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African Journal of Environmental Science and Technology

*Full Length Research Paper*

# Trace metal contamination of groundwater and human health risk in Katuba and Kenya municipalities of Lubumbashi city, Southeastern Democratic Republic of Congo

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**Trace metal contamination of groundwater was assessed in Katuba and Kenya municipalities of Lubumbashi city in 2016 and 2017 to determine whether water was suitable or unsuitable for human consumption. Two hundred and four groundwater samples collected from twenty spade-sunk and four drilled wells in both municipalities were analyzed for their trace metal contents using a sector field inductively coupled plasma mass spectrometry Thermo Element II. Nineteen trace elements including strontium, molybdenum, cadmium, cesium, barium, tungsten, thallium, lead, bismuth, uranium, vanadium, chromium, manganese, iron, cobalt, nickel, copper, zinc and arsenic were recorded at varying concentrations in all samples. Arsenic, cadmium, lead, nickel and copper levels of groundwater exceeded the World Health Organization acceptable limits for drinking water, respectively in 14.44, 8.89, 6.67, 0 and 0%, of samples from Katuba and in 0, 16.67, 25, 16.67 and 16.67% of samples from Kenya municipality. In Katuba, 55.56% of the groundwater samples were acidic (pH 4.7-6.4) in dry season and 61.11% were very alkaline (pH 8.6-11.2) in rainy season. In Kenya municipality, 33.33% of the samples were acidic (pH 5.5-6.2) in rainy season. With such physicochemical and trace metal contamination status of the groundwater in both municipalities, water of many wells is unsuitable for human consumption and presents a health risk to people who use it to meet their drinking water needs.**

**Key words:** Groundwater, pH, trace metals, Lubumbashi city.

## INTRODUCTION

In developing countries, such as the Democratic Republic of Congo where access to tap water is limited, many people depend on groundwater and surface water for drinking and domestic use. Groundwater usually contains very low levels of trace metals depending upon the composition and the dissolution of the rock which is in

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interaction with the aquifer (Vetrimurugan et al., 2017). In urban and peri-urban areas, groundwater and surface water may be metal polluted as a result of anthropogenic activities, such as mining and industrial activities, intensive agriculture, waste mismanagement, unplanned urbanization, etc.

Lubumbashi, the capital city of the Upper-Katanga province in the Southeastern Democratic Republic of Congo (DRC) is located in a region having rich ore deposits of certain metals and which tend to have those metals in groundwater due to naturally occurring rock-water interaction. In the city, active and abandoned mines, ore processing plants, tailings, dumps and industrial wastelands are likely to generate trace metal contamination of soils (Kashimbo, 2016; Muhaya et al., 2016), surface water (Muhaya et al., 2017a, b), sediments (Muhaya et al., 2017c, d) and groundwater (Muhaya et al., 2021). The use of surface and groundwater contaminated with trace metals may present environmental and public health risk in the city, depending on the contamination status. Many researchers have reported on adverse effects of trace metals on the health of people in Lubumbashi (Mudekereza et al., 2016, 2021; Mukendi et al., 2018; Obadia et al., 2018; Cham et al., 2020; Malamba-Lez et al., 2021; Ngoy et al., 2021). Most inhabitants of Katuba and Kenya municipalities have no access to tap water. Spade-sunk (hand-dug) and drilled wells are their main source of water for drinking, cooking, bathing, cleaning and watering of plants and domestic animals but no study on the quality of water has been published so far. It was necessary to conduct the current study because of active and abandoned mining and ore processing history of Lubumbashi city, the various reports on adverse health effects of trace metals in the city, the use of private groundwater wells as the main source of drinking water for most inhabitants of Katuba and Kenya municipalities, and no similar study has been reported so far.

The aim of this study was to assess trace metal contamination of groundwater used for drinking in Katuba and Kenya municipalities of Lubumbashi city to determine whether the water was suitable or unsuitable for human consumption and to suggest actions to be taken to reduce the contamination.

## MATERIALS AND METHODS

### Study area

Lubumbashi, the capital city of the Upper-Katanga province is located at the altitude of 1,230 m between the latitude of 11°40′11″ and the longitude of 27°29′00″ East in South-Eastern DRC, at less than 50 km from the DRC-Zambia border (Figure 1). The city of Lubumbashi comprises seven municipalities/communes including Annex, Kamalondo, Kampemba, Lubumbashi and Ruashi, as well as Katuba and Kenya where groundwater samples were collected (Figure 1).

In 2019, the municipalities of Katuba and Kenya encompassed 445,544 inhabitants and 153,966 inhabitants, respectively (Lubumbashi City Report, 2020). Katuba comprises nine administrative quarters/areas including Bana Katanga, Bukama, North Kaponda, South Kaponda, Kisale, Lufira, Musumba, N'sele and Upemba while Kenya includes three quarters, namely Lualaba, Luapula and Luvua.

The total population of Lubumbashi city was estimated to 2,988,200 inhabitants in 2019 (Lubumbashi City Report, 2020). Thus, with its area of 747 km$^2$ the city had a population density of 4,000 inhabitants/km$^2$ in 2019.

### Sampling campaign

Groundwater samples were collected once a month from seventeen spade-sunk (hand-dug) wells and one drilled well at two sites of each of the nine administrative areas/quarters of Katuba municipality in May and October 2016 (dry season), November 2016, January and March 2017 (rainy season), and from three hand-dug wells and three drilled wells at two sites of each of the three administrative areas of Kenya municipality in December 2016 and February 2017 (rainy season).

At each sampling campaign, two groundwater samples were collected from each well. The depth of hand-dug wells ranged from 2 to 15 m and that of drilled wells ranged from 20 to 60 m.

### Analytical methods

#### *Sample pretreatment*

Collected water samples were filtered on 0.45 µm disposable syringe filters (Chromafil, cellulose mixed ester) and acidified with concentrated hydrochloric acid after determining the pH of the water samples.

#### *Trace metal analysis*

Trace element analysis was carried out by Inductively Coupled Plasma-Sector Field Mass Spectrometry (ICP-SF-MS) (Thermo Scientific Element II).

The instrument was equipped with an Elemental Scientific Incorporation (ESI) Fast autosampler, PFA-ST (Perfluoroalkoxy Series Type) MicroFlow nebulizer, Peltier cooled glass cyclonic spray chamber, quartz injector and torch and Ni cones. Regarding the resolutions used, low resolution was used for strontium, molybdenum, cadmium, cesium, lead, bismuth and uranium; medium resolution was used for vanadium, chromium, nickel, copper, zinc, manganese, iron, cobalt; high resolution was used for arsenic. Rhodium (1 ppb) was used as internal standard in all resolutions.

Standard solutions were prepared from multi-element standard solutions and single element standard solutions. Blanks, standards and Quality Control (QC) samples were reanalysed throughout the procedures. The reference material SW-1 (SPS) was used as QC sample.

### Statistical analysis

The data were statistically processed by R statistical software before being filed by Excel and Excelstat. With the R software, the means and standard deviations of trace element concentrations in the well water of Katuba and Kenya municipalities were calculated. The correlations that would exist between metals and the influence of the seasons on the metal concentrations in the media were verified.

R statistical software is an open source of statistics and a data

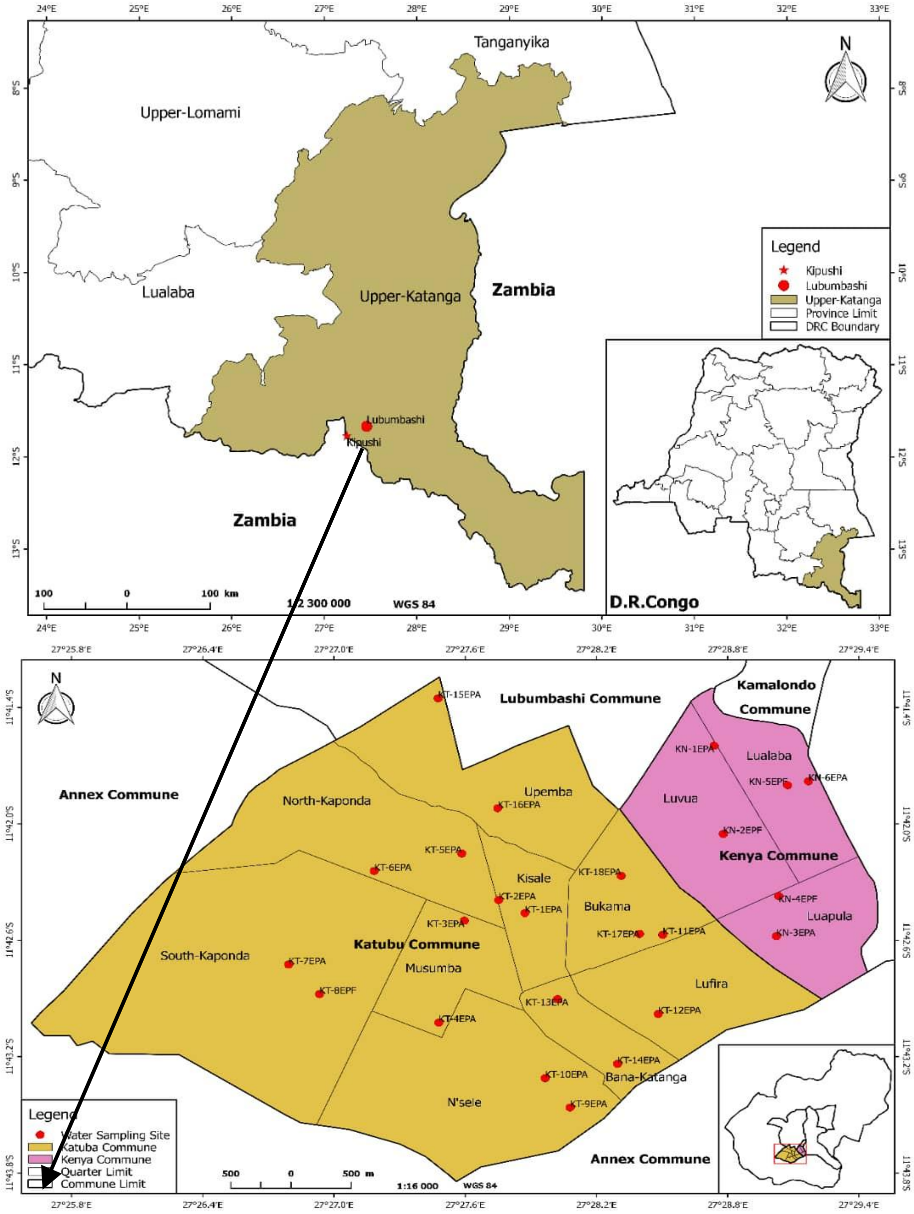

**Figure 1.** Location of the Upper-Katanga province and Lubumbashi city in the southeastern Democratic Republic of Congo, and the sampling sites in Katuba and Kenya municipalities (communes).

science software supported by the R Foundation for Statistical Computing. It is part of the list of GNU packages. GNU is a free software distributed under the terms of the GNU General Public License and available under GNU/Linux, FreeBSD, NetBSD, OpenBSD, MacOS X and Microsoft Windows. For this study, the version 3.0 released in April 2013 was used.

## RESULTS AND DISCUSSION

Trace metal levels and pH values of groundwater recorded in Katuba and Kenya municipalities of Lubumbashi city found in this study are presented in Tables 1 and 2 and Figures 2 to 4. Nineteen trace elements including strontium (Sr), molybdenum (Mo), cadmium (Cd), cesium (Cs), barium (Ba), tungsten (W), thallium (Tl), lead (Pb), bismuth (Bi), uranium (U), vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn) and arsenic (As) were recorded at varying concentrations in all groundwater samples.

From the data shown in Table 1, it was noted that during the rainy season in Katuba municipality, the

**Table 1.** Groundwater pH values and trace metal levels (µg/L) in Katuba municipality in May and October 2016 (dry season) and in November 2016, January and March 2017 (rainy season), and Kenya municipality in December 2016 and February 2017 (rainy season).

| Sampling period | Sampling site | Data type | pH value | Sr88 (µg/L) | Mo98 (µg/L) | Cd114 (µg/L) | Cs133 (µg/L) | Ba138 (µg/L) | W183 (µg/L) | Tl205 (µg/L) | Pb208 (µg/L) | Bi209 (µg/L) | U238 (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dry s. | KT-1EPA | Range | 6.4-7 | 140.177-188.278 | 0.025-0.053 | 0.091-0.053 | 0.041-0.069 | 288.2-212.085 | 0.05-0.099 | 0.024-0.029 | 0.706-1.105 | 0.005-0.023 | 0.081-0.112 |
| Dry s. | KT-1EPA | Mean | 6.7 | 164.228 | 0.039 | 0.199 | 0.055 | 250.143 | 0.075 | 0.027 | 0.906 | 0.014 | 0.097 |
| Dry s. | KT-1EPA | SD | 0.4 | 34.013 | 0.02 | 0.153 | 0.02 | 53.821 | 0.035 | 0.004 | 0.282 | 0.013 | 0.022 |
| Dry s. | KT-2EPA | Range | 6.3-6.8 | 237.247-245.294 | 0.021-0.047 | 0.068-1.33 | 0.147-0.183 | 162.516-174.182 | 0.057-0.105 | 0.082-0.099 | 0.578-1.54 | 0.004-0.011 | 0.095-0.165 |
| Dry s. | KT-2EPA | Mean | 6.5 | 241.271 | 0.034 | 0.699 | 0.165 | 168.349 | 0.081 | 0.091 | 1.059 | 0.008 | 0.13 |
| Dry s. | KT-2EPA | SD | 0.4 | 5.69 | 0.018 | 0.892 | 0.025 | 8.249 | 0.034 | 0.012 | 0.68 | 0.005 | 0.049 |
| Dry s. | KT-3EPA | Range | 6.3-6.8 | 159.807-216.165 | 0.019-0.067 | 0.054-0.487 | 0.034-0.078 | 178.544-233.486 | 0.079-0.107 | 0.013-0.028 | 0.398-1.213 | 0.003-0.018 | 0.074-0.154 |
| Dry s. | KT-3EPA | Mean | 6.5 | 187.986 | 0.043 | 0.271 | 0.056 | 206.015 | 0.093 | 0.021 | 0.806 | 0.011 | 0.114 |
| Dry s. | KT-3EPA | SD | 0.4 | 39.851 | 0.034 | 0.306 | 0.031 | 38.85 | 0.02 | 0.011 | 0.576 | 0.011 | 0.057 |
| Dry s. | KT-4EPA | Range | 6.7-6.8 | 375.77-386.027 | 0.128-0.414 | 0.052-0.402 | 0.015-0.048 | 169.932-206.661 | 0.073-0.102 | 0.027-0.037 | 0.263-1.219 | 0.002-0.012 | 0.371-0.566 |
| Dry s. | KT-4EPA | Mean | 6.8 | 380.899 | 0.271 | 0.227 | 0.032 | 188.297 | 0.088 | 0.032 | 0.741 | 0.007 | 0.469 |
| Dry s. | KT-4EPA | SD | 0.1 | 7.253 | 0.202 | 0.247 | 0.023 | 25.971 | 0.021 | 0.007 | 0.676 | 0.007 | 0.138 |
| Dry s. | KT-5EPA | Range | 6.2-6.8 | 61.162-61.647 | 0.047-0.047 | 0.044-0.815 | 0.034-0.063 | 96.147-104.504 | 0.036-0.067 | 0.015-0.016 | 0.68-1.362 | 0.001-0.019 | 0.065-0.094 |
| Dry s. | KT-5EPA | Mean | 6.5 | 61.404 | 0.047 | 0.43 | 0.049 | 100.326 | 0.052 | 0.016 | 1.021 | 0.01 | 0.08 |
| Dry s. | KT-5EPA | SD | 0.4 | 0.343 | 0 | 0.545 | 0,021 | 5,909 | 0.022 | 0.001 | 0.482 | 0.013 | 0.021 |
| Dry s. | KT-6EPA | Range | 4.7-6.3 | 71.002-74.5 | 0.025-0.051 | 0.21-1.115 | 0.261-1.311 | 237.323-483.548 | 0.103-0.568 | 0.159-0.193 | 2.494-8.763 | 0.02-0.067 | 0.147-0.986 |
| Dry s. | KT-6EPA | Mean | 5.5 | 72.751 | 0.038 | 0.663 | 0.786 | 360.436 | 0.336 | 0.176 | 5.629 | 0.044 | 0.567 |
| Dry s. | KT-6EPA | SD | 1.1 | 2.473 | 0.018 | 0.64 | 0.742 | 174.107 | 0.329 | 0.024 | 4.433 | 0.033 | 0.593 |
| Dry s. | KT-7EPA | Range | 5.1-5.9 | 33.277-69.359 | 0.016-0.083 | 0.174-0.899 | 0.023-0.153 | 22.157-38.394 | 0.043-0.155 | 0.017-0.023 | 0.954-1.632 | 0.002-0.096 | 0.045-0.207 |
| Dry s. | KT-7EPA | Mean | 5.5 | 51.318 | 0.050 | 0.537 | 0.088 | 30.276 | 0.099 | 0.02 | 1.293 | 0.049 | 0.126 |
| Dry s. | KT-7EPA | SD | 0.6 | 25.514 | 0.047 | 0.513 | 0.092 | 11.481 | 0.079 | 0.004 | 0.479 | 0.066 | 0.115 |
| Dry s. | KT-8EPF | Range | 6.8-7.8 | 66.312-69.423 | 0.126-0.182 | 0.348-0.704 | 0.019-0.042 | 15.909-24.913 | 0.054-0.123 | 0.005-0.007 | 0.549-2.133 | 0.002-0.03 | 0.099-0.131 |
| Dry s. | KT-8EPF | Mean | 7.3 | 67.867 | 0.154 | 0.526 | 0.031 | 20.411 | 0.089 | 0.006 | 1.341 | 0.016 | 0.115 |
| Dry s. | KT-8EPF | SD | 0.7 | 2.199 | 0.039 | 0.252 | 0.016 | 6.367 | 0.049 | 0.001 | 1.12 | 0.02 | 0.023 |
| Dry s. | KT-9EPA | Range | 6.8-7.5 | 178.282-186.186 | 0.031-0.039 | 0.067-0.264 | 0.013-0.118 | 55.518-76.119 | 0.045-0.152 | 0.005-0.014 | 2.094-9.234 | 0.001-0.013 | 0.641-0.719 |
| Dry s. | KT-9EPA | Mean | 7.2 | 182.234 | 0.035 | 0.166 | 0.066 | 65.819 | 0.099 | 0.01 | 5.664 | 0.007 | 0.68 |
| Dry s. | KT-9EPA | SD | 0.5 | 5.589 | 0.006 | 0.139 | 0.074 | 14.567 | 0.076 | 0.006 | 5.049 | 0.008 | 0.055 |
| Dry s. | KT-10EPA | Range | 6-6 | 19.773-24.772 | 0.019-0.076 | 0.312-0.380 | 0.084-0.17 | 80.847-144.611 | 0.034-0.122 | 0.021-0.027 | 0.522-2.34 | 0.001-0.029 | 0.098-0.176 |
| Dry s. | KT-10EPA | Mean | 6 | 22.273 | 0.048 | 0.346 | 0.127 | 112.729 | 0.078 | 0.024 | 1.431 | 0.015 | 0.137 |
| Dry s. | KT-10EPA | SD | 0 | 3.535 | 0.04 | 0.048 | 0.061 | 45.088 | 0.062 | 0.004 | 1.286 | 0.02 | 0.055 |
| Dry s. | KT-11EPA | Range | 4.9-5.6 | 123.970-487.60 | 0.16-0.38 | 6.98-7.10 | 0.072-0.079 | 91.25-133.789 | 0.058-0.084 | 0.049-0.083 | 0.413-1.331 | 0.01-0.012 | 1.06-1.10 |
| Dry s. | KT-11EPA | Mean | 5.3 | 305.785 | 0.27 | 7.040 | 0.076 | 112.52 | 0.071 | 0.066 | 0.872 | 0.011 | 1.080 |
| Dry s. | KT-11EPA | SD | 0.5 | 257.125 | 0.156 | 0.085 | 0.005 | 30.08 | 0.018 | 0.024 | 0.649 | 0.001 | 0.028 |

**Table 1.** Contd.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dry s. | KT-12EPA | Range | 6.7-6.9 | 159.353-209.894 | 0.023-0.076 | 0.075-0.227 | 0.046-0.148 | 137.937-181.43 | 0.05-0.092 | 0.019-0.055 | 0.557-1.967 | 0.001-0.017 | 0.882-0.974 |
| Dry s. | KT-12EPA | Mean | 6.8 | 184.624 | 0.05 | 0.151 | 0.097 | 159.684 | 0.071 | 0.037 | 1.262 | 0.009 | 0.928 |
| Dry s. | KT-12EPA | SD | 0.1 | 35.738 | 0.037 | 0.107 | 0.072 | 30.754 | 0.03 | 0.025 | 0.997 | 0.011 | 0.065 |
| Dry s. | KT-13EPA | Range | 5.1-6 | 56.531-65.661 | 0.024-0.035 | 0.083-0.233 | 0.049-0.302 | 80.436-157.765 | 0.313-0.632 | 0.085-0.137 | 1.032-2.224 | 0.024-0.005 | 0.911-1.321 |
| Dry s. | KT-13EPA | Mean | 5.6 | 61.096 | 0.03 | 0.158 | 0.176 | 119.101 | 0.473 | 0.111 | 1.628 | 0.015 | 1.116 |
| Dry s. | KT-13EPA | SD | 0.6 | 6.456 | 0.008 | 0.106 | 0.179 | 54.68 | 0.226 | 0.037 | 0.843 | 0.018 | 0.29 |
| Dry s. | KT-14EPA | Range | 5.6-5.9 | 58.906-133.545 | 0.021-0.031 | 0.273-0.402 | 0.03-0.122 | 212.171-365.036 | 0.119-0.13 | 0.02-0.02 | 0.486-1.559 | 0.004-0.009 | 0.082-0.11 |
| Dry s. | KT-14EPA | Mean | 5.8 | 96.226 | 0.026 | 0.338 | 0.076 | 288.604 | 0.125 | 0.02 | 1.023 | 0.007 | 0.096 |
| Dry s. | KT-14EPA | SD | 0.2 | 52.778 | 0.007 | 0.091 | 0.065 | 108.092 | 0.008 | 0 | 0.759 | 0.004 | 0.02 |
| Dry s. | KT-15EPA | Range | 5.8-5.9 | 216.375-247.752 | 0.029-0.115 | 0.593-0.677 | 0.063-0.156 | 100.751-130.111 | 0.237-0.355 | 0.055-0.061 | 5.156-6.164 | 0.02-0.016 | 0.103-0.155 |
| Dry s. | KT-15EPA | Mean | 5.9 | 232.064 | 0.072 | 0.635 | 0.11 | 115.431 | 0.296 | 0.058 | 5.66 | 0.018 | 0.129 |
| Dry s. | KT-15EPA | SD | 0.1 | 22.187 | 0.061 | 0.059 | 0.066 | 20.761 | 0.083 | 0.004 | 0.713 | 0.003 | 0.037 |
| Dry s. | KT-16EPA | Range | 6.5-6.7 | 110.043-114.18 | 0.027-0.138 | 0.379-0.634 | 0.04-0.117 | 156.264-179.427 | 0.056-0.246 | 0.032-0.037 | 3.722-6.802 | 0.01-0.023 | 0.253-0.34 |
| Dry s. | KT-16EPA | Mean | 6.6 | 112.112 | 0.083 | 0.507 | 0.079 | 167.846 | 0.151 | 0.035 | 5.262 | 0.017 | 0.297 |
| Dry s. | KT-16EPA | SD | 0.1 | 2.925 | 0.078 | 0.18 | 0.054 | 16.379 | 0.134 | 0.004 | 2.178 | 0.009 | 0.062 |
| Dry s. | KT-17EPA | Range | 6.3-6.7 | 174.838-259.652 | 0.036-0.038 | 0.57-1.467 | 0.018-0.134 | 71.194-95.971 | 0.049-0.115 | 0.024-0.035 | 1.501-6.307 | 0.002-0.013 | 0.17-0.327 |
| Dry s. | KT-17EPA | Mean | 6.5 | 217.245 | 0.037 | 1.019 | 0.076 | 83.583 | 0.082 | 0.03 | 3.904 | 0.008 | 0.249 |
| Dry s. | KT-17EPA | SD | 0.3 | 59.973 | 0.001 | 0.634 | 0.082 | 17.52 | 0.047 | 0.008 | 3.398 | 0.008 | 0.111 |
| Dry s. | KT-18EPA | Range | 6.7-6.8 | 288.844-390.794 | 0.173-0.945 | 1.231-4.47 | 0.355-0.625 | 55.288-152.252 | 0.134-0.26 | 0.104-0.113 | 9.016-14.253 | 0.01-0.075 | 0.384-0.517 |
| Dry s. | KT-18EPA | Mean | 6.8 | 339.819 | 0.559 | 2.851 | 0.49 | 103.77 | 0.197 | 0.109 | 11.635 | 0.043 | 0.451 |
| Dry s. | KT-18EPA | SD | 0 | 72.09 | 0.546 | 2.29 | 0.191 | 68.564 | 0.089 | 0.006 | 3.703 | 0.046 | 0.094 |
| Rainy s. | KT-1EPA | Range | 8.1-10.4 | 116.944-180.383 | 0.034-0.16 | 0.031-0.286 | 0,039-0.06 | 137.985-243.05 | 0.092-0.159 | 0.018-0.025 | 0.063-1.415 | 0.002-0.011 | 0.043-0.303 |
| Rainy s. | KT-1EPA | Mean | 9.2 | 157.732 | 0.084 | 0.131 | 0.047 | 195.887 | 0.133 | 0.022 | 0.913 | 0.005 | 0.153 |
| Rainy s. | KT-1EPA | SD | 1.1 | 35.396 | 0.067 | 0.136 | 0.012 | 53.349 | 0.036 | 0.004 | 0.74 | 0.005 | 0.135 |
| Rainy s. | KT-2EPA | Range | 8.1-10.3 | 193.263-241.318 | 0.017-0.42 | 0.194-0.794 | 0.023-0.161 | 52.062-87.651 | 0.083-0.3 | 0.043-0.096 | 0.016-1.67 | 0.001-0.014 | 0.117-0.339 |
| Rainy s. | KT-2EPA | Mean | 9.2 | 209.857 | 0.162 | 0.53 | 0.082 | 75.438 | 0.217 | 0.062 | 0.968 | 0.006 | 0.196 |
| Rainy s. | KT-2EPA | SD | 1.1 | 27.260 | 0.224 | 0.306 | 0.071 | 20.251 | 0.117 | 0.03 | 0.855 | 0.007 | 0.124 |
| Rainy s. | KT-3EPA | Range | 8.4-10.7 | 155.676-173.887 | 0.051-0.117 | 0.093-0.385 | 0.034-0.063 | 73.06-183.801 | 0.087-0.249 | 0.022-0.048 | 1.589-6.824 | 0.002-0.035 | 0.089-0.179 |
| Rainy s. | KT-3EPA | Mean | 9.7 | 163.878 | 0.085 | 0.275 | 0.049 | 111.113 | 0.169 | 0.039 | 4.493 | 0.014 | 0.147 |
| Rainy s. | KT-3EPA | SD | 1.2 | 9.239 | 0.033 | 0.159 | 0.015 | 62.973 | 0.081 | 0.014 | 2.664 | 0.019 | 0.051 |
| Rainy s. | KT-4EPA | Range | 8.3-10.7 | 331.77-423.209 | 0.189-3.758 | 0.06-0.356 | 0.011-0.269 | 69.122-227.428 | 0.335-0.918 | 0.02-0.139 | 0.006-1.844 | 0.002-0.011 | 0.446-1.352 |
| Rainy s. | KT-4EPA | Mean | 9.6 | 391.701 | 1.422 | 0.238 | 0.099 | 167.311 | 0.539 | 0.063 | 0.999 | 0.005 | 0.841 |
| Rainy s. | KT-4EPA | SD | 1.2 | 51.925 | 2.024 | 0.157 | 0.147 | 85.746 | 0.328 | 0.066 | 0.928 | 0.005 | 0.464 |
| Dry s. | KT-12EPA | Range | 6.7-6.9 | 159.353-209.894 | 0.023-0.076 | 0.075-0.227 | 0.046-0.148 | 137.937-181.43 | 0.05-0.092 | 0.019-0.055 | 0.557-1.967 | 0.001-0.017 | 0.882-0.974 |
| Dry s. | KT-12EPA | Mean | 6.8 | 184.624 | 0.05 | 0.151 | 0.097 | 159.684 | 0.071 | 0.037 | 1.262 | 0.009 | 0.928 |
| Dry s. | KT-12EPA | SD | 0.1 | 35.738 | 0.037 | 0.107 | 0.072 | 30.754 | 0.03 | 0.025 | 0.997 | 0.011 | 0.065 |

**Table 1.** Contd.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dry s. | KT-13EPA | Range | 5.1-6 | 56.531-65.661 | 0.024-0.035 | 0.083-0.233 | 0.049-0.302 | 80.436-157.765 | 0.313-0.632 | 0.085-0.137 | 1.032-2.224 | 0.024-0.005 | 0.911-1.321 |
| Dry s. | KT-13EPA | Mean | 5.6 | 61.096 | 0.03 | 0.158 | 0.176 | 119.101 | 0.473 | 0.111 | 1.628 | 0.015 | 1.116 |
| Dry s. | KT-13EPA | SD | 0.6 | 6.456 | 0.008 | 0.106 | 0.179 | 54.68 | 0.226 | 0.037 | 0.843 | 0.018 | 0.29 |
| Dry s. | KT-14EPA | Range | 5.6-5.9 | 58.906-133.545 | 0.021-0.031 | 0.273-0.402 | 0.03-0.122 | 212.171-365.036 | 0.119-0.13 | 0.02-0.02 | 0.486-1.559 | 0.004-0.009 | 0.082-0.11 |
| Dry s. | KT-14EPA | Mean | 5.8 | 96.226 | 0.026 | 0.338 | 0.076 | 288.604 | 0.125 | 0.02 | 1.023 | 0.007 | 0.096 |
| Dry s. | KT-14EPA | SD | 0.2 | 52.778 | 0.007 | 0.091 | 0.065 | 108.092 | 0.008 | 0 | 0.759 | 0.004 | 0.02 |
| Dry s. | KT-15EPA | Range | 5.8-5.9 | 216.375-247.752 | 0.029-0.115 | 0.593-0.677 | 0.063-0.156 | 100.751-130.111 | 0.237-0.355 | 0.055-0.061 | 5.156-6.164 | 0.02-0.016 | 0.103-0.155 |
| Dry s. | KT-15EPA | Mean | 5.9 | 232.064 | 0.072 | 0.635 | 0.11 | 115.431 | 0.296 | 0.058 | 5.66 | 0.018 | 0.129 |
| Dry s. | KT-15EPA | SD | 0.1 | 22.187 | 0.061 | 0.059 | 0.066 | 20.761 | 0.083 | 0.004 | 0.713 | 0.003 | 0.037 |
| Dry s. | KT-16EPA | Range | 6.5-6.7 | 110.043-114.18 | 0.027-0.138 | 0.379-0.634 | 0.04-0.117 | 156.264-179.427 | 0.056-0.246 | 0.032-0.037 | 3.722-6.802 | 0.01-0.023 | 0.253-0.34 |
| Dry s. | KT-16EPA | Mean | 6.6 | 112.112 | 0.083 | 0.507 | 0.079 | 167.846 | 0.151 | 0.035 | 5.262 | 0.017 | 0.297 |
| Dry s. | KT-16EPA | SD | 0.1 | 2.925 | 0.078 | 0.18 | 0.054 | 16.379 | 0.134 | 0.004 | 2.178 | 0.009 | 0.062 |
| Dry s. | KT-17EPA | Range | 6.3-6.7 | 174.838-259.652 | 0.036-0.038 | 0.57-1.467 | 0.018-0.134 | 71.194-95.971 | 0.049-0.115 | 0.024-0.035 | 1.501-6.307 | 0.002-0.013 | 0.17-0.327 |
| Dry s. | KT-17EPA | Mean | 6.5 | 217.245 | 0.037 | 1.019 | 0.076 | 83.583 | 0.082 | 0.03 | 3.904 | 0.008 | 0.249 |
| Dry s. | KT-17EPA | SD | 0.3 | 59.973 | 0.001 | 0.634 | 0.082 | 17.52 | 0.047 | 0.008 | 3.398 | 0.008 | 0.111 |
| Dry s. | KT-18EPA | Range | 6.7-6.8 | 288.844-390.794 | 0.173-0.945 | 1.231-4.47 | 0.355-0.625 | 55.288-152.252 | 0.134-0.26 | 0.104-0.113 | 9.016-14.253 | 0.01-0.075 | 0.384-0.517 |
| Dry s. | KT-18EPA | Mean | 6.8 | 339.819 | 0.559 | 2.851 | 0.49 | 103.77 | 0.197 | 0.109 | 11.635 | 0.043 | 0.451 |
| Dry s. | KT-18EPA | SD | 0 | 72.09 | 0.546 | 2.29 | 0.191 | 68.564 | 0.089 | 0.006 | 3.703 | 0.046 | 0.094 |
| Rainy s. | KT-1EPA | Range | 8.1-10.4 | 116.944-180.383 | 0.034-0.16 | 0.031-0.286 | 0,039-0.06 | 137.985-243.05 | 0.092-0.159 | 0.018-0.025 | 0.063-1.415 | 0.002-0.011 | 0.043-0.303 |
| Rainy s. | KT-1EPA | Mean | 9.2 | 157.732 | 0.084 | 0.131 | 0.047 | 195.887 | 0.133 | 0.022 | 0.913 | 0.005 | 0.153 |
| Rainy s. | KT-1EPA | SD | 1.1 | 35.396 | 0.067 | 0.136 | 0.012 | 53.349 | 0.036 | 0.004 | 0.74 | 0.005 | 0.135 |
| Rainy s. | KT-2EPA | Range | 8.1-10.3 | 193.263-241.318 | 0.017-0.42 | 0.194-0.794 | 0.023-0.161 | 52.062-87.651 | 0.083-0.3 | 0.043-0.096 | 0.016-1.67 | 0.001-0.014 | 0.117-0.339 |
| Rainy s. | KT-2EPA | Mean | 9.2 | 209.857 | 0.162 | 0.53 | 0.082 | 75.438 | 0.217 | 0.062 | 0.968 | 0.006 | 0.196 |
| Rainy s. | KT-2EPA | SD | 1.1 | 27.260 | 0.224 | 0.306 | 0.071 | 20.251 | 0.117 | 0.03 | 0.855 | 0.007 | 0.124 |
| Rainy s. | KT-3EPA | Range | 8.4-10.7 | 155.676-173.887 | 0.051-0.117 | 0.093-0.385 | 0.034-0.063 | 73.06-183.801 | 0.087-0.249 | 0.022-0.048 | 1.589-6.824 | 0.002-0.035 | 0.089-0.179 |
| Rainy s. | KT-3EPA | Mean | 9.7 | 163.878 | 0.085 | 0.275 | 0.049 | 111.113 | 0.169 | 0.039 | 4.493 | 0.014 | 0.147 |
| Rainy s. | KT-3EPA | SD | 1.2 | 9.239 | 0.033 | 0.159 | 0.015 | 62.973 | 0.081 | 0.014 | 2.664 | 0.019 | 0.051 |
| Rainy s. | KT-4EPA | Range | 8.3-10.7 | 331.77-423.209 | 0.189-3.758 | 0.06-0.356 | 0.011-0.269 | 69.122-227.428 | 0.335-0.918 | 0.02-0.139 | 0.006-1.844 | 0.002-0.011 | 0.446-1.352 |
| Rainy s. | KT-4EPA | Mean | 9.6 | 391.701 | 1.422 | 0.238 | 0.099 | 167.311 | 0.539 | 0.063 | 0.999 | 0.005 | 0.841 |
| Rainy s. | KT-4EPA | SD | 1.2 | 51.925 | 2.024 | 0.157 | 0.147 | 85.746 | 0.328 | 0.066 | 0.928 | 0.005 | 0.464 |
| Rainy s. | KT-5EPA | Range | 8.6-11.2 | 70.898-75.056 | 0.048-0.167 | 0.064-0.296 | 0.032-0.036 | 114.25-128.315 | 0.068-0.164 | 0.013-0.04 | 0.007-1.624 | 0.001-0.008 | 0.056-1.435 |
| Rainy s. | KT-5EPA | Mean | 10.1 | 73.115 | 0.095 | 0.148 | 0.035 | 122.409 | 0.11 | 0.025 | 0.795 | 0.004 | 0.54 |
| Rainy s. | KT-5EPA | SD | 1.3 | 2.093 | 0.064 | 0.128 | 0.002 | 7.298 | 0.049 | 0.014 | 0.809 | 0.004 | 0.776 |
| Rainy s. | KT-6EPA | Range | 6.9-8.9 | 46.309-95.162 | 0.035-0.043 | 0.305-0.607 | 0.069-0.207 | 143.095-257.21 | 0.098-0.135 | 0.016-0.079 | 1.588-3.15 | 0.005-0.015 | 0.079-0.162 |
| Rainy s. | KT-6EPA | Mean | 7.8 | 65.346 | 0.038 | 0.437 | 0.121 | 185.605 | 0.112 | 0.044 | 2.516 | 0.009 | 0.113 |
| Rainy s. | KT-6EPA | SD | 1 | 26.150 | 0.004 | 0.155 | 0.075 | 62.373 | 0.02 | 0.032 | 0.822 | 0.005 | 0.044 |

**Table 1.** Contd.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rainy s. | KT-7EPA | Range | 7.3-9.8 | 52.68-74.03 | 0.015-0.021 | 0.143-1.237 | 0.023-0.203 | 17.86-43.143 | 0.082-0.277 | 0.010-0.034 | 0.981-14.161 | 0-0.026 | 0.034-0.271 |
| Rainy s. | KT-7EPA | Mean | 8.7 | 66.71 | 0.018 | 0.633 | 0.103 | 26.482 | 0.153 | 0.021 | 5.938 | 0.009 | 0.128 |
| Rainy s. | KT-7EPA | SD | 1.3 | 12.154 | 0.003 | 0.556 | 0.092 | 14.432 | 0.108 | 0.012 | 7.172 | 0.015 | 0.126 |
| Rainy s. | KT-8EPF | Range | 9-11 | 165.707-187.83 | 0.117-0.416 | 0.12-1.013 | 0.006-0.024 | 13.1-83.512 | 0.057-0.101 | 0.003-0.005 | 0.5-4.929 | 0.001-0.004 | 0.159-0.999 |
| Rainy s. | KT-8EPF | Mean | 10 | 176.591 | 0.222 | 0.471 | 0.015 | 53.926 | 0.089 | 0.004 | 2.682 | 0.002 | 0.583 |
| Rainy s. | KT-8EPF | SD | 1 | 11.066 | 0.168 | 0.476 | 0.009 | 36.541 | 0.011 | 0.001 | 2.215 | 0.002 | 0.420 |
| Rainy s. | KT-9EPA | Range | 8.9-11 | 163.159-200.204 | 0.092-0.151 | 0.046-0.506 | 0.008-0.014 | 52.91-65.519 | 0.019-0.057 | 0.004-0.005 | 0.862-1.535 | 0.002-0.01 | 0.759-1.106 |
| Rainy s. | KT-9EPA | Mean | 10 | 183.377 | 0.127 | 0.212 | 0.012 | 59.231 | 0.038 | 0.005 | 1.171 | 0.007 | 0.884 |
| Rainy s. | KT-9EPA | SD | 1.1 | 18.754 | 0.031 | 0.256 | 0.003 | 6.305 | 0.019 | 0.001 | 0.34 | 0.004 | 0.193 |
| Rainy s. | KT-10EPA | Range | 7.1-11 | 55.444-66.412 | 0.024-0.066 | 0.367-0.490 | 0.052-0.101 | 112.142-509.052 | 0.095-0.156 | 0.028-0.099 | 0.58-1.41 | 0-0.006 | 0.066-0.162 |
| Rainy s. | KT-10EPA | Mean | 8.7 | 62.215 | 0.038 | 0.438 | 0.082 | 370.696 | 0.134 | 0.062 | 0.987 | 0.004 | 0.118 |
| Rainy s. | KT-10EPA | SD | 2.0 | 5.920 | 0.024 | 0.064 | 0.027 | 224.098 | 0.034 | 0.036 | 0.415 | 0.003 | 0.048 |
| Rainy s. | KT-11EPA | Range | 7.4-10.7 | 576.046-672.2 | 0.47-0.586 | 21.581-37.78 | 0.234-0.336 | 71.269-77.441 | 0.734-1.432 | 0.161-0.303 | 3.856-5.788 | 0.011-0.063 | 1.895-2.081 |
| Rainy s. | KT-11EPA | Mean | 9.1 | 631.495 | 0.531 | 29.416 | 0.288 | 74.932 | 1 | 0.246 | 4.874 | 0.032 | 1.986 |
| Rainy s. | KT-11EPA | SD | 1.6 | 49.744 | 0.058 | 8.112 | 0.051 | 3.244 | 0.377 | 0.075 | 0.97 | 0.027 | 0.093 |
| Rainy s. | KT-12EPA | Range | 8.5-11 | 113.831-137.234 | 0.025-0.17 | 0.098-0.843 | 0.034-0.046 | 134.169-177.814 | 0.052-0.135 | 0.01-0.019 | 0.947-6.059 | 0.002-0.008 | 0.278-1.021 |
| Rainy s. | KT-12EPA | Mean | 9.9 | 128.023 | 0.077 | 0.456 | 0.04 | 148.997 | 0.085 | 0.015 | 3.15 | 0.005 | 0.737 |
| Rainy s. | KT-12EPA | SD | 1.3 | 12.471 | 0.081 | 0.373 | 0.006 | 24.96 | 0.044 | 0.005 | 2.628 | 0.003 | 0.401 |
| Rainy s. | KT-13EPA | Range | 6.8-8.8 | 43.998-68.175 | 0.038-0.325 | 0.13-0.892 | 0.14-0.166 | 157.876-185.018 | 0.572-0.666 | 0.128-0.141 | 1.221-2.813 | 0.003-0.019 | 1.239-1.297 |
| Rainy s. | KT-13EPA | Mean | 7.8 | 58.013 | 0.188 | 0.587 | 0.155 | 170.556 | 0.629 | 0.133 | 1.984 | 0.009 | 1.259 |
| Rainy s. | KT-13EPA | SD | 1 | 12.54 | 0.144 | 0.403 | 0.013 | 13.659 | 0.050 | 0.007 | 0.798 | 0.009 | 0.033 |
| Rainy s. | KT-14EPA | Range | 8.5-10 | 42.644-95.628 | 0.04-0.084 | 0.132-0.482 | 0.039-0.056 | 255.44-307.843 | 0.101-0.124 | 0.016-0.041 | 1.536-3.21 | 0.002-0.011 | 0.089-0.14 |
| Rainy s. | KT-14EPA | Mean | 9.1 | 77.424 | 0.056 | 0.281 | 0.048 | 287.531 | 0.113 | 0.024 | 2.244 | 0.006 | 0.118 |
| Rainy s. | KT-14EPA | SD | 0.8 | 30.132 | 0.025 | 0.181 | 0.009 | 28.117 | 0.012 | 0.014 | 0.866 | 0.005 | 0.026 |
| Rainy s. | KT-15EPA | Range | 7.4-10.4 | 167.134-194.989 | 0.037-0.071 | 0.794-1.031 | 0.063-0.082 | 81.688-101.428 | 0.117-0.3 | 0.041-0.05 | 16.553-24.769 | 0.003-0.014 | 0.088-0.134 |
| Rainy s. | KT-15EPA | Mean | 8.9 | 183.582 | 0.052 | 0.908 | 0.071 | 93.589 | 0.203 | 0.046 | 19.752 | 0.01 | 0.113 |
| Rainy s. | KT-15EPA | SD | 1.5 | 14.596 | 0.017 | 0.119 | 0.01 | 10.478 | 0.092 | 0.005 | 4.399 | 0.006 | 0.023 |
| Rainy s. | KT-16EPA | Range | 8.2-10.6 | 107.217-113.831 | 0.035-0.053 | 0.422-0.666 | 0.041-0.051 | 101.428-177.814 | 0.063-0.074 | 0.032-0.035 | 5.233-11.992 | 0.004-0.008 | 0.278-0.355 |
| Rainy s. | KT-16EPA | Mean | 9.4 | 110.691 | 0.044 | 0.505 | 0.046 | 171.839 | 0.069 | 0.034 | 7.761 | 0.006 | 0.316 |
| Rainy s. | KT-16EPA | SD | 1.2 | 3.32 | 0.009 | 0.139 | 0.005 | 6.57 | 0.006 | 0.002 | 3.687 | 0.002 | 0.039 |
| Rainy s. | KT-17EPA | Range | 8.2-9.8 | 115.557-162.76 | 0.043-0.191 | 0.299-0.68 | 0.014-0.108 | 91.909-171.428 | 0.076-0.122 | 0.011-0.028 | 2.69-8.9 | 0.001-0.014 | 0.216-0.362 |
| Rainy s. | KT-17EPA | Mean | 9.2 | 131.356 | 0.101 | 0.531 | 0.049 | 117.863 | 0.104 | 0.022 | 6.342 | 0.006 | 0.3 |
| Rainy s. | KT-17EPA | SD | 0.9 | 27.197 | 0.079 | 0.204 | 0.052 | 46.396 | 0.024 | 0.01 | 3.246 | 0.007 | 0.075 |
| Rainy s. | KT-18EPA | Range | 8.5-11 | 370.293-447.029 | 1.516-2.143 | 3.414-16.451 | 0.37-0.51 | 86.937-96.145 | 0.132-0.287 | 0.092-0.217 | 4.274-4.845 | 0.005-0.02 | 0.976-1.475 |
| Rainy s. | KT-18EPA | Mean | 9.9 | 408.075 | 1.815 | 11.825 | 0.433 | 91.503 | 0.206 | 0.139 | 4.467 | 0.013 | 1.146 |
| Rainy s. | KT-18EPA | SD | 1.3 | 38.381 | 0.315 | 7.296 | 0.071 | 4.604 | 0.078 | 0.068 | 0.328 | 0.008 | 0.285 |

**Table 1.** Contd.

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rainy s. | KN-1EPA | Range | 6.8-7.6 | 216.183-312.915 | 0.123-0.264 | 0.16-0.283 | 0.032-0.039 | 82.82-130.943 | 0.063-0.097 | 0.022-0.029 | 1.204-2.006 | 0.005-0.009 | 0.095-4.473 |
| Rainy s. | KN-1EPA | Mean | 7.2 | 264.549 | 0.193 | 0.221 | 0.036 | 106.881 | 0.08 | 0.026 | 1.605 | 0.007 | 2.284 |
| Rainy s. | KN-1EPA | SD | 0.6 | 68,4 | 0.1 | 0.087 | 0.005 | 34.028 | 0.024 | 0.005 | 0.567 | 0.003 | 3.096 |
| Rainy s. | KN-2EPF | Range | 8.1-8.4 | 85.238-86.997 | 0.18-0.476 | 0.564-1.225 | 0.022-0.037 | 14.099-47.277 | 0.175-0.82 | 0.006-0.031 | 3.991-4.088 | 0.01-0.02 | 0.282-0.368 |
| Rainy s. | KN-2EPF | Mean | 8.2 | 86.117 | 0.328 | 0.894 | 0.029 | 30.688 | 0.498 | 0.018 | 4.04 | 0.015 | 0.325 |
| Rainy s. | KN-2EPF | SD | 0.2 | 1.243 | 0.209 | 0.467 | 0.011 | 23.461 | 0.456 | 0.018 | 0.069 | 0.007 | 0.06 |
| Rainy s. | KN-3EPA | Range | 7.2-7.9 | 18.079-19.349 | 0.019-0.02 | 0.058-0.112 | 0.02-0.044 | 88.09-98.038 | 0.045-0.086 | 0.016-0.065 | 11.97-15.19 | 0.002-0.002 | 0.064-0.102 |
| Rainy s. | KN-3EPA | Mean | 7.5 | 18.714 | 0.02 | 0.085 | 0.032 | 93.064 | 0.065 | 0.04 | 13.58 | 0.002 | 0.083 |
| Rainy s. | KN-3EPA | SD | 0.5 | 0.898 | 0.001 | 0.039 | 0.017 | 7.034 | 0.029 | 0.034 | 2.277 | 0 | 0.027 |
| Rainy s. | KN-4EPF | Range | 5.5-5.8 | 4.604-5.004 | 0.023-5.004 | 0.056-0.127 | 0.022-0.023 | 65.417-69.077 | 0.037-0.098 | 0.017-0.017 | 1.459-2.839 | 0.025-0.043 | 0.079-0.13 |
| Rainy s. | KN-4EPF | Mean | 5.6 | 4.804 | 0.028 | 0.091 | 0.023 | 67.247 | 0.067 | 0.017 | 2.149 | 0.034 | 0.105 |
| Rainy s. | KN-4EPF | SD | 0.2 | 0.282 | 0.007 | 0.05 | 0.001 | 2.588 | 0.043 | 0 | 0.976 | 0.013 | 0.036 |
| Rainy s. | KN-5EPF | Range | 8-8 | 123.325-125.518 | 0.181-0.366 | 0.099-0.852 | 0.058-0.162 | 106.27-167.746 | 0.058-1.769 | 0.038-0.052 | 1.194-1.731 | 0.001-0.009 | 0.302-0.456 |
| Rainy s. | KN-5EPF | Mean | 8 | 124.422 | 0.273 | 0.475 | 0.11 | 137.008 | 0.913 | 0.045 | 1.463 | 0.005 | 0.379 |
| Rainy s. | KN-5EPF | SD | 0 | 1.551 | 0.131 | 0.532 | 0.074 | 43.470 | 1.21 | 0.01 | 0.38 | 0.005 | 0.109 |
| Rainy s. | KN-6EPA | Range | 5.9-6.2 | 83.244-91.345 | 0.04-0.053 | 374.753-384.405 | 0.087-0.123 | 44.364-73.073 | 1.496-2.538 | 0.038-0.039 | 5.955-14.481 | 0.01-0.02 | 7.634-8.839 |
| Rainy s. | KN-6EPA | Mean | 6 | 87.294 | 0.047 | 379.579 | 0.105 | 58.719 | 2.017 | 0.038 | 10.218 | 0.015 | 8.237 |
| Rainy s. | KN-6EPA | SD | 0.2 | 5.728 | 0.009 | 6.825 | 0.025 | 20.301 | 0.736 | 0.001 | 6.029 | 0.007 | 0.852 |

| Sampling period | Sampling site | Data type | pH value | V51 (µg/L) | Cr52 (µg/L) | Mn55 (µg/L) | Fe56 (µg/L) | Co59 (µg/L) | Ni60 (µg/L) | Cu63 (µg/L) | Zn66 (µg/L) | As75 (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dry s. | KT-1EPA | Range | 6.4-7 | 0.327-0.608 | 0.211-0.475 | 11.895-14.735 | 31.823-166.126 | 0.669-1.717 | 0.645-1.158 | 7.793-11.123 | 15.425-16.875 | 0.157-0.18 |
| Dry s. | KT-1EPA | Mean | 6.7 | 0.468 | 0.343 | 13.315 | 98.975 | 1.193 | 0.902 | 9.458 | 16.15 | 0.169 |
| Dry s. | KT-1EPA | SD | 0.4 | 0.199 | 0.187 | 2.008 | 94.967 | 0.741 | 0.363 | 2.355 | 1.025 | 0.016 |
| Dry s. | KT-2EPA | Range | 6.3-6.8 | 0.163-0.653 | 0.162-0.622 | 7.32-51.465 | 21.317-314.077 | 1.129-2.341 | 0.745-1.459 | 3.932-11.975 | 12.539-23.394 | 0.096-0.227 |
| Dry s. | KT-2EPA | Mean | 6.5 | 0.408 | 0.392 | 29.393 | 167.697 | 1.735 | 1.102 | 7.954 | 17.967 | 0.162 |
| Dry s. | KT-2EPA | SD | 0.4 | 0.346 | 0.325 | 31.215 | 207.013 | 0.857 | 0.505 | 5.687 | 7.676 | 0.093 |
| Dry s. | KT-3EPA | Range | 6.3-6.8 | 0.252-0.653 | 0.146-0.446 | 39.564-51.42 | 212.648-300.658 | 0.741-1.583 | 0.877-1.012 | 4.288-7.808 | 8.114-11.155 | 0.372-0.625 |
| Dry s. | KT-3EPA | Mean | 6.5 | 0.444 | 0.296 | 45.492 | 256.653 | 1.162 | 0.945 | 6.048 | 9.635 | 0.499 |
| Dry s. | KT-3EPA | SD | 0.4 | 0.272 | 0.212 | 8.383 | 62.232 | 0.595 | 0.095 | 2.489 | 2.15 | 0.179 |
| Dry s. | KT-4EPA | Range | 6.7-6.8 | 0.713-0.994 | 0.125-0.566 | 25.324-82.246 | 5.735-221.27 | 0.487-1.679 | 1.076-4.655 | 6.137-9.294 | 9.233-26.481 | 0.838-2.257 |
| Dry s. | KT-4EPA | Mean | 6.8 | 0.854 | 0.346 | 53.785 | 113.503 | 1.083 | 2.866 | 7.716 | 17.857 | 1.548 |
| Dry s. | KT-4EPA | SD | 0.1 | 0.199 | 0.312 | 40.250 | 152.406 | 0.843 | 2.531 | 2.232 | 12.196 | 1.003 |
| Dry s. | KT-5EPA | Range | 6.2-6.8 | 0.391-0.742 | 0.146-0.708 | 5.621-34.787 | 58.167-375.777 | 0.641-2.067 | 0.518-1.33 | 6.823-12.521 | 11.448-23.104 | 0.14-3.368 |
| Dry s. | KT-5EPA | Mean | 6.5 | 0.567 | 0.427 | 20.204 | 216.972 | 1.354 | 0.924 | 9.672 | 17.276 | 1.754 |
| Dry s. | KT-5EPA | SD | 0.4 | 0.248 | 0.397 | 20.623 | 224.584 | 1.008 | 0.574 | 4.029 | 8.242 | 2.283 |
| Dry s. | KT-6EPA | Range | 4.7-6.3 | 0.99-1,869 | 0.128-0.92 | 169.96-332.686 | 153-133.927 | 14.81-63.506 | 12.42-16.048 | 20.804-261.66 | 51.048-420.851 | 9.4-11.33 |
| Dry s. | KT-6EPA | Mean | 5.5 | 1.430 | 0.524 | 251.321 | 143.98 | 39.158 | 14.234 | 141.232 | 235.95 | 10.365 |

**Table 1.** Contd.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dry s. | KT-6EPA | SD | 1.1 | 0.622 | 0.56 | 115.067 | 13.487 | 34.433 | 2.565 | 170.311 | 261.49 | 1.365 |
| Dry s. | KT-7EPA | Range | 5.1-5.9 | 0.117-1.396 | 0.713-1.202 | 64.865-103.248 | 308.1-481.3 | 5.886-12.308 | 5.403-10.78 | 10.981-17.783 | 39.947-56.881 | 1.396-6.006 |
| Dry s. | KT-7EPA | Mean | 5.5 | 0.757 | 0.958 | 84.057 | 394.70 | 9.097 | 8.092 | 14.382 | 48.414 | 3.701 |
| Dry s. | KT-7EPA | SD | 0.6 | 0.904 | 0.346 | 27.141 | 122.471 | 4.541 | 3.802 | 4.81 | 11.974 | 3.26 |
| Dry s. | KT-8EPF | Range | 6.8-7.8 | 1.331-1.883 | 0.365-0.718 | 13.947-43.658 | 236.504-461.938 | 0.533-2.123 | 1.414-2.891 | 13.893-18.013 | 36.194-99.313 | 6.28-7.16 |
| Dry s. | KT-8EPF | Mean | 7.3 | 1.607 | 0.542 | 28.803 | 349.221 | 1.328 | 2.153 | 15.953 | 67.754 | 6.72 |
| Dry s. | KT-8EPF | SD | 0.7 | 0.39 | 0.25 | 21.009 | 159.406 | 1.124 | 1.044 | 2.913 | 44.632 | 0.622 |
| Dry s. | KT-9EPA | Range | 6.8-7.5 | 0.381-9.735 | 1.55-5.19 | 95.389-296.597 | 568.93-351.957 | 0.972-7.955 | 0.345-2.414 | 5.637-25.01 | 8.797-29.693 | 3.176-10.895 |
| Dry s. | KT-9EPA | Mean | 7.2 | 5.058 | 3.37 | 195.993 | 460.444 | 4.464 | 1.38 | 15.324 | 19.245 | 7.036 |
| Dry s. | KT-9EPA | SD | 0.5 | 6.614 | 3.56 | 142.276 | 153.423 | 4.938 | 1.463 | 13.699 | 14.776 | 5.458 |
| Dry s. | KT-10EPA | Range | 6-6 | 0.2-0.59 | 0.146-1.026 | 1344.49-1575.42 | 1767.42-4826.95 | 6.284-31.718 | 2.883-5.342 | 4.406-22.386 | 46.045-80.928 | 2.182-2.907 |
| Dry s. | KT-10EPA | Mean | 6 | 0.395 | 0.586 | 1459.96 | 3297.18 | 19.001 | 4.113 | 13.396 | 63.487 | 2.545 |
| Dry s. | KT-10EPA | SD | 0 | 0.276 | 0.622 | 163.292 | 2163.42 | 17.985 | 1.739 | 12.714 | 24.666 | 0.513 |
| Dry s. | KT-11EPA | Range | 4.9-5.6 | 0.83-4.474 | 0.772-1.24 | 13.729-15.413 | 1581.64-1653.45 | 361.4-571.3 | 1.559-2.784 | 36.93-131.76 | 128.67-779.05 | 1.28-3.994 |
| Dry s. | KT-11EPA | Mean | 5.3 | 2.785 | 1.006 | 14.571 | 1617.55 | 466.35 | 2.172 | 8.435 | 45.386 | 2.061 |
| Dry s. | KT-11EPA | SD | 0.5 | 2.765 | 0.331 | 1.191 | 50.777 | 148.422 | 0.866 | 6.705 | 45.989 | 2.734 |
| Dry s. | KT-12EPA | Range | 6.7-6.9 | 0.109-2.316 | 0.157-1.559 | 31.228-68.176 | 19.674-695.011 | 0.596-2.947 | 1.667-2.006 | 4.543-14.078 | 10.129-25.345 | 0.178-2.053 |
| Dry s. | KT-12EPA | Mean | 6.8 | 1.213 | 0.858 | 49.702 | 357.343 | 1.772 | 1.837 | 9.311 | 17.737 | 1.116 |
| Dry s. | KT-12EPA | SD | 0.1 | 1.561 | 0.991 | 26.126 | 477.535 | 1.662 | 0.24 | 6.742 | 10.759 | 1.326 |
| Dry s. | KT-13EPA | Range | 5.1-6 | 0.36-1.996 | 0.254-1.754 | 87.7-146.55 | 83.391-79.862 | 2.27-9.055 | 0.832-2.978 | 6.197-19.314 | 20.016-32.325 | 1.2-2.866 |
| Dry s. | KT-13EPA | Mean | 5.6 | 1.178 | 1.004 | 117.125 | 81.627 | 5.663 | 1.905 | 12.756 | 26.171 | 2.033 |
| Dry s. | KT-13EPA | SD | 0.6 | 1.157 | 1.061 | 41.613 | 2.495 | 4.798 | 1.517 | 9.275 | 8.704 | 1.178 |
| Dry s. | KT-14EPA | Range | 5.6-5.9 | 0.112-1.141 | 0.138-1.155 | 55.919-104.047 | 308.03-384.854 | 6.448-6.977 | 4.791-11.114 | 9.011-12.086 | 42.891-46.976 | 9.27-23.075 |
| Dry s. | KT-14EPA | Mean | 5.8 | 0.627 | 0.647 | 79.983 | 346.442 | 6.713 | 7.953 | 10.549 | 44.934 | 16.173 |
| Dry s. | KT-14EPA | SD | 0.2 | 0.728 | 0.719 | 34.032 | 54.323 | 0.374 | 4.471 | 2.174 | 2.889 | 9.762 |
| Dry s. | KT-15EPA | Range | 5.8-5.9 | 0.189-1.063 | 0.169-1.193 | 199.272-403.337 | 40.543-41.161 | 4.282-8.867 | 16.182-16.622 | 23.803-28.005 | 54.39-60.123 | 0.606-2.008 |
| Dry s. | KT-15EPA | Mean | 5.9 | 0.626 | 0.681 | 301.305 | 40.852 | 6.575 | 16.402 | 25.904 | 57.257 | 1.307 |
| Dry s. | KT-15EPA | SD | 0.1 | 0.618 | 0.724 | 144.296 | 0.437 | 3.242 | 0.311 | 2.971 | 4.054 | 0.991 |
| Dry s. | KT-16EPA | Range | 6.5-6.7 | 0.814-2.558 | 0.325-1.691 | 13.988-42.702 | 66.359-628.403 | 3.731-11.157 | 0.774-2.051 | 57.261-101.888 | 34.091-53.097 | 0.527-1.378 |
| Dry s. | KT-16EPA | Mean | 6.6 | 1.686 | 1.008 | 28.345 | 347.381 | 7.444 | 1.413 | 79.575 | 43.594 | 0.953 |
| Dry s. | KT-16EPA | SD | 0.1 | 1.233 | 0.966 | 20.304 | 397.425 | 5.251 | 0.903 | 31.556 | 13.439 | 0.602 |
| Dry s. | KT-17EPA | Range | 6.3-6.7 | 0.524-4.232 | 0.23-2.42 | 165.479-1748.17 | 70.499-2073.51 | 18.503-30.058 | 1.582-3.703 | 18.111-52.681 | 41.222-51.492 | 0.338-0.913 |
| Dry s. | KT-17EPA | Mean | 6.5 | 2.378 | 1.325 | 956.83 | 1072 | 24.281 | 2.643 | 35.396 | 46.357 | 0.626 |
| Dry s. | KT-17EPA | SD | 0.3 | 2.622 | 1.549 | 1119.134 | 1416.34 | 8.171 | 1.5 | 24.445 | 7.262 | 0.407 |
| Dry s. | KT-18EPA | Range | 6.7-6.8 | 4.43-4.518 | 0.356-2.308 | 212.307-331.156 | 2515.73-1657.20 | 54.596-133.045 | 2.229-2.961 | 133.235-347.829 | 272.037-1003.53 | 0.802-1.375 |
| Dry s. | KT-18EPA | Mean | 6.8 | 4.474 | 1.332 | 271.732 | 2086.47 | 93.821 | 2.595 | 240.532 | 637.784 | 1.089 |
| Dry s. | KT-18EPA | SD | 0 | 0.062 | 1.38 | 84.039 | 607.072 | 55.472 | 0.518 | 151.741 | 517.244 | 0.405 |

**Table 1.** Contd.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rainy s. | KT-1EPA | Range | 8.1-10.4 | 0.142-1.446 | 0.059-0.674 | 5.01-78.672 | 69.407-433.541 | 0.647-2.019 | 0.306-1.097 | 1.674-12.692 | 4.196-48.956 | 0.164-0.913 |
| Rainy s. | KT-1EPA | Mean | 9.2 | 0.66 | 0.393 | 31.377 | 191.721 | 1.331 | 0.786 | 8.135 | 23.441 | 0.458 |
| Rainy s. | KT-1EPA | SD | 1.1 | 0.692 | 0.311 | 41.049 | 209.427 | 0.686 | 0.422 | 5.751 | 23.029 | 0.4 |
| Rainy s. | KT-2EPA | Range | 8.1-10.3 | 0.229-0.624 | 0.063-0.324 | 3.661-83.944 | 2.616-84.746 | 2.587-68.96 | 1.228-8.422 | 13.943-30.527 | 39.057-79.027 | 0.192-0.497 |
| Rainy s. | KT-2EPA | Mean | 9.2 | 0.367 | 0.231 | 53.454 | 57.31 | 24.83 | 4.006 | 22.901 | 52.792 | 0.305 |
| Rainy s. | KT-2EPA | SD | 1.1 | 0.223 | 0.146 | 43.483 | 47.366 | 38.218 | 3.866 | 8.372 | 22.728 | 0.167 |
| Rainy s. | KT-3EPA | Range | 8.4-10.7 | 0.223-0.401 | 0.255-0.564 | 63.987-99.164 | 49.234-130.588 | 2.081-10.127 | 1.817-7.704 | 14.18-45.424 | 24.38-51.353 | 0.173-11.735 |
| Rainy s. | KT-3EPA | Mean | 9.7 | 0.303 | 0.419 | 75.92 | 85.826 | 4.923 | 5.206 | 26.981 | 40.153 | 4.676 |
| Rainy s. | KT-3EPA | SD | 1.2 | 0.09 | 0.155 | 20.132 | 41.288 | 4.513 | 3.043 | 16.368 | 14.056 | 6.19 |
| Rainy s. | KT-4EPA | Range | 8.3-10.7 | 0.51-1.448 | 0.059-0.677 | 0.397-15.304 | 2.999-89.147 | 1.228-27.768 | 1.508-1.707 | 8.383-16.392 | 27.833-36.853 | 0.986-2.395 |
| Rainy s. | KT-4EPA | Mean | 9.6 | 1.024 | 0.331 | 8.834 | 43.038 | 10.776 | 1.615 | 12.588 | 32.879 | 1.494 |
| Rainy s. | KT-4EPA | SD | 1.2 | 0.475 | 0.315 | 7.646 | 43.394 | 14.753 | 0.1 | 4.02 | 4.605 | 0.782 |
| Rainy s. | KT-5EPA | Range | 8.6-11.2 | 0.471-0.578 | 0.052-0.593 | 0.158-49.648 | 1.745-261.241 | 1.118-2.713 | 0.278-1.726 | 1.077-13.791 | 2.788-28.943 | 0.126-9.566 |
| Rainy s. | KT-5EPA | Mean | 10.1 | 0.522 | 0.318 | 19.428 | 109.96 | 1.682 | 0.882 | 7.012 | 14.273 | 3.331 |
| Rainy s. | KT-5EPA | SD | 1.3 | 0.054 | 0.271 | 26.5 | 135.002 | 0.894 | 0.753 | 6.399 | 13.365 | 5.4 |
| Rainy s. | KT-6EPA | Range | 6.9-8.9 | 0.301-0.572 | 0.328-0.686 | 42.434-165.617 | 138.486-238.699 | 5.865-12.273 | 2.875-9.612 | 10.06-25.235 | 17.855-71.87 | 11.172-30.03 |
| Rainy s. | KT-6EPA | Mean | 7.8 | 0.403 | 0.557 | 95.570 | 191.905 | 9.205 | 6.588 | 18.379 | 38.034 | 21.262 |
| Rainy s. | KT-6EPA | SD | 1 | 0.147 | 0.199 | 63.309 | 50.434 | 3.213 | 3.421 | 7.693 | 29.483 | 9.498 |
| Rainy s. | KT-7EPA | Range | 7.3-9.8 | 0.88-5.167 | 0.2-2.705 | 70.54-275.835 | 1269.2-2310.18 | 1.02-7.509 | 0.796-4.302 | 7.057-13.33 | 72.33-220.631 | 1.6-10.47 |
| Rainy s. | KT-7EPA | Mean | 8.7 | 2.322 | 1.222 | 140.164 | 1731.353 | 5.037 | 2.711 | 9.709 | 126.744 | 7.49 |
| Rainy s. | KT-7EPA | SD | 1.3 | 2.464 | 1.315 | 117.508 | 530.207 | 3.51 | 1.775 | 3.247 | 81.651 | 5.101 |
| Rainy s. | KT-8EPF | Range | 9-11 | 0.547-1.996 | 0.29-2.09 | 95.54-313.386 | 945.08-2325.44 | 1.46-6.517 | 0.416-1.999 | 3.84-25.471 | 5.583-41.344 | 11.246-8.494 |
| Rainy s. | KT-8EPF | Mean | 10 | 1.352 | 0.973 | 179.589 | 1555.17 | 4.014 | 1.193 | 17.623 | 29.315 | 17.270 |
| Rainy s. | KT-8EPF | SD | 1 | 0.738 | 0.975 | 117.134 | 703.982 | 2.519 | 0.792 | 11.975 | 20.553 | 9.729 |
| Rainy s. | KT-9EPA | Range | 8.9-11 | 0.751-1.028 | 0.125-0.261 | 19.776-50.498 | 51.011-130.124 | 0.421-1.45 | 0.448-0.546 | 2.792-14.767 | 8.088-11.194 | 2.762-3.352 |
| Rainy s. | KT-9EPA | Mean | 10 | 0.867 | 0.181 | 30.656 | 77.720 | 0.836 | 0.508 | 7.99 | 9.513 | 3.012 |
| Rainy s. | KT-9EPA | SD | 1.1 | 0.144 | 0.071 | 17.215 | 45.386 | 0.542 | 0.053 | 6.142 | 1.569 | 0.305 |
| Rainy s. | KT-10EPA | Range | 7.1-11 | 0.055-0.15 | 0.2-0.51 | 881.85-2229.49 | 1823-6392.32 | 3.088-21.194 | 1.089-5.539 | 1.63-12.21 | 16.752-62.807 | 0.471-1.499 |
| Rainy s. | KT-10EPA | Mean | 8.7 | 0.106 | 0.319 | 1639.41 | 3192.23 | 14.453 | 4.144 | 6.501 | 39.265 | 1.017 |
| Rainy s. | KT-10EPA | SD | 2.0 | 0.048 | 0.167 | 689.254 | 2780.95 | 9.899 | 2.649 | 5.34 | 23.045 | 0.517 |
| Rainy s. | KT-11EPA | Range | 7.4-10.7 | 8.001-9.531 | 0.237-1.627 | 41.381-130.782 | 213.386-1183.66 | 739.085-1083.11 | 7.405-10.63 | 149.495-228.215 | 1317.05-2214.14 | 3.18-3.418 |
| Rainy s. | KT-11EPA | Mean | 9.1 | 8.828 | 0.823 | 82.479 | 643.793 | 919.264 | 9.502 | 193.323 | 1706.63 | 3.262 |
| Rainy s. | KT-11EPA | SD | 1.6 | 0.773 | 0.72 | 45.134 | 494.312 | 172.594 | 1.818 | 40.114 | 460.029 | 0.135 |
| Rainy s. | KT-12EPA | Range | 8.5-11 | 0.596-1.114 | 0.366-0.5 | 12.62-39.864 | 94.209-132.567 | 2.122-18.373 | 0.67-1.724 | 10.663-75.675 | 34.462-63.509 | 3.52-9.005 |
| Rainy s. | KT-12EPA | Mean | 9.9 | 0.833 | 0.416 | 23.229 | 118.572 | 8.517 | 1.117 | 35.169 | 46.177 | 6.352 |
| Rainy s. | KT-12EPA | SD | 1.3 | 0.262 | 0.073 | 14.587 | 21.177 | 8.661 | 0.545 | 35.336 | 15.317 | 2.747 |

**Table 1.** Contd.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rainy s. | KT-13EPA | Range | 6.8-8.8 | 0.227-0.848 | 0.276-0.557 | 134.245-187.679 | 45.652-199.329 | 7.393-23.896 | 2.581-3.843 | 15.121-20.722 | 40.741-85.395 | 3.774-7.83 |
| Rainy s. | KT-13EPA | Mean | 7.8 | 0.493 | 0.456 | 162.795 | 107.996 | 12.954 | 3.219 | 17.344 | 64.336 | 5.366 |
| Rainy s. | KT-13EPA | SD | 1 | 0.32 | 0.156 | 26.905 | 80.836 | 9.476 | 0.631 | 2.974 | 22.435 | 2.164 |
| Rainy s. | KT-14EPA | Range | 8.5-10 | 0.118-0.401 | 0.281-0.403 | 47.834-62.121 | 38.165-224.596 | 5.869-12.648 | 5.742-15.471 | 12.045-18.396 | 14.477-25.833 | 4.58-8.061 |
| Rainy s. | KT-14EPA | Mean | 9.1 | 0.303 | 0.329 | 54.635 | 142.935 | 8.498 | 9.28 | 15.024 | 21.819 | 6.388 |
| Rainy s. | KT-14EPA | SD | 0.8 | 0.161 | 0.065 | 7.168 | 95.34 | 3.636 | 5.38 | 3.194 | 6.368 | 1.744 |
| Rainy s. | KT-15EPA | Range | 7.4-10.4 | 0.427-0.965 | 0.306-0.653 | 83.944-262.521 | 84.568-217.147 | 5.287-12.155 | 7.416-8.525 | 42.233-81.255 | 140.293-289.295 | 1.92-8.06 |
| Rainy s. | KT-15EPA | Mean | 8.9 | 0.669 | 0.497 | 146.206 | 138.174 | 7.721 | 8.121 | 64.691 | 191.185 | 4.034 |
| Rainy s. | KT-15EPA | SD | 1.5 | 0.273 | 0.176 | 100.815 | 69.835 | 3.846 | 0.613 | 20.168 | 84.986 | 3.488 |
| Rainy s. | KT-16EPA | Range | 8.2-10.6 | 1.114-1.625 | 0.366-0.845 | 17.204-58.858 | 132.567-235.205 | 5.055-13.887 | 0.67-2.08 | 75.675-160.911 | 31.892-34.462 | 1.618-3.659 |
| Rainy s. | KT-16EPA | Mean | 9.4 | 1.31 | 0.587 | 34.391 | 185.837 | 10.422 | 1.301 | 106.965 | 33.567 | 2.322 |
| Rainy s. | KT-16EPA | SD | 1.2 | 0.276 | 0.242 | 21.76 | 51.43 | 4.713 | 0.717 | 46.917 | 1.451 | 1.158 |
| Rainy s. | KT-17EPA | Range | 8.2-9.8 | 0.405-2.683 | 0.029-1.123 | 100-136.81 | 130.553-509.457 | 81.377-138.279 | 1.592-2.56 | 58.501-135.78 | 45.4-80.47 | 0.356-0.73 |
| Rainy s. | KT-17EPA | Mean | 9.2 | 1.214 | 0.525 | 119.968 | 290.67 | 118.985 | 2.181 | 105.352 | 60.189 | 0.565 |
| Rainy s. | KT-17EPA | SD | 0.9 | 1.274 | 0.554 | 18.603 | 196.147 | 32.573 | 0.517 | 41.174 | 18.169 | 0.191 |
| Rainy s. | KT-18EPA | Range | 8.5-11 | 1.537-2.338 | 0.516-2.26 | 235.06-310.588 | 661.32-2983.76 | 854.38-1346.34 | 3.821-15.503 | 72.53-216.35 | 986.875-1066.76 | 1.322-1.7 |
| Rainy s. | KT-18EPA | Mean | 9.9 | 2.055 | 1.604 | 263.515 | 1647.43 | 1094.28 | 9.344 | 132.402 | 1037.91 | 1.469 |
| Rainy s. | KT-18EPA | SD | 1.3 | 0.449 | 0.949 | 41.062 | 1200.18 | 246.206 | 5.867 | 74.872 | 44.322 | 0.203 |
| Rainy s. | KN-1EPA | Range | 6.8-7.6 | 0.11-0.574 | 0.426-0.449 | 15.846-146.279 | 80.939-111.771 | 2.989-3.078 | 3.56-5.567 | 10.755-16.999 | 26.41-54.751 | 7.234-7.316 |
| Rainy s. | KN-1EPA | Mean | 7.2 | 0.342 | 0.437 | 81.062 | 96.355 | 3.033 | 4.563 | 13.877 | 40.581 | 7.275 |
| Rainy s. | KN-1EPA | SD | 0.6 | 0.328 | 0.017 | 92.23 | 21.802 | 0.063 | 1.419 | 4.415 | 20.04 | 0.058 |
| Rainy s. | KN-2EPF | Range | 8.1-8.4 | 0.997-1.364 | 0.48-0.83 | 113.841-245.776 | 48.417-185.365 | 1.319-18.205 | 2.122-4.408 | 25.601-30.29 | 69.285-103.978 | 0.133-2.016 |
| Rainy s. | KN-2EPF | Mean | 8.2 | 1.181 | 0.655 | 179.809 | 116.891 | 9.762 | 3.265 | 27.946 | 86.632 | 1.074 |
| Rainy s. | KN-2EPF | SD | 0.2 | 0.26 | 0.248 | 93.292 | 96.837 | 11.940 | 1.616 | 3.316 | 24.532 | 1.331 |
| Rainy s. | KN-3EPA | Range | 7.2-7.9 | 0.027-0.117 | 0.292-0.354 | 11.975-38.057 | 106.628-404.275 | 2.612-2.877 | 4.365-4.493 | 5.062-62.705 | 37.535-40.733 | 1.604-5.046 |
| Rainy s. | KN-3EPA | Mean | 7.5 | 0.072 | 0.323 | 25.016 | 255.451 | 2.745 | 4.429 | 33.884 | 39.134 | 3.325 |
| Rainy s. | KN-3EPA | SD | 0.5 | 0.064 | 0.044 | 18.443 | 210.469 | 0.187 | 0.091 | 40.76 | 2.261 | 2.434 |
| Rainy s. | KN-4EPF | Range | 5.5-5.8 | 0.043-0.071 | 0.337-0.81 | 9.779-10.06 | 104.686-134.525 | 3.409-3.435 | 5.615-5.694 | 6.383-14.427 | 46.45-47.388 | 0.402-5.662 |
| Rainy s. | KN-4EPF | Mean | 5.6 | 0.057 | 0.573 | 9.919 | 119.606 | 3.422 | 5.654 | 10.405 | 46.919 | 3.032 |
| Rainy s. | KN-4EPF | SD | 0.2 | 002 | 0.335 | 0.199 | 21.099 | 0.018 | 0.056 | 5.688 | 0.663 | 3.719 |
| Rainy s. | KN-5EPF | Range | 8-8 | 0.094-0.263 | 0.09-0.276 | 13.77-67.157 | 15.926-60.083 | 0.586-3.605 | 1.372-6.255 | 8.567-38.492 | 42.62-235.715 | 0.071-0.237 |
| Rainy s. | KN-5EPF | Mean | 8 | 0.178 | 0.183 | 40.463 | 38.004 | 2.095 | 3.813 | 23.529 | 139.167 | 0.154 |
| Rainy s. | KN-5EPF | SD | 0 | 0.119 | 0.132 | 37.75 | 31.224 | 2.135 | 3.453 | 21.161 | 136.54 | 0.118 |
| Rainy s. | KN-6EPA | Range | 5.9-6.2 | 0.107-0.6 | 0.417-0.952 | 1346.41-1390.05 | 236.321-419.968 | 432.319-446.724 | 94.949-108.518 | 9558.19-9753.56 | 48900.05-49053.03 | 0.21-0.725 |
| Rainy s. | KN-6EPA | Mean | 6 | 0.353 | 0.684 | 1368.23 | 328.145 | 439.522 | 101.733 | 9655.88 | 48976.54 | 0.468 |
| Rainy s. | KN-6EPA | SD | 0.2 | 0.348 | 0.379 | 30.852 | 129.858 | 10.186 | 9.594 | 138.147 | 108.173 | 0.364 |

Dry s.: Dry season; EPA: hand-dug well; EPF: drilled well; KN: Kenya municipality; KT: Katuba municipality; Rainy s.: rainy season; SD: standard deviation.

**Table 2.** Mean and standard deviation values of pH and elevated trace element concentrations (µg/L) in Katuba and Kenya groundwater higher than the WHO (2017), US EPA (2018) and/or EU (2020) acceptable limits for drinking water.

| Parameter | WHO MCLs | US EPA MCLs | EU MCLs | Katuba/Dry season | KT-2EPA | KT-3EPA | KT-4EPA | KT-5EPA | KT-6EPA | KT-7EPA | KT-8EPF | KT-9EPA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH value | 6.5-8.5 | 6.5-8.5* | 6.5-9.5** | N=4 | 6.5±0.4 | 6.5±0.4 | 6.8±0.1 | 6.5±0.4 | 5.5±1.1 | 5.5±0.6 | 7.3±0.7 | 7.2±0.5 |
| As (µg/L) | 10 | 10 | 10 | N=4 | - | - | - | - | 10.365±1.365 | - | - | - |
| Cd (µg/L) | 3 | 5 | 5 | N=4 | - | - | - | - | - | - | - | - |
| Cu (µg/L) | 2000 | 1300 | 2000 | N=4 | - | - | - | - | - | - | - | - |
| Fe (µg/L) | Na | 300* | 200** | N=4 | - | 256.653±62.236 | - | 216.972±224.584 | - | 394.7±122.471 | 349.221±159.406 | 460.444±153.423 |
| Mn (µg/L) | Na | 300* | 50** | N=4 | - | - | 53.785±40.25 | - | 251.321±115.067 | 84.057±27.141 | - | 195.993±142.276 |
| Ni (µg/L) | 70 | 100* | 20 | N=4 | - | - | - | - | - | - | - | - |
| Pb (µg/L) | 10 | 15 | 5 | N=4 | - | - | - | - | 5.629±4.433 | - | - | 5.664±5.049 |
| Zn (µg/L) | Na | 2000* | Na | N=4 | - | - | - | - | - | - | - | - |

| Parameter | WHO MCLs | US EPA MCLs | EU MCLs | Katuba/Rainy season | KT-2EPA | KT-3EPA | KT-4EPA | KT-5EPA | KT-6EPA | KT-7EPA | KT-8EPF | KT-9EPA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH value | 6.5-8.5 | 6.5-8.5* | 6.5-9.5** | N=6 | 9.2±1.1 | 9.7±1.2 | 6.8±0.1 | 6.5±0.4 | 7.8±1 | 8.7±1.3 | 10±1 | 7.2±0.5 |
| As (µg/L) | 10 | 10 | 10 | N=6 | - | - | - | - | 21.262±9.498 | - | 17.27±9.729 | - |
| Cd (µg/L) | 3 | 5 | 5 | N=6 | - | - | - | - | - | - | - | - |
| Cu (µg/L) | 2000 | 1300 | 2000 | N=6 | - | - | - | - | - | - | - | - |
| Fe (µg/L) | Na | 300* | 200** | N=6 | - | 256.653±62.236 | - | 216.972±224.584 | - | 1731.35±530.207 | 1555.17±703.982 | 460.444±153.423 |
| Mn (µg/L) | Na | 300* | 50** | N=6 | 53.454±43.483 | 75.92±20.132 | - | - | 95.57±63.309 | 140.164±117.508 | 179.589±117.134 | - |
| Ni (µg/L) | 70 | 100* | 20 | N=6 | - | - | - | - | - | - | - | - |
| Pb (µg/L) | 10 | 15 | 5 | N=6 | - | - | - | - | 5.629±4.433 | 5.938±7.172 | - | 5.664±5.049 |
| Zn (µg/L) | Na | 2000* | Na | N=6 | - | - | - | - | - | - | - | - |

| Parameter | WHO | US EPA | EU | Kenya/Rainy season | KN-1EPA | KN-2EPA | KN-3EPA | KN-4EPA | KN-5EPA | KN-6EPA | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH value | 6.5-8.5 | 6.5-8.5* | 6.5-9.5** | N=4 | 7.2±0.6 | 8.2±0.2 | 7.5±0.5 | 5.6±0.2 | 8±0 | 6±0.2 | - | - |
| As (µg/L) | 10 | 10 | 10 | N=4 | - | - | - | - | - | - | - | - |
| Cd (µg/L) | 3 | 5 | 5 | N=4 | - | - | - | - | - | 379.579±6.825 | - | - |
| Cu (µg/L) | 2000 | 1300 | 2000 | N=4 | - | - | - | - | - | 9655.88±138.147 | - | - |
| Fe (µg/L) | Na | 300* | 200** | N=4 | - | - | 255.451±210.469 | - | - | 328.145±129.858 | - | - |
| Mn (µg/L) | Na | 300* | 50** | N=4 | 81.062±92.23 | 179.809±93.292 | - | - | - | 1368.23±30.852 | - | - |
| Ni (µg/L) | 70 | 100* | 20 | N=4 | - | - | - | - | - | 101.733±9.594 | - | - |
| Pb (µg/L) | 10 | 15 | 5 | N=4 | - | **13.58**±2.277 | - | - | - | 10.218±6.029 | - | - |
| Zn (µg/L) | Na | 2000* | Na | N=4 | - | - | - | - | - | 48976.54±108.173 | - | - |

| Parameter | WHO MCLs | US EPA MCLs | EU MCLs | Katuba/Dry season | KT-10EPA | KT-11EPA | KT-12EPA | KT-13EPA | KT-14EPA | KT-15EPA | KT-16EPA | KT-17EPA | KT-18EPA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH value | 6.5-8.5 | 6.5-8.5* | 6.5-9.5** | N=4 | 6.0±0 | 5.3±0.5 | 6.8±0.1 | 5.6±0.6 | 5.8±0.2 | 5.9±0.1 | 6.6±0.1 | 6.5±0.3 | 6.8±0 |
| As (µg/L) | 10 | 10 | 10 | N=4 | - | - | - | - | 16.173±9.762 | - | - | - | - |
| Cd (µg/L) | 3 | 5 | 5 | N=4 | - | 7.04±0.085 | - | - | - | - | - | - | - |
| Cu (µg/L) | 2000 | 1300 | 2000 | N=4 | - | - | - | - | - | - | - | - | - |
| Fe (µg/L) | Na | 300* | 200** | N=4 | 3297.18±2163.42 | 1617.55±50.777 | 357.343±477.535 | - | 346.442±54.323 | - | 347.381±397.425 | 1072±1416.34 | 2086±607.072 |
| Mn (µg/L) | Na | 300* | 50** | N=4 | 1459.96±163.292 | - | - | 117.125±41.613 | 79.983±34.032 | 301.305± 144.296 | - | 956.83±1119.134 | 271.732±84.039 |
| Ni (µg/L) | 70 | 100* | 20 | N=4 | - | | - | - | - | - | - | - | - |

**Table 2.** Contd.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pb (µg/L) | 10 | 15 | 5 | N=4 | - | - | - | - | - | 5.66± 0.713 | 5.262± 2.178 | - | 11.635± 3.703 |
| Zn (µg/L) | Na | 2000* | Na | N=4 | - | - | - | - | - | - | - | - | - |
| pH value | 6.5-8.5 | 6.5-8.5* | 6.5-9.5** | N=6 | 8.7±2.0 | 9.1±1.6 | 6.8±0.1 | 7.8±1 | 9.1±0.8 | 8.9±1.5 | 9.4±1.2 | 9.2±0.9 | 9.9±1.3 |
| As (µg/L) | 10 | 10 | 10 | N=6 | - | - | - | - | 16.173±9.762 | - | - | - | - |
| Cd (µg/L) | 3 | 5 | 5 | N=6 | - | 29.416±8.112 | - | - | - | - | - | - | 11.825±7.296 |
| Cu (µg/L) | 2000 | 1300 | 2000 | N=6 | - | - | - | - | - | - | - | - | - |
| Fe (µg/L) | Na | 300* | 200** | N=6 | 3192.23±2780.95 | 643.793±494.312 | 357.343±477.535 | - | 346.442±54.323 | - | 347.381±397.425 | 290.67±196.147 | 1647.43±1200.18 |
| Mn (µg/L) | Na | 300* | 50** | N=6 | 1639.41±89.254 | 82.479±45.134 | - | 162.795±26.905 | 54.635±7.168 | 146.206±00.815 | - | 119.968± 18.603 | 263.515±41.062 |
| Ni (µg/L) | 70 | 100* | 20 | N=6 | - | - | - | - | - | 19.752± 4.399 | - | - | - |
| Pb (µg/L) | 10 | 15 | 5 | N=6 | - | - | - | - | - | 5.66± 0.713 | 7.761±3.687 | 6.342± 3.246 | 11.635±3.703 |
| Zn (µg/L) | Na | 2000* | Na | N=6 | - | - | - | - | - | - | - | - | - |

| Parameter | WHO | US EPA | EU | Kenya/Rainy season |
|---|---|---|---|---|
| pH value | 6.5-8.5 | 6.5-8.5* | 6.5-9.5** | N=4 |
| As (µg/L) | 10 | 10 | 10 | N=4 |
| Cd (µg/L) | 3 | 5 | 5 | N=4 |
| Cu (µg/L) | 2000 | 1300 | 2000 | N=4 |
| Fe (µg/L) | Na | 300* | 200** | N=4 |
| Mn (µg/L) | Na | 300* | 50** | N=4 |
| Ni (µg/L) | 70 | 100* | 20 | N=4 |
| Pb (µg/L) | 10 | 15 | 5 | N=4 |
| Zn (µg/L) | Na | 2000* | Na | N=4 |

*United States Environmental Protection Agency 2018 Drinking Water Health Advisories (2018); **: European Union Drinking Water Indicator Parameters (2020); EU (European Union) Revised Drinking Water Directive (2020); MCLs: acceptable maximum contaminant levels for drinking water; Na: no available data; USEPA: United States Environmental Protection Agency 2018 Drinking Water Standards and Health Advisories (2018); Splg: sampling; WHO: World Health Organization Guidelines for Drinking-Water Quality (2017).

highest mean concentrations of several potential toxic elements including As (21.262 µg/L), Ba (370.696), Cs (0.433 µg/L), Co (1,094.28 µg/L), Pb (19.752 µg/L), Mn (1,639.41 µg/L), Mo (1.815 µg/L), Sr (631.495 µg/L), Tl (0.246 µg/L), and V (8.828 µg/L) were recorded in groundwater samples collected from various hand-dug wells. During the same season in Kenya municipality, the highest mean concentrations of Cd (379.579 µg/L), Cu (9,655.88 µg/L), Ni (101.734 µg/L), U(8.237 µg/L), W (2.017 µg/L), and Zn (48,976.54 µg/L) were found in samples from one hand-dug well (KN-6EPA). In dry season, only Cr, Fe, and Ni had the highest concentrations (3.37, 3,297.19, and 16.408 µg/L, respectively) in samples collected from three different spade-sunk wells in Katuba municipality. Elevated mean trace element concentrations in Katuba and Kenya groundwater are higher than the acceptable limits set for drinking water by WHO (2017), US EPA (2018) and/or EU (2020) presented in Table 2. The elevated metal concentrations might be due to atmospheric and soil pollutants taken away by rainwater and drained into the poorly protected hand-dug wells. Besides, the spade-sunk wells were very shallow (2- to 10-m deep), not well covered and could be easily reached by rainout and dust than the better protected drilled wells which were 15- to 60-m deep. Also, the Katuba and Kenya municipalities are close to the Lubumbashi slag heap that contains several potentially toxic metals and might permanently contaminate the surrounding soils, surface water and groundwater with those metals through rainwater drainage into the surface water and the water table. The high metal contamination of those wells might also be due to metal polluted rivers that flow near both municipalities as an interaction between surface and groundwater

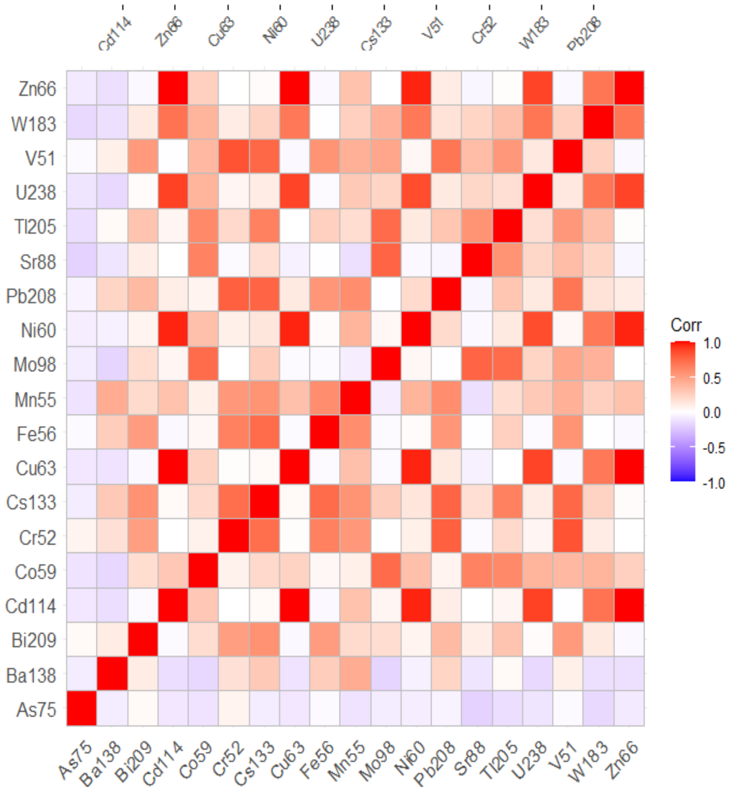

**Figure 2.** Evolution and correlation of nineteen trace elements recorded on the same vein in well waters in Katuba and Kenya municipalities of Lubumbashi city during the period of May 2016 March 2017.

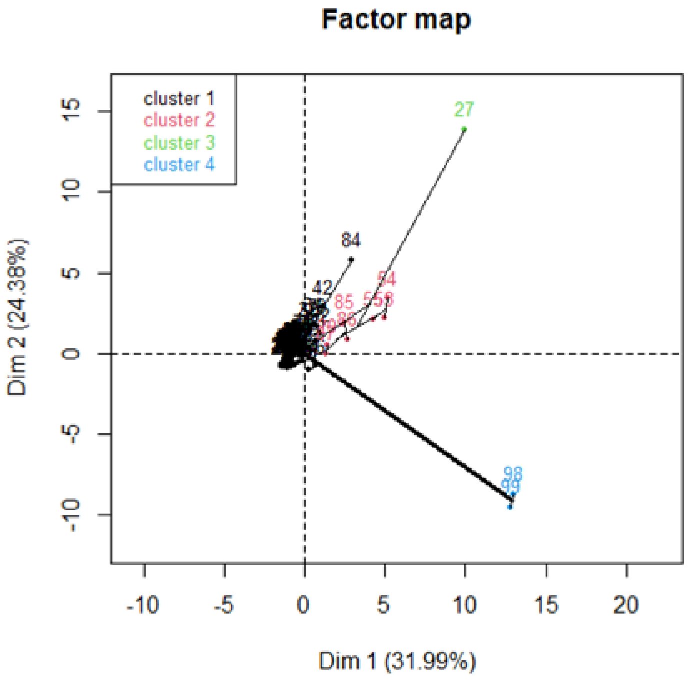

**Figure 3.** Graphical representation in classes of toxic trace elements in well waters in Katuba and Kenya municipalities of Lubumbashi city for the period of May 2016 to March 2017.

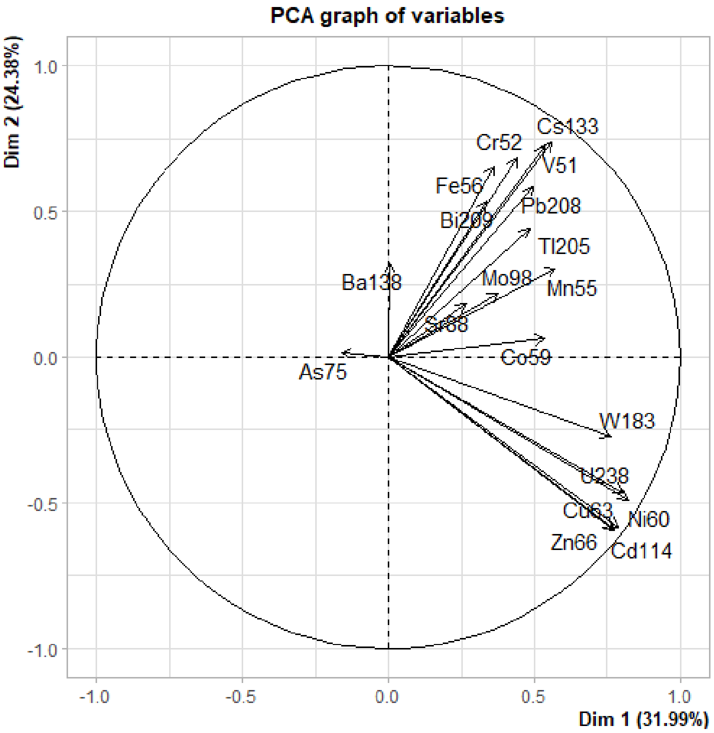

**Figure 4.** ACP (Principal Component Analysis) representation of potentially toxic trace elements in well waters in Katuba and Kenya municipalities of Lubumbashi city for the period of May 2016 to March 2017.

could not be excluded. Numerous researchers have pointed out trace metal contamination of Lubumbashi soils (Kashimbo, 2016; Muhaya et al., 2016), rivers (Muhaya et al., 2017a, b) and groundwater (Muhaya et al., 2021), and adverse human health effects of trace metals in Lubumbashi (Mukendi et al., 2018; Obadia et al., 2018; Cham et al., 2020; Malamba-Lez et al., 2021; Mudekereza et al., 2021; Ngoy et al., 2021) mainly due to anthropogenic activities including artisanal and industrial mining, ore processing, and waste disposal and mismanagement.

The acceptable drinking water maximum contaminant levels (MCLs) set by WHO (2017), USEPA (2018), and EU (2020) are shown in Table 3. As, Cd and Pb levels of groundwater, respectively exceeded the WHO, USEPA and EU drinking water MCLs in 12.22, 8.89 and 7.78% of the groundwater samples from Katuba municipality, and Cd, Pb, Ni and Cu exceeded the MCLs in 16.67, 25, 16.67 and 16.67% of the well water samples from Kenya municipality.

Also, Mn and Fe levels of groundwater above the EU (drinking water) indicator parameters of 50 and 200 µg/L were, respectively noted in 61.11 and 45% of the groundwater samples from Katuba municipality with the highest levels of 2,229.49 and 6,392.32 µg/L, respectively in 58.33 and 33.33% of the groundwater samples from Kenya municipality with the highest levels of 1,390.05 and 419.968 µg/L, respectively. Mn, Fe and Zn levels of groundwater exceeding the USEPA drinking water health advisories of 300, 300 and 2,000 µg/L (USEPA, 2018) were, respectively recorded in 11.11, 37.78 and 1.11% of the groundwater samples from Katuba municipality with the highest levels of 3,326.86, 13,392.65 and 2,214.14 µg/L, respectively in 16.67, 25 and 16.67% of the samples from Kenya municipality with the highest levels of 1,390.05, 419.968 and 49,053.03 µg/L.

The recorded concentrations of Ba, Cr, Tl and U in groundwater in Katuba and Kenya municipalities were far below the drinking water MCLs set for those elements by the WHO (2017), USEPA (2018) or EU (2020) as the highest concentrations of those metals in groundwater in both Katuba and Kenya municipalities were respectively 509.052 µg/L and 167.746 µg/L for Ba, 9.119 µg/L and 0.952 µg/L for Cr, 0.303 µg/L and 0.065 µg/L for Tl, and 2.081 µg/L and 8.839 µg/L for U (Table 1). The highest concentrations of Mo (5.857 µg/L) and Sr (672.2 µg/L) noted in groundwater in this study were below the USEPA (2018) drinking water health indicators of 40 µg/L and 4,000 µg/L, respectively. The Mo and Sr as well as the other trace metal levels of groundwater in both municipalities were probably associated with anthropogenic contamination but geogenic sources might

**Table 3.** WHO, USEPA, and EU drinking water optimum pH range values and acceptable maximum contaminant levels (µg/L).

| WHO, USEPA & EU MCLs | Optimum pH values | Sr88 (µg/L) | Mo98 (µg/L) | Cd114 (µg/L) | Cs133 (µg/L) | Ba138 (µg/L) | W183 (µg/L) | Tl205 (µg/L) | Pb208 (µg/L) | Bi209 (µg/L) | U238 (µg/L) | V51 (µg/L) | Cr52 (µg/L) | Mn55 (µg/L) | Fe56 (µg/L) | Co59 (µg/L) | Ni60 (µg/L) | Cu63 (µg/L) | Zn66 (µg/L) | As75 (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WHO | 6.5-8.5 | Na | Na | 3 | Na | 1,300 | Na | Na | 10 | Na | 30 | Na | 50 | Na | Na | Na | 70 | 2,000 | Na | 10 |
| USEPA | 6.5-8.5* | 4,000* | 40* | 5 | Na | 2,000 | Na | 2 | 15 | Na | 30 | Na | 100 | 300* | 300* | Na | 100* | 1,300 | 2,000* | 10 |
| EU | 6.5-9.5** | Na | Na | 5 | Na | Na | Na | Na | 5 | Na | 30 | Na | 25 | 50** | 200** | Na | 20 | 2,000 | Na | 10 |

*:United States Environmental Protection Agency 2018 Drinking Water Health Advisories (2018); **: European Union Drinking Water Indicator Parameters (2020); EU (European Union) Revised Drinking Water Directive (2020); MCLs: acceptable maximum contaminant levels for drinking water; Na: no available data; USEPA: United States Environmental Protection Agency 2018 Drinking Water Standards and Health Advisories (2018); WHO: World Health Organization Guidelines for Drinking-Water Quality (2017).

not be excluded. Harkness et al. (2017) reported that groundwater typically has low Mo (<2 µg/L) and that elevated levels are associated with anthropogenic contamination, although geogenic sources have been reported.

Sr concentrations in Katuba and Kenya groundwater wells were in the range of low concentrations (<2,000 µg/L) reported for untreated groundwater wells used for public supply in the United States (Water Resources, 2021). The report indicated that about 2.3% of drinking-water wells in the United States have concentrations of Sr at levels that present a potential human health risk, and that these wells provide water for an estimated 2.3 million people. According to the same source, concentrations in drinking-water wells that exceeded the health-based screening level of 4,000 µg/L largely occurred in carbonate-rock aquifers and in areas where upwelling brines mix with potable groundwater. Elevated Sr concentrations can adversely affect bone development and mineralization. Conventional water treatment processes, such as coagulation/filtration, are largely ineffective at removing Sr from drinking water. However, water-softening treatments such as lime-soda ash or cation-exchange water softners designed to reduce calcium concentrations also can decrease Sr concentrations (Water Resources, 2021). High Ba concentrations in groundwater are generally associated with very low $SO_4$ concentrations (<5 mg/L) resulting from sulfate reduction, suggesting a solubility control of Ba through barite ($BaSO_4$) precipitation (Bondu et al., 2020).

Heavy metals always evolve together. The presence of one indicates the presence of one or more others. Thus, thanks to the statistical analysis, we found the presence of metals which evolve together and which are predominantly found in the well water of Katuba and Kenya municipalities (Figure 2). The correlation is marked by the red color. The more bright-red is the color, the greater the correlation between the metals from 50 to 100%, the less vivid it is from 1 to 50% and the threshold is above or moderately above the WHO (2017) standards for drinking water: Cd and Cu, Cd and Ni, Cd and U, Cd and W, and Cd and Zn. Then, there is a weak correlation and the threshold is below 50% of the drinking water maximum concentration limits set by the WHO (2017) for the elements. It is white when the correlation is zero, that is to say 0%, and purple when the correlation is less than 0%.

The positively correlated variables are grouped together (Figure 3). Negatively correlated variables are positioned on opposite sides of the origin of the graph (opposite quadrants). The distance between the variables and the origin measures the quality of representation of the variables. Many of those trace elements, such as As, Cd, Cu, Fe, Mn, Ni, Pb and Zn in some wells had concentrations much higher than the WHO (2017), US EPA (2018) and EU (2020) permissible MCLs for drinking water. Variables that were far away from the origin are well represented by the principal component analysis (PCA) (Figure 4).

With PCA, we found that 31.9% of the trace elements were on the positive side of the origin of the graph and many of them tended to touch the edge of the quadrant. For these elements, the more the values of cos2 were used to estimate the quality of the representation, the closer a variable was to the correlation circle, and the better its representation on the PCA map (and it was more important for interpreting the principal components in consideration). The variables which were close to the center of the graph were less important for the first components.

The General Linear Model (GLM) allowed us to understand the affinities or correlations between trace elements and their environment, and between trace elements and the seasons. From this analysis, it was noted that all the trace elements were subject to seasonal influence in both Katuba and Kenya municipalities. Although the impact might be less significant when considering the 5% threshold of water pollution impact on human health, the concentrations of these trace elements could have adverse health effects following bioaccumulation and bio-amplification of some of the metals by the consumers of that water.

During the dry season, As, Pb, Cu, Cd, and Zn concentrations in water from many wells in both Katuba and Kenya municipalities were higher than the acceptable maximum concentration limits set for drinking water by WHO (2017), USEPA (2018) and EU (2020). During the rainy season, the concentrations of trace elements increased, probably due to the rainwater infiltration into the water table, the leaching of the topsoil with erosion as this leaching water ended up in poorly protected hand-dug wells and even in the better protected ones (the drilled wells).

The highest Bi, Cd, Co, Cu, Pb, Mn, Mo, Ni, Sr, U and Zn concentrations noted in groundwater in this study exceeded those of 0.049, 52.585, 54.026, 634.8, 38.162, 1,242.68, 0.498, 64.647, 290.98, 2.492 and 9,900.72 µg/L, respectively recorded in groundwater in the Lubumbashi, Kampemba and Kamalondo municipalities of Lubumbashi city (Muhaya et al., 2021). On the contrary, the highest levels of As (65.458 µg/L), Ba (740.24 µg/L), Cs (1.431 µg/L), Cr (10.014 µg/L), Fe (17,325.98 µg/L), Tl (0.409 µg/L), W (35.31 µg/L), and V (27.363 µg/L) reported for groundwater in Lubumbashi, Kampemba and Kamalondo municipalities (Muhaya et al., 2021) were above those respectively found in groundwater in this study. Pb levels of groundwater in the current study were much lower than those (110 - 490 µg/L, mean level: 270 µg/L) reported by Olusola et al. (2017) for twenty-one groundwater wells in Southwestern Nigeria.

The highest mean As and U levels of groundwater wells in Katuba and Kenya communes were lower than those estimated by Communications and Publishing (2021) in a new U.S. Geological Survey study. The study provided an updated, statewise estimate of high levels of naturally occurring As and U in private well water across the state of Connecticut and indicated that 3.9% of private wells across that state contained water with As at concentrations higher than the U.S. Environmental Protection Agency's acceptable maximum level (10 µg/L) for public drinking-water supplies. That research also projected that 4.7% of private wells in the state had U concentrations higher than the EPA's standard of 30 µg/L. Except the highest mean concentration of Ni (101.73 µg/L) noted in one hand-dug well, mean Ni concentrations recorded in groundwater wells in this study were far lower than those (55.95 - 88.09 µg/L) reported by Ghobadi and Jahangard (2017) for groundwater resources of Asadabad plain in Iran. However, mean Cr and Mn concentrations reported by these authors were much lower than those found in some groundwater wells in the current study. Concentrations of As, Cd, Cu, Fe, Mn, Ni, Pb and

Zn in some groundwater wells in this study were also higher than those reported by Tomasek et al. (2022) for groundwater wells, springs and tap water systems around Mount Meru, Arusha, Tanzania. However, the concentrations of U and Mo recorded in groundwater wells in this study were much lower than those (>30 and >70 µg/L, respectively) reported by these researchers.

Of the nineteen trace elements found in groundwater in this study, only Co, Cr (Cr III), Cu, Fe, Mn, Mo and Zn are essential for human body and they play an important biological role at low concentrations in the body (Boyers, 2018; U.S. Geological Survey, 2018). In the case of high levels or deficiency of these essential substances, adverse health effects may occur and induce some dysfunction of the body (Leyssens et al., 2017; U.S. Geological Survey, 2018; Guo et al., 2021). The other trace elements noted in this study have no known biological importance for human body and most of them are toxic to humans, even at low concentrations. Tl, Cd, As, Pb, U, Cr (Cr VI) and Ni are those which have the most deleterious impacts on human health, even at very low concentrations (U.S. Geological Survey, 2018). Numerous researchers have reported on adverse effects on human health due to exposure to some of these trace elements in drinking water. This is the case of exposure to As (Smith et al., 2018; U.S. Geological Survey, 2018; Ramadan and Haruna, 2019; Khandare et al., 2020; Malamba-Lez et al., 2021), Cd (Browar et al., 2018; U.S. Geological Survey, 2018; Ramadan and Haruna, 2019; Khandare et al., 2020; Malamba-Lez et al., 2021), Cr VI (U.S. Geological Survey, 2018; Ramadan and Haruna, 2019; Khandare et al., 2020; Malamba-Lez et al., 2021), Pb (Browar et al., 2018; Jain, 2018; U.S. Geological Survey 2018; Khandare et al., 2020; Malamba-Lez et al., 2021), Ni ( U.S. Geological Survey, 2018; Malamba-Lez et al., 2021), Tl (Osorio-Rico et al., 2017; Jain, 2018; U.S. Geological Survey, 2018; Malamba-Lez et al., 2021; Nuvolone et al., 2021), U (Corlin et al., 2016; Li et al., 2021; Malamba-Lez et al., 2021) and V (Ngwa et al., 2017; Sengupta and Dutta, 2018).

Although no drinking water standards have been set for Bi, Cs, Sr, Tl, V, and W by WHO (2017) and EU (2020), these trace elements are known to be toxic to humans (Jain, 2018; Al-Khatib et al., 2019; Khandare et al., 2020; Roshandel et al., 2020; Mirzaee et al., 2021; Li et al., 2021; Malamba-Lez et al., 2021). The highest concentrations of those metals recorded in groundwater in Katuba and Kenya municipalities were, respectively 0.096 and 0.043 µg/L for Bi, 1.311 and 0.162 µg/L for Cs, 672.2 and 312.915 µg/L for Sr, 0.303 and 0.065 µg/L for Tl, 9.735 and 1.364 µg/L for V, and 1.432 and 2.538 µg/L for W (Table 1). The levels of these trace elements were still low but their adverse health effects to people who drink the contaminated water could not be excluded as these metals might bioaccumulate and biomagnify in some human organs, such as the liver and kidneys.

Mean groundwater pH values in Katuba municipality ranged from 5.3 to 7.3 in dry season with 38.9% of the water samples having mean pH values below the WHO (2017) drinking water pH optimum range values of 6.5 to 8.5, meaning that 38.9% of the water samples were acidic with mean pH values ranging from 5.3 to 6.0. In rainy season, mean groundwater pH values ranged from 7.7 to 10.1 with 88.9% of the water samples which were too alkaline (mean pH values ranging from 8.7 to 10.1) in Katuba municipality and from 5.6 to 8.2 with 11.1% of the groundwater samples which were acidic (mean pH values of 5.6 and 6.0) in Kenya municipality. Groundwater from many of the sampled wells in both municipalities being acidic or very alkaline, its physicochemical quality was not suitable for water intended to human consumption. Acidic water makes dissolved trace metals dissolved more available for bioaccumulation. The alkaline conditions (very high pH) of groundwater in many wells in Lubumbashi city might probably be due to the roach hosting the groundwater as the roach is made of dolomite (calcium and magnesium carbonate) which is very rich in calcium. During rainy season in Lubumbashi city (from November to March), the level of groundwater goes up and brings with it deep alkaline solutions which make the wellwater alkaline to very alkaline. It has been reported that if the soil or bedrock around groundwater sources includes carbonate, bicarbonate, or hydroxide compounds, those materials get dissolved and travel with the water, and these mineral deposits also increase the alkalinity of the water (Eldorado Marketing, 2021). According to this source, highly alkaline water can smell and taste unpleasant too, and high levels of pH in water can indicate that pollutants or unwanted chemicals are present; and those substances can be harmful to human health.

The trace metal contamination of groundwater wells in the Katuba and Kenya municipalities of Lubumbashi city might be from natural and anthropogenic origins, mainly from abandoned and ongoing mining and ore processing activities in the city and its neighborhood. It might also be partially from infiltration of surface water and runoff of rainwater through metal contaminated soils to the groundwater during rainy season, as well as from atmospheric fallout during dry season. The studied hand-dug wells were not well protected and the tools used for withdrawing water from those wells were open and left in the air, thus facilitating contamination of the wells with dust and rainwater. Trace element contamination of the groundwater might also partially result from an interconnexion between surface water and groundwater. Indeed, water and sediments of the rivers that flow through Lubumbashi city (Muhaya et al., 2017a, b, c, d) and the city soil (Kashimbo, 2016; Muhaya et al., 2016) have been reported to be highly contaminated with various trace elements.

Groundwater in both Katuba and Kenya municipalities might be a source of chronic exposure to toxic metals and metalloids that the body does not require, and to high levels of some essential metals including Co, Cu, Fe, Mn and Zn.

## Conclusions

Trace metal levels and pH of groundwater in Katuba and Kenya municipalities of Lubumbashi city were investigated in two hundred and four groundwater samples collected from twenty hand-dug wells and four drilled wells in May and October 2016 (dry season) and November 2016 to March 2017 (rainy season). Recorded mean pH values and levels of nineteen trace elements of the groundwater samples, including strontium, molybdenum, cadmium, cesium, barium, tungsten, thallium, lead, bismuth, uranium, vanadium, chromium, manganese, iron, cobalt, nickel, copper, zinc and arsenic, were compared to the drinking water maximum contaminant levels set by the World Health Organization, the United States Environmental Protection Agency and the European Union. Water of many wells in both municipalities was acidic or very alkaline and highly contaminated with arsenic, cadmium, lead, manganese, iron, nickel, zinc and other trace metals. This implies that the groundwater is unsuitable for human consumption and presents a high risk for the health of people who use it to meet their drinking water needs.

It is recommended that further research be carried out to compare seasonal variation of metal contamination of the groundwater. The authors also suggest that the municipal authority forbids the consumption of water from very contaminated wells and that provincial and national governments enhance financing and better management of REGIDESO (the Congolese Water Supply Company) in order to provide all Lubumbashi city inhabitants with safe drinking water, and strictly implement the Congolese Mining Regulations for pollution reduction, and better environmental and public health protection.

## CONFLICT OF INTERESTS

The authors have no conflict of interests to be declared.

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# Assessing the role of community members in waste disposal in Lilongwe - Capital City of Malawi

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**The study assessed the roles of community members on community level waste disposal in the city of Lilongwe in Malawi. The communities are basically low income and densely populated where a lot of people depend on small scale businesses. The study used a mixed methods approach. The target population was the community members of eighteen years of age and above. The sample size was 40 and the participants were selected using simple random sampling. Likert scale was used which helped in weighing forty questionnaires which were administered to the respondents. The data collected was analyzed using content analysis and statistical package for social science (SPSS). The results from the study show that community members of Lilongwe City have to work together and embrace different effective skills in mitigating poor waste disposal. In total 63% of the respondents indicated that the community lacked waste management skills while 93% of the respondents stated that an increase in the population leads to an increase in the waste produced in the communities accordingly. A total of 65% indicated that members of the community were not willing to pay for waste management in their areas while 70% attributed the waste management responsibility to the government. The study recommends that the stakeholders should plan for awareness programs; community members should identify their capabilities to turn waste into briquettes which they can use for cooking and selling to generate income; the government should provide loans to disadvantaged communities for small scale businesses in waste re-cycling and that the government should provide free waste collection services to the underprivileged urban communities.**

**Key words:** Waste, disposal, communities, garbage.

## INTRODUCTION

According to Swedberg (2014), disposal is process of managing and getting rid of products that turn into trash or garbage. Wastes can be solid, liquid and gas. These wastes are disposed or managed in different ways like; some burn the wastes, some construct pit holes and dispose them in the pit holes, others dump the wastes in water resources.

The world has been affected by the poor waste disposal and management. Due to the problem, Chavez (2009) and Damian (2017) indicated waste generation rates are rising and in 2009 the world's cities generated 2.01 billion tons of solid wastes, resulting to a footprint of 0.74 kg/person a day. The study adds that, with rapid population growth and urbanization, the annual waste

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generation is expected to increase by 75% from levels of 3.40 billion tons in 2050. Compared to those in developed nations, residents in developing countries especially the urban poor are more severely impacted by unsustainably managed wastes. In low-income countries, over 90% of waste is often disposed in unregulated dumps or openly burned, which results to serious health, safety and environmental problems. Poorly managed wastes serve as breeding ground of vectors, contributing to global climate change.

Khonje (2012) conducted a pilot study on the case of Malawi, more especially in the city of Lilongwe. The city is one of the largest cities in the country with a population of 670,000 growing at a rate of 4.3 per year. With the increase in population in Lilongwe, the rate of wastes also is increasing. A study done by the Monitoring and Evaluation Office of Community Servings (2010) indicates that the city generates 109 tons of solid wastes per day; a total of 15% is derived from industries, 25% from commercial areas, 20% from hospitals and 40% from residential areas. The study indicates that the city has been hit by a sanitation problem in both solid and liquid waste management. Waste disposal has also affected many Malawian urban communities around Lilongwe City. People of the communities also have their own ways of dumping wastes, for instance some use pit latrines and others dispose the wastes in water sources found in the communities like, streams, dams and roadsides.

## Problem statement

Lilongwe as a capital city of Malawi is made up of the communities which are highly affected by poor waste disposal. People dump wastes without considering the health hazards, for instance, some dump the wastes in water sources. Wastes like diapers are commonly dumped in streams, swamps and rivers near the community. The end result of this improper waste disposal has led to the communities in the city being un-hygienic. People suffer from both water borne and vector borne diseases. These diseases make a lot of people fail to focus on productive activities which could help them generate income, since some are busy taking care of the patients suffering from these diseases whilst others are becoming victims of water and vector borne diseases. Therefore, the study aims at assessing roles of community members on community level waste disposal in Lilongwe City.

## Overall objective

The overall objective of the study is to assess the roles of community members on community level waste disposal in Lilongwe City in Malawi.

## Specific objectives

(a) To identify the causes of poor waste disposal in the communities of Lilongwe City.
(b) To assess the community perception towards poor waste disposal in Lilongwe City.
(c) To assess how poor wastes disposal affects the communities in Lilongwe City.
(d) To identify the roles of community members in mitigating the poor waste disposal in Lilongwe City

## LITERATURE REVIEW

### Causes of poor waste disposal in the community

Barre (2014) in her study titled ‘Waste Market in Urban Malawi’ indicated that most community members lack waste management skills. This is to say that most of the people in Malawian society do not know waste management skills such as reduce, reuse and recycle. For example, most of the plastic bottles are recyclable materials, but most people in Malawi do not have the skills on how they can recycle the bottles and, in the end, they throw the bottles irresponsibly, thereby putting more communities at risk due to improper management of the wastes.

A study done by the National Statistic Office of Republic of Malawi (2008), proved that since the overall level of waste production is positively correlated with the population of country, an increase in population automatically implies an increase in the amount of overall waste. There are official waste disposal sites that people may use to get rid of the large amounts of waste. However, there is a small but still significant amount of people who just dump their trash illegally in the woods and water sources. This problem is increasing with an increase in population since more waste is produced, and thus the probability for more waste dumping is likely to increase.

Most of the people avoid paying fees at waste management sites. Busa (2009) supports this claim more especially in cases of residents. In various parts of communities, disposing wastes illegally is on the rise. This habit is associated with the avoidance of paying disposal fees at waste management sites. The people who engage in such acts are of the opinion that the prevailing waste collection fees are excessive. Therefore, instead of following the rightful channels for disposing waste or paying third party waste pick up services, they illegally dispose the waste in remote locations. Some third-party waste pick-up services have also gotten into the habit of dumping waste on illegal dumpsites to avoid paying the disposal fees.

Busa (2009) suggested that poor waste disposal is caused by ignorance, where most people do not understand and are not very much aware of the consequences of poor dumping. Busa (2009) argued that regardless, some individuals simply do not see the need for recycling waste or follow the proper waste disposal channel and therefore go to highly unusual lengths to dispose waste illegally. Some people are simply too lazy to bring their trash to official dumping sites. A fraction of the society also does not care about the poor dumping problem and its consequences. They do so by completely avoiding prosecution and detection, which means that they do know the act, is unlawful. As a matter of fact, most of the items illegally disposed of, such as old appliances, white goods and furniture can be easily recycled or even reused. So, it can be suggested that most of the people engaging in acts of poor waste disposal simply do not understand the importance of reuse or the concept of recycling wastes.

## Community's perception towards poor waste disposal

Poor waste disposal is often regarded as a minor issue by many people; hence, Trevor (2017) concluded that this is due to social norms a particular community may possess. Humans are known to be influenced quite a lot by the people they mostly interact with. Some community members consider poor waste disposal as not a big deal or they actively contribute to it. They are also more likely to see it as an appropriate method of getting rid of trash. Thus, social norms and the behavior of close people play an essential role in how likely people are to accept or reject the idea of poor waste.

Neidell et al. (2019) argue that people in the community believe that dumping of wastes improperly is the only way of making the soil fertile. Carlsess (2007) also adds some people are of the idea that wastes make the soil fertile and large piles of wastes are dumped on land to make the soil fertile. On the same note, some are of the view that dumping wastes anyhow creates manure, hence, most of the community people dump wastes poorly to obtain large amount of manure more especially compost manure for their fields.

Lilongwe City Council (2015) is of the view that people believe that, it is the government's duty to take care of the disposed wastes. They dispose wastes poorly hoping that the government will one day appear to clean up the large piles of wastes. For instance, this is the case with most Malawian urban markets where the market users dump large piles of wastes on land or on the dumping site, hoping that the government through the city council will come and clean up the mess.

Williams et al. (2017) in an article titled 'Preliminary study of wastes management' suggested that, people believe that waste disposal is something they do not have control over and that it is only nature that has control over the wastes, hence, they dispose wastes freely, believing that nature will do the controlling or the mitigation of the wastes for instance, the case with diapers. Many people dispose them in swamps, streams, rivers and wells because they believe managing them is out of their hands, so they leave it in the hands of nature to do the magic. That is why we see a lot of diapers in water sources waiting to be washed away by running rain water in the rainy season.

## Effects of poor waste disposal at the community

Williams (2005) in his study titled 'waste treatment and disposal'' adds that soil contamination plays a bigger role in affecting the community. Ideally it is people's desire that plastic, glass, metal and paper waste end up at a recycling facility. It then returns to the people as a renewable product. But the reality is entirely different. Contamination occurs by spilling and burying hazardous components in the soil. For example, when a plastic water bottle is incorrectly sent to a landfill, or left, at any other place, to be absorbed by the soil: plastic water bottles eventually break down to release a harmful component called, DIETHYLHYDROXYLAMINE (DEHA), a carcinogen which hurts the reproductive capabilities, causes liver dysfunction and weight loss issues. DEHA seeps into the surrounding areas of the soil and water bodies to harm the animal and plant life which depends on it. If the soil is contaminated with the DEHA component it means people's farm lands will be affected too.

Moreover, water contamination has proved to have a significant effect to the community. Kaseva (2004) and Abdoli (2020) concluded that, when wastes are disposed into water bodies, they are often dissolved by the water bodies, which in turn end up forming poisonous substances that may be harmful to living organisms including humans. This is also harmful to people's domestic activities especially those who use the water sources for cooking, washing and drinking. If the water is contaminated, the community can fail to use the water for domestic purposes.

Poor waste disposal impacts the climate in various ways. According to Beal (2012) and Brigham (2018), poor waste disposal disturbs the climate. When the wastes are disposed off improperly, they form harmful greenhouse gases which are created from decomposing waste. These rise up to the atmosphere and trap heat and adversely cause extreme weather reactions in the form of storms and typhoons. He also adds that the level of precipitation in the air can be destructed which in the end leads to acidic rains to severe hail storms and global warming.

According to Giusti (2009), poor waste disposal has an impact on human health. Salman (2021) states that when wastes are dumped everywhere either on land or water sources, this in turn creates a health hazard to people nearing the site where the wastes are dumped. For instance, wastes dumped in water sources can create a breeding ground for mosquitos and in the end, people living near the water source may suffer from malaria and other water borne diseases like cholera. Additionally, when people come in contact with waste, it causes skin irritation and blood infections. People also contract diseases from flies which are carriers of illnesses after breeding on solid waste.

## Roles played by community members in mitigating poor waste disposal in the community

Although poor waste disposal brings negative impact to the community, there are still some roles which community members can take up to mitigate the problem. According to Blantyre City Council (2013), organizing activities based on community clean up days can help to mitigate poor waste disposal. Community leaders can mobilize volunteer groups for each clean-up initiative and organize special clean-up days in which all members of the community participate twice a year or more often if possible. The council also indicated that clean up days have proven to be a tremendous initiative in the sense that people take full responsibility of their community and to dump wastes poorly becomes difficult, clean up days help to save resources where government financial resources like money is saved, which could be used to employ people to clean up the wastes, but the coming in of community members to clean up their own community stops the burden of losing money by the government through the city councils.

The problem of poor waste disposal basically is the process which involves people committing the act, so to stop the act the community members also have responsibility in reporting of illegal dumping. Wilson (2007) argued that it is possible for people in all communities and societies to stand up against poor waste dumping. The people that engage in poor waste dumping activities do so knowingly and are always on the lookout for places where the environmental regulatory authorities hardly patrol. Hence, if people can take the responsibility of reporting any witnessed act of illegal dumping, it can impressively help in curbing the activity. This strategy should also work towards establishing a special task force that includes the environmental, health, police, and public works departments to work in cooperation with the local people.

Study by Anjum (2013), towards the mitigation of poor waste disposal, stated that wastes can be managed if the environmental authorities, together with the local community chiefs, set lower disposal fees to encourage people to use the lawfully stipulated waste disposal systems. At the same time, the relevant regulatory bodies against poor dumping must set higher fines to discourage the habit. This can be done by re-defining the fines and punishments for poor dumping as well as the licensing and charge rates for dumping services. For instance, it has been cited that in some areas, it may be less costly to illegally dump and pay a fine than using legitimate waste disposal channels. By employing this strategy, societies can become less vulnerable to poor dumping of wastes.

A report produced by UNEP (2015), suggested that members of the community should be in a position to embrace the practice of Reducing, Recycling, Reusing (The 3R). Alexis and Mihelcic (2009) note that poor waste dumping is a result of a high level of overall waste production. The amount of waste generated can be reduced, then the outcome will be fewer, and there will be fewer scenarios of poor dumping of wastes. All people should always strive to reduce the amount of waste they generate by only purchasing and using essential products. Also, the promotion of recycling initiatives such as the opening up of various designated areas for free collection of used and obsolete appliances, furniture and other home products for recycling can reduce poor dumping. The practice of reusing, such as donating or selling used products that are still in good condition, should as well be encouraged to cut back on poor disposal of appliances, white goods and furniture.

## RESEARCH METHODOLOGY

The study used a descriptive research design which involved describing the events pertaining to community level waste disposal. The study used the mixed methods of research. This enabled the researchers to collect data and explain the phenomena more deeply and exhaustively. This was made possible because much information was gathered from respondents. The study employed quantitative design because it helped the researcher to come up with questionnaires which easily made quantifiable presentation of quantitative data. The research was conducted in Lilongwe City in Malawi.

### Study population

The study population targeted people of ages ranging from 18 years and above. In total 40 participants were sampled for the study.

### Sampling techniques

The study adopted simple random sampling because in random sampling, every person has an equal chance of being selected or picked in a sample. Taherdoost (2016) pin pointed that this sampling technique is used when the elements of population are spread over a wide geographical area. The population was divided into sub-groups called clusters on the basis of their geographical location.

### Sample size

A total of 40 participants were sampled for the study and given questionnaires to complete. All the 40 participants responded to the questionnaires.

**Table 1.** Gender of respondents.

| Gender of respondents | Frequency | Percentage |
|---|---|---|
| Male | 17 | 42.5 |
| Female | 23 | 57.5 |
| Total | 40 | 100.0 |

**Table 2.** Age of respondents.

| Age of respondents | Frequency | Percentage |
|---|---|---|
| 18-23 | 17 | 42.5 |
| 24-29 | 11 | 27.5 |
| 30-35 | 4 | 10.0 |
| 36-41 | 2 | 5.0 |
| ≥41 | 6 | 15.0 |
| Total | 40 | 100 |

## RESULTS AND DISCUSSION

### Response rate

The study achieved a 100% response rate.

### Gender of respondents

Gender was included in the research study because it is the only way of addressing gender imbalance in a country like Malawi, hence, the study gave room to both type of gender to avoid gender imbalance as indicated in Table 1.

Among 40 participants, 23 were females who participated in the research and 17 were males. This represents 57.5% for the females and 42.5% for the males, respectively. According to the results, it has clearly shown that more females responded to the questionnaires.

### Age of respondents

Age is an important aspect to consider in research because it helps the researcher to learn different knowledge and ideas from different age groups.

The age range of the respondents was divided into 18-23, 24-29, 30-35, 36-41 and 41 above. From Table 2, the researcher can conclude that 18-23 recorded the highest number of respondents which represents 42.5%; this also gives a clear reflection that more participants were youths in the age range of 18-23.

### Marital status of respondents

Marital status involves distinct relationships among people. It is imperative to consider marital status in research because it helps the researcher determine how different relationships view things around them.

The Figure 1 shows marital status of respondents which were grouped into single, married, divorced and widowed, hence the results show that, 27 participants were single, 8 were married, and 3 participants were widowed and 2 were divorced. This proves that more participants were single.

### To identify what causes poor waste disposal in the communities of Lilongwe City

#### *Most of the community members lack waste management skills*

Figure 2 indicates that most of the community members lack waste management skills in the city.

According to Figure 2, a total of 63% of respondents strongly agreed to the statement, 35% agreed to the statement and only 2% of the respondents were not sure about the statement. Based on the results, it has given a clear proof that indeed most community members lack waste management skills. Harrison (2013) argues that most community members lack waste management skills like reducing, reusing and recycling, these skills are not known by community members because they are not trained on how to use them, as a result the people end up dumping the wastes poorly.

#### *Increase in population which implies an increase in the amount of wastes to the community*

The study sought to establish the effect of the increase in the population on the volume of waste generated by the

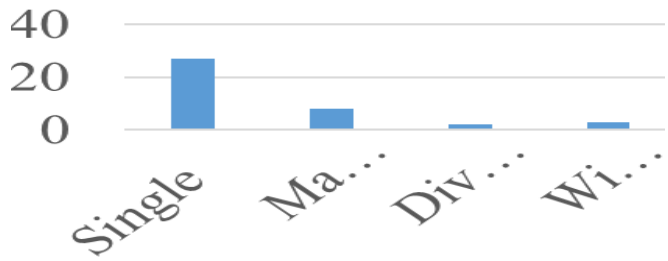

**Figure 1.** Marital status of respondents. Ma, married; Div, divorce; WI, widow.

**Figure 2.** Community members lack of waste management skills.

**Table 3.** Increase in population implies an increase in the amount of wastes to the community.

| Variable | Frequency | Percentage |
|---|---|---|
| Strongly agree | 22 | 55 |
| Agree | 15 | 37.5 |
| Not sure | 2 | 5 |
| Disagree | 1 | 2.5 |
| Total | 40 | 100 |

communities in Lilongwe City. The results are tabulated in Table 3.

Out of 40 participants 55% strongly agreed, 37.5% agreed, 5% were not sure and 2.5% disagreed to the statement. From the presentation, it gives a clear indication that indeed increase in population also implies an increase in the amounts of waste produced in the community. This is so because most of the respondents strongly agreed to the statement than those who disagreed to the statement. Assa (2018) argues that high population has a very big impact on the community in the sense that as the community is ever increasing, the demand for necessities also increases and some of these necessities need to be dumped after use and because of increase in population the demand for the dumping sites also become high and end up being filled up and the end result is that, people start to dump wastes recklessly. For instance, in India, parts of Gurugram are highly populated and due to high population, the level of poor waste disposal has also increased.

### *Most of the people avoid paying fees at waste management sites*

The study established that most people in the communities are not willing to pay for waste management services in Lilongwe City. The results are indicated in Figure 3.

Figure 3 demonstrates that, 40% of participants agreed,

**Figure 3.** People avoid paying at waste management sites.

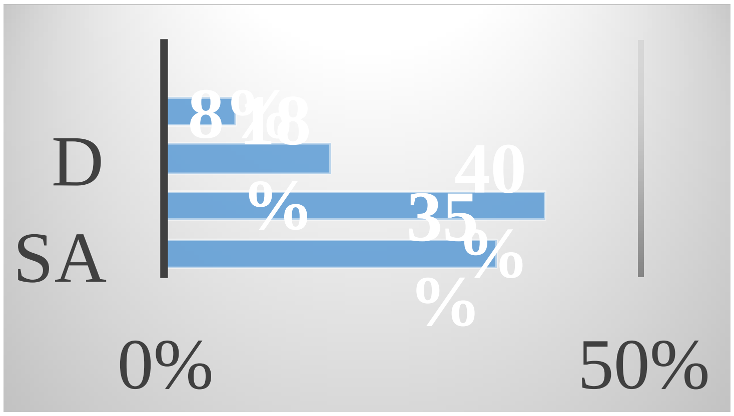

**Figure 4.** Community members ignorance in waste management.

25% of participants strongly agreed, 25% of participants were not sure about the statement, 5% disagreed and also 5% of the participants strongly disagreed. Based on the response from the participants it has shown that most of them were in favor of the statement. This arguably means that indeed most people avoid paying fees at waste management sites. Report done by Liongwe Water Board (2009), supports the statement that, most people avoid paying fees at wastes management sites because the fee rates are high which fails to give room to people, who are less privileged and such kind of people end up dumping the wastes poorly. For example, people have to pay 3500.00 kwacha per month for their wastes to be dumped at waste management site, but this case only favors people who are more privileged and the less privileged who always live on the same 3500.00 kwacha per day have nowhere to dump the wastes and hence ending up dumping the wastes anyhow.

### ***Community members are ignorant, hence this contributes to poor waste disposal***

It was further established that the ignorance of the communities in waste management led to poor waste disposal in Lilongwe City as shown in Figure 4.

Figure 4 proves that more of the participants are in favor of the statement which states that most community members are ignorant. Teka (2006) states that most of the people are illiterate, hence, they lack knowledge. Due to this reason, they see no problem in dumping wastes poorly; hence if level of people who lack knowledge about wastes is high, it simply means the overall amount of wastes in the community can also increase, this also shows that out of 100% of the response rate, 40% agreed, 35% strongly agreed, 18% disagreed and 8% strongly disagreed to the statement. The results for objective one which was to identify what causes poor waste disposal in the communities of Lilongwe City are summarized in Table 4

Statements in objective 1, which was the causes of poor waste disposal in the communities in Lilongwe City were all answered by the respondents and this basically provided a 100% of the response rate. Statements like most community members lack waste management skills, increase in population which implies an increase in the amounts of wastes to the community, most people avoid paying fees at wastes management sites and community members are ignorant hence contributing to poor wastes disposal shows the highest degree of strongly agree and agree. This means that statements like these are really

**Table 4.** Summary of objective 1.

| Causes of poor waste disposal to the community | SA | A | NS | D | SD |
|---|---|---|---|---|---|
| Most community members lack waste management skills | 25 | 14 | 1 | - | - |
| Increase in population which implies an increase in the amounts of wastes to the community | 22 | 15 | 2 | 1 | - |
| Most of the people avoid paying fees at waste management sites | 10 | 16 | 10 | 2 | 2 |
| Community members are ignorant hence this contributes to poor waste disposal. | 14 | 16 |  | 7 | 3 |
| Total | 71 | 61 | 13 | 10 | 5 |

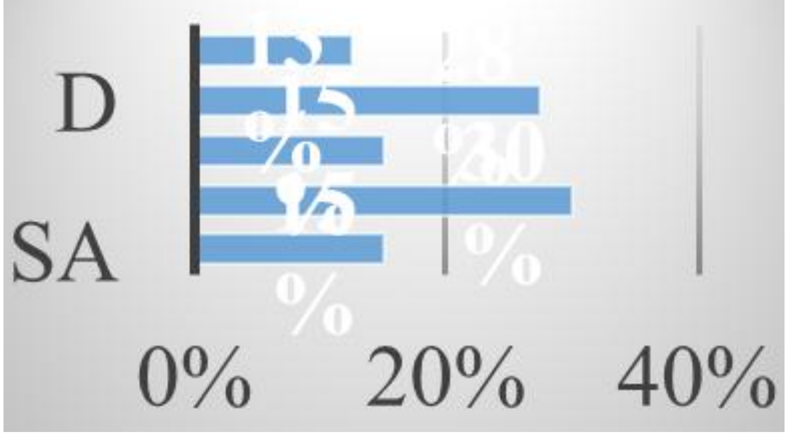

**Figure 5.** Community members' beliefs towards waste disposal as a way of life.

**Figure 6.** Community members' belief that dumping of wastes is the only way of making soil fertile.

the causes of poor wastes disposal to the community and it is imperative that community members become aware of the causes in order for them to avoid practicing these poor habits (Figure 6).

### People's perception towards waste disposal in Lilongwe City

The study sought to establish the community member's perceptions towards waste disposal in the city as shown in the Figure 5.

The results indicate that 30% of the respondents agreed to the statement, 28% disagreed to the statement, 15% strongly agreed to the statement, 15% was not sure about the statement and 13% strongly disagreed to the statement. To support this statement, environmental behaviorist concluded that behavior is something that can be passed from person to person, the same applies to issues to deal with wastes disposal. The idea of dumping wastes poorly can be passed on from generation to generation, it is imperative that we check our behavior when it comes to waste disposal so that the future generations may emulate proper habits of dumping

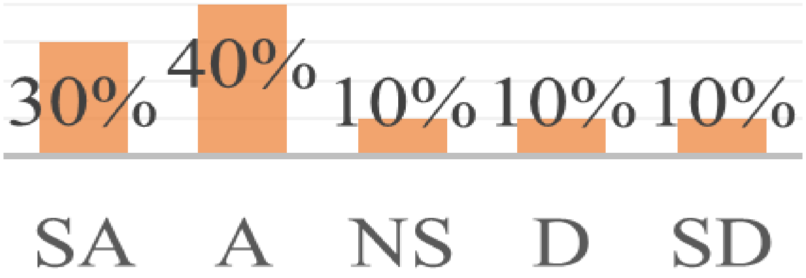

**Figure 7.** Community members' belief that it is the government's duty to take care of the disposed wastes.

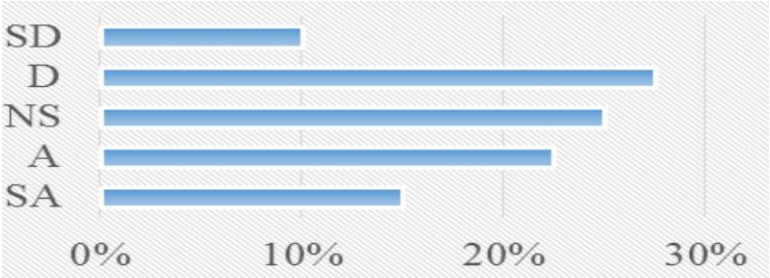

**Figure 8.** Community members' belief that they do not have control over waste management

wastes.

### *People in the community believe that dumping of wastes is the only way of making soil fertile*

Figure 6 shows the results of the community members' belief that the dumping of waste is one way of making the soil fertile.

The presentation clearly shows that most of the respondents strongly agreed to the statement with 40% strongly agreeing. Seconded by agree with 30% of respondents agreeing to the statement, 15% of respondents were not sure about the statement while 13% of the respondents disagreed to the statement whereas only 3% of the respondent strongly disagreed to the statement. From the results we can prove that indeed people believe that dumping of wastes is one way of making soil fertile. Alexis and Mihelcic (2009) gave evidence that people of the community believe that wastes make the soil fertile and these beliefs are much common in rural communities where most people dispose large piles of wastes to obtain manure.

### *People believe that it is the government duty to take care for the disposed wastes*

Figure 7 shows the study results on the community members' belief that it is the duty of government including local government to take care of waste management.

The statement aimed at proving if people believe that, it is the government's duty to take care of the disposed wastes, from the graphical presentation, it has been shown that 40% of the participants agreed, 30% strongly agreed, 10% were not sure about the statement, 10% disagreed and 10% strongly disagreed to the statement. Based on the results we can prove that most people of the community members do believe that it is the government duty to take care of the disposed wastes. Lilongwe Water Board (2009) added that, the statement usually applies to most Malawian communities, where the community members have the tendency of leaving everything to the government to sort things out. In short, this attitude simply indicates that most community members do not want to take responsibility for their own mess.

### *Community members' belief that disposal is something they do not have control over; it is only nature that has control over wastes*

Figure 8 shows the results of the community members' belief that they have no control over waste management and that this must be left to nature.

According to the results, many of the participants were in disagreement to the statement that people believe that

**Table 5.** Summary of Objective 2.

| People's perception towards waste disposal. | SA | A | NS | D | SD |
|---|---|---|---|---|---|
| Most community members believe that waste disposal is the way of life, since their ancestors also used to dispose wastes without considering the consequences | 6 | 12 | 6 | 11 | 5 |
| People in the community believe that dumping of wastes is the only way of making soil fertile | 16 | 12 | 6 | 5 | 1 |
| People believe that it is the government duty to take care of disposed wastes | 12 | 16 | 4 | 4 | 4 |
| People believe that waste disposal is something they do not have control over, it is only nature that has control over wastes | 6 | 9 | 10 | 11 | 4 |
| Total | 40 | 49 | 26 | 31 | 14 |

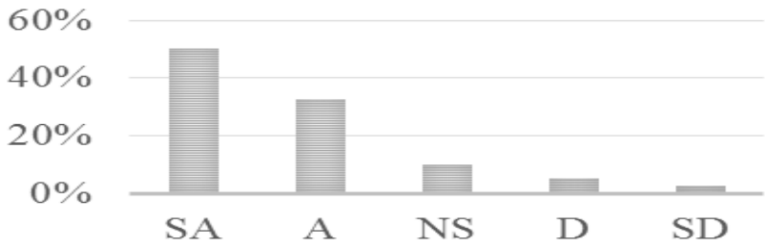

**Figure 9.** Soil contamination plays a bigger role in affecting people's farmlands.

waste disposal is something they do not have control over, it is only nature that controls wastes, some were not sure about the statement, others agreed while others strongly agreed and others strongly disagreed. This shows the percentage how the participants viewed the statement. From the presentation, 28% represents the participants who disagreed, 25% were not sure about the statement, 22% agreed to the statement, 15% strongly agreed, while 10% gives out the participants who strongly disagreed to the statement. Christopherson (2003) indicated that people believe that nature, like water source have the ability to control wastes, a good example can be industries. They dispose wastes in water sources like streams, swamps, rivers and lakes; they usually do this hoping that water bodies will get rid of the wastes. The results for objective two which to assess the community's perception towards waste disposal in Lilongwe City are summarized in Table 5

Objective 2 has proven that people do have different perceptions towards wastes. This is based on how respondents viewed the statements in this objective, so from the results 49% agreed, 40% strongly agreed, 31% disagree, 26% were not sure while 14% strongly disagreed.

## Effects of poor waste disposal on the communities in Lilongwe City

The following were found to be the effects of poor waste disposal on the communities in Lilongwe City.

### *Soil contamination plays a bigger role in affecting people's farmlands*

Figure 9 shows that soil contamination plays a bigger role in affecting the community members' farmland in the city. It shows that, 50% of the respondents strongly agreed to the statement, 32% of the respondents agreed to the statement, 10% were not sure about the statement, 5% of the participants disagreed to the statement while only 3% of the respondent strongly disagreed to the statement. This clearly indicates that, indeed poor waste disposal contaminates the soil, thereby affecting people's farmlands. Wastes pose a threat to the soil where in most cases community members depend on it for farming and hence this contributes to starvation whereby people can go days without food. Osuagwu (2018) gave examples of oil spills and plastic papers which can cause damage to the soil, which in turn have an impact on people who are into farming.

### *Community members fail to use water sources for domestic purposes because water sources are contaminated*

Table 6 shows the results on the failure of the community members to use water sources for domestic purposes due to contamination.

**Table 6.** Failure to use water sources for domestic purposes because water sources are contaminated.

| Variable | Frequency | Percentage |
|---|---|---|
| Strongly agree | 17 | 42 |
| Agree | 20 | 50 |
| Disagree | 3 | 8 |
| Total | 40 | 100 |

**Table 7.** Poor wastes disposal disturbs the climate thereby affecting livelihood activities like farming.

| Variable | Frequency | Percentage |
|---|---|---|
| Strongly agree | 16 | 40 |
| Agree | 13 | 32.5 |
| Not sure | 9 | 22.5 |
| Disagree | 1 | 2.5 |
| Strongly disagree | 1 | 2.5 |
| Total | 40 | 100 |

**Table 8.** People are impacted by various diseases which affect their health.

| Variable | Frequency | Percentage |
|---|---|---|
| Strongly agree | 21 | 52.5 |
| Agree | 17 | 42.5 |
| Disagree | 2 | 5 |
| Total | 40 | 100 |

In total, 50% of the respondents agreed to the statement, 42% of the respondents strongly agreed to the statement and 8% disagreed. From the results it shows that people fail to use water sources for domestic purposes because water sources are contaminated. In relation to study done by World Health Organization (2011) titled ‘guidelines for drinking quality water’’, proved that more water sources are contaminated due to human activities like poor disposal of wastes into water source and this in the end creates water insecurity among community members where sources of getting water for domestic purposes become scarce due to dumping of wastes into water sources.

### *Poor waste disposal disturbs the climate thereby affecting livelihood activities like farming*

Table 7 shows community members’ views on the effect of poor waste disposal on climate and its effect on their livelihoods.

Table 7 indicates that all 40 respondents responded to the statement, where 16 strongly agreed, 13 agreed, 9 were not sure, 1 disagreed and 1 strongly disagreed to the statement. This proves that more people agree to the statement that, poor wastes disposal disturbs the climate thereby affecting livelihood activities like farming. To support this statement Malawi National Environment Action Plan of 1994 added that poor waste disposal contaminates, the ozone layer where a lot of it leaves people feeling hopeless as they feel unable to make necessary changes. For instance, some wastes are burned like paper and plastics which brings out gaseous chemicals, causing the chemicals to be released and accumulated into the air, hence in the end contribute to damaging the ozone layer and also hurt the surroundings. Besides, with chemicals such as dioxin out there, the air has been proven to have harmful effects on people and the environment.

### *People are impacted by various diseases which affect their health*

Table 8 shows the respondents’ views on how community members are impacted by various diseases due to poor

**Table 9.** Summary of Objective 3.

| Effects of poor waste disposal to the community | SA | A | NS | D | SD |
|---|---|---|---|---|---|
| Soil contamination plays a bigger role in affecting people's farm lands | 20 | 13 | 4 | 2 | 1 |
| People fail to use water sources for domestic purposes because water sources are contaminated | 17 | 20 | - | 3 | - |
| Poor waste disposal disturbs the climate thereby affecting livelihood activities like farming | 16 | 13 | 9 | 1 | 1 |
| People are impacted by various diseases which affects their health | 21 | 17 | - | 2 | - |
| Total | 74 | 63 | 13 | 8 | 2 |

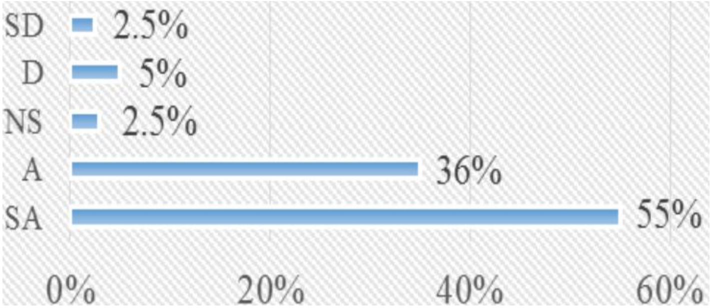

**Figure 10.** Organizing activities which are based on community clean up days

waste disposal.

The presentation of results shows that strongly agree recorded the highest number of respondents with 52.5% strongly agreeing, seconded by agree with 42.5% respondents agreeing to the statement while disagree recorded the least number with 5% respondents disagreeing to the statement. This perfectly proves that poor waste disposal indeed impacts people with various diseases which affect their health. Beech et al. (2017) proved that wastes are breeding grounds of mosquitos and when large piles of wastes are being disposed, it means the level of mosquitos breeding also increases that is why more people in urban areas in Malawi are always suffering from malaria.

Table 9 shows that, the researcher shares the same view with the respondents, where most of the respondents agreed to the statements in objective 3 which states the effects of poor waste disposal in the community, strongly agree recorded highest number of respondents, seconded by agree. Because of the proof given, this is a true reflection that people really experience these effects when they practice poor waste disposal and management.

## Roles played by community members in mitigating poor waste disposal in the communities in Lilongwe City

The following were determined by the study to be the roles played by the community members in mitigating poor waste disposal in the communities within Lilongwe City

### *Organizing activities which are based on community clean up days*

Figure 10 indicates that, 55% of respondents strongly agreed, 36% agreed, 5% disagreed, 2.5% of the respondents were not sure and 2.5% strongly disagreed to the statement. To ensure that poor waste disposal is dealt with, communities can indeed come together and work towards improving their community through conducting special events like community clean-up days, this in turn helps to show how members of the community are accountable to their community and it can also help to instill a sense of responsibility among the members of the community.

### *Reporting of illegal dumping*

Based on the results in Figure 11, it indicates that, 50% of the participants agreed, 32% of the participants strongly agreed, 10% strongly disagreed, 5% were not sure and 3% of the participants disagreed to the statement of reporting illegal dumping. Environmental Management Council (2013) supported the statement by adding that members of the community can report individuals who are practicing illegal dumping to people who are custodians of rule of law like the police, local chiefs, and the elders of the community. With such kind of attitude, it

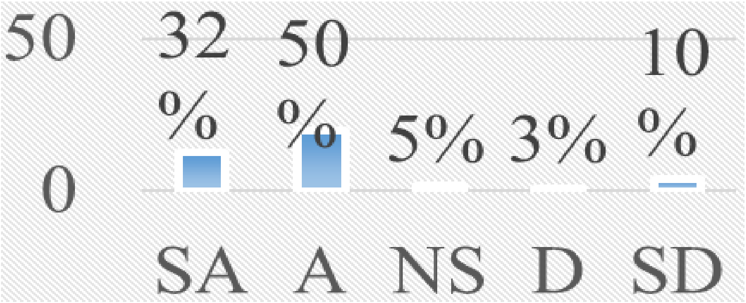

**Figure 11.** Reporting of illegal dumping.

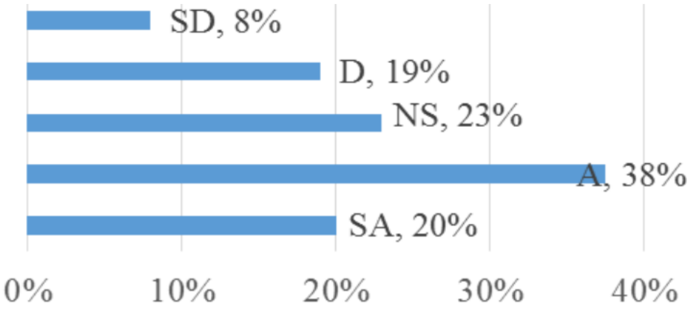

**Figure 12.** Setting lower disposal fees to encourage people use the lawfully stipulated waste disposal systems.

**Table 10.** Embrace the practice of reduce, reuse and recycle.

| Variable | Frequency | Percentage |
|---|---|---|
| Strongly agree | 27 | 67.5 |
| Agree | 9 | 22.5 |
| Not sure | 1 | 2.5 |
| Disagree | 3 | 7.5 |
| Total | 40 | 100 |

can help the community members to desist from practicing improper dumping of wastes because they will fear that eyes are everywhere watching them and in turn, they can end up practicing appropriate means of dumping wastes.

### *Setting lower disposal fees to encourage people use the lawfully stipulated waste disposal systems*

The results in Figure 12 indicate that the highest number of respondents agreed to the statement, with 38% of the respondents agreeing. 23% of the respondents were not sure about the statement, 20% of the respondents strongly agreed to the statement and 19% of the respondents disagreed to the statement, 8% of the respondents strongly disagreed to the statement.

Holbrook (2011), indicated that most of the people dump wastes poorly because fees of garbage collectors are high and because the community members have no other means to dispose the wastes, they end up dumping wastes improperly, to be fair enough, it is imperative that these local garbage collectors set up lower disposal fees so that community members can have the chance to dispose the wastes to proper wastes management sites.

### *Embrace the practice of reduce, reuse and recycle waste*

In total, 67.5% strongly agreed, 22.5% agreed, 7.5% disagreed and 2.5% was not sure about the statement of embracing the practice of reducing, reusing and recycling (Table 10). It can be concluded that embracing the

**Table 11.** Summary of Objective 4.

| Identifying roles applied by community members to mitigate poor waste disposal | SD | A | NS | D | SD |
|---|---|---|---|---|---|
| Organizing activities which are based on community clean up days. | 22 | 14 | 1 | 2 | 1 |
| Reporting of illegal dumping | 13 | 20 | 2 | 1 | 4 |
| Setting up lower fees to encourage people use the lawfully stipulated waste disposal systems | 8 | 15 | 7 | 7 | 3 |
| Embrace the practice of reduce, reuse and recycle | 27 | 9 | 1 |  | 3 |
| Total | 70 | 58 | 11 | 10 | 11 |

practice of reduce, reuse and recycle is indeed an effective way which community members can use in mitigating poor waste disposal.  It is imperative that community members start to embrace these three practices for they have been proven to be effective practices, for instance; these practices help to save space for landfills. Carless (2007) suggested that, instead of dumping the wastes at dumping sites, the community members can reuse the wastes to make new other products for instance members can reuse the wastes to make briquettes, which in turn can also be helpful in saving the environment, plastic bags can also be reused, instead of dumping plastic bags, people can reuse them as shopping bags when going out for shopping. The results of objective four which is to identify the roles played by community members in mitigating poor waste disposal in the communities in Lilongwe City are summarized in Table 11.

The results give a clear indication that people can apply the statements and use them to mitigate poor waste disposal in the community, this is so because the response proves that more respondents were in favor of the statements. In the end, if applied, they can be effective ways in mitigating poor waste disposal.

## Conclusion

The research found that indeed more community members have a role to play in mitigating poor waste disposal in the community, for example in objective four which has statements like: embrace the practice of reduce, reuse and recycle has given a clear indication that, the community members need to truly embrace this practice as one of their roles in mitigating poor waste disposal, so based on this statement, 67.5% of respondent strongly agreed to the statement and 22.5% of respondents agreed to the statement, which gives a clear indication that indeed community members should be encouraged to embrace the practice of reducing, reusing and recycling as one way of mitigating poor waste disposal in the community. The data that has been provided can be used for awareness campaigns, where by community members can be given an awareness on the impact of practicing poor waste disposal so that they can take up mindset change, on issues to deal with wastes. It is imperative to the community members that as they are being made aware of their roles, capacity building areas can also be easily identified through the community members. For instance, awareness can be a tool whereby they can easily identify the skills which community members have. Instead of practicing poor wastes disposal, community members can use the skills to make various goods out of the wastes. The results of the study have given a clear picture that community members of Lilongwe City have a bigger role to play in mitigating poor waste disposal in their community. It is crucial that people of this community work hand in hand with other stakeholders to ensure that every member fulfills the role of trying to improve the community, so that the problem of vector and water borne diseases can also be mitigated once and for all.

## Recommendations

(1) Stakeholders should plan for waste management awareness programs.
(2) Community members should identify their capabilities to turn waste into briquettes which they can use for cooking and selling to generate income.
(3) Government should provide loans to the communities for small scale waste recycling businesses.
(4) Government should provide free waste collection services to some underprivileged urban communities.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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