Original Research Article

EVALUATION OF SELECTED HEAVY METALS IN INDOOR DUST AND INTERIOR PAINTED WALLS OF NURSERY SCHOOLS IN NAIROBI COUNTY, KENYA

ABSTRACT

School playgrounds found in painted environments have become death chambers for millions of innocent children who unknowingly ingest toxic metals. The objective of this study is to determine the levels of the heavy metals in paint chips from painted interior walls and indoor dust samples from 14 selected nursery schools in Nairobi County. The paint chips and indoor dust samples collected were digested using the Environmental Protection Agency method SW846 3050B then analyzed using Flame Atomic Absorption Spectrometry. Iron(Fe) had the highest concentrations in both the paint chip from interior walls and the indoor dust while Cadmium (Cd) had the lowest concentration followed by Chromium (Cr), Lead (Pb)andZinc (Zn) respectively. 50% of the nursery schools had Lead (Pb) concentrations that exceeded the 90 µg/g limit set by KEBS. For Cadmium (Cd) and Chromium (Cr), the concentrationin the nursery schools and the indoor dustwas below the 200 µg/g used in Germany. Generally, the correlation between the various metal pairs for the samples analyzed showed a non-significant correlation with exception ofLead - Iron(Pb-Fe) andChromium - Cadmium(Cr-Cd) for the indoor dust samples from pre-schools. The t-tests carried out show that levels of the heavy metals in the paint chip did not differ significantly with the levels in the indoor dust for nursery schools at 95% confidence level.

Key words: paint; heavy metals; Atomic Absorption Spectroscopy; pre-schools.

1.0 INTRODUCTION

Paints are formulations of emulsions that consist of a variety of organic/inorganic pigments, binders and a variety of additives/solvents. Paints have a variety of uses, ranging from surface protection, decoration as well as preservation. A wide range of pigments, both natural and synthetic, are used in paint manufacture. They include mica, silicas, iron III oxide, titanium dioxide, lead chromate, lead carbonate and cadmium yellow(Aslam *et al.,* 2021).The manufacture of paint entails a three-step process namely: mixing, milling/tinting and thinning. The pigments employed in paint processing contain a wide range of toxic heavy metals such as

Cadmium (Cd), Cobalt (Co), Chromium (Cr), Lead (Pb) and Nickel (Ni).Binders are usually made of resinous or polymer-based material dissolved in the paint or floats on the paint by means of emulsifiers. The binders hold the pigment particles together and ensure that once the paint is dry, a continuous film is formed on the surface to which the paint has been applied. The binders also play an important role in giving the film desirable properties. The ideal properties of binders are adhesion, flexibility, durability and toughness (Guy, 2004). The binders are dispersed in carrier solvents which can either be inorganic, like water, or organic in nature. Inorganic pigments are compounds of d-block metals, usually oxides of the metals. Other constituents of paint include additives present in lesser quantities to improve the properties of pigments and binders present in paint. Freshly applied paints don't pose a threat to children as far as heavy metal exposure is concerned (Gaitens*et al*., 2009). However, painted surfaces age over time, weathering occurs and the paints chip off from the surfaces on which they had been applied (Dixon*et al*., 2009). These processes result in the heavy metals that were constituents of the paint accumulating in indoor dust and the soil outdoor presenting a health hazard to children who learn and play in such environments (Nganga *et al.*, 2012).Metal-laced dust may also be produced in huge amounts when the old layer of paint is scrubbed off in preparation for the application of fresh paint (Sussel and Ashley, 2002). Children may get exposed to heavy metals when they come in contact with polluted soil and dust. The situation is worse in toddlers as they usually ingest almost everything they come in contact with since they are still in a stage of development called hand-to-mouth (Adekola and Dosumu, 2001). This usually happens to children below the age of six (Bakain*et al.*, 2012). Chips from paint pose a much greater danger due to the fact that the concentration of heavy metals in paints is way higher than the levels found in dust and soil. The situation is worsened when children lick or chew painted objects as this leads to direct ingestion of heavy metals, causing bioaccumulation in organs and tissues over time (Nganga *et al.*, 2012).

Children are a curious lot since they are always obsessed with discovering their environment hence, they end up engaging in hand-to-mouth behaviour during the early stages of their growth and development (Latif *et al.*, 2014). For instance, a toddler may end up ingesting about 100 mg of house dust or soil daily if left unattended to (Nganga *et al.*, 2012). So, if either the dust or soil is contaminated with heavy metals, the metals will find their way into the tissues and ultimately body organs where they will bioaccumulate over a period of time. A number of heavy metals have no meaningful use in living organisms and if taken up in huge amountscan prove fatal to the health and wellbeing of the organisms. These heavy metals include Lead (Pb), Cadmium (Cd), Mercury (Hg) and Nickel (Ni) (Ondoo*et al.*, 2019).The rate at which lead metal is absorbed in children suffering from nutritional deficiency diseases is much higher compared to perfectly healthy children (Latif *et al.*, 2014). Consistent use of paint-based products has been shown to result in the bioaccumulation of heavy metals in human tissues either through contact, ingestion or through the food chain (Ahenda *et al.*, 2020).Research has shown that painters are usually exposed to multiple carcinogens which cause lung and bladder cancer. Dye and pigment manufacturers also get exposed to carcinogens such as benzinides, cadmium and chromium VI which may lead to lung, prostate and kidney cancer. Over 80% of cancer cases in Kenya are detected at an advanced stage which makes it impossible and very expensive to treat (Daily nation, 2016). This study seeks to address the health risks that school going children are exposed to while in school as a result of poorly painted surfaces such as classroom walls. The paint chips from these walls contain high concentrations of toxic heavy metals such as Lead, Cadmium, Chromium, Zinc and Iron which have serious health effects when they bioaccumulate in human tissues.

2.0 MATERIALS AND METHODS

2.1 Study Area

The County of Nairobi, Kenya formed the area of study. The samples to be analysed were obtained from fourteen nursery schools within the study area, as shown in Table 1 below which presents the coordinates of the sampling sites.

Table 1: Sampling sites coordinates

SAMPLING POINT	LATITUDE	LONGITUDE
Sampling Point 1	-1.27286	36.831159
Sampling Point 2	-1.2815	36.7436
Sampling Point 3	-1.25318	36.872046
Sampling Point 4	-1.3038	36.774
Sampling Point 5	-1.23868	36.893806
Sampling Point 6	-1.30916	36.910684
Sampling Point 7	-1.24773	36.733747
Sampling Point 8	-1.3908	36.7639
Sampling Point 9	-1.29397	36.861158

Sampling Point 10	-1.20736	36.897183
Sampling Point 11	-1.3216	36.7989
Sampling Point 12	-1.31844	36.893475
Sampling Point 13	-1.35911	36.733134
Sampling Point 14	-1.26879	36.922186

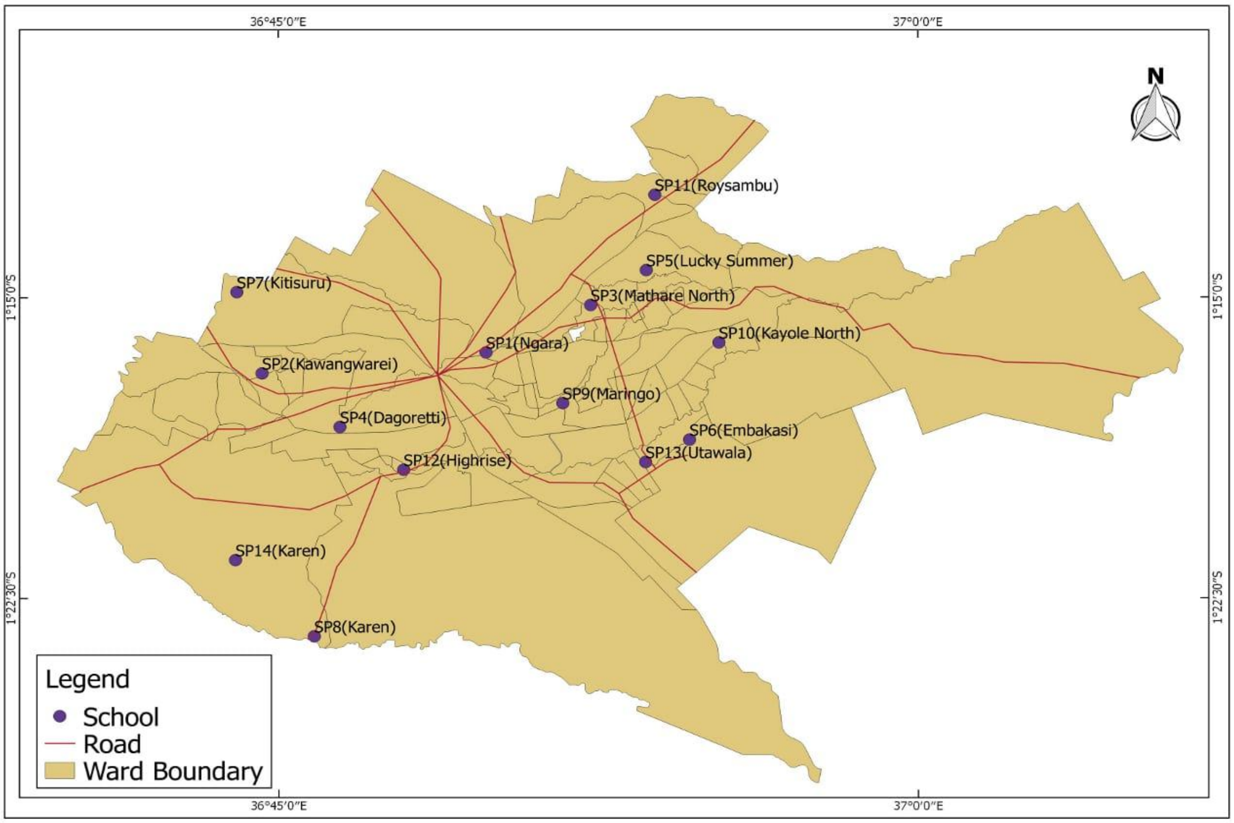

Figure 1: A map of the study area with sampling sites

2.1 Sampling

Random sampling method was used to select the fourteen nursery schools under study. Both the paint chips and dust were taken from the same room with the dust collected from surfaces close to the walls from which the paint chips were taken. Collection of the indoor dust sample was done via sweeping the area where the dust had accumulated using a brush then the dust collected using a plastic dust pan. Metallic dust pans were not used in order to avoid contamination. For the schools, the choice of indoor sampling sites was based on corners likely to have very little disturbance. The collection of paint chip samples was done by the use of a blade, where the chips were chipped off the walls of the room. After sample collection, the samples were stored in a closed polythene bag.

2.2 Sample Pre-treatment

After transportation to the laboratory, a razor blade was used to cut the paint chips into smaller pieces. The dust samples were passed through a 200-micrometer sieve to remove large particles and any other debris and hence obtain dust particles of a specific particle size.

2.3 Cleaning Glassware

The sampling bottles, plastics and glassware were cleaned using a detergent and rinsed using distilled de-ionized water. They were then soaked in 20% v/v nitric acid for 48 hours andrinsed using distilled water. Drying of the glassware was carried out in an oven at 110 ^{0}C for a period of 2 hours.

2.4 Sample Digestion

Sample analysis was carried out in accordance with the SW846 3050B EPA methodwith slight modification as captured in Ogilo*et al.,* (Ogilo*et al.*, 2017; USEPA, 1996). To 0.5g of paint/dust sample, 10 mL of nitric acid was added then heated at 95 ^{0}C ± 5 ^{0}Cfollowed by 15 minutes of refluxing. After cooling, 5 mL of 65% nitric acid were added and the mixture covered, then refluxed for another 30 minutes. 5 mL of 65% nitric acid was added until no brown fumes of NO_2 were produced. This solution was further heated at 95 ^{0}C ± 5 ^{0}C for approximately two hours. After cooling, 2 mL of distilled water was added followed by the addition of 30% hydrogen peroxide and further heating was done. The mixture was then cooled, after which an aliquot of 1 mL of 30% hydrogen peroxide was added followed by continuous warming until the sample volume reduced to 5 mL; followed by the addition of 10 mL of 37% hydrochloric acid and the samples heated at 95 ^{0}C ± 5 ^{0}C for approximately 15 minutes. Filtration of the digestate was done using Whatman No. 41 filter paper. The concentration of heavy metals in the sample was measured in triplicate using Shimadzu AA 6200 Flame Atomic Absorption Spectrophotometer.

3.0 RESULTS AND DISCUSSION

3.1 Heavy Metal Concentration in Paint Chip Samples

The samples collected showed the presence of Fe, Cd,Cr, Pb and Zn. Figure 2 gives box plots visualizing the concentration of heavy metals (Pb, Zn, Cr, Cd and Fe) in paint chips from nursery schools. Figure 3 gives the concentration of heavy metals (Pb, Zn, Cr, Cd and Fe) in paint chips from nursery schools with more details regarding the variations and concentrations at each of the fourteen sampling points. Table 2 shows the concentration of heavy metals (Pb, Zn, Cr, Cd and

Fe) in paint chips for the fourteen sampling points.Table 4 showsthe pearsoncorrelations for dust samples from pre-schools

the correlation coefficient matrix for heavy metals in dust.

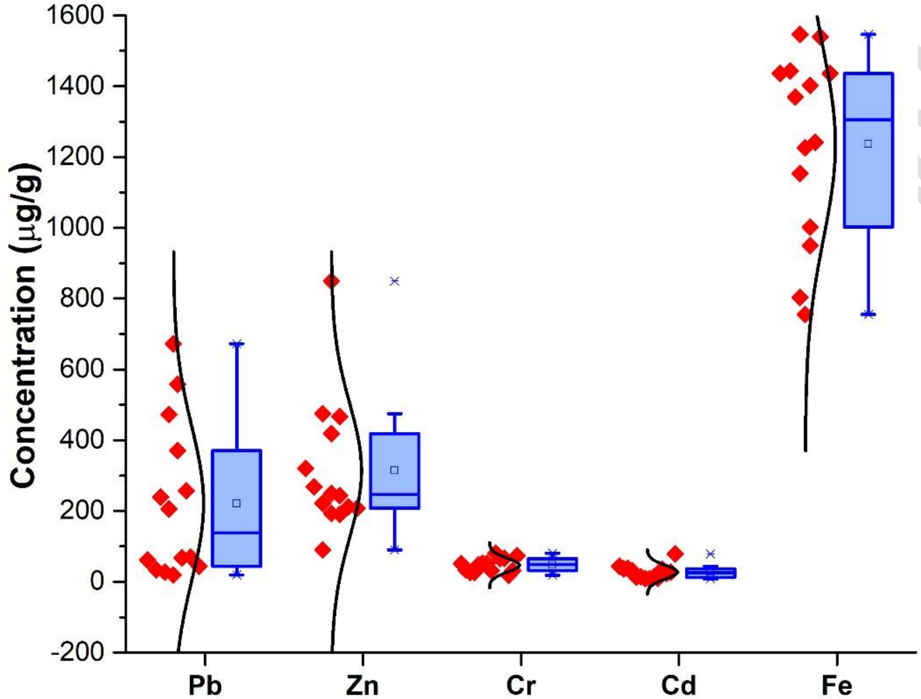

Figure 2: Box plot for the concentration of heavy metals (Pb, Zn, Cr, Cd and Fe) in paint chips from nursery schools

Significant variations were recorded for Chromium (41.71% - the least recorded) and Cadmium (98.79% - the highest recorded). These variations can be attributed to different brands of paint, the shade/colour of paint, mode of renovation carried out on the building as well as the number of paint layers applied on the walls of buildings. Brightly coloured paints, especially enamel paints, are highly likely to have high concentration of pigment which translates to high levels of heavy metals in the paint (CEJAD, 2017; Okewole and Omin, 2013). The level of heavy metals in paint also differs considerably from one manufacturer to the other (Apanpa-Qasim and Adeyi, 2017; CEJAD, 2017; Ng'ang'a *et al.*, 2012) and as such, the brand of paint applied on a surface will have significant impact as far as the concentration of heavy metals on the painted surface is concerned.

A common practice during renovation is that the old layer of paint should be scrapped from the surface/walls before applying a new coat. However, this standard practice is never adhered to as fresh coats are usually applied on top of the old ones leading to surfaces having multiple coats from different brands of paint. Another practice during painting is the application of several undercoats before the final coat is applied, leading to the presence of several coats of paint on a surface(Gaitens*et al*., 2009). Paint chips from such surfaceswill not only comprise of several paint samples from different manufacturers, but also lead to elevated levels of heavy metal in the paint samples.

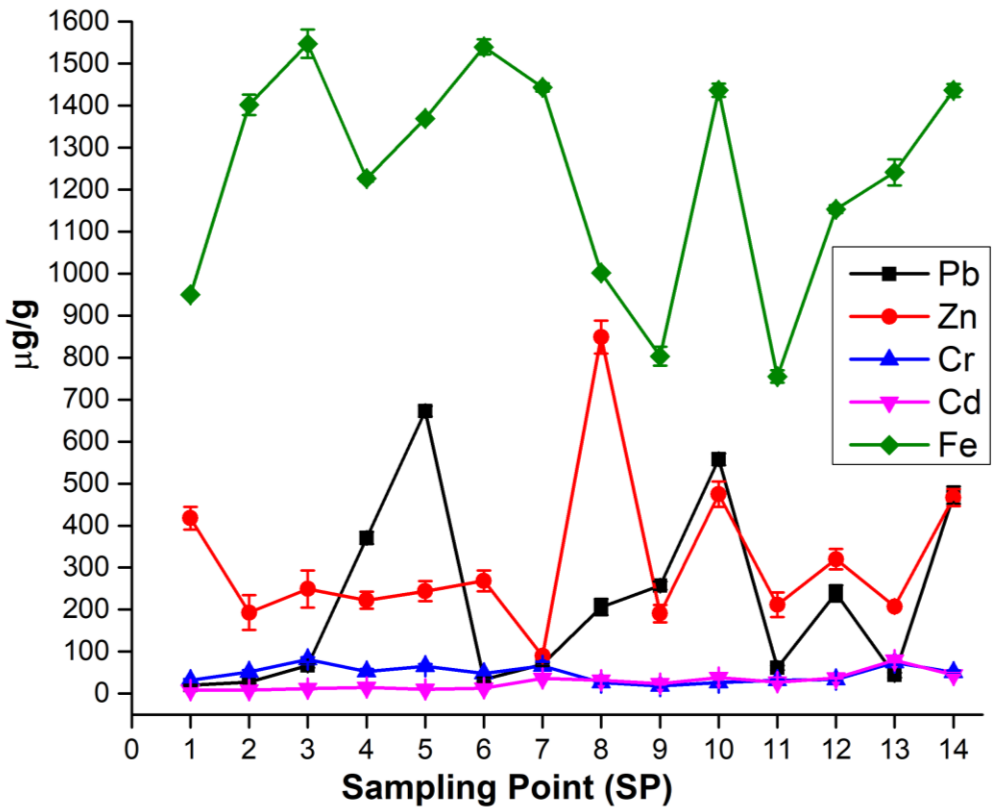

Figure3: Concentration of heavy metals (Pb, Zn, Cr, Cd and Fe) in paint chips from nursery schools

3.1.1 Lead

Lead continues to find applications in the manufacture of various products owing to some of its excellent properties such as high corrosion resistance, ductility, malleability and high density. However, due to its acute toxicity as a neurotoxin, the use of Lead in various consumer products was halted in the 90s and replaced by safer alternatives such as Zinc and Copper. Before 1963, basic Lead carbonate 2.$PbCO_3$. Pb $(OH)_2$(white lead) and Lead tetraoxide Pb_3O_4 (red lead) were the two most common types of Lead pigments used in surface decoration. The European Community Directive of 1977 requires that Lead – based paint exceeding 5000 mg/kg should not be accessed by children. This was in a bid to stop the inclusion of white lead to paint meant for domestic purposes (Turner *et al.*, 2023).The concentration of Pb ranged from 19.73 ± 1.16 µg/g to 672.28 ± 12.28 µg/g, with a mean concentration of 221.27 µg/g. Since bioaccumulation of lead leads to inflammation of the brain and the spinal cord, (Provin and Pitt, 2010) the WHO recommends as lead-free environment as possible. It is therefore a cause of worry and concern given that nursery schools are attended by children under the age of six years and exposure to these dangerous levels of lead at such an early age can lead to bioaccumulation and cause serious ailments when their bodies are not yet fully developed. Several countries such as Japan, Germany and Australia have placed a limit on the amount of lead in paint at 200 ppm (TEIB, 2003). Given that the mean concentration of lead was 221.27 µg/g, the concentration of lead from 50% of the sampled schools (N =7) was above the 90 µg/g levels recommended by the Kenya Bureau of Standards (KEBS), indicating danger of exposure to lead from lead-based paints. The mean concentration of lead in this study was much higher than that reported by Darus *et al*., (31.24 µg/g) and Tahir and Jafar(51.00 µg/g) (Darus*et al*., 2012; Tahir, Chee & Jaafar, 2007).The deviation of the mean concentration of lead from the standard value was statistically significant at 95% level of confidence (P = 0.043) as per one sample t – test.

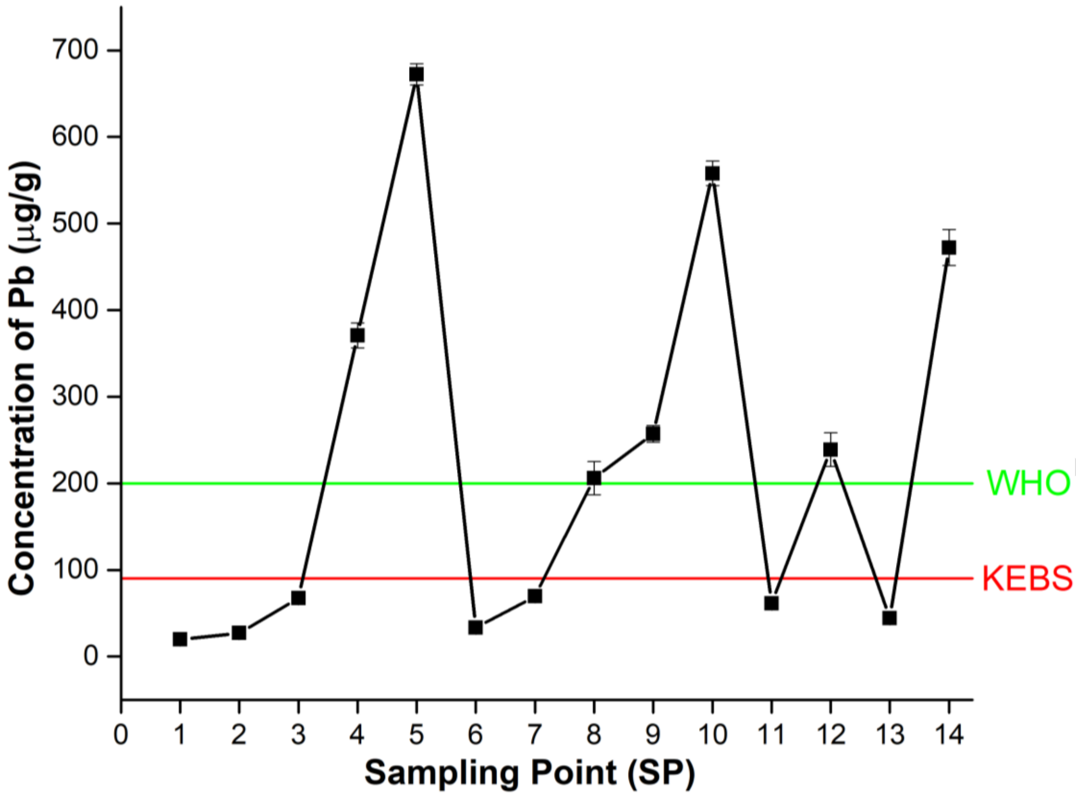

Figure4: Concentration of lead in paint chips from nursery schools as compared to WHO and KEBS limits

3.1.2 Chromium

Chromium is a heavy metal with a density of 7.15 g/cm^3. Chromium finds wide use application in the manufacture of pigments and dyes for paints, coloured glass, electroplating and leather tanning. Chromium (VI) is the most form of Chromium as it leads to Chromium poisoning which can be manifested through liver and kidney disease, lung cancer, bronchitis and sinusitis.The metal is a major component of red rubies when combined with aluminium oxide and usually reacts with oxygen to form a protective layer of Chromium (III) oxide which is highly resistant to corrosion and it's on this basis that it is used as a pigment in corrosion resistant paints (Blundell *et al.*, 2020).The concentration of Chromium in the paint chip samples ranged from 26.10 ± 2.17 µg/g to 81.11 ± 5.93 µg/g, with a mean concentration of 46.96 µg/g. Chromium III plays a vital role in the human body in controlling blood sugar levels. However, exposure to high levels of chromium IV may lead to kidney and liver complications (Dyan and Paine, 2001). The concentration of chromium from this study was much higher than that reported by Popoola *et al.*, (10.53 µg/g) during the analysis of heavy metal concentration in classrooms in Lagos city, Nigeria (Popoola *et al.*, 2012) but much lower than those reported byChen *et al.*, (149.20 µg/g) during the determination of heavy metals in kindergartens and elementary schools in Xi'an, China (Chen *et al.*, 2014).

3.13 Cadmium

Cadmium is the 64th most abundant metal in the earth's crust with a density of 8.69 g/cm^3. The metal is found in combined form with Zinc and the only Cadmium-rich mineral is Greenockitein which Cadmium is combined with Sulphur. Cadmium finds use in the manufacture of pigments used in the manufacture of glass, manufacture of pigments for corrosion resistant plating, Nickel – Cadmium batteries, pesticides and as a stabilizer in plastic production. Cadmium is a highly toxic metal and bioaccumulation of the metal in human tissues may lead to health complications such as kidney failure, infertility, cancer, DNA impairment and complications in the central nervous system (Blundell *et al.*, 2020).The levels of cadmium in paint chips ranged from 7.98 ± 0.78 µg/g to 79.18 ± 1.57 µg/g with a mean value of 27.38 µg/g. Exposure to high levels of cadmium affects male fertility by lowering the sperm count. Cadmium also destroys internal body organs such as kidney, heart and liver by hardening them (Johannes *et al.*, 2006).The level of cadmium reported in this study was much higher than those reported by Latif *et al.*, (0.23 µg/g) during the study of exposure to heavy metals in children in Malaysian schools (Latif *et al.*, 2014).

3.14 Zinc

The 24th most abundant metal in the earth's crust has a density of 7.134 g/cm^3, with the most common ores being Zinc blende and Zinc silicate. The metal finds wide applications in the manufacture of paints, soaps, cosmetics, deodorant, ink, textiles and cosmetics. It can also be combined with other metals to form alloys of brass and bronze. Frequent exposure to Zinc may result in bioaccumulation which may cause serious health effects such as anemia, low body immunity, complications of the pancreas, low levels of copper and fatigue. (Blundell *et al.*, 2020).The levels of zinc in paint chips ranged from 89.55 ± 4.41µg/g to 848.99 ± 39.58 µg/g, with a mean concentration value of 314.64 µg/g. Very low levels of zinc in the body lead to poor development of sex organs, birth defects and retarded growth in children. Exposure to high levels of zinc leads to damage of organs such as the pancreas as well as gastrointestinal discomforts (ATSDR, 2005). The levels of zinc reported in this study were much lower than those reported by Tong and Lam (2293.56 µg/g) but way higher than those reported by Latif et al., (144.90

μg/g) in the study of heavy metal levels in Hong Kong nursery schools and preschools in Malaysia (Tong and Lam, 1998; Latif *et al.*, 2014).

3.15 Iron

Oxides of iron find wide application in the manufacture of pigments and paints due to their high and pure hue and excellent tinting strength. Their colours range from yellow, red and orange. The largest use of iron oxides is the building and construction in the colouring of concrete and mortar due to their excellent dispersion and tinting strength. These oxides are widely used in the manufacture of coloured tiles, paving blocks and stamped concrete. In order to generate excellent colouring effects and maintain high film strength. Special applications of iron oxides find use in the manufacture of cosmetics, drugs, wood polish, rubber and fertilizers (Esaar, 2023).The concentration of iron ranged from 755.03 ± 14.83 μg/g to 1547.25 ± 33.90 μg/g with an average concentration of 1713.90 μg/g. Deficiency of iron causes anemia whereas very high concentration of iron in the body may lead to blood coagulation, dizziness and rapid heartbeat (Nazir. *et.al.,* 2015). The levels of iron reported in this study were much lower than those reported during the study of heavy metals in Malaysian preschools (4801.00 μg/g) by Latif *et al.* (Latif *et al.*, 2014).

Table 2. Concentration of heavy metals (Pb, Zn, Cr, Cd and Fe) in paint chips from nursery schools

	Pb (μg/g)	**Zn (μg/g)**	**Cr (μg/g)**	**Cd (μg/g)**	**Fe (μg/g)**
SP1	19.73 ± 1.16	418.00 ± 27.06	31.83 ± 2.78	7.98 ± 0.78	949.81 ± 3.72
SP2	27.17 ± 2.91	193.08 ± 41.52	51.82 ± 4.16	8.69 ± 1.40	1402.21 ± 24.49
SP3	67.34 ± 5.40	249.30 ± 44.11	81.11 ± 5.93	11.92 ± 2.14	1547.25 ± 33.90
SP4	370.66 ± 14.53	222.37 ± 20.11	52.15 ± 6.53	14.24 ± 1.71	1226.28 ± 7.24
SP5	672.28 ± 12.28	243.79 ± 24.04	65.56 ± 4.62	10.46 ± 0.83	1369.05 ± 1.89
SP6	33.20 ± 4.77	268.47 ± 25.00	48.25 ± 1.50	13.16 ± 1.01	1539.75 ± 17.80
SP7	69.46 ± 3.70	89.55 ± 4.41	66.31 ± 9.42	36.15 ± 1.37	1443.40 ± 10.15
SP8	206.03 ± 19.32	848.99 ± 39.58	26.10 ± 2.17	31.77 ± 0.93	1001.64 ± 3.07
SP9	257.22 ± 9.59	190.66 ± 20.59	18.38 ± 3.83	23.68± 0.51	803.33 ± 22.33
SP10	557.84 ± 14.19	474.56 ± 30.20	26.29 ± 1.30	37.80 ± 0.50	1436.43 ± 15.75
SP11	61.38 ± 5.62	211.51 ± 29.39	31.62 ± 1.91	27.47 ± 0.60	755.03 ± 14.83
SP12	238.97 ± 19.38	320.21 ± 24.70	33.76 ± 1.99	36.80 ± 0.38	1153.55 ± 9.29
SP13	44.28 ± 5.83	207.52 ± 5.86	73.75 ± 5.42	79.18 ± 1.57	1241.19 ± 30.84
SP14	472.28 ± 20.78	467.01 ± 20.22	50.56 ± 4.40	43.98 ± 0.26	1436.38 ± 15.56

3.2 Pearson Correlation Coefficient for Paint Chips

The correlation coefficient, r, has values that range between $-1 \leq r \leq +1$; where an r value of – 1 indicates negative correlation, an r value of +1 denotes positive correlation whereas an r value of 0 denotes no linear relationship between the variables under study (Miller, J. N. and Miller, 2010). In the analysis of heavy metals in paint chips, chromium – zinc and lead – chromium recorded a negative correlation ($r = -0.462$, $n = 14$, $p = 0.096$) and ($r = -0.116$, $n = 14$, $p = 0.693$) respectively. The correlations of both metal pairs were not significant at $p > 0.05$. However, positive correlations were recorded in the following metal pairs: chromium – iron ($r = 0.239$, $n = 14$, $p = 0.411$), cadmium – iron ($r = 0.234$, $n = 14$, $p = 0.421$), and lead – zinc ($r = 0.232$, $n = 14$, $p = 0.425$) registered weak correlations. The following metal pairs registered very weak correlations. They include zinc – iron ($r = 0.194$, $n = 14$, $p = 0.507$), chromium – cadmium ($r = 0.114$, $n = 14$, $p = 0.698$), lead – iron ($r = 0.112$, $n = 14$, $p = 0.703$), cadmium – zinc ($r = 0.081$, $n = 14$, $p = 0.784$), and lead – cadmium ($r = 0.002$, $n = 14$, $p = 0.994$). From the above results, none of the metal pairs were significantly correlated at $p > 0.05$ confidence level.

The lack of significant correlation between the various metal pairs is indicative of the presence of different brands of paint on the interior walls of the pre – schools, which can be attributed to the different ingredients used by the different manufacturers during the process of paint production. In addition, different schools use varying shades/colours of paint is the major cause for the varying degrees of heavy metal concentration in the different paints (Okewole and Omin, 2013).

3.3 Heavy Metal Concentration in Indoor Dust Samples

All the dust samples collected from the different nursery schools had varying concentrations of heavy metals (Cd, Cr, Pb and Zn) as shown in Figure5 and 6 below.Table 4 shows the correlation coefficient matrix for heavy metals in dust samples from pre-schools.

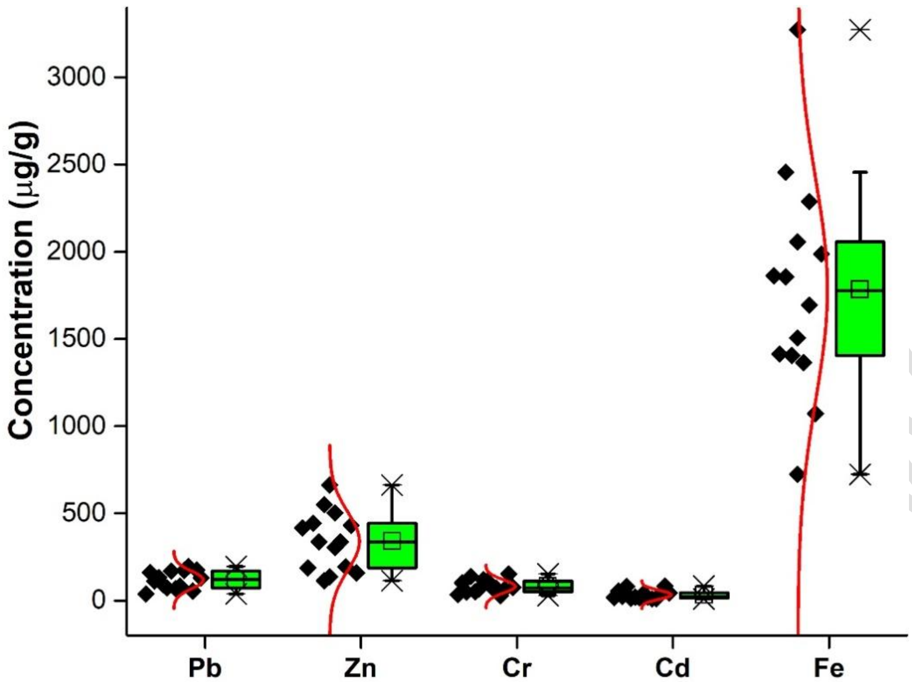

Figure 5: Box plot for the concentration of heavy metals (Pb, Zn, Cr, Cd and Fe) from indoor dust samples of nursery schools

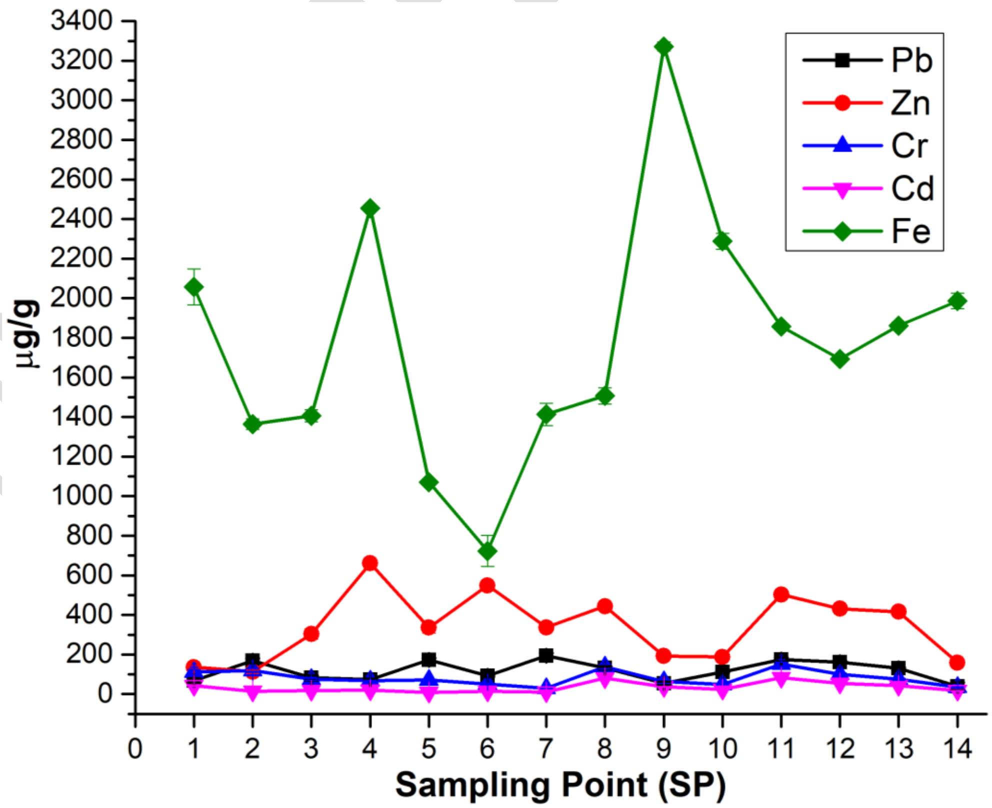

Figure6: Concentration of heavy metals (Pb, Zn, Cr, Cd and Fe) from indoor dust samples of nursery schools with more detail regarding the variations and concentrations at each of the fourteen sampling points

3.3.1 Lead

The double salt of white Lead ($2.PbCO_3.Pb(OH)_2$) finds wide applications in the manufacture of white paint. However, given the fact that Lead and other compounds of Lead are affect the nervous system, the manufacture and use of Lead-based paints has been discontinued in many parts of the World. However, research shows that Lead – based paints are still manufactured in other parts of the World where environmental pollution laws are not strictly upheld, mostly in developing countries. Despite this ban, lead-based pigments are crucial paint additives as they are added in small quantities as pigments, corrosion resistant agents and also as driers (Turner and Sogo, 2011).The concentration of lead in indoor dust samples ranged from 68.57 ±9.98 µg/g to 194.70 ± 13.28 µg/g with a mean concentration of 118.48 µg/g. The concentration of lead in this study was much lower than that reported during the analysis of heavy metals in indoor dust samples for pre - schools in Malaysia (Latif *et al.*, 2014) and that recorded during the evaluation of heavy metals in kindergarten schools in Hong Kong (Tong and Lam, 1998).

3.3.2 Chromium

With the exception of the most toxic heavy metals such as Mercury and Cadmium, compounds of other equally toxic heavy metals still find wide use application in the formulation of paint products such as corrosion inhibitors, driers, paint dispersive agents as well as pigment additives(Turner and Sogo, 2011). This includes compounds of Chromium VI which also find wide use application in the manufacture of herbicides, wood preservatives and pigment for paint formulation.Chromium levels in the indoor dust samples had concentrations ranging from 28.62 ± 1.84 µg/g to 152.67 ± 9.48 µg/g with an average concentration of 81.47 µg/g.The levels of chromium from this study were much lower than those recorded by Lu, Zhang, Li, & Chen (159.70 µg/g) during the assessment of heavy metals in nursery schools in Xi'an, China (Lu, Zhang, Li, & Chen, 2014).

3.3.3 Cadmium

Cadmium, together with other heavy metals such as Chromium, Manganese, Cobalt and Nickel has a density of more than 5 g/cm^3. The bioaccumulation of Cadmium in human tissues can lead to formation of free radicals which may damage the DNA leading to mutations that can be cancerous. Cadmium inhibits the mechanism by which DNA repairs itself leading to oxidative effects which are manifested through base modification, DNA strand scission and depurination. Cadmium also inhibits the absorption of Zinc in the body, leading to Zinc deficiency (Blundel *et al.,* 2020).Cadmium levels in the indoor dust samples had concentrations ranging from 9.38 ± 1.96µg/g to 82.60 ± 1.71 µg/g with a mean concentration of 33.51 µg/g.The levels of cadmium obtained from this study were much higher than those reported by Tong and Lam (8.48 µg/g) as well as those reported by Popoola et al., (0.09 µg/g) during the study of heavy metal concentrations in Hong Kong nursery schools Nigerian primary schools respectively (Tong and Lam, 1998; Popoola *et al*., 2012).

3.3.4 Zinc

Zinc, together with elements like Copper, Iron and Manganese is essential in the formation and maintenance of a strong skeletal system, regulation of acid – base equilibrium and is a major structural component of enzymes and hormones. Zinc oxide finds applications in the manufacture of paints, cosmetics, ink, textile and deodorants. Zinc when mixed with other metals forms alloys of brass and bronze. Bioaccumulation of Zinc causes anaemia, low immune function and pancreatic complications (Blundel *et al.,* 2020).Zinc in indoor dust samples had concentrations ranging from 113.37 ± 8.54 µg/g to 661.45 ± 11.56 µg/g, with an average concentration of 340.80 µg/g.Zinc concentrations recorded in this study were well within the range reported by Lu, Zhang, Li, & Chen and Tahir, Chee & Jaafar during the evaluation of heavy metals from indoor dust of nursery schools in Xi'an, China (462.60 µg/g) and Dungun, Terengganu (558.00 µg/g) (Lu, Zhang, Li, & Chen, 2014; Tahir, Chee & Jaafar, 2007).

3.3.5 Iron

Iron is the 6th most abundant element in the universe. Oxides of iron have been used as pigments since the days of early man. There are a number of iron oxide pigments which are derived from a number of minerals ranging from hematite (red pigment) and magnetite (black iron) to ochres, seirras and umbers (yellow and brown pigments). The pigments made from oxides of iron are relatively cheap with high resistance to corrosion. Natural pigments of iron find application in undercoats where colour is not given much consideration, whereas synthetic iron pigments are usually applied in topcoat paints where colour quality is critical. Micaceous oxides of iron possess excellent properties when used in paints. They include resistance to moisture and gas penetration into the surface, prevent rusting and corrosion of painted surfaces and also resist cracking and peeling of the painted surface (Potter J.M., 2018).The levels of iron in the indoor dust samples of the pre-schools was 723.13 ± 78.62 µg/g to 3272.36 ± 23.87 µg/g with a mean concentration of 1853.52 µg/g. The concentration of iron reported in this study was way lower than that recorded by Darus *et al.*, in the determination of heavy metals in nursery school buildings (4225.33 µg/g) (Darus*et al.*, 2012).

Table 3: Concentration of heavy metals from indoor dust samples of nursery schools

	Pb (µg/g)	Zn (µg/g)	Cr (µg/g)	Cd (µg/g)	Fe(µg/g)
SP1	68.57 ± 9.98	136.41 ± 7.30	111.47 ± 13.43	42.29 ± 1.26	2056.79 ± 91.12
SP2	169.32 ± 11.44	113.37 ± 8.54	120.34 ± 9.75	14.72 ± 0.85	1364.09 ± 26.13
SP3	82.14 ± 13.11	303.49 ± 26.18	76.14 ± 5.54	18.85 ± 0.89	1406.13 ± 30.65
SP4	73.56 ± 4.20	661.45 ± 11.56	67.41 ± 2.96	19.88 ± 0.98	2455.38 ±96.14
SP5	172.69 ± 10.42	336.38 ± 28.33	71.32 ± 1.68	9.38 ± 1.96	1071.48 ±23.19
SP6	92.18 ± 4.74	549.11 ± 16.34	50.62 ± 1.71	13.36 ± 0.84	723.13 ± 78.62
SP7	194.70 ± 13.28	336.90 ± 6.18	28.62 ± 1.84	11.19 ± 1.21	1413.21 ± 56.51
SP8	133.02 ± 8.13	443.62 ± 10.92	138.49 ± 11.29	81.87 ± 6.16	1506.69 ± 40.90
SP9	55.12 ± 7.35	192.95 ± 4.45	64.11 ± 9.17	37.42 ± 1.39	3272.36 ± 23.87
SP10	112.35 ± 5.25	187.61 ± 7.03	48.65 ± 2.79	22.88 ± 1.27	2287.69 ± 40.49
SP11	174.85 ± 9.04	503.05 ± 1.41	152.67 ± 9.48	82.60 ± 1.71	1856.56 ±11.85
SP12	161.68 ± 4.60	431.96 ± 8.17	100.68 ± 8.19	53.72 ± 1.84	1693.87 ± 17.98
SP13	130.00 ± 5.55	416.09 ± 3.31	75.54 ± 5.42	43.72 ± 2.94	1862.22 ± 18.70
SP14	38.48 ± 18.85	158.75 ± 1.28	34.52 ± 2.81	17.22 ± 0.43	1986.42 ± 39.94

3.4 Range of Heavy Metals in Indoor Dust Samples

All the heavy metals under study recorded a range of more than 30%; with Cadmium recording the highest spread with range = 73.90% whereas iron recorded the least spread with a range value of 38.27%. The observed differences in the range values can be attributed to the locations of the nursery schools, as different schools are in different parts of Nairobi County. The proximity of different schools to the numerous pollution sources is also another key factor that explains the huge differences in the range values. The closer a school is to a pollution source; the more likely it is to be exposed to high levels of heavy metals. The number of learners in a particular classroom has been shown to be directly proportional to the concentration of heavy metals in indoor dust (Boseila*et al.*, 2004, Gaitens*et al.*, 2009) and therefore schools with high number of pupils are most likely to register higher levels of heavy metals in indoor dust of their classrooms.In addition,the buildings used by the schools are of varying ages making the paint on the walls of different schools to be either in the early or late stages of deterioration(Dixon*et al.*, 2009, Lanphear *et al.*, 1996) hence the paint chips on the classroom walls will be of different brands and the level of heavy metals in them will vary from one wall to another.

Renovations also influence the level of heavy metals in the indoor dust to a greater extent. During renovations, the old paint on the walls is scrapped off and a new applied. This leads to an increase in the concentration of heavy metals on the walls(Dixon*et al.*, 2009); therefore, nursery schools that underwent renovations recently are most likely to record elevated levels of heavy metals in their indoor dust. The renovation technique, whether the old painting on the walls was scrapped off or not, will have a significant impact on the heavy metal content in the floor dust.

Comparisons were drawn between the spread of heavy metals in paint chips and indoor samples. It was found that zinc, iron and lead registered lower spreads in dust samples whereas cadmium and chromium registered slightly higher spread in indoor dust samples.

3.5 Pearson Correlation Coefficient for Indoor Dust Samples

Three metal pairs registered a negative correlation. There were: lead – iron ($r = -0.610$, $N=14$, $p = 0.021$); zinc – iron ($r = -0.309$, $N=14$, $p = 0.282$) and chromium – iron ($r = -0.192$, $N=14$, $p = 0.511$). The rest of the metal pairs registered positive correlation; they include the strong correlation of chromium – cadmium Cr-Cd ($r = 0.693$, $N=14$, $p = 0.006$) as well as the weak correlations of lead – chromium ($r = 0.326$, $N=14$, $p = 0.256$), cadmium - zinc ($r = 0.267$, $N=14$, $p = 0.356$), and lead – cadmium ($r = 0.204$, $N=14$, $p = 0.483$) lead – zinc ($r = 0.178$, $N=14$, $p = 0.543$), cadmium – iron ($r = 0.104$, $N=14$, $p = 0.631$) and chromium – zinc ($r = 0.113$, $N=14$, $p = 0.701$).The correlation between two metal pairs, chromium – cadmium and lead – iron was statistically significant at ($p<0.05$) level of significance. This significant correlation points to the fact that these metals have a common origin. There was no statistical significance between the remaining heavy metals and this point to the fact that these metals are not from a common source/origin.

Table 4: The Pearson Correlations for Dust Samples from Pre-schools

		Pb	Cr	Cd	Fe	Zn
Pb	r	1	0.326	0.174	-.0610*	0.178
	Sig.		0.256	0.552	0.021	0.543
	N	14	14	14	14	14
Cr	r	0.326	1	0.774**	-0.192	0.113
	Sig.	0.256		0.001	0.511	0.701
	N	14	14	14	14	14
Cd	r	0.174	0.774**	1	0.104	0.262
	Sig.	0.552	0.001		0.725	0.366
	N	14	14	14	14	14
Fe	r	-0.610*	-0.192	0.104	1	-0.309
	Sig.	0.021	0.511	0.725		0.282
	N	14	14	14	14	14
Zn	r	0.178	0.113	0.262	-0.309	1
	Sig.	0.543	0.701	0.366	0.282	
	N	14	14	14	14	14

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

3.6 Heavy Metal Comparison between Dust and Paint Chips

The level of lead was much higher in paint chips compared to the dust samples as shown in figure7below; whereas Zinc, Iron, Cadmium and Chromium had dust having a much higher concentration of heavy metals being much higher in dust than paint chips.

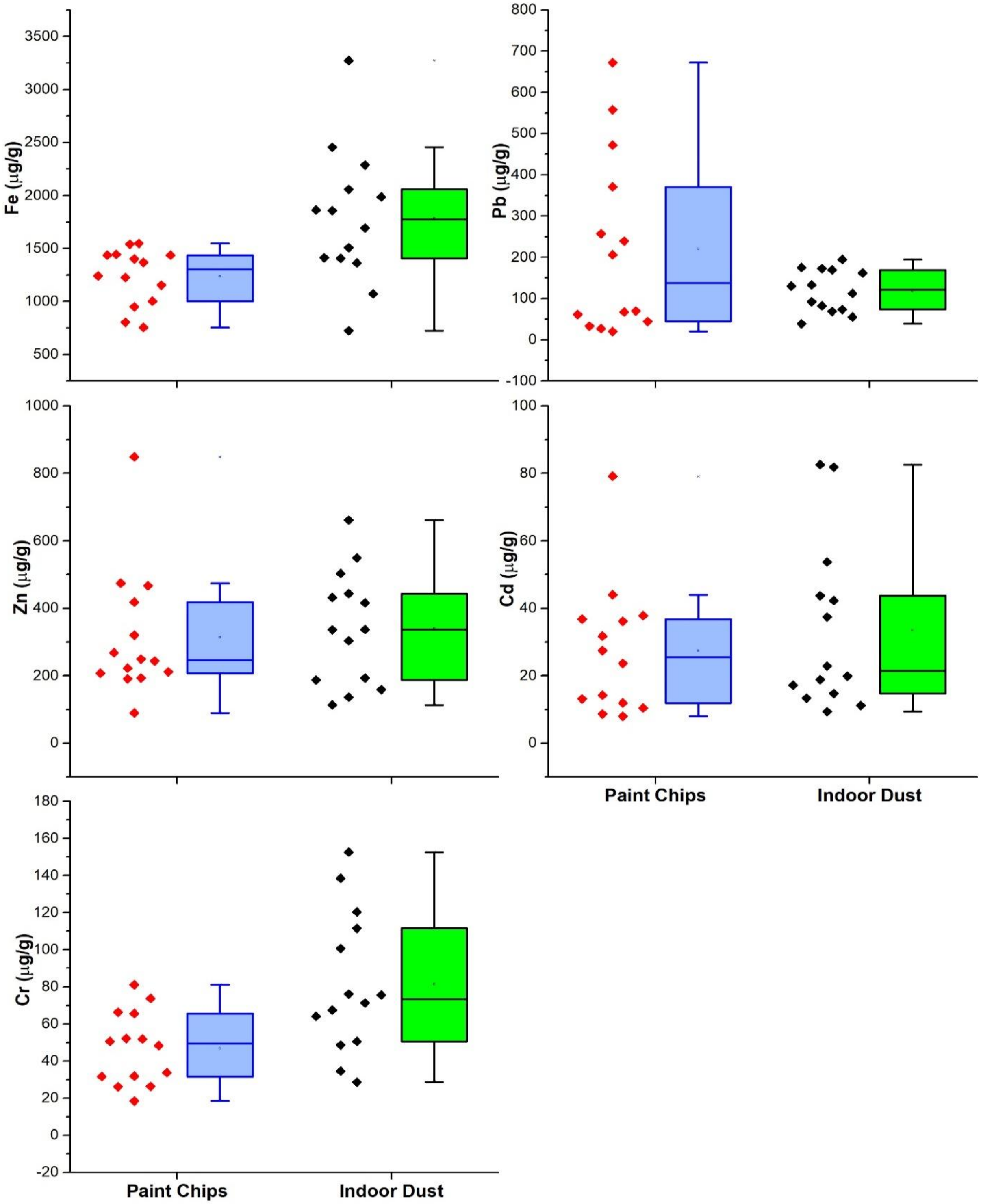

Figure 7: Box plots showing comparisons in the concentration of heavy metals (Fe, Pb, Zn, Cd and Cr) of paint chips and indoor dust

The mean heavy metal concentrations in paint chips and indoor dust samples in the 14 pre-schools sampled were of the order: Fe>Zn>Pb>Cr>Cd as presented in fig. 8below.

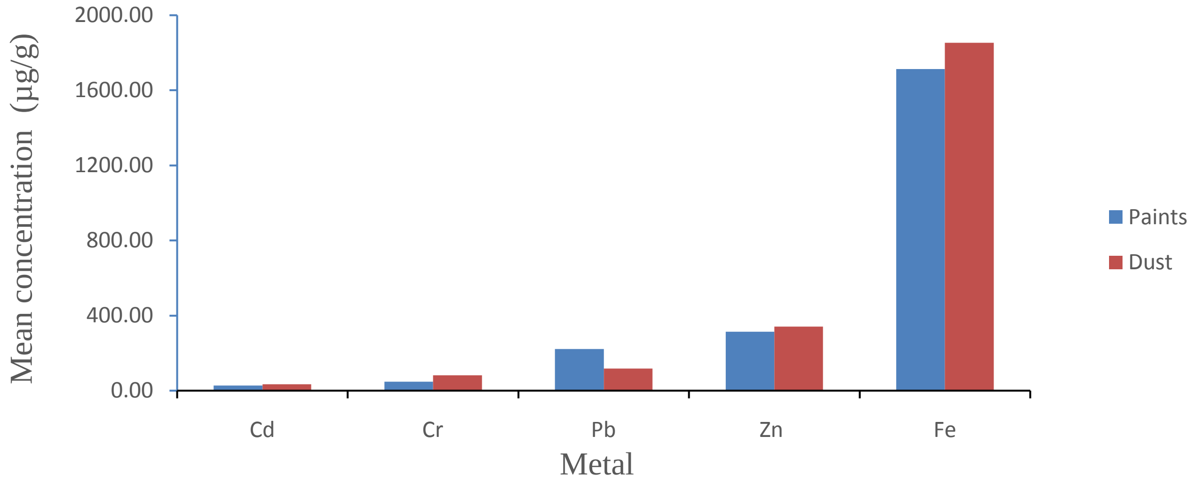

Figure 8: Mean heavy metal concentration in paint chips versus indoor dust samples

The significant difference between heavy metal concentration in paint chips and indoor dust samples was determined using paired t – test. Chromium registered a significant difference between the concentration of heavy metals in paint chips and indoor dust samples ($p = 0.02$). But for lead, cadmium, iron and zinc, there was no significant difference in the concentration of heavy metals in dust and paint chips at p = 0.119, 0.414, 0.645 and 0.716 level of significance respectively.

To establish the correlation between concentration in paint chips and indoor dust samples, Pearson correlation coefficient was calculated. The following metals recorded a negative r value: Lead ($r = -0.125$, N=14, $p = 0.671$), Chromium ($r = -0.357$, N=14, $p = 0.210$), Iron ($r = -0.002$, N=14, $p = 0.995$) and Zinc ($r = -0.078$, N=14, $p = 0.792$) whereas Cadmium registered a positive but weak correlation ($r = 0.260$, N=14, $p = 0.369$). No single correlation was statistically significant at $p>0.05$ level of significance.The lack of correlation in elemental concentration of paint chips and indoor dust samples points to the fact that the heavy metals present in the paint chips and dust samples could have originated from different sources and not just the paint chips that fall on the floor from the walls. These external sources could be exterior walls, soils and any other exterior sources such as wind blow dust from outside the classrooms.

Table 5: Paired Samples Correlations for Pre-schools

		N	Correlation	Sig.
Pair 1	Level of Pb in paint chips from schools & Level of Pb in dust from schools	14	-0.125	0.671
Pair 2	Level of Cr in paint chips from schools & Level of Cr in dust from schools	14	-0.357	0.21
Pair 3	Level of Cd in paint chips from schools & Level of Cd in dust from schools	14	0.26	0.369
Pair 4	Level of Fe in paint chips from schools & Level of Fe in dust from schools	14	-0.002	0.995
Pair 5	Level of Zn in paint chips from schools & Level of Zn in dust from schools	14	-0.078	0.792

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion

For the fourteen nursery schools that were considered in this study, the concentration range of heavy metals in paint chips were as follows: Lead (19.73 ± 1.16 µg/g to 672.28 ± 12.28 µg/g),Chromium (26.10 ± 2.17 µg/g to 81.11 ± 5.93 µg/g), Cadmium (7.98 ± 0.78 µg/g to 79.18 ± 1.57 µg/g), Zinc (89.55 ± 4.41µg/g to 848.99 ± 39.58 µg/g), and Iron (755.03 ± 14.83 µg/g to 1547.25 ± 33.90 µg/g). The range of heavy metal concentrations for indoor dust samples for the five metals was: Iron (723.13 ± 78.62 µg/g to 3272.36 ± 23.87) Zinc (µg/g, 113.37 ± 8.54 µg/g to 661.45 ± 11.56 µg/g) Lead (68.57 ± 9.98 µg/g to 194.70 ± 13.28 µg/g) Chromium (28.62 ± 1.84 µg/g to 152.67 ± 9.48 µg/g) and Cadmium (9.38 ± 1.96µg/g to 82.60 ± 1.71 µg/g). Chromium and Cadmium recorded a much higher spread in the indoor dust samples compared to the paint chips samples; whereas the remaining three metals, Zinc, Iron and Lead, registered a much higher spread in the paint chips samples relative to the indoor dust samples. The Pearson correlation for paint chips samples was not statistically significant and this is indicative of the fact that the paints under study were from different sources. However, the correlation for Lead – Iron and Chromium – Cadmium metal pairs were statistically significant, a clear indication that these metals are from a common origin/source. There was no significant correlation between the levels of heavy metals in paint chips and indoor dust samples, pointing to the fact that deterioration of paint from walls is not the only source of heavy metals in indoor dust, windblown dust from outside the classrooms could also be responsible for the high levels of heavy metals in indoor dust samples.

4.2 Recommendations

The high concentrations of heavy metals in indoor dust samples are a potential exposure pathway for children learning in these environments. This can lead to bioaccumulation in tissues, which can prove fatal over time. The study recommends the following measures to be taken to keep children safe from heavy metal exposure:

a. The classrooms should be cleaned on a regular basis to prevent the accumulation of indoor dust.
b. During classroom renovations, the layers of paints that had previously been applied on the walls should be scrapped off before fresh paint is applied.
c. The study reported lead levels above the KEBS permissible limits of 90 µg/g.Due to the high levels of Lead in both the paint chips and indoor dust samples, water-based paints or certified lead-free paints should be used.
d. Awareness creation should be carried out, especially on the dangers posed by heavy metals such as Lead, Chromium VI and Cadmium not only in paints but in other consumer products as well.
e. The Kenya Bureau of Standards (KEBS) and Word Health Organization (WHO) should broaden their scope of limitation to capture other equally toxic heavy metals such as Cadmium, Nickel, Cobalt and Manganese, as Lead is the only heavy metal that has been extensivelycaptured by these regulatory bodies.
f. Non-destructive methods such as the use of handheld X – ray fluorescence (XRF) spectrophotometer should be employed in future analysis since most schools were reluctant to give their paint samples owing to the destructive nature of the sampling process.
g. Since some metals registered much higher concentration of heavy metals in indoor dust samples relative to the paint samples, a separate study should be conducted to establish the sources of these heavy metals in indoor dust as wind-blown dust may not be the only source of heavy metals in indoor dust samples.

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