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Deployment Pattern of Lead (Pb) in Jenggawah Area, Jember, East Java

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Abstract: The damaging effects of lead (Pb) contamination in soil has been significant public health concern, mainly due to its toxicity. Jenggawah district, located in Jember regency, Indonesia, has experienced growing anthropogenic activity in recent years, leading to the necessity to map the prevalence of this dangerous element in this area. Therefore, this research aims to evaluate the spatial and vertical distribution of lead (Pb) contamination level in the soil of the Jenggawah area. The soil samples were collected using random sampling techniques from seven different locations at various distances from the roadside (0, 25 m, and 50 m) and different depths (0, 15 cm, and 30 cm). Then, the soil sample containing lead (Pb) content were extracted through an acid-based destruction and quantified using Atomic Absorption Spectrophotometry. This study explained that lead (Pb) concentrations in all soil samples from the Jenggawah area were below established thresholds (1 - 8 ppm) and consistently reduced with increasing soil depth. Additionally, the variation of lead content in terms of distance from the roadside revealed a more fluctuating pattern, possibly affected by ground surface conditions and wind factors. In conclusion, these results can provide environmental information and enhance the understanding of heavy metal risks in areas with moderate anthropogenic activity, such as Jenggawah.

Keywords: AAS, contamination, Jenggawah, lead, soil.

INTRODUCTION

The adverse effects of heavy metal contamination on environmental and human health highlight the urgency to address this pollution problem [1]. The term ‘heavy metal’ (HM) indicates metallic elements or metalloids that demonstrate toxic effects even at low concentrations (parts per billion level) [2]. Among the many classes of heavy metals, Lead (Pb) has become the second-rank in the Agency for Toxic Substances and Disease Registry (ATSDR) 2022 Substance Priority List [3] and included among the 10 chemicals of primary public health concern based on the World Health Organization (WHO) [4].

The lead (Pb) contamination in the environment can originate from natural or anthropogenic sources [3,5]. Naturally, Pb is found as a mineral deposit, Galena (PbS) [6], and constitutes 0.002% of the earth's crust [7]. Meanwhile, vehicle fuel emissions have been identified as a significant anthropogenic contributor to environmental lead (Pb) deposition [8]. Despite the ban on leaded gasoline since the early 2000s [9], lead (Pb) particles from vehicle engine combustion persist in soil, particularly in areas with prolonged exposure to emissions, such as gas stations, terminals, and roadsides [9,10]. Furthermore, current Pb contamination in soil can be attributed to the applications of fertilizers and pesticides [5], as well as residual industrial and household activities such as building construction, furniture trade, peeling paint, vehicle maintenance, lead-containing pipes, and oil spills [7,11].

Soil, an essential component of terrestrial ecosystems, is critical to the sustainability of various life activities, especially agricultural production [12]. Lead (Pb) content in soil tends to accumulate in the surface layer and exhibits considerable persistence due to its limited mobility [13]. Soil contaminated with lead (Pb) can facilitate a significant route for heavy metal transfer to the human body through processes including plant uptake [2,10], ingestion of Pb-contaminated water [5], and direct contact [13]. This exposure has been shown to cause various adverse effects in humans, such as behavioral abnormalities, hearing deficits, neuromuscular weakness [14], impaired cognitive function in children [10], inflammation and immunological dysfunction [15], an elevated risk of cardiovascular, kidney, fertility problems [6], and the possibility of cancer [16].

Given the significant toxicity of Lead (Pb), various studies have been conducted to map its distribution in different regions of Indonesia. For example, previous study analyzed Pb concentrations in 102 samples spread across seven sub-districts in Bandung Regency. Spatial and vertical analysis revealed contrasting patterns: Pb levels tended to decrease along an upstream-to-downstream gradient in the textile industry area (n > 80). In contrast, in non-industrial areas (n < 30), Pb concentrations were highest in the middle soil layer, followed by the upper and lower layers [17]. Another study measured Pb levels in water, sediment, fish, and crustaceans at four coastal locations in Pangandaran during two seasons. The results showed that Pb concentrations were higher during the dry season, indicating a significant contribution of tourism to Pb accumulation in the ecosystem [11].

The Jenggawah area in Jember Regency has experienced increased anthropogenic activities, i.e., transport, tourism, agriculture, and demographic density over the past several years. These activities have the potential to increase the risk of heavy metal pollution in the soil. However, there is a lack of research that examines the spatial and vertical distribution of lead (Pb) in this area as per the author’s knowledge. Therefore, this research was conducted to evaluate the spatial and vertical distribution of lead (Pb) metal in some representative locations near the Jenggawah area. The outcome is to provide environmental information and enhance the understanding of heavy metal risks in areas with moderate anthropogenic activity, such as Jenggawah.

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METHODS

Material and Equipment

The materials used were soil samples (sourced from the highway in Jenggawah sub-district), concentrated nitric acid (HNO_3) (Merck, Germany), lead standard solution, and distilled water. Meanwhile, the equipment used in this study were Atomic Absorption Spectroscopy (AAS) (Shimadzu, Japan), oven (Memmert, German), 2mm sieve (10mesh), Whatman No. 1 filter paper (Cytiva, UK), and analytical balance (Shimadzu, Japan).

Sampling Preparation

The sampling of the soil was completed using the simple random sampling method. Soils were taken randomly without considering their type and properties. The samples obtained were then homogenized and taken proportionally using random sampling to be used as laboratory samples. The soil sampling points were divided into three groups: the Jenggawah market (1), the area north of the Jenggawah gas station (2), and in the engine assembly workshop area (3) as shown in Figure 1.

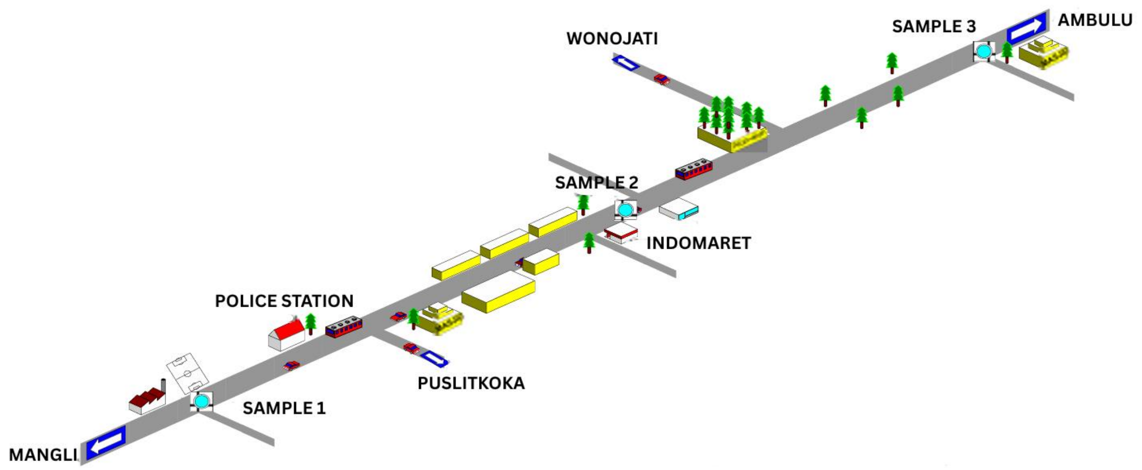

Figure 1. Sampling Plan on the Jenggawah-Jember Road

Soil samples were manually collected using a hoe at depths of 0, 15, and 30 cm, with the distances of 0, 25, and 50 meters from the highway, respectively. The collecting samples were then put into plastic and labeled with a location mark. The sampling method was as follows: at a distance of 0 meters from the edge of the road and a depth of 0 cm, five sampling points were established. Four of the points were arranged to form a square with sides of 20 cm, and the fifth point was located at the center of the square, as shown in Figure 2. The same sampling pattern was applied at each specified distance and depth. Soil from the five sampling points at each depth was combined and homogenized to form one composite sample for further analysis.

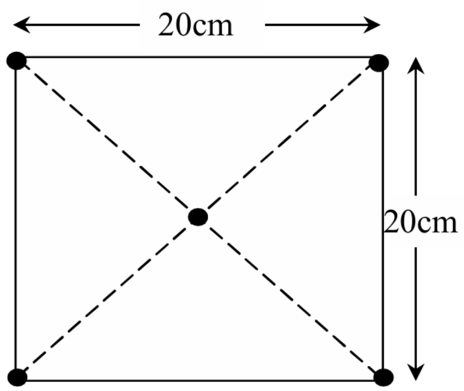

Figure 2. Sampling Points Illustration

Wet Destruction of Soil Sample

The initial step in sample processing is to dry the sample in an oven until a constant weight is achieved. The dried sample is then ground using a mortar and sieved to obtain a fine soil sample. In the wet destruction process, 1 g of the sample was dissolved in 5 mL of concentrated HNO_3. Distilled water was then added up to the marked volume, and the mixture was left to stand overnight to initiate decomposition. The mixture was subsequently heated at 100°C to 150°C until the solution became clear. The resulting solution was filtered into a 100 mL volumetric flask, and distilled water was added to the calibration mark. The solution was then ready to be analyzed for its lead (Pb) content.

Determination of Lead (Pb) Levels in Soil Samples

The measurement of lead (Pb) levels is carried out using a calibration curve by first measuring the absorbance of the standard solution and followed by the sample solution using Atomic Absorption Spectroscopy (AAS) instrument. The AAS wavelength for Pb was set 217 nm. The concentration of Pb in soil sample solution was determined by substituting the absorbance of sample value into the regression equation from Pb standard curve ($y = 0.0012x - 0.00005$, $R^2 = 0.9944$).

RESULT AND DISCUSSION

The Influence of Roadside Distance on Lead (Pb) Concentration

Lead (Pb) is a heavy metal that often pollutes the soil due to motor vehicle emissions around highways. In general, Pb concentrations tend to be higher in areas closer to the roadside and decrease with enhancing distance [18]. The following graph shows the distribution pattern of Pb in the soil at various locations in Jenggawah based on their distance from the roadside.

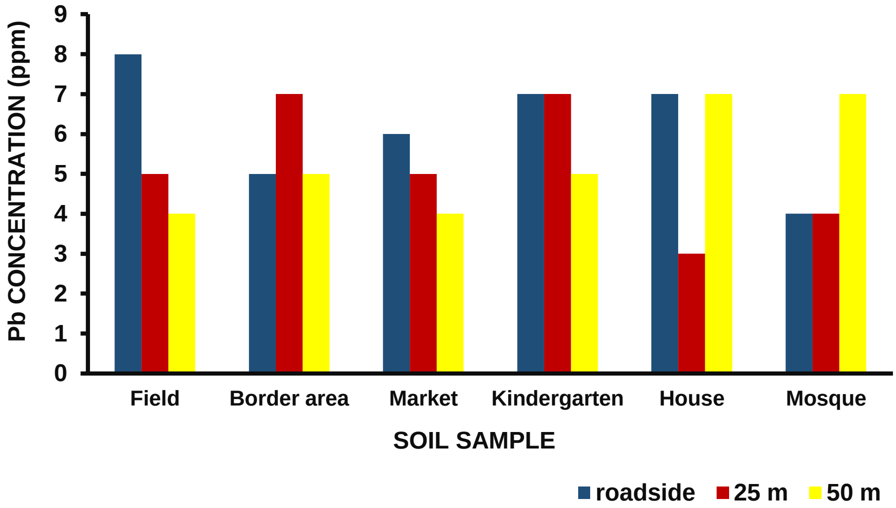

Figure 3. Lead (Pb) Distribution Profile by Distance from the Road

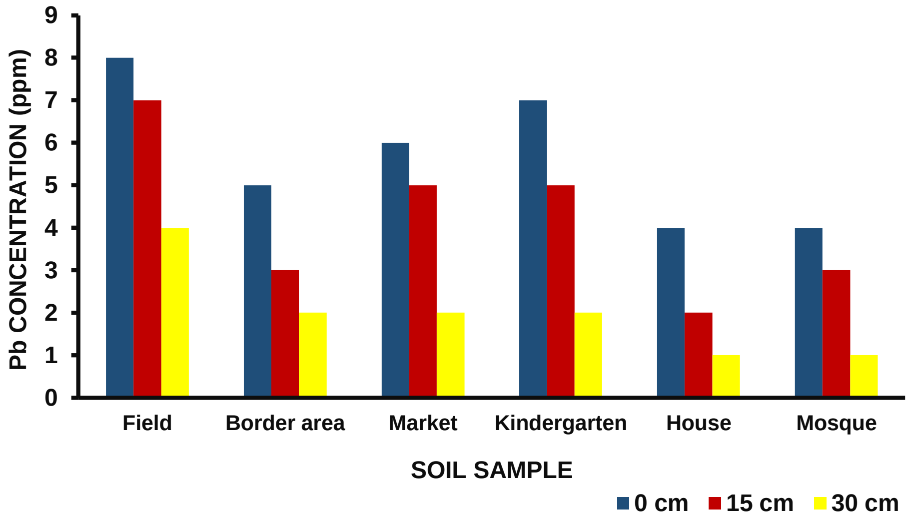

Figure 4. Lead (Pb) Concentration Profiles Based on Soil Depth

The Figure 3 illustrated the variations in lead (Pb) concentration in the soil at six different locations, namely Field, Border Area, Market, Kindergarten, House, and Mosque. Measurements were taken at three points of distance from the highway: the roadside, 25 meters, and 50 meters. In the Field, the highest Pb levels were found at the roadside and decreased drastically at distances of 25 meters and 50 meters. This is in accordance with the assumption that open areas on the roadside are directly exposed to heavy metal emissions from vehicles exhaust due to the absence of physical barriers that can reduce the deposition of Pb particles. This condition allows Pb particles from exhaust gases, brake wear, and vehicle tires to settle directly to the ground surface [18,19]. Meanwhile, in Border Area, there was an anomaly where the Pb levels were actually highest at a distance of 25 meters. This is likely due to environmental factors such as wind direction or other human activities around the area. Research by Nakamura *et. al* (2022) showed that the dominant wind direction can cause higher Pb accumulation on certain points of the pollution source because Pb particles drift and settle along the wind direction [21]. In addition, a study by Jakhar et. al (2023) found that activities such as burning garbage or small workshops can be additional sources of Pb pollution [22].

Markets and kindergartens show a more consistent pattern, with the highest Pb levels at the edge of the road and decreasing with increasing distance. This reflects the high intensity of vehicle activity in the market area and the proximity of the kindergarten location to the main road. In residential areas (Houses), there is a significant decrease in Pb levels from the edge of the road to a distance of 50 meters, indicating that the area is relatively protected from direct exposure to motor vehicles. A unique case occurred in the Mosque, where the highest Pb levels were actually at a distance of 50 meters from the road. This pattern could be caused by micro-environmental conditions such as the location of the building which is protected at the front but more open at the back, or other activities such as parking lots or air circulation areas that cause pollutant accumulation [22-24].

Lead (Pb) Concentration Profiles Based on Soil Depth

Soil pollution by heavy metals is an important environmental issue, especially in areas close to transportation and residential activities. Once heavy metals entering the soil, some would remain for extended period due to their low mobility. However, some of them may migrate downward to deeper depths layer and potentially reaching groundwater. In general, the levels of heavy metal pollutants such as lead (Pb) tend to be higher in the upper layers of the soil and decrease with increasing depth [26], [27].

Figure 4 shows the levels of lead (Pb) at various locations on the edge of the highway based on soil depth (0 cm, 15 cm, and 30 cm). In general, the highest Pb levels were found at the soil surface (0 cm) and declined with increasing depth. This reflects the general pattern of heavy metal accumulation originating from surface activities, especially vehicle emissions that settle in the topsoil [28].

The open areas, such as Fields and Kindergartens have the highest Pb levels on the surface, indicating significant potential for pollution due to direct exposure to road traffic. In contrast, at locations such as Houses and Mosques, although there was a decrease in Pb levels with depth, the pollution levels were relatively lower compared to other locations. This occurred due to the slightly dense residential of the building or the lower intensity of activities in the area [29]. The pattern of decreasing Pb concentrations with depth indicates that pollution mainly originates from the surface and is not significantly absorbed into deeper soil layers, supporting the finding that heavy metals such as Pb tend to settle on the soil surface [12].

Lead (Pb) Concentration Profiles at 25 m from Roadside

The lead (Pb) concentration, analyzed at 25 meters from the roadside across depths of 0, 15, and 30 cm in the soil samples, is represented in Graph 3. All soil samples from different locations were still below the threshold, which is 140 ppm [30]. In addition, the observed trend of decreasing Pb concentration with the soil depth in each sample aligns with previous studies conducted in diverse environments, including the surface soil across Melbourne metropolitan area, Australia [31]; forest soil at Dinghushan, southern China [32]; rural soil in Southeast China [33], farmland in Dareta village, northern Nigeria [34]; and soils along major roads in Poznań, Poland [35]. The increasing lead (Pb) concentrations observed in the upper soil depths likely originate from anthropogenic activities [5,7].

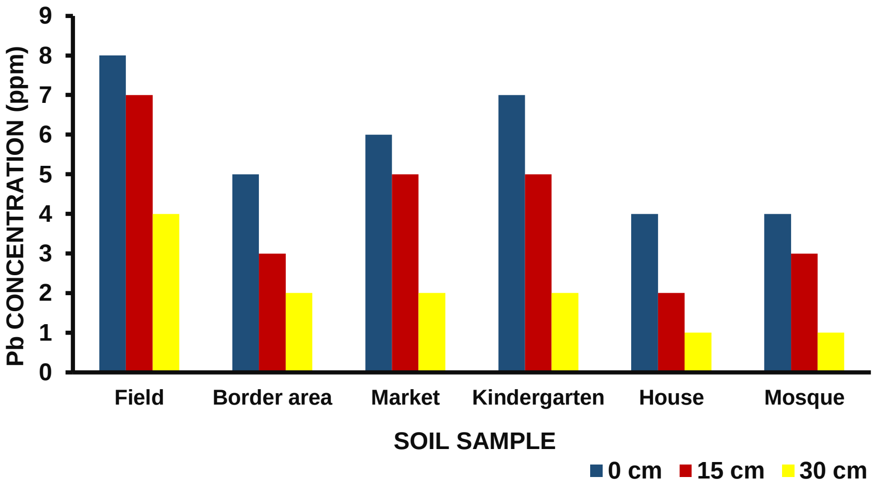

Figure 3. Lead (Pb) Concentration Profiles at 25 m from Roadside

Analysis of the soil surface (0 cm depth) revealed the highest Pb concentrations are at the border area and kindergarten locations, both around 7 ppm. These two locations also exhibited the highest Pb levels at 15 cm depth (5 ppm each) and 30 cm depth (4 ppm each). In contrast, soil samples collected from house locations consistently displayed the lowest Pb concentrations across all sampled depth levels, which were 3 ppm at the surface, 2 ppm at 15 cm, and 1 ppm at 30 cm. While a slightly differing from prior findings, the elevated Pb concentrations at the Jenggawah border area and kindergarten are explicable. The higher Pb contamination in border area, which defined by vast rice fields, could be derived from farming activities since the continuous application of irrigation water, inorganic fertilizers, and Pb based pesticides can lead to Pb accumulation in agricultural soil [1,30]. Similarly, the higher Pb concentration recorded at the kindergarten location likely contributes to continuous human activity, particularly the dense road traffic characteristic of busy sites.

Lead (Pb) Concentration Profiles at 50 m from Roadside

Graph 4 depicts the influence of soil depth on the Pb concentration profiles observed at a distance of 50 m from the roadside. Consistent with previous findings, Pb concentrations also showed a gradual decline along with increasing soil depth at 50 m from the roadside, reflecting the effect of anthropogenic activities in surface accumulation. Moreover, the highest Pb concentrations recorded at this distance, 7 ppm, were consistent with the general trend that Pb concentrations decrease with increasing distance from the roadside, showing notably lower levels compared to samples collected closer to the road (which is at 0 m or 25 m). Our findings are aligned with previous studies conducted by Ciazela and Siepak (2016), who reported a 45% decrease in the Pb concentration at the interval of 1 to 10 m from the road edge [35]. In addition, another study in the Melbourne metropolitan area also pointed to a reduction in soil Pb concentrations with increasing distance from roadways (from 5 m to 50 m) in two transects within urban parks [36]. The data emphasizes that roadside soils serve as the primary storage sites for Pb accumulation in the Jenggawah area, as it proved that Pb may even have an impact on roadside soil up to 320 m away from the road [37].

Specifically, the highest Pb concentration was recorded at both the house and the mosque with the same pattern. At these sampling locations, surface Pb concentrations measured 7 ppm, decreasing to 4 ppm at 15 cm depth and then 2 ppm at 30 cm depth. The high soil Pb in these residential sites might be due to combination factor. Aside from deteriorated lead-containing factor [38], building structures may influence Pb deposition from external sources. As Laidlaw, et. al (2017) and Bao et. al (2024) described, prevailing winds significantly disperse lead (Pb) in roadside soils by carrying airborne particulate matter [31,38]. At this distance, structures like the mosque and houses act as physical barriers, sheltering the immediate soil behind them from direct wind-borne deposition from the main road. This sheltering effect can lead to more settled and concentrated Pb profiles in that area.

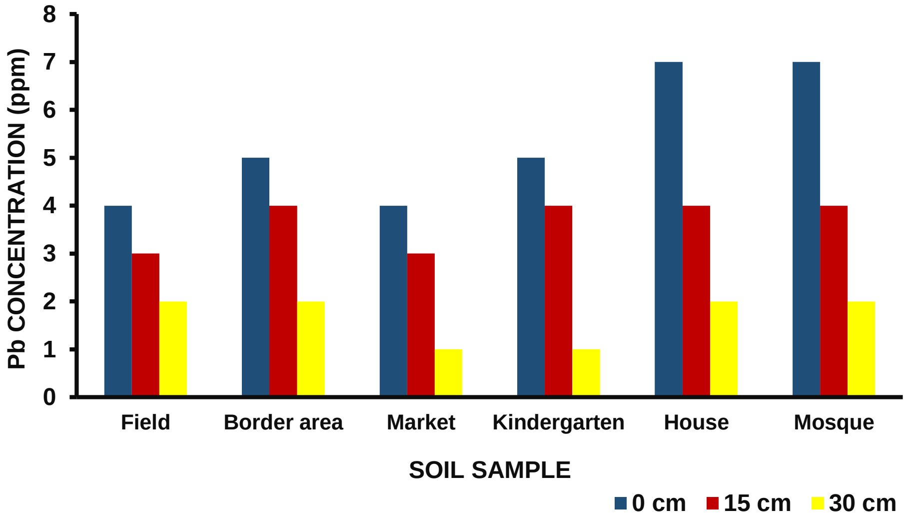

Figure 4. Lead (Pb) Concentration Profiles at 25 m from Roadside.

CONCLUSION

This study evaluated the spatial and vertical distribution of lead (Pb) in soils across various representative locations within the Jenggawah area. Our findings indicate that as a moderate anthropogenic area, all soil samples in Jenggawah exhibited Pb concentrations below the established threshold. While the highest Pb concentrations varied among sampling points, a consistent vertical trend emerged: lead content decreased with increasing soil depth. Regarding horizontal distribution, the influence of roadside proximity on Pb concentration in Jenggawah showed a slightly different pattern compared to similar previous research, likely could be due to ground surface characteristics and wind patterns. Overall, these findings not only provide valuable baseline data on lead contamination in an area with moderate anthropogenic influence but also offering critical information for future land management and environmental monitoring in Jenggawah.

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