Apart from this, they are also used in soil to retain its nutritive composition (Sánchez-Brunete *et al.*, 2007).

Sludge used in agricultural activities are not only cost effective but also eco-friendly. There production in urban areas has gained pace in recent years (Bright and Healey, 2003). Major drawback associated with sludge used for agricultural purposes

are pollutants present in it. Components like metals, harmful organic compounds and pathogenic microbes are cause major issues (Holmstrup *et al.,* 2001; Tsakou *et al.,* 2001). Sludge used during agriculture activities need proper care and understanding to prevent any kind of harm to the soil or human (Clarke and Smith, 2011). The sludge usage if it is contaminated with organic pollutants, metals and pathogens can be hazardous to the soil and its biodiversity (Tas, 2010). The resultant effect could be on the complete food chain, making the deleterious effect to be permanent (Roig *et al.,* 2012). The problem severity is much higher if disease spreading pathogens or toxic compounds get percolated to the superficial and subterranean waters (Keller *et al.,* 2002). In consideration to its eco-friendly nature and its wide applications, worldwide efforts are made to develop new methods for better sewage sludge products with less or no traces of contaminants and pollutants (Tas, 2010).

The natural attenuation is a process that occurs in favorable conditions in the ecosystem, that results in reduction of the mass, toxicity, mobility, volume, or concentration of contaminants. Several physical, chemical and biological processes like biodegradation, dispersion, dilution, adsorption, volatilization, transformation causes reduction of toxicity to certain extend (USEPA, 1999a).

Evaluation of the environmental samples by chemical methods is obligatory for assessing the real time damage in the contaminated areas. This evaluation leads to information on concentration of toxic compounds in the environment but can never lead to extent of effect of contaminants on the surrounding biota (Moreira *et al.,* 2008). Bioassay are required to be conducted to determine the actual situation to extract information on actual effect of contaminants on the environment and biota (Plaza *et al.,* 2005). Benefit of bioassays over chemical assays are that the former gives actual picture of individual effect of toxic compounds, their combined effect and association of biochemical and physiological processes (Roos *et al.,* 2004). One of the common example is *Allium cepa* species that is quite commonly used to study the environmental decontamination processes and its effectiveness as it is present as suitable biomarkers of cellular and genetic damages (Mazzeo *et al.,* 2011; Souza *et al.,* 2013).

Besides establishing method for bioassays, stringent rules have also been launched that defines the concentrations that must be present in sewage sludge prior to disposing it in soil. This ensures prevention of disposal of harmful agents directly in the soil. Potential toxic substances like inorganic and organic substances (e.g., heavy metals, polycyclic aromatic hydrocarbons, halogenated organic compounds, and linear alkyl benzene sulphonates) or pathogenic microorganisms are ought to be under certain limit in the sludge. Thus, the disposal of SS in the soil must be performed following the legislation prescribed in each country, for example, Directive 86/278/EEC in Europe, Regulation 40 CFR Part 503 in the USA, and Resolution 375 of CONAMA in Brazil.

A wide range of contaminants are known to be present in sewage sludge, based on the severity, emerging pollutants and endocrine disruptors are the one that have grabbed attention of researchers. Endocrine disruptors are highly active agents and known to target living cells and disrupt proper functioning of endocrine system's functioning (Giudice and Young, 2011). Other chemical compounds tend to bind with the Estrogen Receptor (ER) at even very low concentrations that may cause infertility and reproduction issues in animals, that may gradually reach to human and express its fatal effect in population (Fatta-Kassinos *et al.,* 2011).

Table.1 Common microbial contaminants and their adverse effect on human health.

S.No.	Category	Name of pathogen	Major disease or symptoms
1	**Bacteria**	*Campylobacter jejuni*	Gastroenteritis
2		*Escherichia coli*	Gastroenteritis
3		*Salmonella* spp.	Salmonellosis, typhoid, paratyphoid
4		*Shigella* spp.	Bacillary dysentery
5		*Vibrio cholerae*	Cholera
6		*Yersinia* spp.	Gastroenteritis
7	**Viruses**	Adenovirus	Upper respiratory infection and gastroenteritis
8		Astrovirus	Gastroenteritis
9		Coxsackie virus	Meningitis, pneumonia, fever
10		Echovirus	Meningitis, paralysis, encephalitis, fever
11		Hepatitis A virus	Infectious hepatitis
12		Hepatitis E virus	Infectious hepatitis, miscarriage, and death
13		Human calicivirus	Epidemic gastroenteritis with severe diarrhea
14		Polio virus	Poliomyelitis
15		Reovirus	Respiratory infections, gastroenteritis
16		Rotavirus	Acute gastroenteritis with severe diarrhea
17		TT hepatitis	Hepatitis
18	**Protozoa**	*Balantidium coli*	Balantidiasis
19		*Cryptosporidium* spp.	Cryptosporidiosis
20		*Entamoeba histolytica*	Acute amoebic dysentery
21		*Giardia duodenalis*	Giardiasis
22		*Toxoplasma gondii*	Toxoplasmosis
23	**Helminths**	*Ascaris lumbricoides*	Ascariosis
24		*Ascaris suum*	Coughing and chest pain
25		*Hymenolepis nana*	Hymenolepiasis
26		*Necator americanus*	Hookworm disease
27		*Taenia saginata*	Insomnia, anorexia
28		*Taenia solium*	Insomnia, anorexia
29		*Toxocara canis*	Fever, abdominal pain, muscle ache
30		*Trichuris trichiura*	Diarrhea, anemia, weight loss

Table.2 Guidelines for safe limits of heavy metals (adapted from Srivastava *et al*., 2020)

Sample	Standards	Cr	Cu	Cd	Ni	Mn	Pb	Zn
Water (mg L^{-1})	FAO (1985)	0.10	0.20	0.01	0.20	0.20	5	2
	European Union Standards (EU 2002)	-	-	-	-	-	-	-
	USEPA (2000)	-	1	0.005	-	-	0.015	2
	Indian Standard (Awashthi 2000)	0.05	0.05	0.01	-	0.10	0.10	5
Soil (mg kg^{-1})	WHO/FAO (2007)	-	-	-	-	-	-	-
	European Union Standards (EU 2002)	150	140	3	75	-	300	300
	USEPA (2000)	-	50	3	-	-	300	200
	Indian Standard (Awashthi 2000)	-	135-270	3-6	75-150	-	250-500	300-600
Plant (mg kg^{-1})	WHO/FAO (2007)	-	40	0.20	-	-	5	60
	Commission regulation (EU 2006)	-	-	0.20	-	-	0.30	-
	USEPA (2000)	-	-	-	-	-	-	-
	Indian Standard (Awashthi 2000)	20	30	1.5	1.5	-	2.5	50

Fig.1 Treatment process of sewage sludge

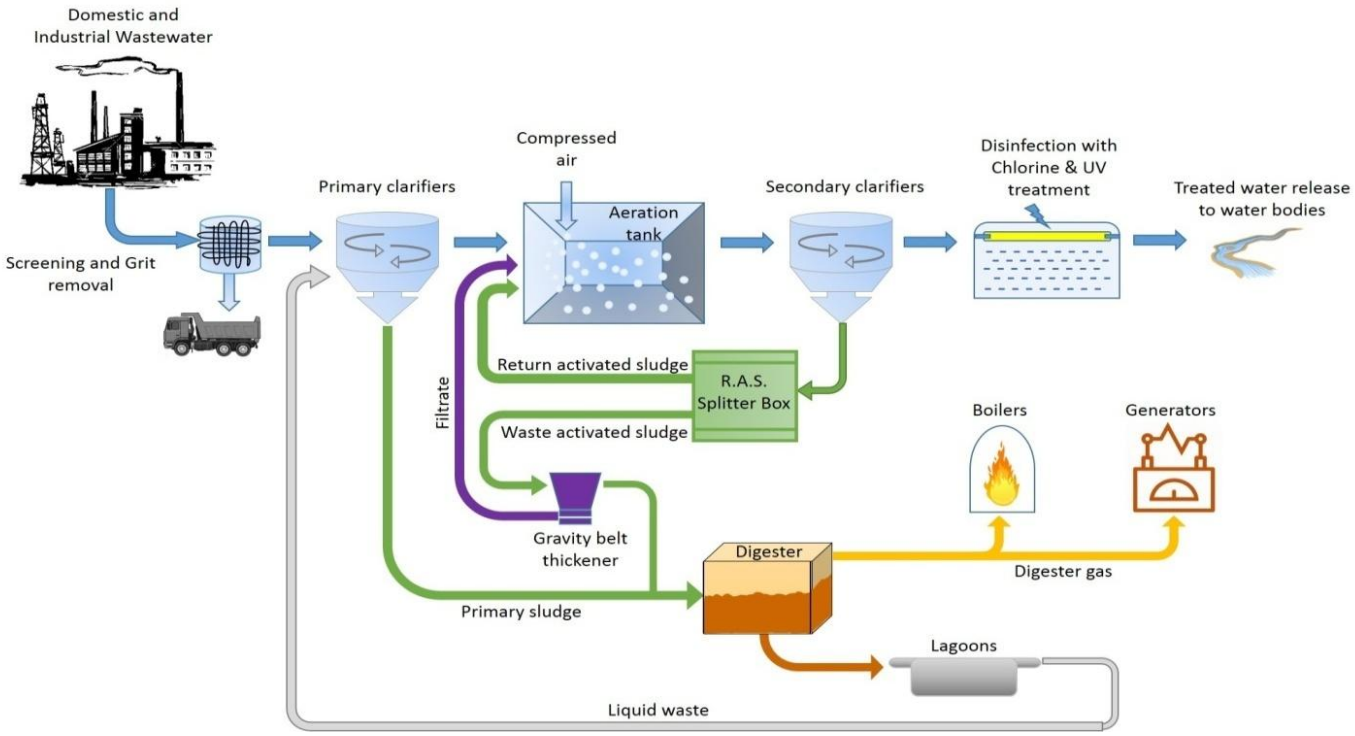

Table.3 Recommended concentration of Pollutants (mg/kg)

S. No.	Pollutant	Recommended concentration (mg/kg)
1	Zinc	7500
2	Copper	4300
3	Lead	840
4	Nickel	420
5	Selenium	100
6	Cadmium	85
7	Molybdenum	75
8	Mercury	57

Furthermore, some dioxin-like compounds are capable of interacting to Aryl hydrocarbon Receptor (AhR) and subsequently their activation (Engwall and Hjelm, 2000). This activation may lead to the initiation of step of the metabolic pathways resulting in production of toxic and very damaging contaminants like such as 2,3,7,8-tetrachlorodibenzo-(p)-dioxin (TCDD), co-planar PCBs, and benzopyrenes. Some fatal effects are immune dysfunction, endocrine disruption, reproductive toxicity, developmental defects, and cancer in vertebrates (Nebert *et al.*, 1993).

Bioassays have been reported to detect compounds against both of these receptors i.e., ER- or AhR-ligands. These are known as yeast-based assays or RYA (Recombinant Yeast Assay), they are known to be standard tools to detect ER- and AhR-binding activities in various samples and matrices (Noguerol *et al.*, 2006a; Noguerol *et al.*, 2006b).

Apart from being a major source of contaminants in soil, these sewage sludges are also known to cause contamination of water. Water is polluted by contaminants of sewage sludge by process of runoff or leaching, potentially affecting marine organisms (Eriksen *et al.*, 2009). Zebrafish embryo assays is method of choice for evaluating the toxicity of environmental samples associated with aquatic contamination due to the high sensitivity of these organisms to xenobiotics (Hallare *et al.*, 2005).

Other biomarker-based method are also available where gene specific toxic responses are analyzed by the inducing pollutant or stress associated genes. Example of marker that is used is cytochrome P450 1A gene, CYP1A, whose expression increases in zebrafish embryos (and adults) upon exposure to AhR ligands (Goksoyr and Forlin, 1992; Mcclain *et al.*, 2003; Voelker *et al.*, 2007; Olivares *et al.*, 2013). Favorable use of sewage sludge still needs refining steps prior to its use to prevent any harmful effect (Domene *et al.*, 2008; Ramírez *et al.*, 2008; Rathod *et al.*, 2009; Roig *et al.*, 2012; Tas, 2010).

Among the method specify for bioremediation of environmental toxic waste, natural attenuation (including weathering) is considered an efficient and economic pre-processing practice. Its effectiveness for eliminating several recalcitrant, vastly bioactive contaminants needs to be checked (Bhupathiraju *et al.*, 2002; Morel and Fardeau, 1990).

Application in Agriculture

Sewage sludge are very rich source of Phosphorus (P) and therefore have extensive applicability in agricultural activities. It is considered as a substitute of Phosphorus as compost. Thermally conditioned sewage sludge (TCSS) is yet to explored for their significance as P-fertilizer. Municipal sewage sludge is known as a byproduct of the metropolitan waste-water treatment process. As per the European Commission directive, treatments, including biological and heat, decrease ecological risk by restrictive water contamination, heavy metal pollution, and high pathogen concentration (Fatta-Kassinos *et al.*, 2011). Metropolitan sewage sludge generation has, hence, increased wide-reaching.

Sewage sludge is a process of obtaining the essential components of soil by recycling (Zufiaurre *et al.,* 1998). Enhancement of phosphorus content in sewage sludge by removal of pollutants and contaminants using recent technologies and furthermore it has become an alternative of fertilizer rich in phosphorus for agricultural purposes (Ahmed *et al.,* 2010; Siddique and Robinson, 2003). As the sewage sludges are high on nitrogen and phosphorus content, they will improve soil health by raising plant-available nutrients (Andrés *et al.,* 2011; Boen *et al.,* 2013; Gavalda *et al.,* 2005). Moreover, sewage sludge also plays significant role in improving soil microbial activity, soil respiration, and also enzymatic activities of soil, these effect are resultant of organic matter degradation from soil by metropolitan sewage sludge (Andrés *et al.,* 2011).

The sewage sludge increased level of microbe biomass is because of the high level of organic carbon (Singh and Agrawal, 2008). Changes in organic content causes rise in phosphorus microbial immobilization (Wang *et al.,* 2011). The usage of sewage sludge as rich source of phosphorus needs the toxic pollutants to be monitored under certain define limits.

A method named as P radiotracer is developed to determine P-availability for plants from mineral fertilizers. Method has been carried out for greenhouse trials, as diammonium phosphate (Gallet *et al.,* 2003; Morel and Fardeau, 1989; Morel and Fardeau, 1990) single super phosphate (Mohanty *et al.,* 2006; Srivastava *et al.,* 2009) KH_2PO_4 (Sinaj *et al.,* 2002), hydroxyl apatite (Ca_{10}-P) (Wang *et al.,* 2011), or triple superphosphate (TSP). The method adapts a process where it calculates exact. Therefore, this method can be considered as appropriate method for determination of P released from various sources (Armstrong *et al.,* 1993). Method of P-Radiotracer mainly focusses on filter substrate sewage sludge ash (Nanzer *et al.,* 2014), or municipal sewage sludge (Mohanty *et al.,* 2006). Whereas no such method is available for thermally conditioned sewage sludge (TCSS) by (Keller *et al.,* 2002) P-labeling.

The review highlight's significant role of sewage sludge and its end products that have extensive agricultural application and potential alternatives of chemical fertilizers. The study also emphasizes on the negative impact of residual trace metals, toxicants and microbial pathogens in sewage sludge. The diverse complex composition of SS has been point of concern assessed from several bioassays. Their direct disposal of SS to soil without removal of toxicants can lead to its. Bioremediation is one of several cost-effective methods that has scope in eliminating pathogenic microbes and other toxicant contaminants from environment. Besides having several challenges and limitations, this process has high potential to contribute towards sustainability.

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Conflict of Interest

The authors have no Conflict of Interest among them for the authorship of any kind.

References

Ahmed H K, Fawy H A, Abdel-Hady E S. Study of

sewage sludge use in agriculture and its effect on plant and soil. AgricBiol J North Am. 2010; 1:1044–1049. https://doi.org/10.5251/abjna.2010.1.5.1044.1049

Andrés P, Mateos E, Tarrasón D. *et al.*, Effects of digested, composted, and thermally dried sewage sludge on soil microbiota and mesofauna. Appl Soil Ecol. 2011; 48:236–242. http://dx.doi.org/10.1016/j.apsoil.2011.03.001

Armstrong R D, Helyar K R, Prangnell R. Direct assessment of mineral phosphorus availability to tropical crops using ^{32}P labelled compounds. Plant Soil. 1993; 150:279–287. https://doi.org/10.1007/BF00013025

Arvaniti and Stasinakis. Review on the occurrence, fate and removal of perfluorinated compounds during waste-water treatment. Sci Total Environ. 2015; 524-525:81-92. https://doi.org/10.1016/j.scitotenv.2015.04.023

Ashbolt N. J. Microbial contamination of drinking water and disease outcomes in developing regions. *Toxicology*. 2004; 198:229–238. https://doi.org/10.1016/j.tox.2004.01.030

Bhupathiraju V K, Krauter P, Holman H-Y N. *et al.*, Assessment of in situ bioremediation at a refinery waste-contaminated site and an aviation gasoline contaminated site. Biodegradation. 2002; 13:79–90. https://doi.org/10.1023/A:1020415626554

Boen A, Haraldsen T K, Krogstad T. Large differences in soil phosphorus solubility after the application of compost and biosolids at high rates. ActaAgricScand Sect B Soil Plant Sci. 2013; 63:473–482. https://doi.org/10.1080/09064710.2013.801508

Bright D A, Healey N. Contaminant risks from biosolids land application: contemporary organic contaminant levels in digested sewage sludge from five treatment plants in Greater Vancouver, British Columbia. Environ Pollut.2003; 126:39–49. https://doi.org/10.1016/s0269-7491(03)00148-9

Cai L, Zhang T. Detecting human bacterial pathogens in wastewater treatment plants by a high-throughput shotgun sequencing technique. Environ. Sci. Tech. 2013;47:5433–5441. https://doi.org/10.1021/es400275r

Clarke B O, Smith S R. Review of 'emerging' organic contaminants in biosolids and assessment of international research priorities for the agricultural use of biosolids. Environ Int. 2011; 37:226–247. http://dx.doi.org/10.1016/j.envint.2010.06.004

Domene X, Ramírez W, Mattana S. *et al.*, Ecological risk assessment of organic waste amendments using the species sensitivity distribution from a soil organisms test battery. Environ Pollut. 2008; 155:227–236. https://doi.org/10.1016/j.envpol.2007.12.001

Engwall M, Hjelm K. Uptake of dioxin-like compounds from sewage sludge into various plant species — assessment of levels using a sensitive bioassay. Chemosphere. 2000; 40:1189–1195. https://doi.org/10.1016/s0045-6535(99)00368-9

Eriksen G, Amundsen C, Berndorf A. *et al.*, Risk Assessment of Contaminants in Sewage Sludge Applied on Norwegian Soils. Norwegian Scientific Committee for Food Safety, Oslo. 2009. https://doi.org/10.9734/ejnfs/2021/v13i1130458

Fatta-Kassinos D, Kalavrouziotis I K, Koukoulakis P H. *et al.*, The risks associated with waste-water reuse and xenobiotics in the agroecological environment. Sci Total Environ. 2011; 409:3555–3563. https://doi.org/10.1016/j.scitotenv.2010.03.036

Gallet A, Flisch R, Ryser J-P. *et al.*, Nösberger J, Frossard E, Sinaj S. Uptake of residual phosphate and freshly applied diammonium

phosphate by *Lolium perenne* and *Trifolium repens*. J Plant Nutr Soil Sci. 2003; 166:557–67.

Gavalda D, Scheiner J D, Revel J C. *et al.*, Agronomic and environmental impacts of a single application of heat-dried sludge on an Alfisol. Sci Total Environ. 2005; 343:97–109. https://doi.org/10.1016/j.scitotenv.2004.10.009

Gerardi M. H, Zimmerman. John Wiley & Sons; Hoboken, New Jersey: 2010. Troubleshooting the sequencing batch reactor.

Gerba C P, Smith J E. Sources of pathogenic microorganisms and their fate during land application of wastes. *Journal of Environmental Quality*. 2005; 34:42–48.

Giudice B D, Young T M. Mobilization of endocrine-disrupting chemicals and estrogenic activity in simulated rainfall runoff from land-applied biosolids. Environ ToxicolChem. 2011; 30:2220–2228. https://doi.org/10.1002/etc.631

Goksoyr A, Forlin L. The cytochrome P-450 system in fish, aquatic toxicology and environmental monitoring. AquatToxicol.1992; 22:287–311. https://doi.org/10.1016/0166-445X(92)90046-P

Hallare A, Kosmehl T, Schulze T. *et al.*, Assessing the severity of sediment contamination in Laguna Lake, Philippines using a sediment contact assay with Zebrafish (*Danio rerio*) embryos. Sci Total Environ. 2005; 347:254–271. https://doi.org/10.1016/j.scitotenv.2004.12.002

Harrison E Z, Oakes S R. Investigation of alleged health incidents associated with land application of sewage sludges. New Solutions. 2003; 12: 387–408. https://doi.org/10.2190/0FJ0-T6HJ-08EM-HWW8

Holmstrup M, Krogh P H, Lokke H. *et al.*, Effects and risk assessment of linear alkylbenzene sulfonates in agricultural soil, 4. The influence of salt speciation, soil type, and sewage sludge on toxicity using the collembolan *Folsomia fimetaria* and the earthworm *Aporrectodea calginosa* as test organisms. Environ ToxicolChem. 2001; 20:1680–1689.

Keller C, Mcgrath P, Duham S J. Trace metal leaching through a soil–grassland system after sewage sludge application. J Environ Qual. 2002; 31:1550–1560.

Lewis D L, Gattie D K. Pathogen Risks from Applying Sewage Sludge to Land. Environ SciTechnol. 2002; 36: 286A–293A. https://doi.org/10.1021/es0223426

Mazzeo D E C, Fernandes T C C. Marin-Morales M A. Cellular damages in the *Allium cepa* test system, caused by BTEX mixture prior and after biodegradation process. Chemosphere. 2011; 85:13–18. https://doi.org/10.1016/j.chemosphere.2011.06.056

Mcclain J S, Oris J T, Burton Jr. G A. *et al.*, Laboratory and field validation of multiple molecular biomarkers of contaminant exposure in rainbow trout (*Oncorhynchus mykiss*). Environ ToxicolChe. 2003; 22:361–370.

Mohanty S, Paikaray N K, Rajan A R. Availability and uptake of phosphorus from organic manures in groundnut (*Arachis hypogea* L.)-corn (*Zea mays* L.) sequence using radio tracer technique. Geoderma. 2006; 133:225–230. https://doi.org/10.1016/J.GEODERMA.2005.07.009

Moreira R, Sousa J P, Canhoto C. Biological testing of a digested sewage sludge and derived composts. BioresourTechnol. 2008; 99:8382–8389. https://doi.org/10.1016/j.biortech.2008.02.046

Morel C, Fardeau J C. Agronomical evaluation of phosphate fertilizer as a nutrient source of phosphorus for crops: isotopic procedure. Fertil Res. 1990; 24:115–22. https://doi.org/10.1007/BF01073230

Morel C, Fardeau J C. Native soil and fresh fertilizer phosphorus uptake as affected by rate of application and P fertilizers. Plant Soil.1989; 115:123–128. https://doi.org/10.1007/BF02220702

Nanzer S, Oberson A, Berger L. *et al.,* The plant availability of phosphorus from thermo-chemically treated sewage sludge ashes as studied by ^{33}P labeling techniques. Plant Soil. 2014; 377:439–456. https://doi.org/10.1007/s11104-013-1968-6

Nebert D W, Puga A, Vasiliou V. Role of the Ah receptor and the dioxin-inducible [Ah] gene battery in toxicity, cancer, and signal transduction. Ann N Y AcadSci. 1993; 685:624–640. https://doi.org/10.1111/j.1749-6632.1993.tb35928.x

Noguerol T N, Boronat S, Casado M. *et al.,* Evaluating the interactions of vertebrate receptors with persistent pollutants and antifouling pesticides using recombinant yeast assays. Anal BioanalChem. 2006a; 385:1012–1019. https://doi.org/10.1007/s00216-006-0476-4

Noguerol T N, Boronat S, Jaque S. *et al.,* Detection of hormone receptor ligands in yeast by fluorogenic methods. Talanta. 2006b; 69:351–358. https://doi.org/10.1016/j.talanta.2005.09.044

Olivares A, Van Drooge B L, Casado M. *et al.,* Developmental effects of aerosols and coal burning particles in zebrafish embryos. Environ Pollut. 2013; 178:72–79. https://doi.org/10.1016/j.envpol.2013.02.026

Plaza G, Nalecz-Jawecki G, Ulfig K. *et al.,* The application of bioassays as indicators of petroleum-contaminated soil remediation. Chemosphere. 2005; 59:289–296. https://doi.org/10.1016/j.chemosphere.2004.11.049

Ramírez W A, Domene X, Ortiz O. *et al.,* Toxic effects of digested, composted and thermally-dried sewage sludge on three plants. BioresourTechno. 2008; l 99:7168–7175. https://doi.org/10.1016/j.biortech.2007.12.072

Rathod P H, Patel J C, Shah M R. *et al.,* Recycling gamma irradiated sewage sludge as fertilizer: a case study using onion (*Allium cepa*). Appl Soil Ecol. 2009; 41:223–233. https://doi.org/10.1016/j.apsoil.2008.11.001

Roig N, Sierra J, Nadal M. *et al.,* Relationship between pollutant content and ecotoxicity of sewage sludges from Spanish waste-water treatment plants. Sci Total Environ. 2012; 425:99–109. https://doi.org/10.1016/j.scitotenv.2012.03.018

Roos P H, Tschirbs S, Pfeifer F. *et al.,* Risk potentials for humans of original and remediated PAH-con. 2004.

Sánchez-Brunete C, Miguel E, Tadeo J L. Analysis of 27 polycyclic aromatic hydrocarbons by matrix solid-phase dispersion and isotope dilution gas chromatography–mass spectrometry in sewage sludge from the Spanish area of Madrid. J Chromatogr A. 2007; 1148:219–227. https://doi.org/10.1016/j.chroma.2007.03.026

Siddique M T, Robinson J S. Phosphorus sorption and availability in soils amended with animal manures and sewage sludge. J Environ Qual. 2003; 32:1114–1121. https://doi.org/10.2134/jeq2003.1114

Sinaj S, Traore O, Frossard E. Effect of compost and soil properties on the availability of compost phosphate for white clover *Trifolium repens* L. NutrCyclAgroecosyst. 2002; 62:89–102. https://doi.org/10.1023/A:1015128610158

Singh R P, Agrawal M. Potential benefits and risks of land application of sewage sludge. Waste Manag.2008; 28:347–58. https://doi.org/10.1016/j.wasman.2006.12.010

Souza T S, Hencklein F A, Angelis D F, Fontanetti C S. Clastogenicity of land farming soil treated with sugar cane vinasse. Environ Monit Assess. 2013; 185:1627–1636. https://doi.org/10.1007/s10661-012-2656-3

Srivastava P C, Singh A P, Kumar S. *et al.,* Efficacy

of phosphorus enriched post-methanation bio-sludge from molasses based distillery as P source to rice and wheat crops grown in a Mollisol: I. laboratory and greenhouse evaluation with ^{32}P-labeled sources. Geoderma.2009; 149:312–317. https://doi.org/10.1016/j.geoderma.2008.12.019

Srivastava V, Vaish B, Singh A, Singh R. P. Nutrient recovery from municipal waste stream: status and prospects. *Urban Ecology*. 2020; 265-297. https://doi.org/10.1016/B978-0-12-820730-7.00015-X

Tas D O. Respirometric assessment of aerobic sludge stabilization. BioresourTechnol. 2010; 101:2592–2599. https://doi.org/10.1016/j.biortech.2009.10.058

Tsakou A, Roulia M, Christodoulakis N S. Growth of cotton plants (*Gossypium hirsutum*) as affected by water and sludge from a sewage treatment plant: II. Seed and fiber yield and heavy metal accumulation. Bull Environ ContamToxicol.2001; 66:743–747. https://doi.org/10.1007/s00128-001-0071-5

Turek M, Korolewicz T, Ciba J Removal of Heavy Metals from Sewage Sludge Used as Soil Fertilizer. Soil SediContami. 2005; 14: 143–54. https://doi.org/10.1080/15320380590911797

USEPA—United States Environmental Protection Agency Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites. Office of Solid Waste and Emergency Response, Washington, DC. 1999a.

Voelker D, Vess C, Tillmann M. *et al.*, Differential gene expression as a toxicant-sensitive endpoint in zebrafish embryos and larvae. AquatToxico 2007; l 81:355–364. https://doi.org/10.1016/j.aquatox.2006.12.013

Wang X, Guppy C N, Watson L. *et al.*, Availability of sparingly soluble phosphorus sources to cotton (*Gossypium hirsutum* L.), wheat (*Triticum aestivum* L.) and white lupin (*Lupinus albus* L.) with different forms of nitrogen as evaluated by a ^{32}P isotopic dilution technique. Plant Soil 2011; 348:85–98. https://doi.org/10.1007/s11104-011-0901-0

Zubris K A V, Richards B K. Synthetic fibers as an indicator of land application of sludge. Environ Pollut 2005; 138: 201–11. https://doi.org/10.1016/j.envpol.2005.04.013

Zufiaurre R, Olivar A, Chamorro P. *et al.*, Speciation of metals in sewage sludge for agricultural uses. Analyst 1998; 123:255–259.

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