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Estimation of quantities, metal concentrations in components and management of waste rechargeable lighting devices in Nigeria

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Abstract. Rechargeable lighting devices are used in Nigeria as alternative source of lighting due to epileptic power supply. They contain printed wiring board, battery and plastic casings containing heavy metals. This waste category is often neglected and disposed of with household garbage with concomitant deleterious consequences on environment. We estimated quantities, disposal methods and concentrations of selected metals in some components of 34 waste rechargeable lighting devices in Nigeria. Estimated quantities and disposal methods were carried out through online survey. Leached metals were prepared and analyzed using standard methods. Approximately 6000 tons/year of waste rechargeable lighting devices were estimated. An average life span of 9 months and 4 rechargeable lighting devices were estimated to be used per household in Nigeria. The commonest disposal method was with household garbage. Lead and copper contents on the boards and Pb in battery electrodes were far higher than permissible limits. All metals determined in plastic casings were within permissible limits. High lead and copper contents in some components makes waste rechargeable lighting devices to be regarded as hazardous materials and should be handled with care at disposal.

Keywords: rechargeable lighting device; heavy metals; printed wiring board; battery; plastic casing.

1. Introduction

Rechargeable Lighting Devices (RLDs) are electrical equipment that rely on external power supply to function. They contain batteries which store electric charges from the external source and then emit the charges as light. Therefore, they are mainly used for lighting purposes. They range from the simple hand-held ones to the relatively large-sized ones. However, in any case, they are portable. The RLDs are small equipment devices with external dimension not more than 50 cm [1]. The major components of a RLD are plastic casing which is usually colored, battery, Printed Wiring Board (PWB), glass and others. Each of these is made up of different materials that perform specific functions to make the device to provide the required lighting. For instance, the plastic casing is normally fortified with heavy metals which impart the color on them and at times used as stabilizers [2].

In developing countries like Nigeria, disposable battery torches were the major sources of portable devices in-use in the 90s for alternative lighting especially at night in areas where electricity was not available. These disposable touches have been gradually replaced by RLDs which gained much popularity in the 20s. This was partly because the energy efficiency of a disposable battery was poor and when the energy was discharged, the battery could not be recharged, thereby not cost effective. Another reason was the rising amount of waste disposable batteries which was disposed of with household waste stream, thereby constituting a big pollution problem [3]. Again, another reason for the replacement was the fact that the rechargeable devices found in the Nigeria markets were becoming cheaper and easily available in different designs and colors.

The estimated population of Nigeria on July 1 2020 as reported by United Nations World Population Review [4] was put at 206,380,564 people with only 56.5% reported as having access to the National Electricity grid [5]. Even those who are connected to the National grid, the supply is still epileptic as the country generates an average of only 4000 MW nationally [6] which is very insufficient to maintain constant supply. Therefore, there is an ever growing need to find alternative lighting sources. Rechargeable lighting devices readily serve as substitute to fill this gap. They are portable, cheap and can be easily recharged with even the smallest size of generating set. According to Ogundiran *et al.* [7] nearly every household in Nigeria has at least a rechargeable lighting device as an alternative power supply. Furthermore, the authors carried out a survey in Ibadan to know the number of rechargeable torches used, how often they are replaced, the duration of usage before reaching end-of-life and disposed of. The study revealed that, of the 200 respondents to the administered questionnaire, 79% had at least one RLD with a life span of 1 to 6 months.

Incidentally with an increasing population of Nigeria at the rate of 2.6% per annum [4] and with about 56.5% of the total population estimated to have access to electricity [5], the waste generated from alternative lighting devices will be ever on the increase. In Nigeria, waste generated from households are not segregated. In most cases, both household hazardous wastes like waste rechargeable lighting devices and non-hazardous wastes like food scraps, etc. are usually mixed together and

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disposed of by the municipal waste management on waste dumpsites with a very high possibility of leaching of toxic substances with concomitant adverse consequences on surface and ground water and sub-soils. This is highly unsustainable. There is still a gap in literature on studies that quantify waste rechargeable lighting devices, their metal content and management methods at end-of-life. Therefore, the objectives of this study were: (*i*) to estimate an average quantity of Waste Rechargeable Lighting Devices (WRLDs) generated in Nigeria; (*ii*) determine disposal behavior by end users and (*iii*) evaluate the concentrations of Pb, Cu, Cd, Cr and Ni in the plastic casings, PWBs and batteries of 34 EoL RLDs (Rechargeable Lamps and Torches) collected in Aba in Abia State to ascertain their concentrations to know the original manufacturers' compliance level with regulatory limits.

2. Experimental

2.1. Materials

Thirty four WRLDs comprising 8 desk lamps and 26 hand-held torches (Figure 1) were randomly obtained from homes, scavengers and scrap yards in Aba, Abia State, South Eastern Nigeria. The WRLDs were sorted according to color, type, manufacturer and country of manufacture. There were five brands, namely: Lontor (29 samples), Lonen (2 samples), Firesun (1 sample), DP (1 sample) and Yage (1 sample). Each WRLD was weighed whole and subsequently dismantled with simple tools like screwdriver and plier into plastic casing, PWB, battery and others, which were also weighed after dismantling. They were properly labeled and stored in polythene bags prior to preparation for analysis.

2.2. Estimation of Waste Rechargeable Lighting Devices (WRLDs)

A simple Questionnaire was designed using Google Forms to obtain the following major information: average number of RLDs used per annum; life span of RLDs; country of manufacture; most popular brand in use; occupational use; disposal method. The questionnaire was administered online, and the responses were analyzed, documented and reported. Copies of the questionnaire and statistics on responses are attached as supplementary materials.

The method reported by Robinson ([8] was used to calculate the quantities of WRLDs. The formula used for the calculation was:

$$Estimated\ quantities\ of\ WRLDs\ \left(\frac{\text{tons}}{\text{year}}\right) = \frac{Average\ \ weight\ of\ the\ items\ (tons) \times number\ of\ units}{Life\ span\ (year)}$$

2.3. Sample preparation

The sample components were grouped into four categories - the battery, plastic casing, PWBs and others which comprise the wire, glass, and the metallic components. Metal analyses were carried out on plastic casings, batteries and PWBs as these components have been reported to contain high metal content [7].

Plastic casings were grinded using a hammer mill into smaller particles that passed through a 2.0 mm sieve. The grinder was cleaned after each round of grinding by introducing sawdust to clean the blades. This was done to prevent cross contamination. The pulverized samples were stored in polyethylene bags prior to acid leaching. Also, PWBs were crushed with a ceramic mortar and pestle to particles small enough to pass through a 2.0 mm sieve. The mortar and pestle were cleaned each time a sample was pounded with a soft and dry tissue paper to avoid cross contamination and the grinded samples were each stored in polyethylene bag prior to acid leaching.

Figure 1. Photo of assorted waste rechargeable lighting devices studied.

Furthermore, the casings of the batteries were carefully opened using stainless steel screwdriver and plier and the battery electrodes were removed and manually crushed. All the crushed samples were stored in polyethylene bags prior to acid leaching.

2.4. Sample leaching and analysis

Aqua regia leaching solution involving a mixture of concentrated HCl and HNO_3 in the ratio of 3:1 was used. Exactly 2.0 g each of homogenized and sieved plastic samples were weighed and transferred quantitatively into a digestion tube and 12 mL of Aqua regia (9.0 mL of HCl and 3 mL of HNO_3) were added into the digestion vessel. The set up was heated in a water bath for 2 hours with intermittent shaking every 20 minutes. After the leaching, the setup was allowed to cool, and the leachate was filtered using Whatman No. 1 filter paper into a standard flask and made up to mark. This solution was preserved before analysis by spiking with few drops of concentrated HNO_3 and kept in a fridge at temperature <5 ^{o}C. This process was repeated for the rest of the samples. A blank was also taken through the same process in order to check impurities from reagents and procedure. Furthermore, 1.0 g and 0.5 g each of prepared samples of PWBs and batteries respectively, were taken through the above procedure and the leachates were also preserved in the same way prior to analysis. The leachate sample solutions were analyzed for Pb, Cu, Cd, Ni, and Cr using Buck 205 Atomic Absorption Spectrophotometer (AAS), England. All metals were analyzed at the respective λmax, lines; all the cathode ray tube lamps were pre-warmed before analysis commenced for optimal performance; calibration curve for each metal was prepared from working standards prepared from commercial standards (Buck Scientific, UK).

2.5. Quality Control

All the glassware and plastic containers used were washed with detergent solution, rinsed with tap water and then soaked in dilute nitric acid solution overnight. They were then removed and rinsed thoroughly with distilled water and allowed to drain in the open. Furthermore, analytical grade reagents were used throughout in the study. Blank and blind samples were analyzed alongside the samples to monitor any possible impurities and contamination from reagents or procedure/instrument.

2.6. Calculation

$$Concentration\ of\ analyte\ (mg/kg) = \frac{(\mathrm{Mc} - \mathrm{Bc}) \times \mathrm{V}}{\mathrm{W}}$$

Where Mc = analyte concentration in the sample (instrument response in mg/L); Bc = analyte concentration in the blank sample in mg/L; W = weight of sample leached (g); V = Final volume of the leachate in mL (volume made up in a standard flask).

3. Results and discussion

3.1. Estimation of quantities of waste rechargeable lighting devices generation in Nigeria

3.1.1. Number of respondents to the survey across Nigeria. A total of 335 respondents were obtained from 27 States including the Federal Capital Territory, Abuja out of the 36 states and at least one respondent from each of the six geopolitical zones making up Nigeria. The distribution of respondents according to states and 6 geopolitical zones in Nigeria is presented in Figure 2. Copies of the survey questions and response analysis are included as supplementary materials. The high responses indicated for Abia, Cross River, Lagos, Ogun and Oyo States was due to higher number of respondents the authors were able to reach out to complete the survey. The authors thought that though the survey did not get responses from few states in the country, the comments already obtained indicate a true reflection of WRLDs generation and management in Nigeria.

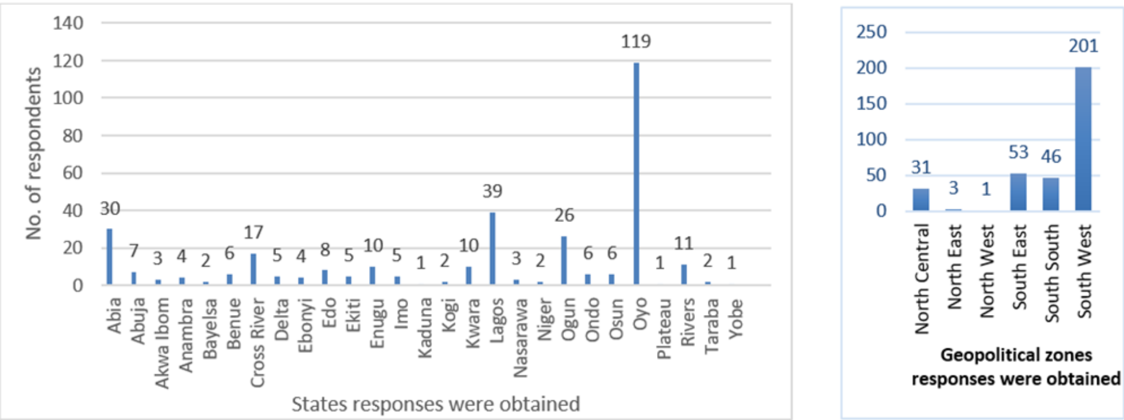

Figure 2. Number of respondents in the various states and geopolitical zones of Nigeria

3.1.2. Average number of rechargeable lighting devices used per annum. Analysis of the 335 responses show that 19%, 30%, 24% and 28% of individuals used average of 1, 2, 3 and 4 > devices, respectively per annum, while 13%, 24%, 21% and 42% of households used average of 1, 2, 3 and 4 > devices, respectively per annum. It could reasonably be concluded that a typical household in Nigeria uses an average of 4 > per annum. This is supported by a relatively high 28% respondents indicating use of 4 > devices per year by individuals. Our results indicate a higher number compared with Ogundiran *et al.* [7]. This could be because we surveyed a larger scale of Nigeria landscape compared to the study by Ogundiran *et al.* [7] that looked at only Ibadan.

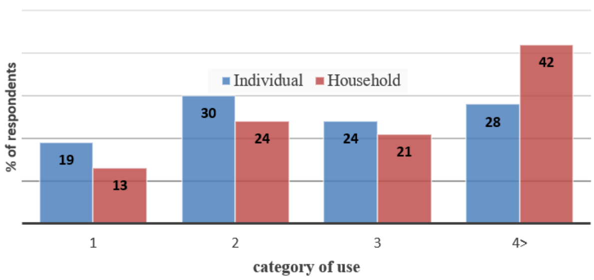

Figure 3. Percentage respondents to survey on number of RLDs used by individuals and households.

3.1.3. Life span of rechargeable lighting devices used in Nigeria. The life span of a rechargeable lighting device is the average time the device takes to come to end-of-life. Judging from the statistics in Figure 3, the authors assumed the average life span of a typical rechargeable device used in Nigeria to be the midpoint between 6 – 12 months as this category showed the highest respondents' percentage of 34%. The midpoint translates to 9 months. Therefore, in this study an average life span of 9 months is assumed as the reasonable period a typical rechargeable device is used before it packs up.

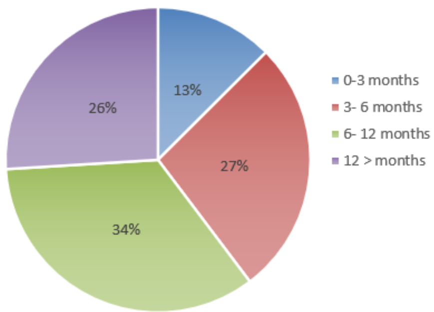

Figure 4. Responses on life span of RLDs

3.2. Summary of statistics of weights of studied WRLDs

Table 1 shows summary of average weights of whole and components of WRLDs studied. The whole weights of the products of same kind were close. All products were found to be made in China. It is obvious that these products are made in various sizes and designs. The batteries indicated the highest average weight for all the samples studied. The high percentage weight of batteries was also observed by Ogundiran *et al*. [7].

Table 1. Statistics on weights (g) of components of WRLDs studied

Maker	Type	No. of samples		Total	Battery	Plastics	PWB	Others
			Average	429	159	106	21.9	142
Lontor	Desk lamp	6	SD	101	26.9	16.2	4.04	59.4
			Range	334-528	132-186	90-132	16.9-26.3	88.4-210
			Average	134	63.1	44.8	7.05	25.7
Lontor	Hand Torch	23	SD	45	19.8	16.4	3.13	14.9
			Range	89.3-226	38.9-92.8	25.7-89.0	3.44-19.0	11.1-83.9
			Average	137	62.9	42.0	5.28	26.6
Lonen	Hand Torch	2	SD	11	17.0	8.0	1.40	2.2
			Range	101-116	50.8-17.9	36.3-47.6	4.29-6.27	25.0-28.1
DP	Desk lamp	1	-	341	135	92.6	17.3	95.8
Firesun	Desk lamp	1	-	537	184	112	26.3	215
Yage	Hand Torch	1	-	110	46.9	25.7	4.41	32.5
		Total		1688	651	423	82.2	538
		Average±SD		281±180	108±58	70.5±37.3	13.7±9.4	89.6±77.2
Quantity of e-waste arising (tons)				6,189	2,379	1,552	302	1,973

3.3. Estimation of e-waste arising from WRLDs in Nigeria

Many methods have been developed/used by different authors to estimate or forecast the quantities of e-waste generated from different electronic equipment categories [7-12]. In most of the estimations, the average weights, number of units and life spans of the electronic devices are used in the calculations. For this study, the method reported by Robinson [8] is adopted as it is much easier to apply.

The estimated population of Nigeria in 2020 as reported by United Nations World Population Review is put at 206,479,789 people [4]. Also, a typical average Nigerian family size was also estimated by United Nations to be ~ 5 persons [13].

The equation according to Robinson (2009) [8] used to calculate e-waste quantities is given thus:

$$Estimated\ e-waste\ quantities\ \left(\frac{tons}{year}\right) = $$
$$= \frac{Average\ \ weight\ of\ the\ items\ \ (tons)\ \times\ number\ of\ units}{Life\ span\ (year)}$$

The following estimations are made and used in the calculation:

(i) From Table 1, average weight of 34 whole WRLDs was calculated as 281 g (0.000281 tons).

(ii) Given Nigeria's population of 206, 479, 789 and an average number in a household to be 5 persons,

$$Estimated\ number\ of\ households\ in\ Nigeria =$$
$$= \frac{206,479,789}{5} = 41{,}295{,}957.8$$

(iii) A household in Nigeria uses conservative average of 4 devices per annum, therefore:

$$No.of\ units/yr = No.HS \times No.units\ used\ per\ HS$$

$$No.ofunits/yr = 41{,}295{,}957.8 \times 4 = 165{,}183{,}831.2\ units$$

(iv) The average life span of the devices as indicated from the responses to the survey is estimated to be 9 months (0.75 year).

Therefore:

$$Estimated\ e-waste\ quantities\ \left(\frac{tons}{year}\right) =$$
$$= \frac{0.0000281\ (tons)\ \times\ 165{,}183{,}831.2\ units}{0.75\ (year)}$$
$$= 6,189\ tons/yr$$

3.4. Other relevant information from responses to the survey

Students in the tertiary institution were the highest respondents with 33% of total followed by civil servants (28%) followed by business personnel (19%) and others (20%). These responses seem to be the reality in Nigeria. As epileptic electricity supply persists, students seem to need this type of lighting category most to read and do assignments followed by civil servants and businesspeople who normally wake up before sunrise to prepare for work and businesses, respectively. The most popular brand as indicated by the responses of over 90% is Lontor. About 89% of the respondents indicated that their lighting devices were made in China. This is not surprising as Chinese goods currently dominate the world market [14]. Hand-held torch and desk lamps were reported to be the most popular types of lighting devices in use.

In Nigeria, rechargeable lighting devices are not given much attention at end-of-life as they deserve. They are treated like any other non-hazardous household waste. Over 42% respondents from the survey indicated that they disposed of their WRLDs with other household waste while 23% indicated they store them up in either homes or offices, most likely waiting for a convenient time to dispose of them with other municipal wastes. This implies that, a greater percentage of this waste category ends up in waste dumpsites with the danger of exposing toxic metals like Pb to the environment.

3.5. Summary of metal concentrations in studied WRLDs components

The summary of concentrations of Cu and Pb determined in PWBs of the WRLDs is presented in Table 2.

Table 2. Summary of metal concentrations (mg/kg) in PWBs of studied WRLDs

Parameters	Lontor		Lonen		DP		Yage		Firesun	
	Pb	Cu	Pb	Cu	Pb	Cu	Pb	Cu	Pb	Cu
No of items	29		2		1		1		1	
Mean	52393	100752	52393	100752	65156	61001	55608	63007	50603	6006
StDev	±5608	±14496	±5608	±14496	-	-	-	-	-	-
Range	26208 to 62314	28506 to 169510	48427 to 56358	90502 to 111002	-	-	-	-	-	-
TTLC[19]	1000	2500	1000	2500	1000	2500	1000	2500	1000	2500
EU RoHS 2011 [1]/China RoHS, 2016 Directives [21] restrict Pb to 1000 mg/kg										

TTLC – Total Threshold Limit Concentration RoHS Directive – Restriction of Hazardous Substances Directive

The metals were chosen because they have been observed in other studies in literature to show prominent concentrations in PWBs [15-18]. In all the samples, Pb ranged from 26,208 – 65,156 mg/kg while Cu ranged from 6,006 – 111,002 mg/kg. The high concentrations of Pb and Cu is certainly as a result of Pb being used as a major component of the solder for joining components together on the board while Cu is used in the circuitry connectivity on the board. Other metals have been found to be in levels of no significant concern. The level of Cu in the five brands studied followed the trend Lonen > Lontor > DP > Yage > Fireman while the trend for Pb was DP > Yage > Lonen > Lontor > Fireman. On the one hand, Pb and Cu concentrations as shown in Table 2 indicate levels at least 50 times for Pb and 2 times for Cu higher than the permissible limits by TTLC [19]. With these levels, if the waste is not disposed of in environmentally sound manner, there is high risk of leaching into the environment with concomitant adverse consequences on human health and the environment. On the other hand, if the waste is well collected and the metals efficiently recovered, there will be economic gains arising from the recovery. For instance, the cost of copper at London Metal Exchange on 21st July, 2020 was 6513 dollars/ton while the cost for Pb was 1814 dollars/tons [20]. This if properly harnessed, there could be some economic gains while human health and the environment are protected.

In the same vein, Figure 5a and 5b show the levels of Pb and Cd in the battery electrodes of the WRLDs studied. The concentration of Pb in the electrodes in all the samples studied was more than 200,000 mg/kg (~20%), a concentration over 200 times higher than TTLC [19], EU RoHS Recast Directive [1] and China RoHS Directive [21] permissible limit of 1000 mg/kg (0.1%). Cadmium indicated very low concentration in the samples compared with permissible limit of 100 mg/kg (0.01%). Few samples indicated Cd concentration reaching 0.6 mg/kg. Cadmium in most of the samples was not detectable. Nickel was less than detection limit in all samples. The battery composition used in the rechargeable lighting devices studied seems not to be the regular reported ones like NiCd, NIMH, etc. as they have high Pb content just as reported by Ogundiran *et al.* [7].

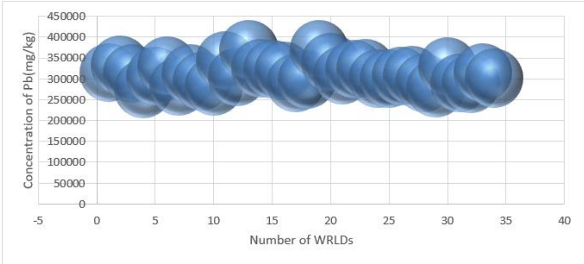

Figure 5a. Concentration of Pb in battery electrodes of WRLDs

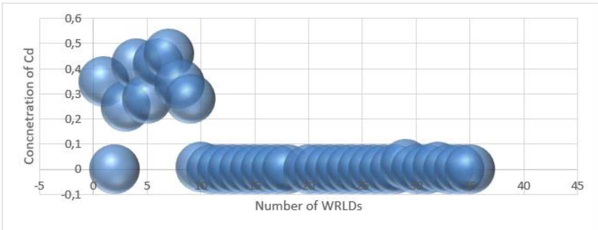

Figure 5b. Concentration of Cd in battery electrodes of WRLDs

Table 3 shows the summary of metal concentrations (mg/kg) in the plastic casings of all WRLDs. Copper indicated the highest average concentration of 5.79±0.93 mg/kg and Cd the least average concentration of 0.07±0.05 mg/kg. The general average trend for all metal concentrations was Cu > Pb > Cr > Ni > Cd. Plastic casings of rechargeable lighting devices are normally designed with different colors as shown in Figure 1 most certainly to be attracted to the users. Some of these colors impacted by transition metals which are components of fillers or processing aids. The concentration of the metals determined were within the same ranges as reported by Ogundiran *et al.* [7] except Pb which showed lower average concentration. The concentrations for all metals were within the widely used TTLC, EU and China RoHS Directives [22].

Table 3. Metal concentrations (mg/kg) in waste RL plastics from different manufacturers

Sample	No. of samples	Cu	Cr	Cd	Ni	Pb
Lontor	29	4.17±0.96	0.91±2.44	0.09±0.09	1.13±0.92	5.33±2.28
Lonen	2	6.27±0.04	4.44±1.33	0.12±0.02	1.01±0.18	3.94±0.08
Yage	1	5.91	3.75	0.04	0.75	4.88

Sample	No. of samples	Cu	Cr	Cd	Ni	Pb
Firesun	1	6.39	6.63	BDL	1.28	5.38
DP	1	6.23	9.00	0.09	0.38	5.13
Average ± SD		5.79±0.93	4.95±3.05	0.07±0.05	0.91±0.35	4.93±0.59

3.6. Influence of color on metal concentrations of plastic component of WRLDs

The commonest inorganic based colorants containing lead chromates, lead sulfochromates, cadmium pigments, etc. have been banned in many countries because of their toxicological issues. They dissolve readily in acidic environment so can easily dissolve and become bioavailable if mistakenly swallowed unlike most other metal pigments which are less soluble [2]. Therefore, there are still some important inorganic pigment combinations, the so-called complex inorganic color pigments formerly called mixed phase metal oxides pigments still in use that have color index number, but not used sometimes as colorants, but mainly as fillers or processing aids [2]. Table 4 shows a list of some inorganic pigments and the color they impact on materials.

Table 4. List of some selected inorganic pigments

S/N	Product	Formular	Color index	Color
1	Bronze	Cu-Zn alloy	P. Metal 2	Golden shiny
2	Chromium oxide	Cr_2O_3	P. Green 17	Green
3	Nickel antimony titanium yellow rutil	$(Ti,Ni,Sb)O_2$	P. Yellow 53	Yellow
4	Nickel barium titanium primrose priderite	$2NiO·3BaO·17TiO_2$	P. Yellow 157	Yellow
5	Nickel niobium titanium yellow rutile	$(Ti,Ni,Nb)O_2$	P. yellow 161	Yellow
6	Chrome niobium titanium buff rutile	$(Ti,Cr,Nb)O_2$	P. yellow 162	Yellow
7	Chrome tungsten titanium buff rutile	$(Ti,Cr,W)O_2$	P. yellow 163	Yellow
8	Cobalt chromite green spinel	$CoCr_2O_4$	P. green 26	Green
9	Chrome antimony titanium buff rutile	$(Ti,Cr,Sb)O_2$	P. brown 24	Orange-yellow
10	Cadmium yellow*	(Cd,Zn)S, CdS	P. yellow 35, 37	Yellow
11	Cadmium red*	Cd(S,Se)	P. red 108	Orange/Yellow/red
12	Lead chromate Yellow*	$Pb(Cr,S)O_4$	P. yellow 34	Yellow
13	Lead chromate molybdate orange/ red*	$Pb(Cr,Mo,S)O_4$	P. red 104	Orange-red
14	Cobalt chromite blue-green spinel*	$Co(Al,Cr)_2O_4$	P. blue 36	Blue/greenish

* No longer in use because of toxicological concerns Source: adopted from Muller [2]

Table 5 presents metal concentrations in plastics of WRLDs studied according to their colors. Materials impacted with green and bluish colors from Table 4 have Cr containing pigments. In Table 5, the blue- and green-colored plastics have relatively high concentration of Cr compared with others. Furthermore, blue is normally impacted by Cu containing pigment even though the pigment type is not indicated in Table 4. The relatively high average concentration of Cu for blue plastics compared to others could explain this. In Table 4, yellow color seem to be impacted by pigments containing most of the metals studied. Yellow is impacted by Ni, Cd, Cr and Pb. Notably, the highest concentration of Pb (10.5 mg/kg) as shown in Table 5 could be associated with pink colored plastics. This is most likely associated with pigment with formular $Pb(Cr,Mo,S)O_4$ (Table 4) that impacts orange–red color which is close to pink. Pigments containing Pb and Cd have been banned in many countries because of toxicological concerns, however, it seems Pb is still intentionally added from the levels expressed in Table 5 possibly because of it cost and ease of workability. In general terms, all the metals detected in WRLDs studied are low and within permissible limits by TTLC, EU and China RoHS Directives.

Table 5. Metal concentrations (mg/kg) in plastic casings of WRLDs according to colors

Color	No. of samples	Cu	Cr	Cd	Ni	Pb
Blue	11	4.80±1.18	2.71±3.79	0.05±0.04	1.30±0.55	4.90±0.80
Green	3	4.70±1.40	1.17±2.02	0.08±0.05	0.96±0.14	3.30±0.52
Orange	7	4.35±1.40	1.82±3.46	0.08±0.11	0.79±0.27	4.56±0.39
Pink	3	3.98±0.32	BDL	0.09±0.09	0.63±0.43	10.5±0.4
Purple	1	6.28	3.25	0.08	4.63	2.25
Red	5	3.85±0.38	BDL	0.11±0.10	0.88±1.19	4.18±1.19
Yellow	4	4.34±1.38	1.34±2.69	0.14±0.13	0.91±0.12	6.90±1.98
Average ± SD		4.34±1.02	1.17±1.99	0.09±0.09	0.91±0.45	5.72±0.88

BDL – Below Detection Limit

4. Conclusions

This study estimated that average e-waste quantities arising from WRLDs per annum to be ~ 6000 tons with PWBs having high concentrations of Pb and Cu and battery electrode high in Pb with magnitudes higher in many degrees than permissible limits. The average life span of a typical lighting device in Nigeria was assessed to be around 9 months. A greater percentage of the respondents indicated that about 4 or more rechargeable devices are used per household per year and WRLDs are trashed with household waste. The high concentrations of Pb and Cu in some of the components make WRLDs regarded as hazardous materials and should be handled specially during disposal.

The authors thought that careful collection of WLDs and recovery of Pb and Cu from the components could have some economic gains while human health and the environment are protected.

Conflict of interest

The authors declare that there was no conflict of interest during the course of this study.

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