

Risk Assessment and Regulatory Overview of Sewage Sludge

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Abstract: With the increase of the global population, the acceleration of urbanization and the impact of climate change, water scarcity is becoming a serious problem. More and more attention has been paid to sewage sludge treated by wastewater treatment plants (WWTP), as potential water resources and soil amendments in agriculture. The application of biosolids can not only increase organic matter and nutrients in soil, but also contribute to the resource utilization of waste. However, the use of biosolids also poses potential environmental and health risks. This review discusses the risks of using biosolids, the harmful substances containing in biosolids, summarizes their concentrations that cause damage to our health, and provides reference standards for the subsequent improvement of national regulations.

Keywords: sewage sludge resource recovery, environmental risks, regulations and management.

1. Introduction

As a renewable carbon neutral biological waste, sludge could be used to remove the pollutant in wastewater[1]. Besides, sludge-based biosolids may hasten plants' growth. Biosolids also contribute to plant health through enhancing soil characteristics and boosting the variety within the rhizosphere's bacterial population[2]. After the purified circulating water turn into a closed water cycle, the wastewater becomes part of the source water[3].

The consistence of sludge is semi-liquid, boasting a significant water content, reaching as high as 98%[4]. The activated sludge, abundant in organic material, phosphorus, and nitrogen, plays a crucial role in the production of fertilizers. As a result, sludge-based biosolids could be used as a kind of soil amendment. Moreover, sludge-based biosolids continue to be widely applied as an organic fertilizer, a cost-effective method for the advantageous recycling of its nutrients and carbon in the soil[5]. The presence of dissolved organic matter (DOM) in biosolids can modify how orthophosphate (inorganic phosphorus) is absorbed by soils, thereby impacting the bioavailability of inorganic phosphorus[5].

However, the ongoing rise of difficult pollutants in biosolids poses a threat to human health, as well as the enduring sustainability of their direct agricultural application[5]. The article presents a brief overview of the applications of biosolids in agriculture. Extra consideration was devoted to the potential risks that brought from the heavy metals, organic contaminants and pathogen in biosolids. Using biosolids blindly would lead to human diseases and environmental damage. Thus, it is necessary to promote sewage sludge treatment efficiency by optimizing processing procedures, develop risk assessment models for calculating human exposure, and improve the existing regulations to control and manage the biosolids.

2. Status of sewage treatment

2.1. Sludge treatment technology

Sludge treatment technology encompasses a variety of methods aimed at reducing the volume of sewage sludge, stabilizing its composition, and ultimately converting it into a form that can be safely managed or reused. These technologies include anaerobic digestion, thermal processes, microwave treatment and composting treatment, each of which presents its unique characteristics.

2.1.1. Anaerobic digestion

The anaerobic treatment is a broadly adopted method[6], allowing the reuse of biogas, and the utilization of digested sludge in agriculture as a nutrient source, thereby diminishing environmental footprint[7]. The early anaerobic digestion plant was built in 1859, India[8]. Similar to various alternative energy methods, World War II advanced anaerobic digestion technology, leading to the foundation of anaerobic digestion facilities in many European countries[9]. In recent years, anaerobic digestion technology has been widely applied.

The process of anaerobic digestion encompasses various steps where microbes decompose organic substances without the presence of oxygen. Through a coordinated process, different bacteria sequentially break down intricate organic substances, converting them into combustible biogas[9]. The biogas is primarily used for generating heat and electricity commercially, while the rest digestate, namely, the leftover solids and organic material can be applied in agriculture as an alternative to fertilizer[9].

Anaerobic digestion stands out as the most eco-friendly and sustainable method, significantly contributing to the generation of renewable energy sources[10]. It consists of four stages in a series of biochemical reactions: hydrolysis, acidogenesis, acetogenesis and methanogenesis[11]. In traditional integrated biomass treatment and energy recovery system, organic waste can be converted into valuable biogas and nutrients through aerobic treatment (Figure 1).

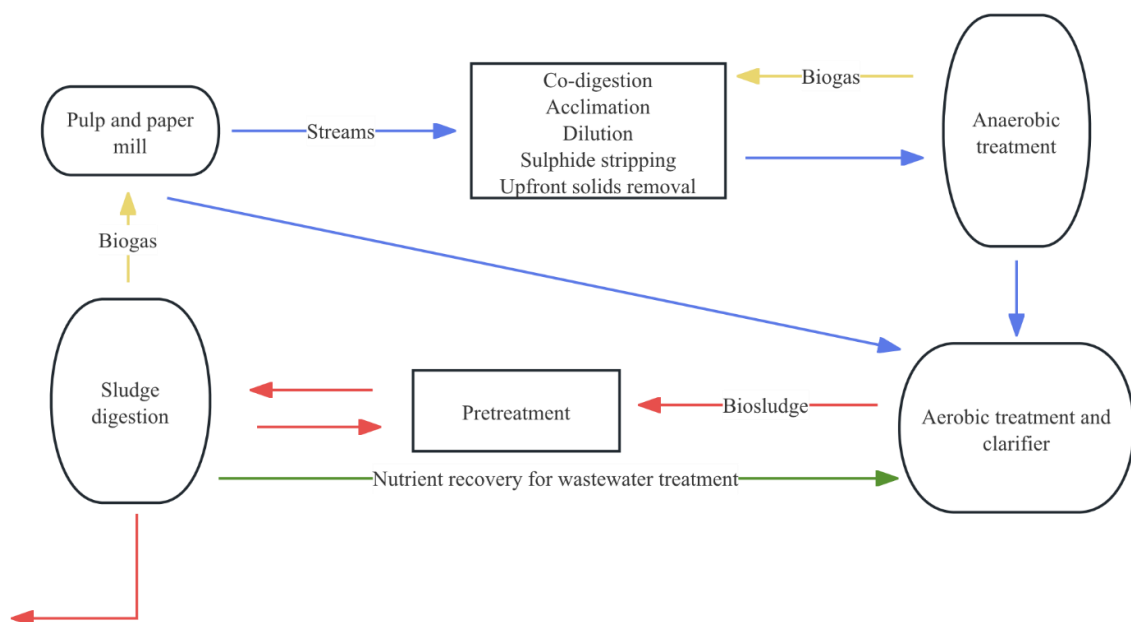


Figure 1: Anaerobic digestion process and substance conversion process in pulp and paper mill.

Organic wastes are released from mill, and after anaerobic treatment, aerobic treatment, clarifier and sludge digestion, these organic wastes can be converted into biogas, biosludge and nutrient. The blue arrows represent the production and transfer of streams, the yellow arrows represent biogas, the red arrows represent biosludge, and the green arrow represents nutrient recovery for wastewater treatment[6].

However, factors like complex compounds in sludge would influence the efficiency of the process[7]. Other factors may also obstruct the process, including the changes of sewage composition and the existence of anaerobic inhibitors[6]. In order to address these obstacles, pretreatment techniques are essential. Pretreatment can increase the digestibility, and thermal treatment and microwave treatment are two of the effective methods[6]. Thermal treatment enhances the following anaerobic digestion. Ranging from 150°C to 200°C, thermal treatment could increase volatile solids destruction, thereby boosting the production of biogas[12]. In some situations additional alkali and ultrasonic technologies are also required.

2.2. Pretreatment techniques

2.2.1. Thermal processes

Another way of disposal sewage sludge is thermal processes, often involving pyrolysis or incineration. Stabilized sewage sludge coming from drug residues, industrial pollutants, household pollutants, POPs and pathogens could not be applied in agriculture. Either through single mono-incineration or pyrolysis, these pollutants could be converted into energy and usable sludge char (Figure 2). The suitability of thermal treatment hinges on whether the system settings are correct or not, and this is crucial to dispose organic matter thoroughly, to reduce emission output and to qualify solid products such as sludge char[13].

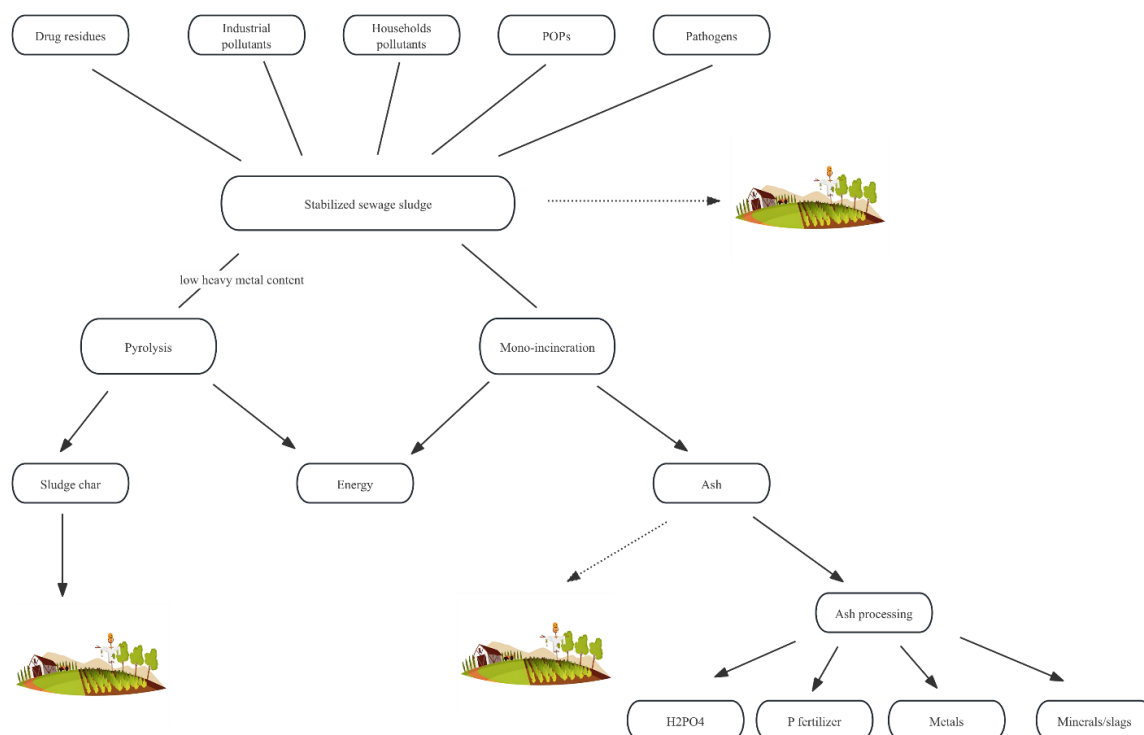


Figure 2: The general process of thermal treatment.

Sewage sludge that come from drug residues, industrial pollutants, household pollutants, POPs and pathogens cannot be applied in agriculture directly. Pyrolysis converts these sewage sludge that do not contain heavy metals into sludge char, which can be used in agriculture. For sewage sludge that contain heavy metals, mono-incineration converts them into ash that can be manufactured as fertilizers and metals. The solid arrows in the figure indicate that they can be applied directly, while the dashed arrows indicate that they cannot be applied directly to agriculture[13].

Thermal treatment processes ensure the eradication of disease-causing risks via elevated treatment temperatures[14]. These processes could also reduce the volume of biosolid and release little odor, thus achieving resource and energy recovery and sustainable management of biosolids[15]. At temperatures between 200 and 800 degrees, biosolids are converted into different forms, which are relatively smaller in size. This reduces storage conditions and expenses.

Even though thermal treatment is an important and efficient disposal path, it still has some shortcomings. Before thermal treatment, water in sewage sludge should be removed in advance, and during the process, all the operations must take place in an inert atmosphere to prevent uncorrelated reactions[13]. To further reduce the water content, thermal drying can be applied. In the end, the volume of sewage sludge can be reduced by 90%[16].

2.2.2. Microwave treatment

Microwave treatment changes the physical and chemical properties of sewage sludge through microwave radiation, thus improving its efficiency in subsequent treatment processes[17]. Microwaves are a form of nonionizing electromagnetic radiation. Their wavelengths range from 100 to 0.1cm, with corresponding frequencies between 300 MHz and 300 GHz. In sewage sludge treatment, through the dipole polarization mechanism, the process of microwave irradiation converts non-ionizing electromagnetic energy into heat[18]. The efficacy of microwave treatment is influenced by the duration of radiation and the temperature. The optimal condition for microwave treatment is 12 minutes of 70% intensity in order to improve the initial lag time of anaerobic digestion[19].

Microwave treatment can inactivate bacteria in sludge and improve the hygienic safety of sludge, as microwave radiation diminishes the cellular function, nearly halting bacterial activities[20]. Moreover, it can accelerate sludge dewatering process, an enhancement that could be attributed to the effect of microwave radiation on pore structure and water distribution within the sludge[21].

2.3. Composting treatment

Aerobic composting proves to be an effective method for handling organic solid waste, especially in agriculture, as it can eliminate pathogens in sewage sludge and reduce the availability of heavy metals(loid)s to plants[22]. The process of composting primarily depends on the metabolic functions of diverse natural microorganisms, including bacteria, actinomycetes, fungi, and protozoa[23]. In essence, it is a process of transforming matter, which hastens the breakdown of organic matter in waste, converting it into a safe product for soil applications[24]. The organic matter could enhance the soil's suitability for plant farming due to its beneficial impact on soil fertility and water retention[25]. If heavy metals and pathogens were removed in composting processes, the sewage sludge could be used as a soil amendment[4].

The benefit of composting lies in its simplicity and stability, coupled with the high efficiency of organic matter degradation, leading to the production of organic fertilizers[26]. Moreover, composting makes it possible to store and use sludge without limitation of time and space, allowing utilization of sludge at a considerable distance from its manufacturing location[27].

Although composting is a useful method of sludge treatment, there are a number of technical and environmental challenges that need to be overcome during implementation. Odor control must be

taken into consideration, as it would bring trouble to the community residents and affects the implementation of the composting program. Adding appropriate puffing ingredients, handling moisture properly, and managing the balance of nitrogen and carbon in compost can be the efficient solutions to odor pollution[28]. Also, NH₃ emission threatens compost quality and leads to air pollution, since 40-80% nitrogen in sewage sludge was lost during composting[29]. Recent researches show that the addition of biochar can significantly reduce nitrogen losses in composting, reaching up to 86%[30].

3. Potential risks of biosolids

As an abundant organic resource, using biosolids in agriculture provides many benefits for soil improvement and crop growth. However, this use would bring controversy. We must recognize that while biosolids bring certain agricultural benefits, they also contain harmful substances that may pose a threat to the environment and human health. Next, we explore these potential risks in depth and assess their possible impacts on ecosystems and public health, for further optimization of this promising resource.

3.1. Heavy metal

Heavy metals refer to metal elements characterized by their higher density relative to water[31]. Heavy metals such as cadmium (Cd), lead (Pb), mercury (Hg), arsenic (As), aluminum (Al), chromium (Cr), copper (Cu), manganese (Mn), nickel (Ni), zinc (Zn), may exist in relatively high concentrations in biosolids. When applied to soil, these heavy metals may be absorbed by plants and thus enter the food chain, posing a risk to human health.

In recent decades, there has been a significant rise in soil heavy metals pollution. Elements such as chemical and agricultural fertilizers, sewage sludge, and wastewater irrigation may result in contaminating environment[32]. When using biosolids in soil for a long time, the concentration of metals in the soil will gradually increase, and the distribution of metals will also change. Typically, this change leads to a heightened accumulation of heavy metals in the tissues of plants that thrive in this soil. Transfers of metals to plant tissues tend to be regulated and governed by the plant[33]. Through specific cellular mechanisms, plants can absorb heavy metal ions in soil, even when the levels of these ions are low. Plants can produce their own less toxic chelating agents that bind to heavy metal ions, leaving them uncharged. Uncharged ions have high mobility, so heavy metal ions penetrate cell membranes more easily[34]. One study presented types and degrees of heavy metal pollution in different parts of maize under vermicompost and sewage sludge treatment. Compared with the control group (V0), heavy metal concentrations of different maize parts were increased under sewage sludge treatment (Figure 3)[35].

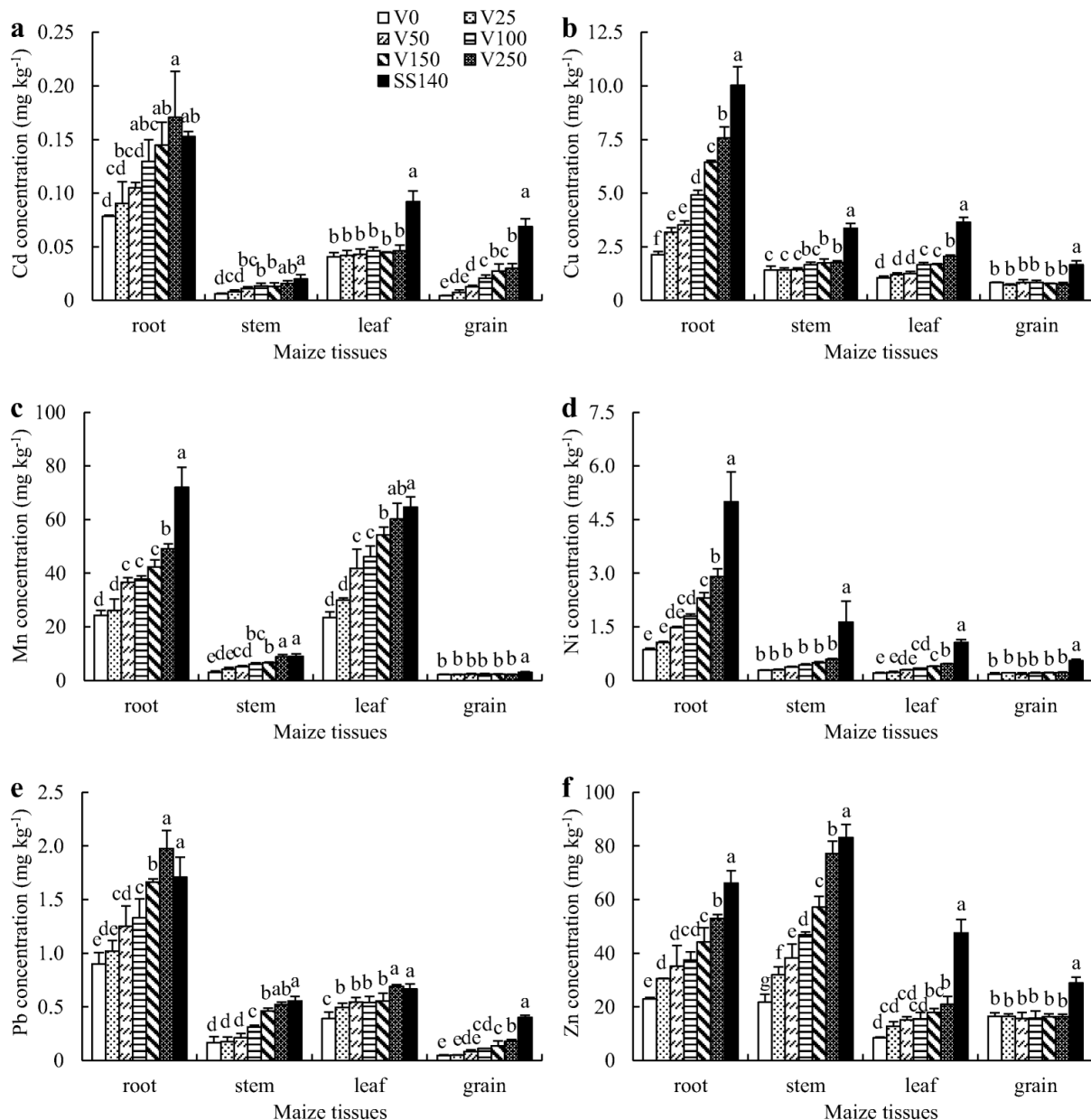


Figure 3: Heavy metal concentrations in different maize plant parts under vermicompost and sewage sludge amendment.

The concentrations of heavy metals Cd (a), Cu (b), Mn (c), Ni (d), Pb (e), and Zn (f) are represented in the form of bar charts. V0, V25, V50, V100, V150, V250 refer to vermicompost treatments based on different amount of vermicompost (0, 25, 50, 100, 150, and 250 t ha⁻¹ on dry weight basis), and SS140 refers to sewage sludge treatment (140 t ha⁻¹ on dry sewage sludge weight basis)[35].

Soil levels of metals can serve as a reliable predictor of human exposure to heavy metals. Elevated soil concentrations of heavy metals often lead to its constant accumulation in plants, which in turn can cause higher levels of heavy metals in vegetables people consume[36]. Even when biosolids are not applied directly to soil, for instance, by applying them to energy crops, they can still influence metal concentrations in the surrounding cultivated land[37]. Furthermore, such exposure can aggravate existing autoimmune conditions[38].

3.2. Organic contaminant

Both natural and synthetic, organic contaminants refer to those compounds consisting mainly of carbon and hydrogen, which do not break down easily[39]. Sewage sludge discharged from cities and intensive farms contains large amount of organic contaminants[40]. Two representative organic contaminants are persistent organic pollutants (POPs) and endocrine-disrupting compounds (EDCs), not only affects human and wildlife health, but also has a lasting harm to the aquatic environment[41].

POPs can be categorized into those originating from the application of pesticides and those emerging as products or byproducts during industrial processes[42]. Gaur provided another classification from different perspective (Figure 4). Based on the source, chemical properties and environmental behavior of POPs, they can be divided into wanted and unwanted products.

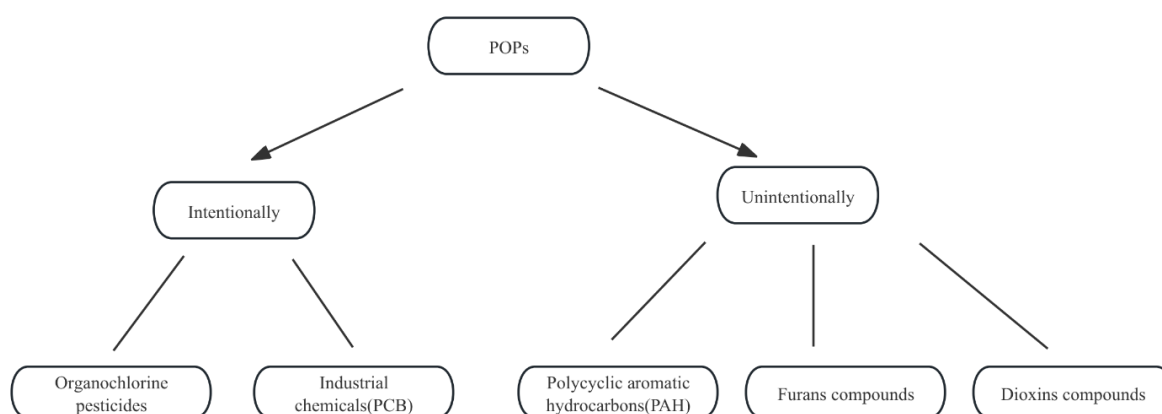


Figure 4: Classification of POPs.

According to sources, POPs can be divided into wanted products and unwanted products(by-products). For wanted products, they can be further subdivided into organochlorine pesticides and industrial chemicals; for by-products, they can be further subdivided into polycyclic aromatic hydrocarbons, furans compounds and dioxins compounds[43].

As semi-volatile organic compounds, polycyclic aromatic hydrocarbons (PAHs) are categorized as POPs, which are produced from organic contaminants combustion during heat treatment and composting of sewage sludge[44]. Emissions from human activities are largely responsible for PAHs pollution in the environment[45]. Residential heating, industrial activities, and vehicle exhaust are considered as main anthropogenic sources[46]. PAHs gathering through food chain could impair human health, for its bioaccumulative property. In addition, breathing in substances containing PAHs elevates the human lung cancer risk[47]. Benzo[a]pyrene (BaP), a representative of the HMW PAHs, is a hydrophobic chemical which accumulate in various organisms. It has been conclusively demonstrated to possess carcinogenic and mutagenic properties[48]. Some PAHs with low water solubility, such as high molecular weight PAHs (HMW PAHs), can persist in the environment because they withstand microbial breakdown, thus posing a greater threat to the environment[49]. In addition, the high hydrophobicity of PAHs enhances their deposition rate in soil and sediment, and forces PAHs be strongly adsorbed onto soil particles, leading to a soil ecosystem full of PAHs[50].

Polychlorinated biphenyls (PCBs) are a group of synthetic, organic chemicals classified as POPs, also possess high toxicity and carcinogenicity[51]. PCBs consist of biphenyl structures adorned with a diverse array of Cl atoms[52]. They own the characteristics of insulation, thermal stability, acid resistance, oxidation resistance, hydrolysis resistance and flame retardant[53]. Because of this, PCBs are extensively used in industry. Consequently, the discharge of industrial wastewater has led to PCB

contamination in sewage sludge. If not treated properly, they can be harmful to humans and the environment. Like PAHs, PCBs can also accumulate in adipose tissues. Prolonged exposure to PCBs would adversely affect the functioning of human skin, liver, gastrointestinal tract, immune and nervous system. Research showed that infants tend to experience cognitive decline and problems with motor coordination and nervous system function, if their mothers have been subjected to high levels of PCBs for an extended period before their birth[54]. When it comes to the environmental impact of PCBs, flaking paint in buildings is considered as a major source of PCBs in urban areas. Strong rainfall washes away the paint surface, as a result, particles containing PCBs are distributed in the city through the sewage system, transmitting to the marine environment and polluting marine sediments[55].

Endocrine-disrupting compound (EDC) is another kind of organic contaminants. EDCs are widely used in domestic and industrial activities and are usually discharged into sewage through textile, paper, detergent and polymer material production. Due to their hydrophobic nature, a significant portion of EDCs in sewage can be absorbed onto activated sludge during the biological treatment processes[56]. They can interfere with natural hormone functions in human body by disrupting those hormones from synthesizing, secreting, transporting, binding or eliminating[57]. Bisphenol A (BPA), a synthetic EDC utilized in the manufacturing of plastics and a broad range of consumer goods, exhibits weak estrogenic properties. This characteristic could increase the risk of breast cancer, hormonal disruptions, and cause adverse effects on human growth and reproductive function[58]. BPA can enter the body through a variety of pathways, including dietary intake, skin contact, and respiratory inhalation. In humans, BPA has been detected in biological samples, including reproductive health-related samples such as follicular fluid and luteinized granulosa cells[59]. EDCs like these can exert hormonal effects by directly interacting with and stimulating hormone receptors, thus affecting the normal physiological function of the organism[60].

3.3. Pathogen contamination

Pathogens are infectious agents that induce illness upon colonizing a host organism, including parasites, viruses and bacteria. Annually, billions of tons of wastewater are produced, which contains large number of pathogenic microorganisms, with more than 75% of the wastewater being discharged into the open land untreated, thereby polluting the environment, and passing on pathogens to humans in some manner[61].

Biosolids may contain a substantial amount of fecal-derived viruses, serving as possible storage for pathogenic viruses and indicator bacteriophages[62]. SARS-CoV-2 RNA has been identified in wastewater and sludge, which serves as a bioindicator, reflecting the spread of COVID-19 within communities[63]. The presence of them can indicate the prevalence of the virus among the population, even before clinical symptoms appear in individuals. In addition, biosolids also contain infectious astrovirus and enteroviruses, which are associated with sludge particles anticipated to be processed in sewage sludge treatment such as mesophilic anaerobic digestion (MAD)[64].

Bacteria are abundant in sewage sludge. Some bacteria survive for a long time in sewage sludge treatment. For instance, *Salmonella* and *Escherichia coli* (*E. coli*) endured for about 2 months in an industrial compost, and *E. coli* B remained viable for a minimum of 9 days, both of which were under a temperature of 60 degrees[65]. The effluent from wastewater treatment may lead to heightened levels of pathogens in the recipient lakes or rivers, including harmful *E. coli* and *Aeromonas* species. Current methods that can remove bacteria include MAD, anaerobic digestion, aerobic digestion, alkaline stabilization with lime, and composting. Lime treatment, pasteurization and thermal hydrolysis are desired treatment for removing *E. coli*, *fecal coliforms* and *somatic coliphages*[62].

Once released into the environment, pathogens can spread in various manners. Pathogens spread across fields through contaminated soil, animal, water, and wind in the form of spores[66]. Although

their active movement within the soil is typically restricted, through animal vectors, water and wind, pathogens can be spread passively over greater distances[67].

Pathogens such as parasites, viruses and bacteria, can be passed from animals to humans via various transmission pathways, causing zoonoses[68]. Zoonoses, also known as zoonoses for pleural, are contagious diseases where the pathogens originate from animals or their excretions, or from food contaminated with microorganisms such as eggs and meat, or even from the environment, including soil and plants[69]. These diseases can be transmitted through wounded or abrasive human skin, ingestion, animal bites, insect vectors, and animal-to-human contact. There are many factors that influence zoonoses, including environmental factors that may affect the pathogen's survival, dissemination, and the host's vulnerability[70]. Strengthening the treatment and safe disposal of sewage and sludge is one of the important measures to prevent and control zoonotic diseases, as pathogens are concentrated in sewage sludge and will spread via sewage sludge if not properly treated.

4. Risk assessment

In the previous discussion, the pollution status of heavy metals, organic contaminants and pathogens in sewage sludge and their potential impact have been described. The specific threat these pollutants pose to human health also ties to the dangerous concentration or intake they reach in the human body. To comprehensively evaluate these risks and craft effective preventive strategies, this section will explore the threshold that can lead to adverse health effects.

4.1. Standards

Risk assessment, including hazard identification, exposure assessment, hazard characterisation and risk characterisation, plays a role in calculating heavy metal intake.

For heavy metals, acceptable/tolerable daily intake (ADI/TDI) and tolerable upper intake level(UL) are major reference standards. ADI refers to the maximum amount of a substance that can be consumed daily in food, and will not pose risks to human health after a period of time[71]. UL refers to the upper limit of the daily intake of a trace element, above which a health threat may be posed. Safety intake levels of Cd, Pb, Hg, As, Al, Cr, Cu, Mn, Ni and Zn are listed (Table 1).

Table 1: Safety intake levels of heavy metals.

Heavy metal	Safety intake levels	Reference
Cd	ADI: 0.4–0.5 mg/week (60–70 µg per day)	[72]
Pb	ADI: 0.004 mg/kg bw/d	[73]
Hg	ADI: 0.571 µg/kg bw/d	[74]
As	ADI: 0.05 mg/kg bw/d	[75]
Al	ADI: 0.6 mg/kg bw/d	[76]
Cr	ADI: 20-45 µg/kg bw/d	[77]
Cu	UL: 10 mg/d	[78]
Mn	UL: 11 mg/d	[79]
Ni	RfD: 20 µg/kg·bw/d (USEPA) ADI: 13 µg/kg·bw (EFSA)	[80]
Zn	UL: 40 mg/d	[81]

Reference dose (RfD) is a term used for the risk assessment of non-carcinogenic substances. The RfDs of PCBs Aroclor 1016 and Aroclor 1254 are shown in Table 2.

Table 2: Safety intake levels of POPs.

POPs	Safety intake levels	Reference
Aroclor 1016	RfD: 0.00007 mg/(kg*d)	[82]
Aroclor 1254	RfD: 0.00002 mg/(kg*d)	[83]

4.2. Regulations

To make full use of biosolids, sewage sludge must be properly disposed of. In addition to upgrading and innovating sewage treatment technology, the supervision and management of laws and regulations is also essential.

At present, the laws and regulations of countries vary greatly, for instance, in European the ADI for BPA is 0.04 ng/kg bw/d, while in the US the RfD for BPA is 50 µg/kg·bw/d. No matter how diverse the legislative standards are, countries should follow a unified standard concerning the heavy metals, organic contaminants and pathogens in sewage sludge. As mentioned before, the tolerable Cd intake for an adult is approximately 0.4–0.5 mg/week (60–70 µg per day), the ADI for Pb is about 0.004 mg/kg bw/d, the ADI for Hg is 0.571 µg/kg bw/d, the ADI for As is 0.05 mg/kg bw/d, the ADI for Al is 0.6 mg/kg bw/d, the ADI for Cr is 20–45 µg/kg bw/d, the UL for Cu is 10 mg/d, the UL for Mn is 11 mg/d, the ADI for Ni is 13 µg/kg bw/d, and the UL for Zn is 40 mg/d. As for pathogens, WHO suggests that fecal coliforms and intestinal nematodes should be monitored during wastewater treatment[84]. Every country should reduce the content of these harmful substances in sewage sludge and control ADI of heavy metals.

When it comes to detecting these harmful substances, the following methods can be taken into consideration.

Considering that the migration and potential uptake of metals by different organisms is complex, a model derived from experimental data is likely to be more effective in assessing the metal concentration within the food chain[85]. Wet digestion method and atomic absorption spectrophotometry (AAS) can be applied to measure the accumulation of heavy metals in plants. In addition to measuring the amount of heavy metals contained in plants themselves, the metal transfer factor (MTF) of heavy metals from soil to plants also needs to be tested, which can be detected by Monte Carlo simulation techniques[86]. Monte Carlo simulation techniques are designed to assess the variability and uncertainty present in the various parameters of human health risk assessment[87]. According to a sensitivity analysis using Monte Carlo simulation techniques, the heavy metal concentration, exposure duration, and ingestion rate would affect MTF[88].

To detect POPs (mainly PAHs and PCBs) in sewage sludge, Soxhlet extraction with GC-MS analysis and microwave extraction with HPLC–DAD or fluorescence are commonly applied[89]. Bulk nanobubbles are emerging techniques that can remove the organic contaminants in sewage sludge. Due to their abilities to promote flotation efficiency, accelerate the metabolism of aerobic microorganisms, and generate free radicals to oxidize organic contaminants, bulk nanobubbles show attractive technological advantages and promising application prospects for wastewater treatment[90].

Molecular characterization techniques, such as polymerase chain reaction (PCR) techniques, can be adopted to detect and quantify these pathogens at the molecular level, as it avoid the influence of the environment and physiological state of the organism[91][92]. ICC-PCR is an experimental technique that combines immunohistochemistry (ICC) and reverse transcription quantitative PCR (RT qPCR), which uses two distinct cell lines to facilitate viral replication and employs serotype-specific qPCR primers for quantification[93]. Through cell culture, ICC-PCR and qPCR, the specific infectious enteric viruses in biosolids can be identified[94]. Complex transport models used in transporting chemical aerosols contribute to the analyses of microbial risk. These models are adept at analyzing the movement and distribution of pathogens[95].

5. Summary

Sewage sludge, as a potential resource for recycling, plays an important role in agriculture. Biosolids are treated sewage sludge. The application of biosolids in agriculture can improve crop productivity through increasing soil organic matter, fertility and nutrient content, promoting a more environmentally friendly and sustainable development pattern. For these reasons, more and more prefer to using biosolids. However, the reuse of treated wastewater and biosolids in agriculture may pose safety concerns regarding agricultural products due to the potential presence of heavy metals, organic pollutants, and pathogens. Current techniques such as anaerobic digestion, thermal processes and composting treatment fail to eliminate these risks completely. Therefore, most pollutants are prevalent in wastewater from sewage treatment plants (i.e. treated wastewater) and biosolids. When treated wastewater and biosolids are utilized for agricultural irrigation and soil amendment, these heavy metals, organic contaminants and pathogens might be transferred from soil to crops through root absorption, particularly affecting raw food products like fresh vegetable and fruits. Risks of heavy metals, organic contaminants and pathogens thus affect human health. If long-term exposure to these pollutants, the human's skeletal, nervous, endocrine, reproductive, immune, cardiovascular systems will suffer varying degrees of damage. Therefore, it is essential to promote sludge treatment existing methods, and innovate new approaches to treat sewage sludge more efficiently and reduce the adverse effects caused by pollution. Also, corresponding legal system should be continuously improved to ensure proper supervision and management. However, in some countries there are inadequacies in laws and regulations about sewage sludge disposal. As a result, it is particularly important to ensure proper supervision and management, namely, taking all the potential pollutants into consideration and adjusting measures to local conditions. Meanwhile, countries should strictly follow the WHO regulations on ADI of heavy metals, and pay attention to the content of organic contaminants and pathogens. The use of sewage sludge poses environmental and health risks, but it could also ease global water shortages. If the abundant sewage sludge can be harnessed as a safe and valuable resource, it will provide a strategic solution to address both environmental challenges and resource scarcity. This review conducts a systematic summary of the deficiencies in existing laws and regulations, with the aim of offering guidance and assistance to enhance the legal frameworks about sewage sludge treatment in developing countries.

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