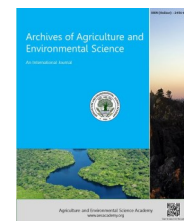




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## REVIEW ARTICLE

**A review on sewage sludge (Biosolids) a resource for sustainable agriculture**Vinod Kumar<sup>1\*</sup>, A.K. Chopra<sup>1</sup> and Ajendra Kumar<sup>2</sup><sup>1</sup>Agro-ecology and Pollution Research Laboratory, Department of Zoology and Environmental Science, Gurukula Kangri Vishwavidyalaya, Haridwar-249404 (Uttarakhand), INDIA<sup>2</sup>Department of Mathematics and Statistics, Gurukula Kangri Vishwavidyalaya, Haridwar-249404 (Uttarakhand), INDIA\*Corresponding author's E-mail: [drvksorwal@gkv.ac.in](mailto:drvksorwal@gkv.ac.in)**ARTICLE HISTORY**Received: 11 August 2017  
Revised received: 16 October 2017  
Accepted: 12 November 2017**Keywords**Agricultural uses  
Biosolids  
Biogas  
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Soil amendment  
Sustainable development**ABSTRACT**

Sewage sludge (Biosolids) generation is fastly increasing resulting from the regular increase of population, urban planning and industrial developments worldwide. The sludge needs to be adequately treated and environmentally managed to reduce the negative impacts of its application or disposal. The present review deals with the different applications of sewage sludge for sustainable agriculture. The scattered literature is harnessed to critically review the uses of biosolids to promote sustainable practices focusing on the productive uses of sewage sludge or biosolids. Biosolids or sewage sludge is the byproduct of municipal wastewater, sewage effluent and effluent treatment plants. The treatment plants are generating huge amount of biosolids. The present review focuses on the different applications of biosolids or sewage sludge as in many countries the biosolids or sewage sludge are frequently using for various purposes like for biogas production, land filling, organic fertilizer, soil amendment, and to enhance the crop yield of agricultural crops. Therefore, biosolids or sewage sludge is in the consideration as a resource worldwide. Besides this higher content of different heavy metals and microorganisms are the important constraints for the application of biosolids or sewage sludge in the various fields. Thus, this review emphasizes the different applications and possible limitations for the use of biosolids or sewage sludge as a resource. Efforts have been made on the possible pretreatment of biosolids or sewage sludge to make it more feasible for their applications. Therefore, different properties of biosolids or sewage sludge, their applications along with possible limitations have been discussed in the present review to formulate the biosolids or sewage sludge as a resource for the sustainable development.

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**INTRODUCTION**

Sewage sludge (also known as biosolids) is defined as the residual, semi-solid substance that is produced as a by-product during the sewage treatment of industrial or municipal wastewater (Kumar and Chopra, 2016a). More specifically, the sewage sludge is formed as the by-product of the different treatment stages of wastewater from domestic households, and sometimes it also includes industrial and commercial effluents (Williams, 2005). Generally, the terms biosolids and sewage sludge are often used interchangeably. The important physico-chemical characteristics of sewage sludge or biosolids includes the specific gravity (1.0 equal to water), solids concentration as the relative fraction of solids and water in the slurry and sludge volume index (SVI). Generally, the physico-chemical characteristics of the biosolids or sewage sludge include 20% content of the fat, 50 carbohydrate content (sugar, starch, and fiber), 30 % to 40 % content of organic matter, 3% total nitrogen, 1.5% total phosphorus, 0.7% total potassium content, 10 % to 20 % C/N ratio, high levels of heavy metal ions: Cu, Zn. The heat value ( $H_o$ ) of the dry

sludge is about 12.000 kJ / kg. The pH of the sewage sludge is normally ranged 6.5 -7.0 as reported by Xu (2014).

Properly treated and processed, sewage sludge becomes biosolids which are nutrient-rich organic materials produced from wastewater treatment facilities (Kumar and Chopra, 2013; Kumar *et al.*, 2016). Moreover, biosolids can be recycled and applied as fertilizer to improve and maintain productive soils and stimulate plant growth. The management practices of sewage sludge increases the usability of the sewage sludge or biosolids and reduces the harmful substances from the sewage sludge to prevent their discharge in the aquatic resources like rivers, lakes, streams etc. (Spinosa, 2008; Rogers, 2012).

The sewage sludge or biosolids generally varied in characteristics and contain organic and inorganic chemicals, toxic metals and pathogens. It is often considered as a resource due to the widespread application in soil amendment, energy generation, nutrient supply etc. The sewage sludge, having about 1% of wastewater when entering to the sewage treatment plant for the treatment, is digested anaerobically and resulted to remove the wastewater from the sludge. Sewage

sludge, at the vent of production after mechanical drying, is having of almost 80% moisture and 20% dry matter. The sewage sludge have different organic and inorganic elements, small quantity of heavy metals such as iron (Fe), chromium (Cr), manganese (Mn), zinc (Zn), mercury (Hg), lead (Pb), nickel (Ni), cadmium (Cd) and copper (Cu) etc. These elements restrict the use of sludge in agriculture, because their accumulation is harmful to the environment and particularly to the food chain (Kumar and Chopra, 2012; Kumar and Chopra, 2016b).

The properties of sludge associated with the origin and amount of flushing water (public toilet, private toilet), its assortment type (on-site, off-site) and following treatment level, for example digestion. Fresh and untreated sludge will have many pathogens, a high proportion of water, high biochemical oxygen demand (BOD) and is normally putrid and odorous. Nevertheless, sludge also contains essential nutrients for plants (e.g. nitrogen and phosphorus) and is potentially a very beneficial fertilizer. The most important component like organic carbon in the sludge, once alleviated, has also capable as a soil conditioner because it likely improves soil structure for plant roots, or can be transformed into energy through bio-digestion or incineration. As sewage may receive harmful pollutants (e.g. heavy metals, pharmaceuticals) from industries and other activities which may accumulate in its sludge (Javier Mateo-Sagasta *et al.*, 2015). Generally, the sewage sludge resulting from primary and secondary water treatment. Before entering the digesters, the sludge is sometimes sieved and is then thickened to a dry solids content of up to 7% in order to avoid too high energy consumption for heating due to excessive water content. Preferably, the sludge can be pretreated by disintegration technologies with the goal to recover the biogas yield. The primary sludge, also called raw sludge, is produced by gravitational sedimentation in the primary sedimentation tank. It has a high content of organic matter and is easily degradable. Under optimum digestion conditions, a methane yield of 315-400 Nm<sup>3</sup>/t organic dry matter (Zhang, 2010). The Secondary sludge, also called excess sludge or activated sludge, results from the biological treatment of wastewater. It has a lesser degradable fraction than primary sludge and as a result reduction in the biogas yield. Under optimum decomposable circumstances, a methane yield of 190-240 Nm<sup>3</sup>/t organic dry matter (Zhang, 2010).

## GLOBAL SCENARIO OF SEWAGE SLUDGE GENERATION

The global population is increasing and concentrating in urban centers. This trend is particularly intense in developing countries, where an additional 2.1 billion people are expected to be living in cities by 2030 (Xu, 2014; Javier Mateo-Sagasta *et al.*, 2015). The sewage treatment plants also generate sludge (a semi solid substance), called sewage sludge, when suspended solids are removed from the wastewater and when soluble organic substances are converted to bacterial biomass which also becomes part of the sludge (Javier Mateo-Sagasta *et al.*, 2015). Ning-Yi Wang *et al.* (2013) reported the emission quantity of greenhouse gases, land filling has the greatest impact (296.9 kg CO<sub>2</sub> eq./t sludge), followed by mono-incineration (232.2 kg CO<sub>2</sub> eq./t sludge) and carbonization (146.1 kg CO<sub>2</sub> eq./t sludge). Co-incineration with municipal solid waste has the benefit of reducing green house gas emission (-15.4 kg CO<sub>2</sub> eq./t sludge). Consequently, the carbonization would be a quite beneficial method of sewage sludge if

the energy generation, distribution and integration processes are made more competent.

## INDIAN SCENARIO OF SEWAGE SLUDGE GENERATION

According to Central Pollution Control Board (CPCB), New Delhi, about 38354 million liter per day (MLD) wastewater generated from cities and towns is the main cause of freshwater pollution in India (CPCB, 2009). A nearly less than half of this quantity only about 11786 MLD is treated by the sewage treatment plants (STPs) and rest of the sewage is discharged without treatment. Therefore, almost all the water bodies including lakes, ponds wetlands, streams, rivers and their catchments areas are severely polluted due to the discharge of untreated or partially treated sewage effluent (Bhardwaj, 2005; CWC, 2012). Additionally, these conditions are also responsible for the outbreak of a number of water borne as well as food borne diseases in these proximities (CGWB, 2011; CWC, 2012). Similarly, the sewage sludge generated during the treatment of sewage effluent is dried in the sludge beds and using for fertilize the agricultural crops (CPHEEO, 2012). In India characteristically, the sewage sludge contained total nitrogen (15400-1920 mg Kg<sup>-1</sup>), available nitrogen (4600-6300 mg Kg<sup>-1</sup>), available phosphorus (44-60 mg Kg<sup>-1</sup>) and available potassium (290-410 mg Kg<sup>-1</sup>). Besides this higher contents of different heavy metals like arsenic (8-23 mg Kg<sup>-1</sup>), Cd (2-9 mg Kg<sup>-1</sup>), Cr (66-1098 mg Kg<sup>-1</sup>), Hg (7-32 mg Kg<sup>-1</sup>), Ni (12-596 mg Kg<sup>-1</sup>) and Pb (26-154 mg Kg<sup>-1</sup>) were reported by Dubey *et al.* (2006). Kumar and Chopra (2013) and Kumar *et al.* (2016) also reported higher contents of nutrients and heavy metals in the municipal sewage sludge.

## SEWAGE SLUDGE AS RESOURCE

During the past years, waste minimization and recycling/reuse policies have been introduced so as to reduce the amount of waste generated and alternative waste management strategies are being exploited, to reduce the environmental impacts of waste management (IPCC, 2006). Notwithstanding, sewage sludge represents a source of material, energy and nutrients, it is possible to utilize it as raw material for industrial production, energy production and soil amendment. There exist several processes through which sewage sludge can be converted into useful output and this includes co-incineration and mono-incineration with energy recovery, anaerobic digestion with biogas production and aerobic composting, pyrolysis, gasification and wet oxidation processes. The selection of a sewage sludge management method or technique from the accessible options should be based on their environmental effect that is which technology creates less impact on the environment. As per the public attention on the environmental effects of the management choices selected for sewage sludge treatment increases, industries are beginning to accept the clean technology approach and assessment of environmental impacts of alternative processes, in process evaluation (Poulsen and Hansen, 2003). Many countries have recently recognized that sewage sludge components can be recycled in a "Productification" strategy which is aimed at making products from sludge which are intended for sale in the market place. Sludge based products can be used for energy and also reused with matter recovery for land application. According to the "Productification" strategy, these products could be used not only on-site, such as at the treatment plants, as has been practiced for many years, but can be sold in the open market as well (Spinosa, 2008; Rogers, 2012). There is a wide range of uses for sewage

sludge that exploit its nutrient, material and energy contents, for instance, drying, incineration, composting, anaerobic digestion, and so on. Among these processes, sludge composting and anaerobic digestion have been receiving more and more attention in terms of their marketable products (BioTEnMaRe, 2014). Biogas technology is one of the options for deployment in conversion of organic residues to

renewable energy and valuable fertilizer. In Figure 1 provide an outline for the generation, recovery of sewage sludge production and possible resource recovery and also suggest the mechanism and strategy for the sewage sludge management. Figure 2 shows the various methods for waste management which can be implemented for the uses of sewage sludge for sustainable agriculture.

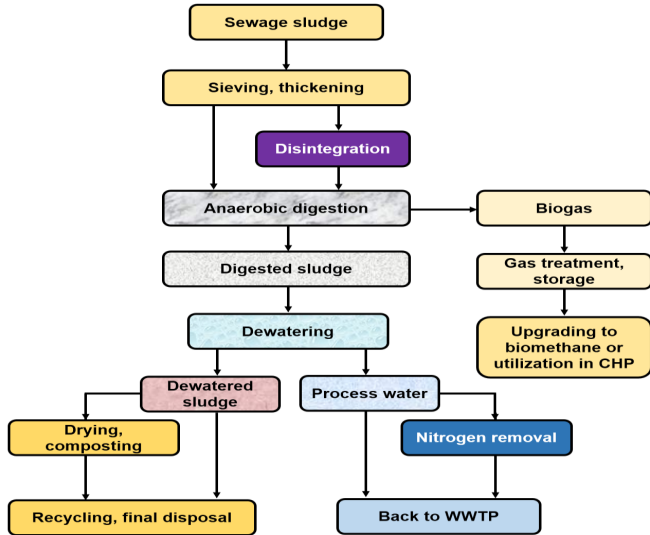


Figure 1. Diagrammatic sketch of sewage sludge production and possible resource recovery (Source: Bachmann, 2015; modified by the authors).

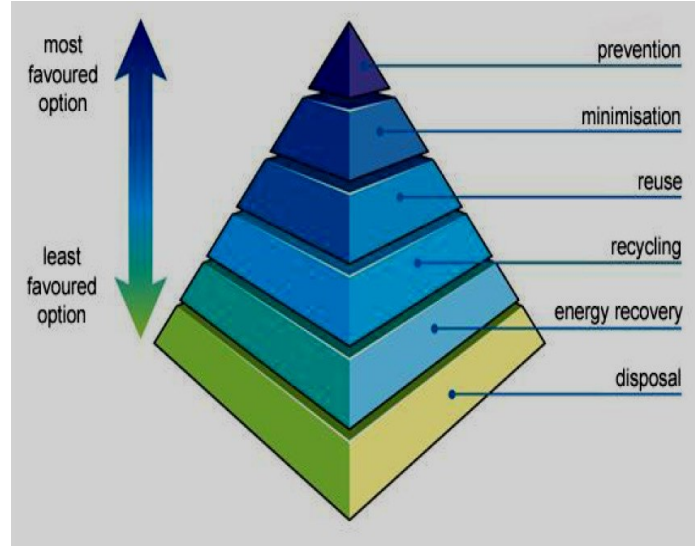


Figure 2. The most suitable methods for waste management (Source: Akwo, 2008).

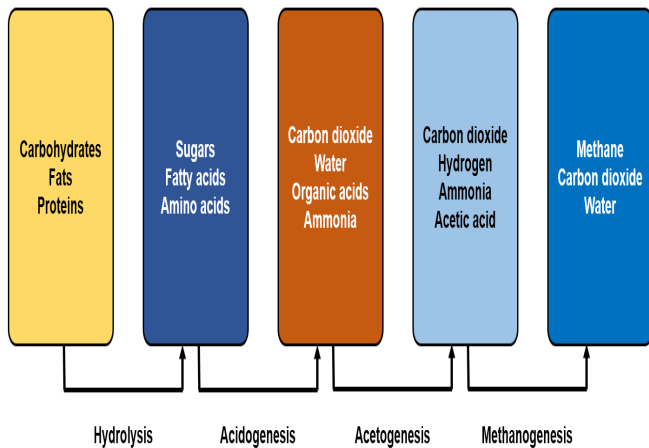


Figure 3. Process of aerobic digestion (Source: Williams 2005; modified by the authors).

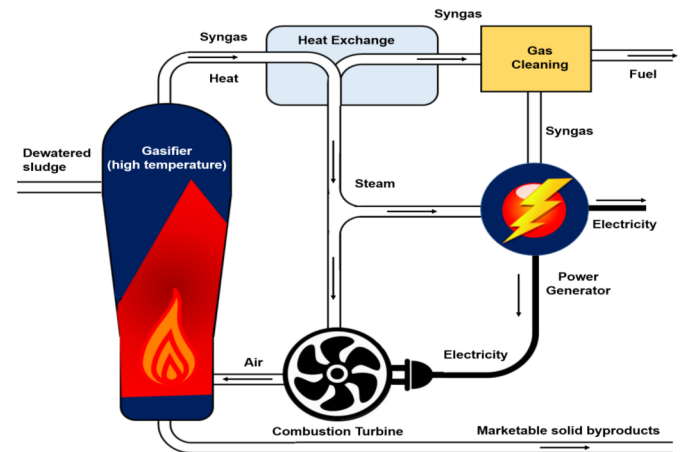


Figure 4. Process of gasification (Source: Baily, 2009; modified by the authors).

**SEWAGE SLUDGE MANAGEMENT PRACTICES**

**Sewage sludge composting:** Sludge composting occurs via an aerobic bacterial decomposition process that stabilizes the organic substances in sludge and produces compost (humus). The overall chemical reaction of composting is (Finstein et al., 1980):



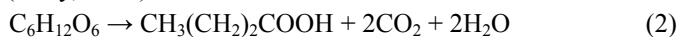
The sludge composting aims to biologically stabilize sludge and control pollution risks, in order to develop agriculture or other end use outlets based on the nutritional or organic value (Bresters, 1997).

**Sewage sludge in biogas production:** The sewage sludge may be utilized for the generation and recovery of the energy, if adequately dry directly, by incineration or, indirectly, using anaerobic digestion, pyrolysis or gasification, that generate bio-fuels such as methane-rich biogas, bio-oil and syngas

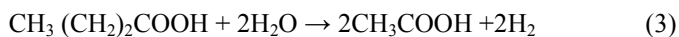
(Kalogo and Monteith, 2012). A mechanism has been provided in the Figure 3 for the effective aerobic digestion of the sewage sludge. The energy content in products for energy use and energy content in raw sludge are two important elements for the estimating of energy recovery efficiency. However, the dried sludge becomes a valuable and renewable energy source with a calorific value similar to lignite (Bachmann, 2009). Pöschl et al. (2010) suggested that, whereas the upgrading of biogas to biomethane for injection into natural gas network potentially increased the primary energy input for biogas utilization by up to 100%; the energy effectiveness of the biogas production method must be improved by up to 65% when natural gas was substituted in place of electricity. It was noticeable that, the effectiveness of the system energy could be additionally enhanced by 5.1-6.1% by using recovery of the residual biogas from the enclosed digestate storage units. The biogas produced from sewage sludge or biosolids is a

clean and renewable energy source. It is an ideal fuel for combined heat and power applications. The biogas can be produced with anaerobic bacteria or fermentation of biodegradable materials. The heat value of it is 21-25 MJ/m<sup>3</sup> (with an average concentration of 65% CH<sub>4</sub>) and 30- 40% lower than natural gas (37.3 MJ/m<sup>3</sup>) (Xu, 2014). Anaerobic digestion is a bacterial decomposition process in the absence of oxygen that stabilizes organic wastes and produces biogas, a mixture of methane and carbon dioxide. The heat value of methane is about similar to natural gas, therefore biogas is considered as a valuable energy resource (Halls, 2000). There are four key biochemical stages in anaerobic digestion, which are hydrolysis, acidogenesis, acetogenesis and methanogenesis (Williams, 2005; Kumar *et al.*, 2017).

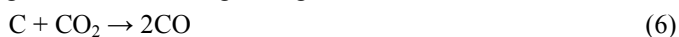
Hydrolysis is the first stage in the decomposition of macromolecular substances such as carbohydrates, fats and proteins (Figure 3). Afterwards some low-molecular substances arise from hydrolytic bacteria activities, such as sugars, fatty acids and amino acids (Baily, 2009). Acidogenesis is the second stage in which products of hydrolysis are decomposed by fermentation bacteria into organic acids, carbon dioxide, water, and sometimes ammonia. The main reaction equation is (Baily, 2009):



Acetogenesis and methanogenesis usually run simultaneously (Figure 3). The former uses bacteria to decompose organic acids into acetic acid and hydrogen. The latter uses methanogenic bacteria to further decompose acetic acid into methane and carbon dioxide, at the same time more methane is created from hydrogen and carbon dioxide by another type of methanogenic bacteria. The reaction equations are (Baily, 2009):



Gasification is a thermal process that can convert organic based sludge materials with air (Sometimes oxygen or steam) into an inflammable gas (Baily, 2009). A diagrammatic sketch shown in Figure 4 has been suggested by Baily (2009) for the gasification of sewage sludge.



**Sewage sludge in soil amendment:** The sewage sludge may be processed using different methods for the reduction of pathogens in the sewage sludge. The important methods are aerobic digestion of the sludge, air drying of sludge, anaerobic digestion, composting, and lime stabilization of the sewage sludge (EPA, 1995). Moreover, in air drying method of sewage sludge, the sewage sludge is dried for months or more on sludge drying beds of sand or paved basins of sludge dryness (EPA, 1985, 1995). Therefore, using the composting method, the sewage sludge is preserved either within a static aerated vessel or windrow composting methods (EPA, 1995), whereas, in the lime stabilization method, the sewage sludge is mixing with lime to increase the pH of the sewage sludge (EPA, 1995).

The sewage sludge can be made utilizable through the land application, and for this the wastewater treatment facility needs to put the sewage sludge into a biosolids form. Currently there are six different categories of sewage sludge or biosolids produced that can be utilized in the land application,

liquid, dewatered, air-dried, alkaline-treated, composted, and heat-dried (EPA, 1985; Walker, 1994). The dewatered form of the sewage sludge can be stabilized by the application of three procedures as aerobic digestion which resulting in 2 to 5% nitrogen content; anaerobic digestion results in 2 to 5% nitrogen content; and lime stabilization resulting in 1 to 3% nitrogen content (Walker, 1994). The alkaline-treated sewage sludge or biosolids can be stabilized in two different methods as a process through kiln dust resulting in 1 to 2% nitrogen content and a procedure lacking kiln dust resulting in 1 to 2% nitrogen content (Walker, 1994). The air-dried form of the sewage sludge can be stabilized in three methods as the aerobic digestion which is resulting in 2 to 4% nitrogen content; second is the anaerobic digestion that results in 2 to 4% nitrogen content; and the third one is the lime stabilization which is resulting in 1 to 3% nitrogen content (Walker, 1994). The composted form of the sewage sludge might be stabilized in many differences of agitated and static aerated procedures in and out of vessels, resulting in 1 to 2% nitrogen content (EPA, 1985; Walker, 1994).

The application of biosolids increases soil microbial biomass and some soil enzymatic activities such as urease, alkaline phosphatase and  $\beta$ -glucosidase linked to C, N, P and S soil cycles (Liang *et al.*, 2003; Tejada *et al.*, 2006). Liang *et al.* (2005) also reported that the incorporation of organic amendments to soil stimulate dehydrogenase activity because the added material may contain intra- and extracellular enzymes and may also stimulate microbial activity in the soil. Tejada *et al.* (2006) and Walker and Bernal (2008) found that the compost or Sewage sludge was effective for the remediation of the saline soil. Abdelbasset *et al.* (2010) reported that the use of municipal solid waste compost (13.3 g Kg<sup>-1</sup>) and sewage sludge (26.6 g Kg<sup>-1</sup>) significantly improved soil physical-chemical properties, especially carbon and nitrogen contents. Accordingly, overall enzyme activities were substantially promoted in presence of both amendments and the higher increases were measured at 13.3 g Kg<sup>-1</sup> of municipal solid waste compost (increases by 107%, 43%, 20%, 11%, and 148% for, DEH,  $\beta$ -GLU, PHO, URE, and CAT, respectively). Therefore, a number of scientists have reported the application of sewage sludge or biosolids for the soil amendment or to fertilize the soil for sustainable agriculture.

**Use of sewage sludge in agriculture:** The application of sewage sludge is found to be very productive for the agricultural crops yield. According to Franz (2008) sewage sludge incineration are rich in phosphorus content, ranging between 4% and 9% and about 90% of phosphorus can be extracted from sewage sludge ash (SSA) to make an adequate phosphate fertilizer. About 37% of sewage sludge produced is actually applied to agricultural land; other main pathways are land reclamation and restoration (12%) and incineration (11%) as reported by Fytli *et al.* (2008). Lundin *et al.* (2004) concluded that two sludge handling options, incineration and direct application to agricultural soil, have respectively economic and environmental restrictions. The development of relatively low cost phosphorus recovery technologies has the potential to reconcile the environmental and economic aspects of sustainability. During the recent past, a number of researchers reported the application of sewage sludge in the soil amendment and cultivation of agricultural crops globally (Table 1). The research reports clearly indicated that the use of sewage sludge enhance the overall growth and yield of agricultural crops and reduce the application of chemical or synthetic fertilizers.

**Table 1.** Toxic chemicals and heavy metals in different crops and soils due to the use of sewage sludge.

| Chemical species as heavy metal / Other toxic element                        | Crop/soil type/soil location   | References                          |
|--|--|-------------------------------------|
| DTPA, Cd, Zn and Mn  | Ultisol (red clay soils) and vertisol  | Ramachandran and D'Souza (1998)     |
| Cu, Zn, Pb, Ni, Cr, Cd   | Chhatarpur and Badarpur  | Shrivastava and Banerjee (2003)     |
| Cd, Zn, Cu   | Seeds of leaf beet<br>(perpetual spinach, <i>Beta vulgaris</i> , Cicla)  | Datta and Young (2004)              |
| Zn, Cu, Mn, Ni, Cd, Mo   | Red clover plant   | McBride <i>et al.</i> (2004)        |
| Cd Cr Cu Mn Ni Pb Zn   | Soil treated with sewage sludge compost  | Selivanovskaya <i>et al.</i> (2004) |
| K, Ca, Mg, Zn, Mn, Cu, Fe, Al and Na   | South Florida, USA   | Sigua <i>et al.</i> (2005)          |
| Zn, Fe, Pb, Cd, Zn, Fe, Pb, Cd   | Fennel plants shoot  | El-Motaium and Abo El-Seoud (2007)  |
| Cd, Cr, Cu, As, Ni, Pb, Zn   | <i>Sorghum bicolor</i> (L.)  | Jamali <i>et al.</i> (2008)         |
| Cd   | Indian mustard,<br>Cabbage and cauliflower,  | Sikka <i>et al.</i> (2009)          |
| Cd, Pb, Cr, Ni, Cu, Zn   | Potato   | Pakhnenkoa <i>et al.</i> (2009)     |
| Fe, Cr, Cu, Mn, Ni, Zn, Cd, Pb, Mg, Na, K, P, N                              | <i>Pinus radiata</i>   | Rodri'guez <i>et al.</i> (2010)     |
| Cu, Zn, Ni, Cd, Cr, Pb   | <i>Brassica juncea</i> (Root and shoot)  | Dede <i>et al.</i> (2012)           |
| Cd, Cr, Ni   | <i>Radish, Turnip, Carrot, Potato, Tomato, Bean, Cauliflower, Brinjal, Cabbage, Spinach, Coriander</i>   | Amlan <i>et al.</i> (2012)          |
| Cu, Fe, Mn, Zn   | Tropical soils   | Nogueirol <i>et al.</i> (2013)      |
| Fe, Zn, Cd, Cu, Pb, Cr   | French Bean ( <i>Phaseolus vulgaris</i> L.) (Shoot, root, leaves, fruit)   | Kumar and Chopra (2014)             |
| Pb, Cr, Cd, Cu, Zn, Ni   | Cabbage  | Ullah and Khan (2015)               |
| Zn, Cu, Ni, Cr   | Sunflower ( <i>Helianthus annuus</i> )<br>(Shoots and roots)   | Belhaj <i>et al.</i> (2016)         |
| Cd, Pb and Zn  | Shoots of <i>Salix</i> and <i>Populus</i>  | Kubátová <i>et al.</i> (2016)       |
| Zn, Cu, Fe, Mn, Ni, Pb, Cd, Cr, As   | Rice grain   | Meena <i>et al.</i> (2016)          |
| Cu, Zn, Cr, Ni, Cd, Pb   | Sugarcane (leaf and juice)   | Leite Moretti <i>et al.</i> (2016)  |
| Fe, Mn, Cu, Zn, Cd, Ni, Pb, Co, Cr, Ca, Mg, Na, K, Cl, N, P, SO <sub>4</sub> | Tomato   | Alghobar and Suresha (2017)         |
| Zn, Cu, Mn, Ni, Pb, Cd, Cr   | Clay loam and clay loam soil of Thessaloniki Plain (Greece)  | Tziachris <i>et al.</i> (2017)      |
| Pb, Cr, Cd, Cu, Zn, Ni, Fe, Mn   | <i>Spinacia oleracea, Brassica oleracea var. capitata, Brassica oleracea var. botrytis, Raphanus sativus, Brassica rapa subsp. Rapa, Benincasa fistulosa, Daucus carota subsp. Sativus, Lactuca, Colocasia esculenta</i> | Ullah <i>et al.</i> (2017)          |
| Cu, Zn, Cd, Pb, Fe, Mn   | Wheat plant ( <i>Triticum aestivum</i> L.)   | Shahbazi <i>et al.</i> (2017)       |
| Fe, Pb, Zn, Mn, Cr, Cu, Ni, Co, Cd   | Cucumbers ( <i>Cucumis sativus</i> L.)   | Eid <i>et al.</i> (2017)            |

## CONSTRAINTS

In most of the time the generated sewage sludge or biosolids is applied, disposed or discharged lacking of any satisfactory treatment. Therefore, it may pose serious environmental and public health impacts (Turovskiy and Mathai, 2006; Hong *et al.*, 2009). Moreover, due to the continuous rapid growing population, the sewage sludge generation is expected to increase significantly in the future. Sewage sludge has potential to contain pollutants and particular metals (Arlt *et al.*, 2002; Ghazy *et al.*, 2009). Moreover, different researchers have reported the presence of toxic chemicals as heavy metals in the soil and various crops due to the application of sewage sludge in agriculture (Table 1).

Exclusive of analysis, it is difficult to enlighten what kind of heavy metals and other pollutants exist in sewage sludge and if the contaminants exist at levels of concern (Clapp *et al.*, 1994). Early users of sewage sludge did not know of the pollutants that existed in the sewage sludge, and how to lower or remove the pollutants to safe levels and this perceptive of sewage sludge resulted in avoidance of sewage sludge as a land amendment (Lue-Hing *et al.*, 1994; Turovskiy and Mathai, 2006; Hong *et al.*, 2009). Eljarrat *et al.* (2008) reported the significant content of Polybrominated diphenyl ethers (PBDE) in sewage sludge ranged from 197 to 1185 ng/g dry weight (dw) and further in the sewage sludge amended soil PBDE levels in soils ranged between 21 and 690 ng/g dw. Moreover, levels about 200 ng/g dw have been reported in

sludge from Sweden and The Netherlands (Sellstrom *et al.*, 1999; de Boer *et al.*, 2002), and around 500 ng/g dw for samples collected in Denmark (Christenson *et al.*, 2003). Higher concentrations were found in USA, with values ranging from 1000 to 2290 ng/g dm for tri- to hexa-BDEs, and from 85 to 4890 ng/g dm for deca-BDE-209, with the mean values of approximately 1600 and 1000 ng/g, respectively (Hale *et al.*, 2003).

The use of biosolids in agriculture is strictly regulated in developed countries but can be encouraged like in Michigan's biosolid and septage programs. Reuse is driven by the intention of closing nutrient loops to ensure that nutrients are returned to agricultural land to improve soil fertility while reducing the pressure on final disposal sites. However, in many developed and industrialized nations, there is a rising obstruction for the application of the sewage sludge or biosolids in the agriculture, due to the anxieties regarding the possible content of persistent and toxic pollutants such as pathogens and heavy metals. In these countries energy recovery from sludge, mainly through bio-digestion and incineration, is gaining momentum (Javier Mateo-Sagasta *et al.*, 2015). Most importantly, although the application of sewage sludge in soil amendment or to fertilize the soil by supplying the essential nutrients significantly affected the growth and crop yield but on the other hand it enhance the chances of contamination of heavy metals and pathogens of agricultural soil and crops.

## Conclusions

The literature harnessed in the present review concluded that the biosolids or sewage is effectively using for various purposes. It is playing a significant role in energy generation, soil amendment and crop production etc. Whereas there are certain drawback for their use as the applications of sewage sludge or biosolids among developing countries are likely to be significantly different in developed countries. Therefore, sludge or biosolids should be sampled and checked for contaminants (pathogens, heavy metals etc) before use in soil amendment and agriculture and other applications. Moreover, the uses of biosolids or sludge should be based on regular monitoring, frequency of sampling and analysis depends on the production and quality of the sludge. Most efficient sludge management strategy should be made with main focus on economic, technological and societal constraints; however, assessment of the overall sustainability of sludge management is now becoming an important aspect for the scientists, researchers and policy makers in decision-making for sustainable development in the future. Therefore, more scientific research should be required on the different aspects of biosolids or sewage sludge to make it more feasible resource for the sustainable development.

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