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GEO-Accumulation Index for Heavy Metals in Groundwater: a Study of Bompai and Sharada Industrial Estates, Kano Metropolis, Nigeria

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Abstract: The level of concentration of heavy metal in soil is detrimental to groundwater quality in Sharada and Bompai industrial areas. A total of 40 sampling points were selected from both two areas. The digested samples were analysed for As, Cd, Cr, Cu, Co, Ni and Pb using Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-OES) machine. Geographic Information Systems (GIS) was used to model and present the spatiotemporal changes of the pollution sources and factors affecting the levels of pollution. Pollution in water and potential risks introduced by heavy metal accumulation were assessed using Geo-accumulation index. Results indicated that Cadmium and Arsenic are the most vulnerable around Bompai with mean of 0.2-0.4/mg/l and 1.3-1.6 mg/l respectively, Geo-accumulation index mapping showed that Arsenic, Cadmium and Copper to have high accumulation index ranging from strong to very strong (0.99-1.48), (0.01-0.22) and (0.27-0.33) respectively, Cobalt to have moderate contamination in Sharada (wet season) with (-0.39-0.12) while lead and Chromium has the least contamination index (uncontaminated). GIS modelling and mapping indicated that all the heavy metals were found in the groundwater of the two areas but among them Cd is more concentrated. South-western part of the study area confronts the most serious heavy metal pollution, hence the need for groundwater treatment before drinking to avoid dangers associated with heavy metals.

Key Words: Groundwater-contermination; geo-accumulation; industrial area characterisation, heavy metals, Kano

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1. Introduction

Groundwater is a natural resource buried beneath the surface in saturated rocks and soils pore spaces, cracks and crevices. It is groundwater that recharge wells, boreholes and springs that supplies water for human utilisation. Larger percentage of the world's human population rely on boreholes to exploit groundwater. Borehole is a hydraulic structure which when properly designed and constructed, permits withdrawal of water in economic quantity from an aquifer. Aquifers in northern Nigerian cities like Kano are under severe environmental pressure due to urbanization, peri-urban agriculture, industrial development and decline in water table due to seasonality of rainfall and climate change affecting the area.

Groundwater is already used extensively in Nigeria through wells and boreholes [1]. This can be attributed to the nature of climate of the country which is fluctuating. The climate and weather of Nigeria are of tropical type but varies from place to place. Nigeria is characterised by two seasons which are wet and dry the highest rainfall is 1800mm in the coastal areas and it decreases northwards inland. In Kano metropolis, the study area average maximum temperature is 39^{o}C in April which is the warmest period, highest rainfall is in July and August with average 315mm [1]. Unfortunately, borehole water, like water from other sources, is never entirely pure. It varies in purity depending on the geological conditions of the soil through which the groundwater flows and some anthropogenic activities. Until very recently, groundwater has been thought of as being a standard of water purity in itself, and to a certain extent, that is indeed true [2]. Groundwater is one of the main sources of water in Kano state like in the other parts of the globe and it is used extensively for domestic, industrial as well as agricultural purposes. Uncensored human activities in developing countries including Nigeria contributes immensely to the poor quality of groundwater. The overexploitation of groundwater as well as pollution of ground and surface water by human activities like dumping of toxic substances and solid wastes into water bodies; the washing of agrochemicals and fertilizers applied to farms by erosion and run-off into streams and rivers causes a serious concern for water resources management. The problem of water quality is much more acute in areas which are densely populated with localized industries. Peculiarly, groundwater can also be contaminated by naturally occurring sources such as Arsenic, Iron and Manganese which are dissolved and can later be found in high concentrations in the water. The quality of groundwater depends on the management of anthropogenic discharges as well as the normal physiochemical characteristics of the catchment areas [3], [4] and [5]. Groundwater can be affected or degraded as a result of anthropogenic activities which introduce contaminants into the aquifers. It can also be affected by natural processes that result in elevated concentrations of certain constituents in the groundwater thereby making the water unfit for human consumption. As industrial wastes contaminate underground water making it toxic these have led to the degradation of the natural source of clean water as well as outbreak of unfamiliar diseases as well as changes in colour and taste of water which are distinctive/peculiar with the areas in which these industries are located and even farther away from the industrial areas. Groundwater contamination in an area contributes to the spread of waterborne diseases (WBSs) [6]. Heavy metals are very dangerous to human health if consumed in food or contaminated water are responsible for ill health and the environment and environmental damages in terms of soil and water [1].

Groundwater in Kano is located in crystalline Basement and fractured Basement due to the nature of the geology of the area that is Basement Complex unlike in Jigawa, Sokoto states and Chad basins which are underlain by sedimentary formations [1]. Kano is the centre of Nigeria's tanning industry in which three industrial estates, Bompai, Challawa, and Sharada, hold 70 percent of Nigeria's tanneries, large number of rubber industries among others that are capable of polluting soil, surface and groundwater in the area with heavy metals which are toxic [7]. Study of the level of heavy metal in the areas is of paramount significant. Particularly the area is characterized by wet and dry condition due to rainfall pattern. One critical factor to consider while assessing groundwater quality in an area is the amount of rainfall in the area [8].

Many studies were conducted like those of [9] evaluated groundwater geochemistry and quality index in south Wadi El-Farigh area, Egypt using NETPATH software and revealed that 92% of the groundwater was found to be suitable for drinking but failed to consider heavy metals. [10] examined level of heavy metals in soils and vegetable in areas under urban and peri-urban farming in northern Nigeria and realized that Cd and Zn were above the acceptable limits and agricultural lands in urban and peri-urban Kano are not suitable. This study failed to determined level of heavy metals in groundwater of those areas. [11] analyzed the level of heavy metals in the effluents around Sharada industrial area of which Pb is within the limit and Cd and Cr are above the standards. This study does not look at the level of these metals in groundwater which is having an indirect link with the effluents that was why they recommends for more comprehensive research that will targeted reducing the extent of such phenomena in the area. [12] evaluated physicochemical parameters and heavy metals in the tannery effluents around Sharada and Challawa industrial areas in Kano and determined that Cr and Pb exceeded the acceptable limits for both treated and untreated effluents which may have negative impact on human heath that depend on surface and groundwater in the area. The study does not look at Bompai area and it was limited only to tannery effluents. [13] in their research assesses the level of physicochemical parameters in selected wells in Kano metropolis and realized that is not safe for drinking. Studies conducted around Sharada and Bompai industrial areas investigated some of the heavy metals but failed to model the areas based on geo-accumulation index. Determining the level of heavy metals in groundwater of the area which people drink and considering the impact it will have on human health and the environment, such study will be of significant important. Furthermore, outcomes of the study are expected to provide adequate data for planning, management and protection of groundwater sources in the area. That is why the aim of the study was to compare and quantify the levels of the selected heavy metals from groundwater sources the industrial areas and to map and characterize the areas based on geo-accumulation index for effective potable water supply.

2. Material and Methods

2.1 The Study Area

The study areas are within Kano metropolis which lies between latitude 11º51ˈ N to 12º6ˈ N and longitude 8º23ˈE to 8º38ˈE (Figure 1). Kano Metropolis bordered by Minjibir LGA on the North east and Gezawa LGA to the East, while Dawakin Kudu LGA to the South East, Madobi and Tofa LGAs to the South West [14].The scope of the study covers Sharada and Bompai industrial areas which covers Dala, Fagge, Gwale, Kano Municipal, Nassarawa, Tarauni, and parts of Kumbotso and Ungogo Local Government Areas (LGA) of Kano Metropolis respectively. The dominant geology of the area is Basement Complex Rocks of Precambrian era. In [1], the geology underlying parts of Kano State is the basement complex and consisting of variety of metamorphic and igneous rocks ranging in age from Precambrian to Jurassic. Metamorphic rocks are migmatite, gneiss, schist and some quartzite which have been deformed structurally into antiforms, synforms and down faulted blocks. The geology of the area and relief may have an indirect influence on ground water quality of the area. The climate of Kano is described as Aw by Koppen, with both annual and seasonal variability's...wet years and dry years may record between 850 and 750mm [15]. The climate of Kano state is characterized by four seasons which are dictated by the movement of ITD that control north easterlies and southwest easterlies. The dominant soil of the area is Eutric-Cambisol soil according to the World Reference Base for Soil Resources, (WRB). The vegetation of Kano State is the semi-arid savannah. The Sudan Savannah is sandwiched by the Sahel Savannah in the north and the Guinea Savannah in the south. The average altitude of Kano metropolis is 472 meters above sea level. Drainage of the area is influenced by the relief of the area. The study area is drained by the two major River; River Jakara and River Kano. The Jakara River is the largest drainage network in Kano Metropolis. The drainage density of the area affects groundwater quality.

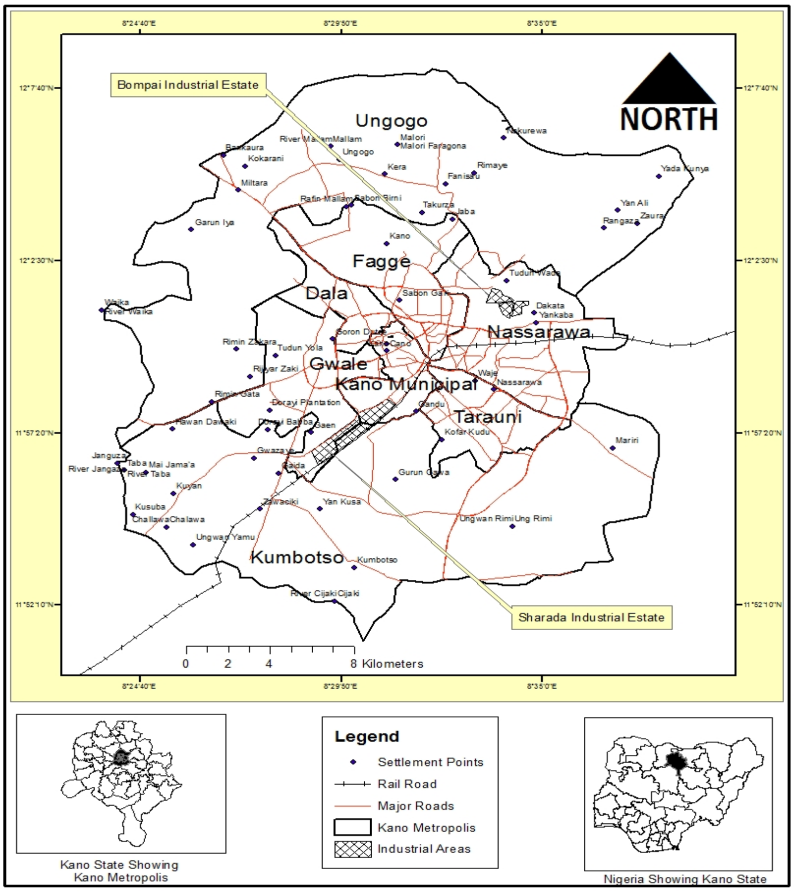


Fig. 1 - Map of Kano Metropolis. Source: GIS Lab Bayero University Kano, 2019

2.2 Sampling Techniques

The areas selected are Sharada and Bompai industrial areas both located in Kano Municipal and Nassarawa Local Government Areas respectively. Because the area where the sample is taken is quite extensive, Quantum Geographical Information System (QGIS) was used to divide the area into grids (36 Squares) and in each square, 1 well and or borehole was randomly selected for sampling in the study area as adopted by [16], [17].

2.3 Water Samples Collection

Water samples were collected in both rainy and dry season in sequence. Each sampling point water was collected in both Sharada and Bompai industrial areas bearing in mind the proximity of the wells to the industries and their coordinates recorded using GPS.

A total number of 40 water samples in both Sharada and Bompai which were placed in an acid washed plastic bottles for storage and further analysis. The samples were taken in 100 ml bottles covered in black polythene bags to avoid unpredictable changes in characteristic as recommended by the standard procedures. The collected samples were filtered (Whatman no. 42), preserved with concentrated, ultra-high-purity nitric acid (HNO3) (Suprapur Merck, Germany) and kept at a temperature of 4 °C for further analysis. The source of the samples are collected, recorded and attached to the bottle immediately after filling for easy recognition as adapted in USGS (1993) techniques of water resource investigation and Environmental Protection Agency's methods with few modifications.

Laboratory tests were processed and analysed both qualitatively and quantitatively. Sample digestion will follow Briggs method (using multi-element reagent), the analysis will follow US EPA Standard Operating Procedure for groundwater sampling whereby the samples are been processed adding 6ml of Nitric acid and placing it on a hot plate to evaporate. The samples were continuously heated over a certain period of time then distilled water is added then placed in an Advanced Microwave Digestion System machine to be digested then placed in to the ICP-OES machine (Inductively Coupled Plasma-Atomic Emission Spectrometry) which was already programmed to analyse the level of concentration of each of the required metals.

2.4 Data Analysis

For successful analysis of the results, the set of 7 heavy metals were chosen because these were the established water pollutants and their concentrations in the water samples were measurable. The following procedures were used; QGIS software package was used to map and grid the area to select sampling points while the Global Positioning System (GPS) was used to provide the co-ordinates of all the sampling wells and boreholes.

The characteristics of the area in terms of groundwater quality was determined using GIS software Arc GIS (version 10.1) software was used for drawing spatial interpolation maps using inverse distance weighted (IDW) interpolation technique available in the spatial analyst module of the software. Geo-Accumulation index was used characterise the degree of contamination in the areas as adopted by [18] and [19].

To quantify the degree of anthropogenic contamination and compare different metals that appear in different ranges of concentration in the study areas, an approach to indexing geo-accumulation, Igeo. A quantitate check of metals pollutions in sediment and in TSM was proposed by Muller and Seuss equation and is called the Index of Geo-accumulation, which is the enrichment on geological substrate and were calculated based on this formula:-

$$Igeo = \ln s\,(Cn/1.5\,Bn) \quad (1)$$

Where, Cn is the measured concentration of the examined metal (n) in the sediment or TSM ug/g, 1.5 is the factor used for lithologic variation of trace metals, and the Bn is the background concentration of the same metal. It's very difficult to establish Bn values for the sediments of some studied areas, as a reference. So, in some works Bn value (references point) has been taken as equal to the metal concentration in shale rocks. The geo accumulation index values were interpreted based on standards adapted from Muller 1969 in [20] (Table 1).

Table 1 - Heavy metals Geo accumulation Index and level of groundwater pollution

S/N	Index of Geo accumulation (I)	Level of pollution
1	I > 2.5	Very strong pollution
2	I = 1.0 – 2.4	Strong pollution
3	I = 0.084 - 0.99	Moderate degree of pollution
4	I = 0.03 – 0.83	Unpolluted or less pollution
5	I < -0.02 – 0.029	Very unpolluted

Source Adapted from Muller 1969 in [20].

3. Results and Discussion

3.1 Index Assessment of Arsenic

Result for the index assessment of arsenic were mapped in the study areas and presented in Figure 2. Arsenic concentration and pollution index are higher during dry season in both Sharada and Bompai with 1.16mg/l and 1.47mg/l respectively. The pollution index is also higher in the dry sea 1.36 and 1.03 mg/l respectively. It is higher in Sharada around Sabuwar Kofa, Yahya Gusau, Gurin Gawa, Gidan Maza 1&2 and Gurin Gawa between (Lat.11.66°-11.55° and Lon. 8.53°-8.51°). Bompai area has the most vulnerable c oncentration of Arsenic around Airport Road, Race Course road, Piccadily Circus, Sule Gaya road (12.00°-12.06° and Lon. 8.57°-8.51°). Sharada area with no arsenic contamination lies within (lat.12.01°, lon.8.57° - lat.12.03°, Lon. 8.53°). Result indicated that areas with arsenic concentration (0.72-0.9mg/l) are of strong geo-index and (1.07-1.36) belongs to geo-index category of very strong meaning very high concentration and pollution level. (Table 2 and Figure 2a & 2b). This is because of concentration of industries that varies from one location to another. The result is higher than that [18] in Kanpur India where the results of Arsenic, has geo-index values of 0.46; which showed unpolluted to moderate contamination.

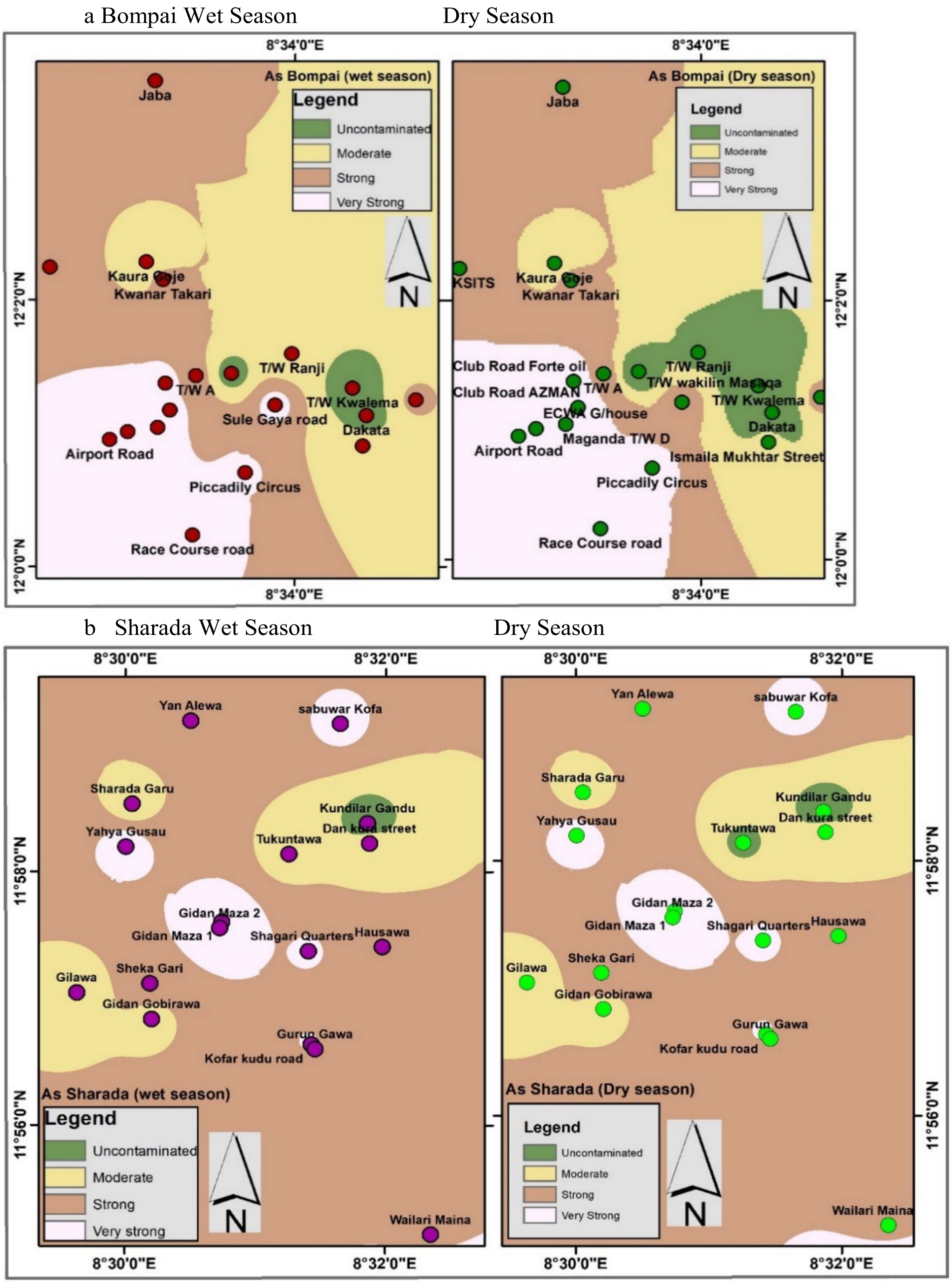


Fig. 2 - (a) & (b) Index assessment of arsenic in the sampling areas

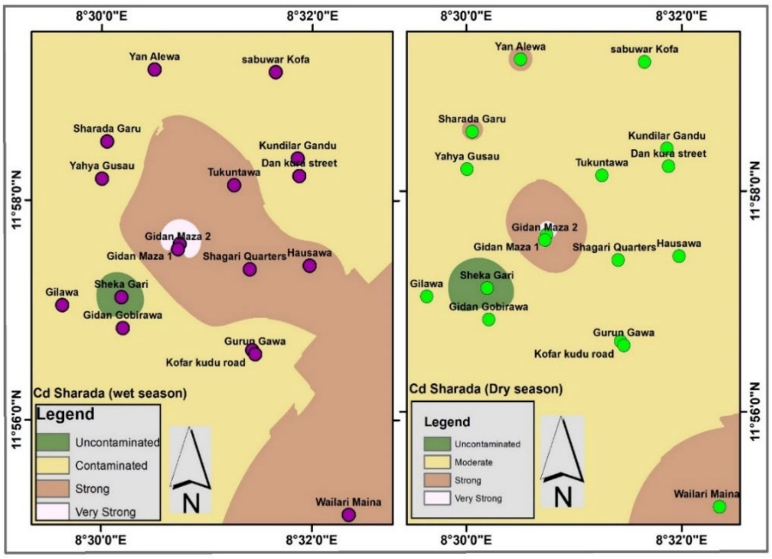
Table 2 - Geo-index for Arsenic

Industrial areas/seasons	Bompai (wet)	Bompai(dry)	Sharada (wet)	Sharada (dry)
Mean Arsenic (mg/l)	0.73	1.10	0.91	1.35
Geo- accumulation Index	0.72	1.07	0.91	1.36
Remark	Uncontaminated	Strong	Moderate	Strong

3.2 Geo-index for Cadmium

The geo-index of cadmium across the study area are presented using maps for for Sharada and Bompai industrial areas and for both wet and dry seasons (figure 3, table 3).

(a) Sharada Wet Season Dry Season



(b) Bompai Wet Season Dry Season

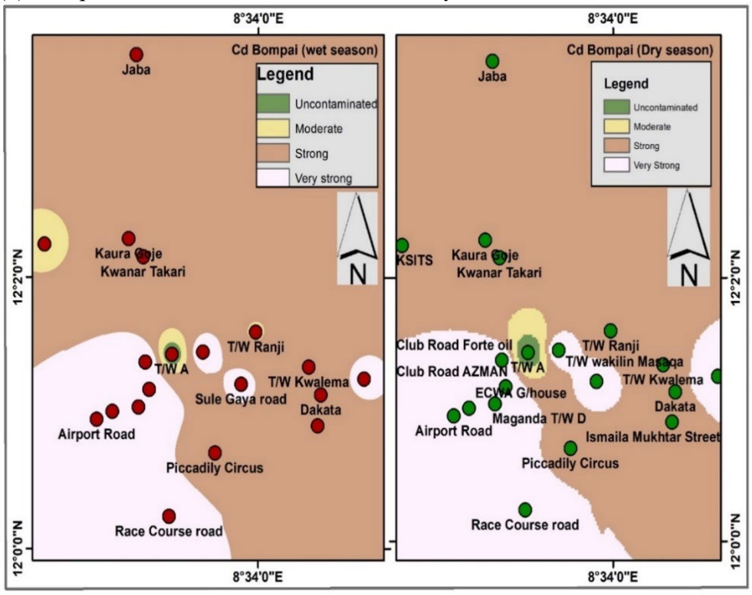


Fig. 3 - (a) & (b) Index assessment of Cadmium in the sampling areas

For Cadmium, Bompai has the highest and most vulnerable concentration (0.2-0.4/mg/l) around Airport road, Race Course road, Ecwa G/house, Club Road AZMAN (latitude 12.00° to 12.06° and longitude 8.51°-8.59°) (Table 2 and Figure 3) which is as a result of the concentration of industries in this area while Sharada has trace concentration of cadmium. The area susceptible to cadmium contamination lies within Latitude 12.01°- 12.07° and Lon. 8.56°-8.58° (Bompai) and Gidan Maza 1& 2 (11.60°-11.98° and Lon.8.61°-8.81°) (Figure 3), while the area with no cadmium contamination lies within lat.12.02°, lon.8.55° - lat.12.03°, Lon. 8.56° (Bompai) and Sheka Gari, Gidan Gobirawa (Lon 8.00° - 8.6°, Lat. 8.51) in Sharada. Concentration of cadmium may be due to the presence of tanneries in the areas affected. Geo-accumulation index indicated very strong contamination in dry season. Because during wet season the metals are diluted by rain. The result is similar to the findings of [18] where the results of Cadmium in Kanpur India, has Igeo values of 1.49 which showed moderate contamination of Cadmium.

Table 3 - Geo-index for Cadmium

Industrial areas/seasons	Bompai (wet)	Bompai(dry)	Sharada (wet)	Sharada (dry)
Mean Cadmium (mg/l)	0.13	0.20	0.40	0.07
Geo- accumulation Index	0.12	0.2	0.41	0.06
Remark	Moderately	Strong	Very Strong	Uncontaminated

3.3 Index assessment of Cobalt

The results of index assessment for Cobalt are presented below (figure 4, table 4).

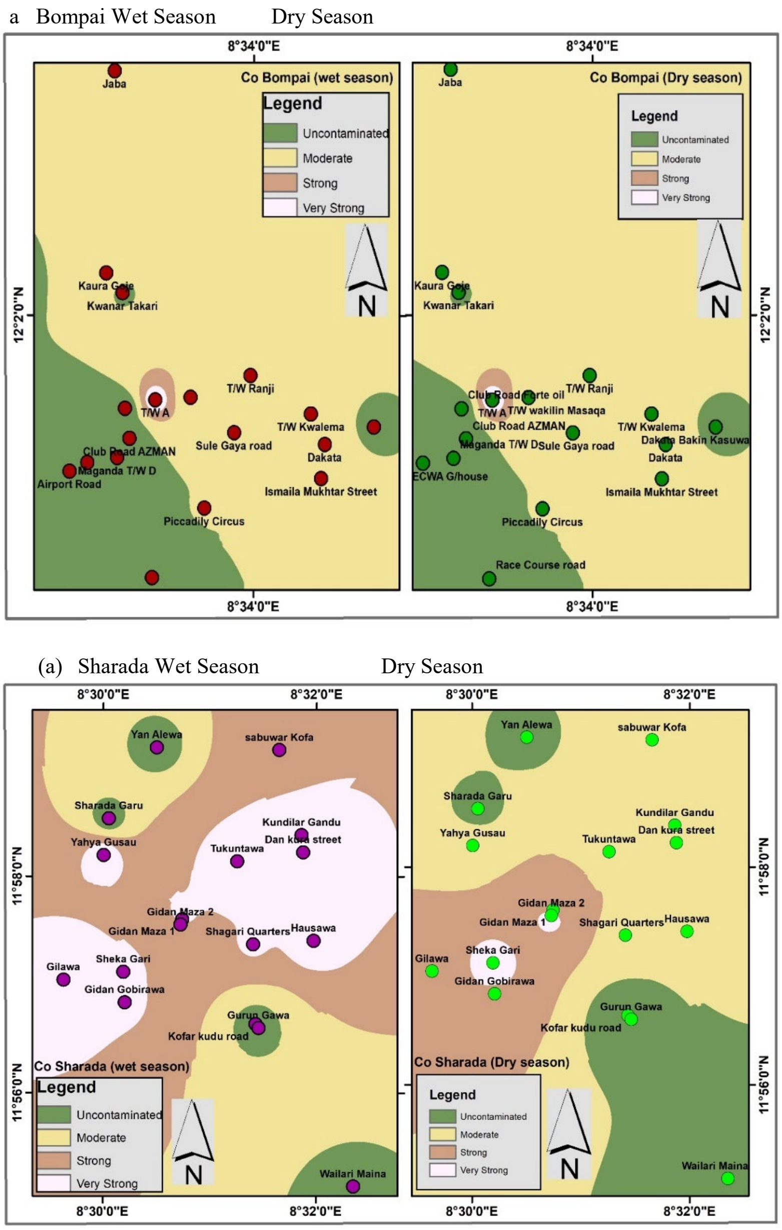


Fig. 4 - (a) & (b) Index assessment of cobalt in the sampling areas

It shows that Bompai area has the highest concentration of Cobalt around Tudun Wada A, (Lat.12.02° and Lon.8.57° and 8.56°) (Figure 4) and in Sharada most vulnerable areas of cobalt concentration are around Yahya Gusau, Gilawa, Kundilar Gandu (latitude 12.01° to 12.04° and longitude 8.55°-8.56°) (Table 4 and Figure 4) which is as a result of the concentration of industries in this area. Geo-accumulation index of all the areas indicated partially uncontaminated (Table 3). The result is higher than the findings of [21] and [18] where the results of Cobalt in Kanpur India, has Igeo values to be 0.46; which showed unpolluted to moderate contamination.

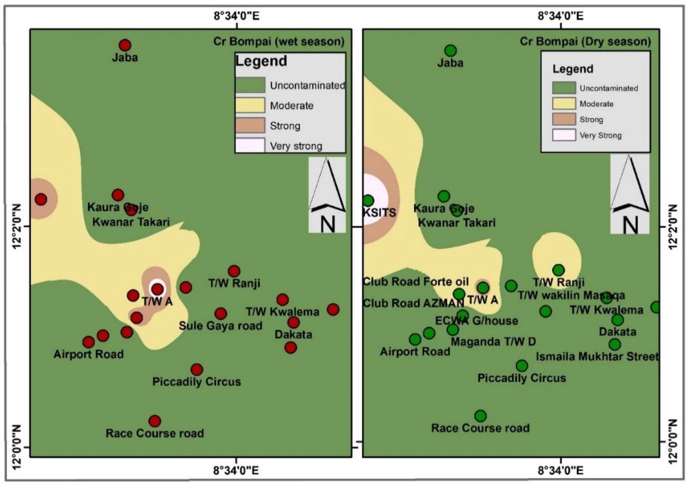
Table 4 - Geo-index for Cobalt

Industrial areas/seasons	Bompai (wet)	Bompai(dry)	Sharada (wet)	Sharada (dry)
Mean Cobalt (mg/l)	-0.21	0.35	0.009	0.10
Geo- accumulation Index	-0.2	-0.36	0.009	0.11
Remark	Practically uncontaminated	Practically uncontaminated	Practically uncontaminated	Moderately contaminated

3.4 Geo-Index of Chromium

Results of the geo-index of Chromium are presented below. It indicated that in Bompai areas that recorded vulnerable level of chromium are around (Tudun Wada A and KSITS) which lies at Lat.12.01° and Lon.8.54°, and Lat.12.03° – Lon. 8.56° (Table 5 and Figure 5) which is as a result of the concentration of industries in this area all other areas are not having chromium vulnerability. Sharada has high concentration of Chromium in Sheka Gari and Gidan Maza 1&2 (Figure 5). The result is similar to the findings of [18] where the results of chromium in Kanpur India, has Igeo values to be 4.32 which showed extreme level of contamination for Cr. Use of tannery effluent for irrigation might have increased the significant amount of Cr build up in groundwater [22].

(a) Bompai Wet season Dry Season



(b) Sharada Wet Season Dry Season

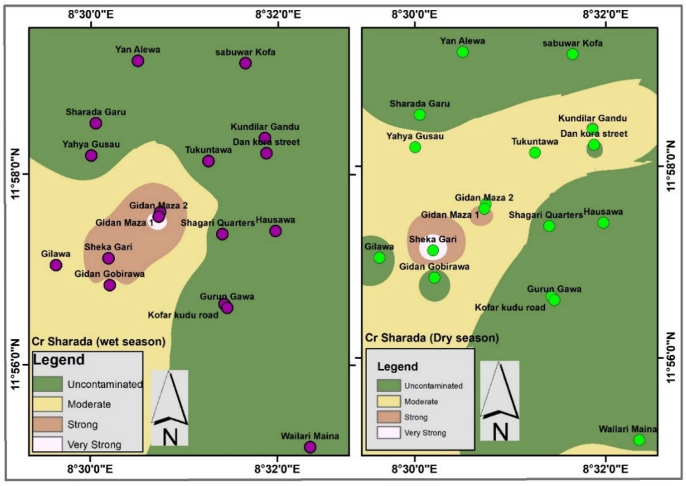


Fig. 5 - (a) & (b) Index assessment of Chromium in the sampling areas

Table 5 - Geo-index for Chromium

Industrial areas/seasons	Bompai (wet)	Bompai(dry)	Sharada (wet)	Sharada (dry)
Mean Chromium (mg/l)	0.16	0.17	0.18	0.06
Geo- accumulation Index	0.15	0.16	0.17	0.05
Remark	strongly contaminated	strongly contaminated	strongly contaminated	strongly contaminated

3.5 Geo-index of Copper

The table and figures below were used to present results for the Copper geo-accumulation index (Figure 6, Table 6).

(a) Bompai Wet Season Dry Season

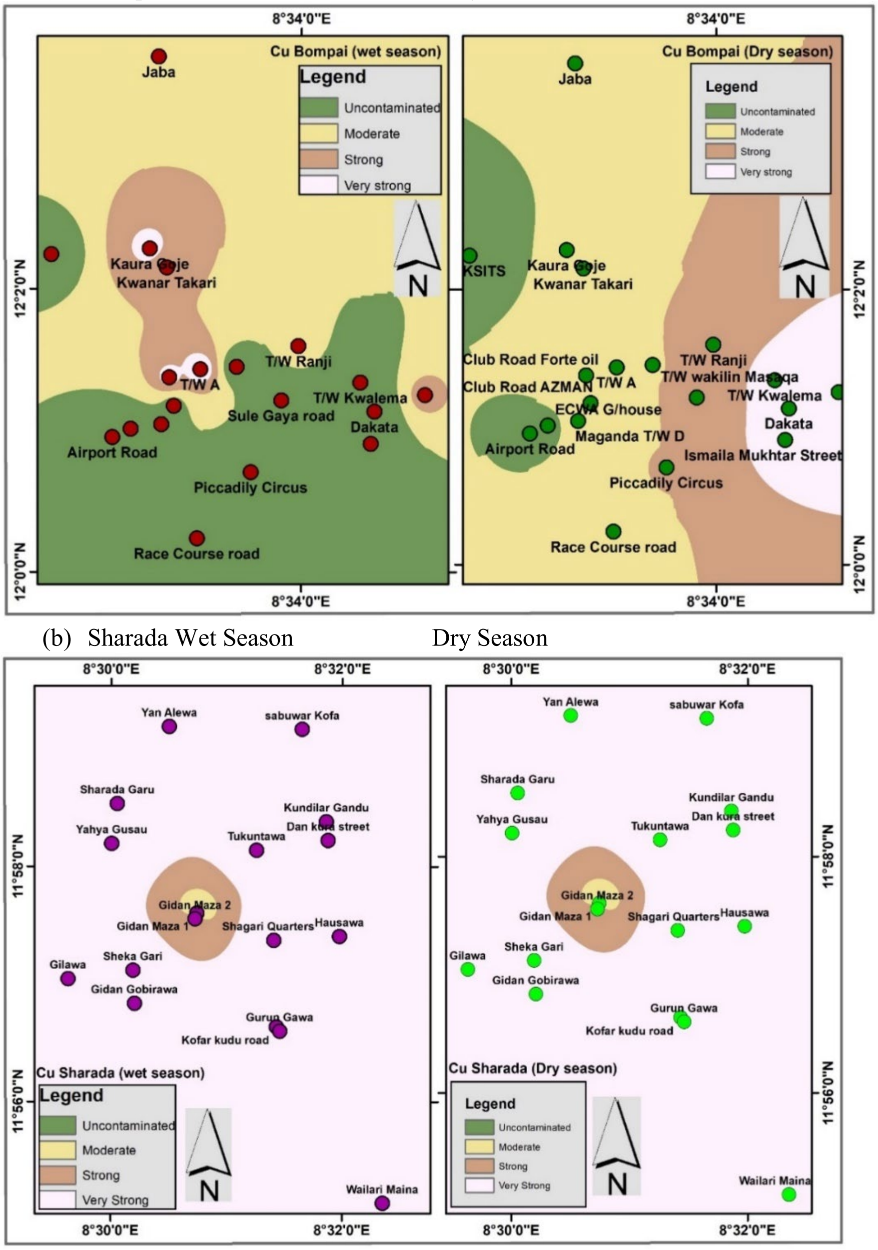


Fig. 6 - (a) & (b) Index assessment of copper in the sampling areas

The concentration of copper in Bompai is very low during wet season but higher during dry season. Area of vulnerability is around Tudun Wada Wakilin Masaqa, T/W Kwalema, Dakata (Lat.12.02° - 12.06° and Lon.8.54° – 8.55°) (Table 5 and Figure 6) while the quality of groundwater in Sharada is very poor in terms

Copper contamination with only Gidan Maza (Figure 6) having low level of contamination as a result of effluents from the industries around the area and influence of geology. The result is similar but higher to the findings of [23] where the results of Copper in the sediment of Tigris River, has Igeo values that is graded (0) no contamination.

Table 6 - Geo-index for Copper

Industrial areas/seasons	Bompai (wet)	Bompai(dry)	Sharada (wet)	Sharada (dry)
Mean Copper (mg/l)	0.04	0.37	-0.02	-0.03
Geo- accumulation Index	0.03	0.25	0.29	0.31
Remark	Practically uncontaminated	Strong	Strongly contaminated	Strongly contaminated

3.6 Geo-index for Nickel

Results geo-index for Nickel is presented below. Bompai has highest Nickel contamination at Tudun Wada A, Airport Road, Piccadilly Circus, Club Road, Maganda Road, Club Road at Lat.12.02° Lon. 8.55° (Table 6 and Figure 7) during wet season but no contamination during dry season. This is because Nickel is a mobile element therefore rainfall causes sorption of the metal into groundwater. Sharada has the highest Nickel contamination at Wailari Maina, Gurin Gawa, Kofar Kudu and Hausawa (Lat. 11.95° - 11.75° and Lon. 8.57°) while larger part of the vulnerable area lies within Sabuwar Kofa, Tukuntawa Shagari Quartes (Lat. 11.60° and Lon. 8.56°) (Figure 7), the remaining area has moderate contamination around Gilawa, Yan-alewa, Gidan Maza 1&2. Goe-accumulation index of -0.37-0.27 in both areas shows moderately uncontaminated to practically uncontaminated (Table 6). This result is similar but lower to the findings of [24]where results of Nickel in city of Porto Alegre, Brazil, has Igeo values in commercial area to be 2.63, residential area to be 2.94 and industrial area to be 1.45; which showed highly to moderately contamination.

Table 7 - Geo-index for Nickel

Industrial areas/seasons	Bompai (wet)	Bompai(dry)	Sharada (wet)	Sharada (dry)
Mean Nickel(Ni) (mg/l)	0.27	0.04	-0.2	-0.37
Geo- accumulation Index	0.25	0.003	-0.18	-0.34
Remark	moderately contaminated	Practically uncontaminated	Practically uncontaminated	Practically uncontaminated

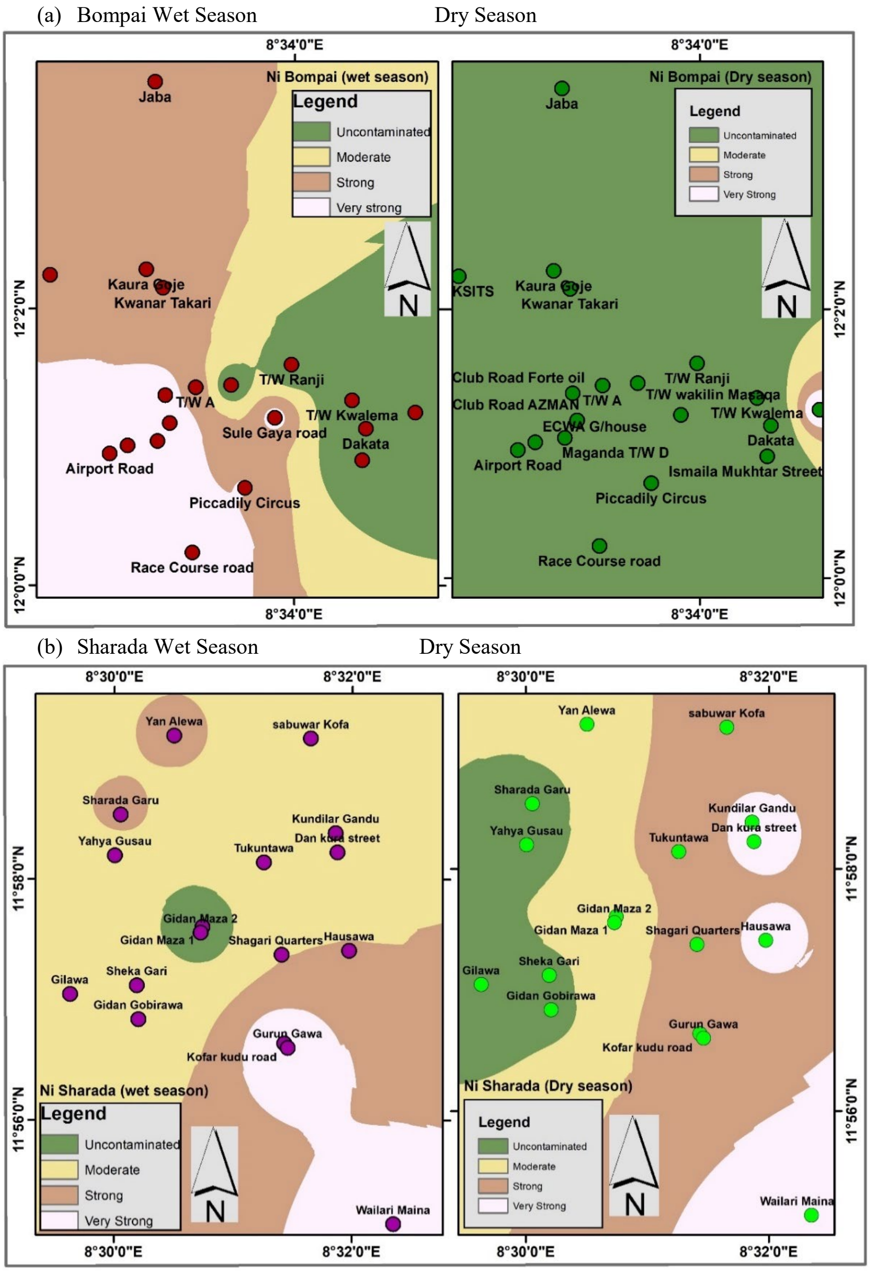


Fig 7 - (a) & (b) Index assessment of nickel in the sampling areas

3.8 Geo-index of Lead

Findings on Lead geo-accumulation index are presented below. Lead contamination is higher around Kaura Goje, TW Ranji, TW wakilin Masaqa, Dakata and TW Kwalema (lat. 12.03° and 12.02° and Lon. 8.55° – 8.56°) (Table 7 and Figure 8) in Bompai Industrial Area. Areas with no lead lies within Lat. 12.06° and Lon. 8.57° (Race Course Road, Airport Road) (Figure 8) all in Bompai area. In Sharada, the pattern of lead contamination is higher at Gurun Gawa, Wailari Maina at Lat. 11.55° (Figure 8) then its decreases from Lat. 11.65 to Lat. 11.65° around Yan Alewa, Kundilar Gandu, Shagari Quarters (Figure 8) making it an area with lead vulnerability which decreases towards Gilawa, Sabuwar Kofa, Gidan Maza (Lat. 11.75° to Lat. 12.00°) (Figure 8). Geo-accumulation index ranges from 0.11-0.25 indicating strong to very strong contamination in both areas (Table 7). The result of these findings is lower to that [24] where the result of Nickel in the city of Porto, Brazil shows a geo index of 2.63 for commercial area, 1.46 for residential area and 1.45 for industrial area to be highly to moderately contaminate.

Table 8 - Geo-index for Lead

Industrial areas/seasons	**Bompai (wet)**	**Bompai(dry)**	**Sharada (wet)**	**Sharada (dry)**
Mean Lead (Pb)) (mg/l)	0.14	0.25	0.11	0.2
Geo- accumulation Index	0.13	0.23	0.1	0.18
Remark	Strong	Very strong	Strong	Very strong

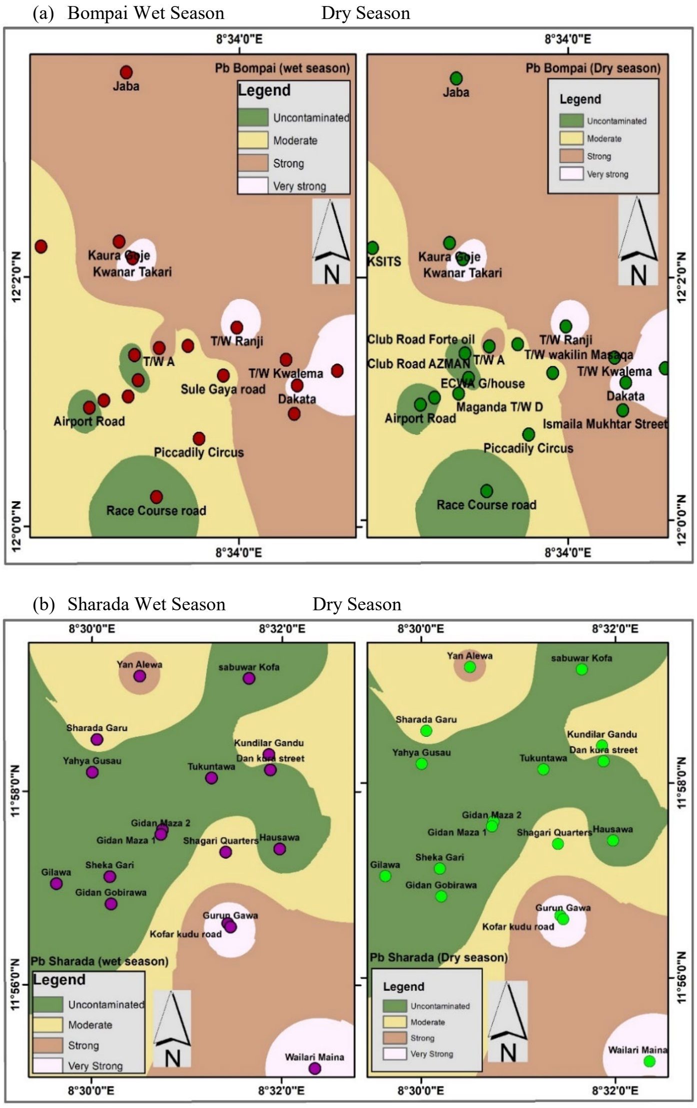


Fig. 8 - (a) & (b) Index assessment of lead in the sampling areas

4. Conclusion

The contamination level and the composition of pollutants is controlled by the impact of industrial sources, peculiarities in the geological structure and hydrogeological differences between the key sites which are similar in many respects for both industrial areas. The study measured the levels of concentrations of the heavy metals in groundwater (As, Cd, Co, Cr, Cu, Ni and Pb) in Sharada and Bompai industrial areas. Geology and anthropogenic activities (domestic and organic pollution) may be responsible for dry season and natural in wet season among others which makes differences between the two seasons of water samples and sources. Therefore, water in Bompai Industrial area is more polluted as a result of the geology of the area and the high number of industries located in the area. The level of heavy metals and geo-accumulation index are higher in Bompia than sharada because there are more industries that released contaminated water in Bompai than

Sharada. With reference to that it is recommended that the industries should be mandated to treat heavy metal before releasing their effluents and groundwater should be treated for before drinking.

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