Proposed Standards For Cadmium And Lead Concentration In Biosolids As Applied As Soil Conditioner In The Philippines Using WHO Guidelines For Decision-Making

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Abstract
Biosolids, or treated sludge, are the semisolid end-product of wastewater treatment plants. They are composed of different substances, including heavy metals, and is commonly used as soil conditioner in the Philippines. Heavy metals, specifically cadmium and lead, are known to be toxic to human health and the environment at high concentrations; however, the country has yet to establish its standard limits. Hence, the study aimed to recommend standards for cadmium and lead for biosolids as applied as soil conditioner in the Philippines. Biosolid samples were obtained from two wastewater treatment plants in Metro Manila and their difference were identified using t-Test. Their associated risks and proposed limit were assessed using risk assessment, while the recommended technology to help achieve these limits was determined using cost-effectiveness analysis. The study found no significant difference between the mean concentration levels of cadmium and lead in the STPs. A limit of 0.4 mg/kg and 150 mg/kg was recommended for cadmium and lead, respectively, in biosolids used as soil conditioner. The study also recommended Biodegradable-agent-assisted Electro Kinetic Treatment to help comply with the proposed limits. Altogether, the study quantified the amount of cadmium and lead in the biosolid samples, determined the difference between their mean concentration, assessed its corresponding risks to human health and the environment, developed recommended limits for cadmium and lead in biosolids as applied as soil conditioner, and recommended technologies to improve the sludge treatment in the country to meet the recommended limits.

Keywords: Cadmium, Lead, Biosolids, Risk assessment, Standards

INTRODUCTION

One of the key areas of study in the field of wastewater treatment is the source and nature of biosolids and sludge. Sludge is the semi-solid byproduct of the wastewater treatment in a sewage treatment plant (STP). The primary source of these materials is human waste, which enters the sewage system through toilets, sinks, and other fixtures in houses and buildings, but they can also come from industrial waste and agricultural runoff.

Sludge requires careful treatment to minimize, if not eliminate, the hazardous microorganisms and particles present in it—especially bacteria and heavy metals. Their treatment must ensure that once they are disposed/utilized outside the STPs, they will not pose risk to human health and the environment. Once treated, this sludge becomes what is known as *"biosolid"* and can be reused for agriculture, where it can act as a soil conditioner, and for sanitation, where it can act as soil for covering landfills.

Biosolids application to soil is becoming more common—such as the case in the Philippines [1]. Considering the heavy metals present in the biosolids, there is a need to establish appropriate limits to ensure the preservation and protection of soil quality, as well as the animals and humans who live near them. Which is why countries like Vietnam and organizations like the World Health Organization (WHO) established standards to protect soil and crop production from heavy metals including cadmium (Cd) and lead (Pb).

However, as of August 2023, the Philippines has yet to set a national standard for heavy metal concentration in biosolids, especially for cadmium and lead. The absence of guidelines results in the lack of mandatory screening for heavy metal content in biosolids. Therefore, biosolids produced from STPs and distributed for agricultural purposes are used without prior assessment for heavy metals. Hence, it is unknown whether the biosolids distributed to farmers contain the said pollutants.

If left unknown, the quality of soil may become toxic for plants and animals over time, which can further affect the crop production and human health once consumed. Consequently, farmers and nearby communities may remain unaware of their day-to-day exposure to the said metals. Hence, quantifying the concentration of heavy metals in biosolids, specifically cadmium and lead, and identifying its effects on soil and public health shall help provide standard for the said

heavy metals in the Philippines. The development of Philippine standard for biosolids shall help mandate all STPs in the country to monitor and limit the cadmium and lead concentration in their biosolids before distributing it for further use.
Hence, the study aimed to develop and recommend numerical standard for heavy metals, particularly cadmium and lead, for biosolids as applied as soil conditioner in the Philippines. Specifically, the study aimed the following: (1) Test and quantify the amount of cadmium and lead in biosolid samples from wastewater treatment plants in Metro Manila; (2) Determine if there is a significant difference between the concentration levels of cadmium and lead in the treatment plants using T-test; (3) Assess the associated risks on health and environment with the presence of cadmium and lead in biosolids as applied as soil conditioner; (4) Develop recommended limits for cadmium and lead in biosolids that will protect human health and the environment via risk assessment; and (5) Recommend improvement in existing sludge treatment technology to meet the recommended limits.
Considering limited resources, the samples examined in the study were limited to the STPs in Metro Manila and their treatment efficiency was not assessed. Moreover, the study only focused on establishing standard limits for cadmium and lead as applied in soil as soil conditioner and did not involve other applications.
The null hypothesis of the study stated that there was no significant difference between the mean cadmium and lead concentration in biosolids from the two sample sources, whereas the alternative hypothesis stated otherwise.

METHODOLOGY

The conceptual framework of the study generally followed four concepts arranged based on the objectives of the study as seen in Figure 1 below.

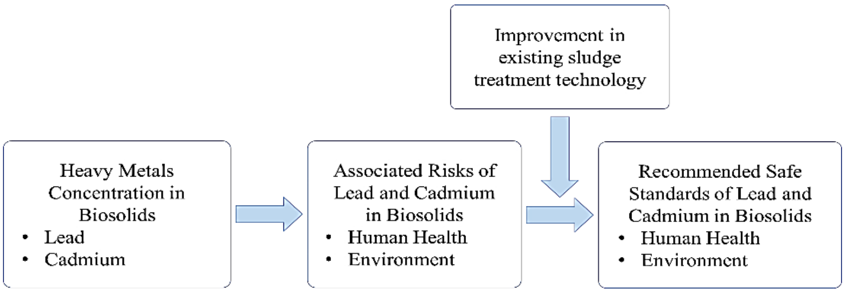

Figure 1. Conceptual framework in developing the proposed guideline values for cadmium and lead present in biosolids in the Philippines.

The concentrations of Cd and Pb were quantified using the FAAS and its associated risks to human health and the environment were determined and assessed. Based on this, the study provided improvements in the existing sludge treatment technology to reduce the concentration of the said heavy metals. Lastly, the study recommended safe standards of cadmium and lead in biosolids.
Specifically, the methodological process of this study was subdivided into five phases and several steps indicated by (n) as shown in Figure 2.

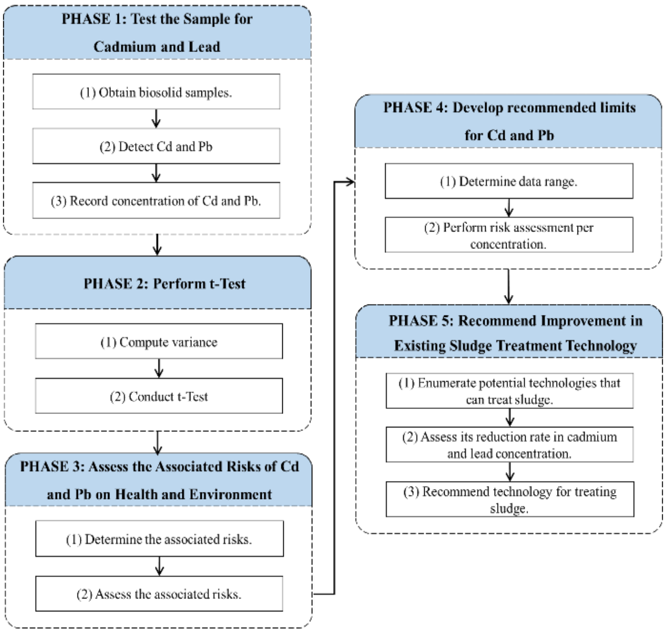

Figure 2. Methodological framework in developing the proposed guideline values for cadmium and lead present in biosolids in the Philippines.

2.1 Testing for cadmium and lead

One-kilogram biosolid samples were collected from two STPs with a one-week interval. There was a total of six samples—three from Source A (Pasay) and three from Source B (Taguig). Then, the samples were placed in a 12x12-inch Ziploc bag and was stored in a room with an average temperature of 22°C. The samples were then tested using the direct air-acetylene flame method (FAAS). Once Cd and Pb was found in the samples, their concentrations were recorded and tabulated using Microsoft Excel.

2.3 Assessing the associated risks of Cd and Pb

The study determined the associated risks on human health and environment given the found concentration of Cd and Pb on the samples using risk assessment.

2.4 Developing recommended limits

The fourth phase of the study developed recommended limits for cadmium and lead as applied as soil conditioner that will protect human health and the environment using the schematic diagram seen in Figure 3 below.

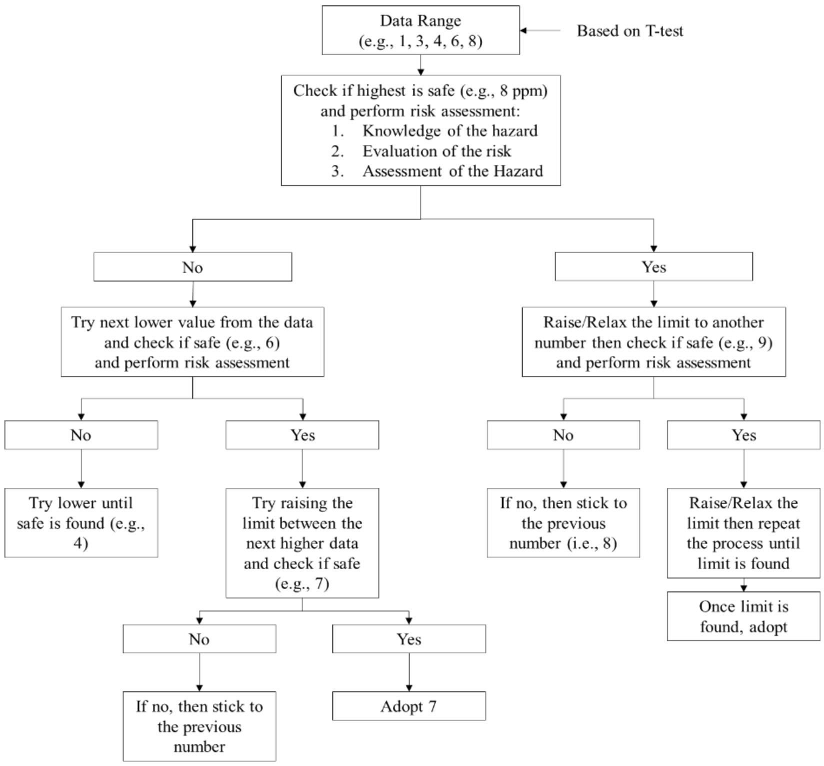

Figure 3. Algorithm in developing the proposed guideline values for cadmium and lead present in biosolids in the Philippines.

Once the concentration of the samples and the results of the T-test were determined in Phase 2, the data were sorted increasingly to determine the range of concentration throughout the samples and to set the initial value for the standard making. Then, the highest concentration was assessed if it was safe for soil application via risk assessment based on literature. When found unsafe, the initial value was lowered (became stricter) to a certain increment until the value for which it is safe was found. Conversely, when found safe, the initial value was raised to a certain increment until the value for which it is no longer safe was found. The last value before failure was the adopted limit.

Specifically, the risk assessment part of the framework was based on Setting environmental standards: Guideline for decision-making [1]. According to de Koning [1], the scientific stage of formulating public policy decisions to establish safety margins for environmental pollution prevention and control mainly include (a) knowledge of the hazard—which identified the property of the hazard and its potential harm to humans and the environment, (b) evaluation of the risk—which assessed and quantified the likelihood and severity of the adverse effects of the hazard [1], and (c) assessment of hazard—which analyzed how and where exposure occurs.

2.5 Recommending improvement in existing sludge treatment technology

The study identified three potential technologies and determined their removal efficiencies and costs. The study assumed hypothetical values that exceeded the recommended limit to determine the ideal technology based on efficiency. Then, they were iterated increasingly until a level where only one technology met the recommended limit.

Among the options, the study recommended the best applicable technology in the Philippines via cost-effectiveness analysis. The technology recommended was the one that ensured that the concentration of Cd and Pb complied with the proposed limits and was the least expensive.

RESULTS AND DISCUSSIONS

3.1 Concentration of Cd and Pb in the samples

Table 1 below shows the concentration of the biosolid samples. As seen in the table, cadmium and lead were present throughout the samples as the concentrations were nonzero.

Table I. Concentration of cadmium and lead in the biosolid samples.

Sample Code	Cd (mg/kg)	Pb (mg/kg)
A1*	< 0.03	61.78
A2	< 0.03	70.22
A3	< 0.03	120.69
B1	<0.03	<0.10
B2	<0.03	60.01
B3	3.75	65.73

***Source** A Sample 1

The concentration of cadmium was uniform throughout the samples except for sample B3. Meanwhile, the concentration of lead in samples A1, A2, B2, and B3 were relatively close to each other (around 60-70 mg/kg) compared to samples A3 and B1.

It was also found that the concentration of cadmium in all samples were evidently lower than lead, whereas the overall concentration of lead in Source A was relatively higher than Source B. This may be due to the difference in the location and source of the samples. Source A treats wastewater from sewage system—thereby providing a more collective sample—while Source B treats wastewater from septic tanks. Hence, it is probable that Source A generates more lead than Source B.

3.2 Difference in the concentration kevels of Cd and Pb in the treatment plants

As seen in Table 2 below**,** the null hypothesis was failed to be rejected since the P-value (0.42) was greater than the significance level (0.05). Hence, the study found no significant difference between the mean concentration of cadmium in Pasay and Taguig.

Table II. t-Test for two-sample with unequal variances for cadmium concentration (α= 0.05).

	Pasay	Taguig
Mean	0.03	1.27
Variance	0	4.6128
Observations	3	3
Hypothesized Mean Difference	0	
df	2	
t Stat	-1	
P(T<=t) one-tail	0.211324865	
t Critical one-tail	2.91998558	
P(T<=t) two-tail	0.422649731	
t Critical two-tail	4.30265273	

Similarly, it was found that the P-value (0.20) for lead was greater than the significance level (0.05) as seen in Table 3 below. Therefore, the study also failed to reject the null hypothesis for lead and has found that there was no significant difference between the mean concentration of lead in Pasay and Taguig.

Table III. t-Test for two-sample with unequal variances for lead concentration (α= 0.05).

	Pasay	Taguig
Mean	84.23	41.94666667
Variance	1014.8071	1321.537233
Observations	3	3
Hypothesized Mean Difference	0	
df	4	
t Stat	1.515170197	
P(T<=t) one-tail	0.102152767	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.204305534	
t Critical two-tail	2.776445105	

Since there were no significant differences between the mean concentration of the samples, the average concentration of cadmium and lead in STPs in Metro Manila in the study were 0.69 mg/kg and 63.09 mg/kg, respectively.

3.3 Associated health and environmental risks

3.3.1 Cadmium

In terms of cadmium, a study by Sakarjo, Zulaehah, and Purbalisa [2] determined that a cadmium concentration of 0.0–1.50 mg/kg in biosolids has no impact on human health and the environment if used as a soil conditioner. Meanwhile, a concentration of 1.50–3.00 mg/kg can affect the normal functions of exposed plants, and 3.00 mg/kg and higher can indirectly affect human health by consuming contaminated plants. Consequently, higher levels can cause human lung cancer and negatively affect the plant's health, growth, and soil fertility.

Considering this, it was found that the average concentration of cadmium (0.69 mg/kg) has no negative impact on human health and the environment if used as a soil conditioner, while the concentration in sample B3 (3.75 mg/kg) can induce harmful effects to humans and the environment.

3.3.2 Lead

On the other hand, an assessment conducted by the UMass Soil and Plant Testing Laboratory [3] determined that a lead concentration of 15–40 mg/kg has no impact on human health and the environment as it naturally occurs at this level. Similarly, a concentration of 41–199 mg/kg poses no effect, although it does not naturally occur in the environment at this level [4]. Meanwhile, concentration levels of 200–999 mg/kg can negatively affect human health, especially prolonged exposure in children and elderly. Likewise, plants exposed to this concentration level may experience negative effects in terms of growth and photosynthesis.

Lastly, concentration levels above 1000 mg/kg have a high possibility of causing significant detrimental effects on human health. They can cause permanent health problems such as kidney damage, fertility problems, and high blood pressure. In addition, plants exposed to this level would likely have a reduced growth rate and water and nutrient intake, while animals may develop health problems concerning their central nervous system.

Considering this, the average (63.09 mg/kg) and maximum (120.69 mg/kg) concentration of lead in Table 1 have no negative impact to human health and the environment if used as a soil conditioner.

3.4 Recommended standard for Cd and Pb in biosolids as applied as soil conditioner

Since the study failed to reject the null hypothesis for both heavy metals as discussed in Section 3.2 of this paper, the data range considered all data. Hence, the highest concentration for cadmium and lead shown in Table 1 is 3.75 mg/kg and 120.69 mg/kg, respectively. Considering this, below are the results of their risk assessments.

3.4.1 Cadmium

3.4.1.1 Knowledge of the hazard

Cadmium is a natural element usually found in soil at low concentration; however, human activities such as smoking, mining, incineration, and long-range atmospheric transport increases their release into the environment and find their way to the sewage system [5].

WHO [6] classified cadmium as carcinogenic to humans and animals and reported sufficient evidence that exposure to cadmium at certain concentrations could cause lung cancer and induce alterations in epigenetic and signal-transduction processes, which may result in restricted cell growth.

The Agency for Toxic Substances and Disease Registry [7] also argued that numerous studies have shown acute inhalation exposure to cadmium can cause death in humans and animals. It also mentioned that children are more susceptible to the health effects of cadmium than adults and may change with developmental age.

3.4.1.2 Evaluated risk

Based on Table 4, the safe cadmium concentration for biosolid-based soil conditioner is 0.4 and 1 mg/kg. Both are stricter as compared to the 5-ppm limit for soil conditioner in the Philippines [8]. A limit of 1 mg/kg offers a more economical option and easier compliance for STPs. However, since accumulation happens in the environment, the assimilative capacity of the soil may be reached faster at this limit. In contrast, a limit of 0.4 mg/kg offers a stricter and more conservative approach, as well as less hazard to human health and the environment. Moreover, 0.4 mg/kg is relatively higher as compared to Class AA/SA and Class D/SD wastewater effluent standards for cadmium which are 0.003 and 0.01 mg/L, respectively [9]. Therefore, the study proposed a limit of 0.4 mg/kg for cadmium in biosolids applied as soil conditioner.

3.4.1.3 Assessment of the hazard

Cadmium contained in soil and water can be taken up by some crops and aquatic organisms and accumulate in the food chain called biomagnification [5]. The pathway of exposure these are the following:

- *Soil* – Applying cadmium–contaminated biosolid on the soil itself.
- *Plants* – Plants can take up cadmium from soil, translocate, accumulate, and pass it to the next group in the food chain.
- *Animals* – via ingestion, inhalation, and non-dietary ingestion (e.g., preening)
- *Human* – Like animals, humans can be exposed to Cd from biosolid soil conditioners via atmospheric transport and consuming the crops grown from it. In fact, Du et al. [25] found that dietary intakes of rice and vegetables were the major pathways of Cd exposure near an active lead-zinc mine and copper smelter in Guixi City, China.

3.4.2 Lead
3.4.2.1 Knowledge of the hazard
According to Lenntech [26], lead can cause harm even in small concentrations upon intake. In humans, lead can cause the following: disruption in the biosynthesis of hemoglobin and anemia, raised blood pressure, kidney damage, miscarriages and subtle abortions, disruption in the nervous system, brain damage, sperm damage, and disruption of learning abilities and behavior of children. Furthermore, lead poisoning can also occur to soil organisms, especially when applied on land.

3.4.2.2 Evaluated risk
As seen in Table 5 (next page), the safe concentration of lead found in soil was below 155 mg/kg. Given that the highest value of lead concentration from Table 1 was 120.69 mg/kg, a limit of 150 mg/kg of lead from biosolids was recommended because: (1) no health and environment risk is related to this level based on Philippine setting, and (2) this limit would not be so strict; thus, can be easily complied by STPs. Moreover, 150 mg/kg is relatively higher compared to Class AA/SA and Class D/SD wastewater effluent standards for lead, which is 0.01 mg/L [9].

3.4.2.3 Assessment of the hazard
The pathway of exposure for lead was found to be similar to that of cadmium. According to the Centers for Disease Control and Prevention [27], inhalation and ingestion are the main pathways for human exposure, while the environment, including plants, animals, and the soil itself, is exposed through direct contact.

Table IV. Human health and environmental risks of cadmium per concentration level.

Concentration Value (mg/kg)	Evaluation of the Risk	Was it recommended?
3.75	In general, cadmium with concentration levels of more than 3mg/kg is considered hazardous to human health and the environment [2]. However, no published document was found specific to the effects of a 3.75 mg/kg cadmium concentration. Alternatively, there were studies based on 3.60, 3.55, and 3.50 mg/kg. Since these values are stricter than 3.75 mg/kg, this part of the study has started with that those. The ATSDR [7] mentioned a study by Vorobeva [10] that showed rats exposed to 3.5 mg/kg cadmium iron oxide dust were found to have interstitial pneumonitis and emphysema after 4-7 months of exposure. Similarly, a study by Sato et al. [11] found that a Wistar rat orally exposed (ingest) to 3.6 mg/kg/day of cadmium chloride ($CdCl_2$) for 31 months had serious lowest-observed-adverse-effect level (LOAEL) and has caused peripheral neuropathy, with its muscle and skeletal system as the most affected. Conversely, the same report cited studies that showed no-observed-adverse-effect level (NOAEL) for 3.5 mg/kg in other strain of rats. In addition, no studies were found regarding respiratory effects in humans after oral exposure to cadmium unlike rats [12]. Considering these, the 3.5 mg/kg limit for soil conditioner was not recommended.	No
3	In general, Ji et al. [13] stated that cadmium concentrations greater than 3 mg/kg can cause harmful effects on human health and the environment as mentioned in Table 18 of this paper. Similarly, EU legislation allows a maximum concentration of 3 mg/kg cadmium in soil. In support, a study by Nomiyama et al. [14] investigated the effects of 300, 30, 3, and 0 ppm of cadmium that was fed daily to ten male rhesus monkeys in 55 weeks. The study found that the lowest exposed group (3 ppm) did not show any biological response to cadmium. In addition, ATSDR [7] mentioned a study by Loeser and Lorke [15] where Wistar rats who ingested 3 mg/kg/day cadmium for three months were found to have their pituitary, adrenals, thyroid, and thymus unaffected. However, Wilson et al. [16] found pancreatic atrophy and pancreatitis in rats who fed on 2.79 mg/kg/day every day for 100 days. ATSDR [7] also cited a study in which intermediate-duration doses in feed or drinking water of less than or equal 3 mg/kg/day of cadmium have either no effect or only a small effect (10-20% decrease) on body weight in rats. Since this concentration value presents both neutral and negative cases, further examination of risks below 3 mg/kg was needed.	No
2.5	According to the ATSDR [12], cadmium doses greater than 2.5 mg/kg caused severe placental damage and fetal death to animals. The Agency cited a study where an oral exposure to seven weeks of 2.5 mg/kg/day of cadmium was found to cause congested myocardium and separation of muscle fibers in male Sprague-Dawley rats, while 2.5 mg/kg/day of cadmium caused anemia. In addition, rats orally exposed to water with 2.5 mg/kg/day of cadmium for 180 days were found to have decrease in litter size and increased interval between litter. Similarly, the Agency cited a study by Jamall et al. [17] wherein histopathologic lesions of heart and decreased production of antioxidant enzymes were found among rats who ingested 2.5 mg/kg/day of cadmium for seven weeks. However, the same concentration was found to have no observed effect on their renal and body weight system.	No
2	A cadmium concentration of 2 mg/kg/day for three months was observed to cause anemia in rats and decreased body weight of 15% to female and 25% to male [7]. It was also mentioned that doses ranging from 1.8 to 12.5 mg/kg/day cadmium were reported to cause proteinuria (high protein level in urine) and histopathologic to rats. In addition, the Agency reported a study in which rats exposed to 0.92 to 1.8 mg/kg/day, which is below 2 mg/kg of cadmium in their drinking water for 30 days (in the form of $CdCl_2$)	No

	had disrupted the daily pattern of amino acid content in their pituitary gland. Considering this, the study did not recommend 2 mg/kg and proceeded at a lower concentration. Moreover, a study by Baranski [18] observed developmental effects at lower cadmium doses such as delayed ossification of the sternum and ribs in the offspring of rats who consumed 2 mg/kg/day of cadmium for 7-16 days.	
1.5	ATSDR [7] cited studies, which utilized parenteral administration with cadmium doses ranging from 0.25 to 1.5 mg/kg considering different route of exposure and duration of 1-12 months, confirmed nephrotoxic effects of cadmium administered in mice, rats, and rabbits. In addition, an experiment study by Gatta et al. [19] found Wistar rat subject to 1.18 mg/kg of cadmium in a period of 4-60 weeks experienced vesiculation of proximal tubules. Considering this, the study did not recommend 1.5 mg/kg and proceeded with a lower concentration.	No
1	According to WHO [20], marine sediments were reported to have a cadmium concentration of 0.03 to 1 mg/kg, although its rate of uptake and toxic impact on aquatic organisms is significantly affected by physicochemical factors such as temperature, ionic concentration, and organic matter content. A study by Doelman et al. [21] found that soil nematode *Aphelenchus avanae* exposed to 1 mg/kg yielded no effect on its population size up to 22 days. Similarly, a study by Sutuo et al. [22] reported no effect was observed on pregnant rats fed with 1 mg/kg/day of cadmium for 9 weeks. Furthermore, a study by Kopp et al. [23] reported no hepatic effects from a chronic exposure of 0.65 mg/kg/day of cadmium in rats for 18 months. Considering these, the study determined that 1 mg/kg is safe for soil application of biosolids.	Yes
0.4	According to the Environmental Health Criteria 135 of WHO [20], the concentration of cadmium in surface soil, non-volcanic soil, and volcanic soil typically ranges between 0.1 to 0.4 mg/kg, 0.01 to 1 mg/kg, and up to 4.5 mg/kg. A study by Masaoka et al. [24] showed that renal dysfunction was found in Rhesus monkeys exposed to 1.2 mg/kg/day of cadmium for 9 years, but not at 0.4 mg/kg/day. It was also reported that the mean cadmium in not-to-be-polluted areas were in the range of 0.2 to 0.4 mg/kg. Considering this, the study determined that this concentration level is safe for soil application.	Yes

Table V. Human health risks of lead per concentration level.

Concentration Value (mg/kg)	Evaluation of the Risk	Was it recommended?
120.69	In a study by Dudka and Miller [28], it was found through a direct soil ingestion exposure model that humans will not intake too much lead if the concentration is less than 300 mg/kg.	Yes
155	According to de Vries et al. [29], the critical metal content, specifically of lead, in soil on grassland in view of food safety in terms of effect to kidney is 155 mg/kg for sand and clay type of soil, and 159 mg/kg for peat type of soil.	No

3.5 Recommended technologies to improve sludge treatment

Table 6 shows the applicable technologies, as well as their corresponding agents and costs, to help comply with the recommended limits. Among these, bioleaching and combined bioleaching/Fenton-like (T3) was the most inexpensive technology. This is followed by biodegradable-agent-assisted electro-kinetic treatment (T1) and biosurfactants-assisted electro-kinetic treatment (T2). Hence, by considering the cost of every technology, the most ideal one was T3.

Table VI. Cost of potential technologies for reduction of heavy metals.

Technology	Cost	
	Agent (PHP/kg)	EKT*
Biodegradable-agent-assisted EKT (T1)		
• Citric Acid	110	PHP
• IDS	290	6,100
• FeCl3	70	/ m^3
Biosurfactants-assisted EKT (T2)	1,100	
Bioleaching and Combined Bioleaching/Fenton-like (T3)	PHP 280 / m^3	

*Electro-Kinetic Treatment

Table VII. Summary of removal efficiencies of applicable technologies.

Technology	Removal Efficiency (%)	
	Cd	Pb
T1		
• Citric Acid	54±2	53±2
• IDS	54.5±2	54±2
• FeCl3	46±2	44.5±2
T2		
• Vicosin-enhanced	33	-
• Rhamnolipid-enhanced	33.5	51.6
• Saponin-enhanced	-	57.4
• Sophorolipid-enhanced	-	52.4
T3	34.8	30.9

On the other hand, in terms of removal efficiency, T1 had the highest removal efficiency for cadmium whereas T2 for lead as seen in Table 7. Considering this, Table 8 shows the new values for cadmium and lead; wherein, all agents used in T1 passed the recommended limit of 0.4 mg/kg for cadmium, while all technologies passed the recommended limit for lead. Specifically, Table 9 shows the new hypothetical values for lead concentrations higher than the 150 mg/kg limit. The only technology that met the recommended standard at 330 mg/kg was the saponin-enhanced T2, which retained a lead concentration of 140.58 mg/kg.

Table VIII. New value of cadmium and lead concentration after removal efficiency.

Technology		New Value (mg/kg)	
		Cd	Pb
T1			
•	Citric Acid	0.299	29.6523
•	IDS	0.29575	29.0214
•	FeCl3	0.351	35.01495
T2			
•	Vicosin-enhanced	0.4355	-
•	Rhamnolipid-enhanced	0.43225	30.53556
•	Saponin-enhanced	-	26.87634
•	Sophorolipid-enhanced	-	30.03084
T3		0.4238	43.59519

However, T3 is significantly cheaper than the recommended T1. Considering that there is still no known detrimental effect at the new value of 0.4238 mg/kg after application of T3 and that the concentration of cadmium from the biosolids gathered was almost constant at a level of 0.3 mg/kg, this can be a potential technology as well for reducing cadmium and lead concentration in biosolids. Altogether, the recommended technology to be used for reducing the average concentration of Cd and Pb to a level below the proposed limit and has the lowest cost is Biodegradable-agent-assisted Electro Kinetic Treatment using $FeCl_3$.

Table IX. New value of lead after assumed concentration.

Pb (mg/kg)	Biodegradable-agent-assisted Electro Kinetic Treatment			Biosurfactant-assisted Electro Kinetic Treatment			Bioleaching and Combined Bioleaching/ Fenton-like
	Citric Acid	IDS	$FeCl_3$	Rhamnolipid-enhanced	Saponin-enhanced	Sophorolipid-enhanced	
160	75.2	73.6	88.8	77.44	68.16	76.16	110.56
170	79.9	78.2	94.35	82.28	72.42	80.92	117.47
180	84.6	82.8	99.9	87.12	76.68	85.68	124.38
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
330	155.1	151.8	183.15	159.72	140.58*	157.08	228.03

* Below 150 mg/kg limit

CONCLUSION AND RECOMMENDATION

4.1 Conclusion

Altogether, the study collected and tested biosolids samples from STPs in Metro Manila and quantified their respective cadmium and lead concentrations using FAAS. Using t-Test, it was found that there was no significant difference between the mean concentration of Cd and Pb in the two sample sources. It was also determined that the average concentration of the samples has no negative effect on human health and the environment based on established literature. However, it was found that one sample had a cadmium concentration that can cause negative effects to humans and the environment.

In addition, the study performed risk analysis to establish a limit for cadmium and lead concentration in biosolids as applied as soil conditioner; wherein, a limit of 0.4 mg/kg was recommended for cadmium while a limit of 150 mg/kg was recommended for lead. Lastly, the study recommended biodegradable-agent-assisted electro-kinetic treatment using $FeCl_3$ to help wastewater treatment plants in the Philippines to reduce the concentration of cadmium and lead in their biosolids and comply with the recommended limits.

4.2 Recommendation

The study identified several areas for improvement. First, the study recommends performing experimental and observational studies to observe the effects of a specific concentration of heavy metal in biosolids as applied as soil conditioners. Using a control and experimental group is recommended to compare and contrast the difference between different concentrations directly. Furthermore, this can help further validate the results of this study. Second, the study recommends increasing the sampling frequency, site, and period to obtain a more accurate average concentration of heavy metals in biosolids in STPs in Metro Manila. Due to the limited time frame and financial sources, the sampling frequency was limited to only three weeks. Thus, the mean concentration of cadmium and lead was only based on three samples. Lastly, the study strongly suggests exploring other biosolid applications, such as soil filler and concrete aggregate.

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