Bayero Journal of Physics and Mathematical Sciences / Vol. 17, No. 1 / Feb., 2026. ISSN: 1597 – 9342, Online ISSN: 2795 - 3866

BAJOPMAS JOURNAL 17(1): 1 – 13
Printed in Bayero University, Kano - Nigeria.

ANALYSIS OF HEAVY METALS CONCENTRATIONS IN WATER SAMPLES FROM SELECTED LOCAL GOVERNMENTS IN BORNO STATE, NIGERIA

[1]Bukar, M. I.; [2]Fagge, N. I.; [2]Ibrahim, U. M.; [2]Ahmed F and [3]Ali, Y.
[1]Department of Physics University of Maiduguri, P.M.B, 1069, Borno State, Nigeria
[2]Department of Physics, Bayero University, Kano, P.M.B 3011, Kano State, Nigeria
[3]Department of Physics, Federal University Dutse, P.M.B, 7156, Jigawa State, Nigeria

ABSTRACT:

For humans, plants, and animals to survive and preserve their health, access to drinkable water is necessary. This study measured the levels of lead (Pb), chromium (Cr), and cadmium (Cd) in a few chosen water samples and examined the dangers to human health that resulted from ingesting exposure pathways. The analysis was done using Atomic Absorption Spectrometry (AAS) at the Central Laboratory, Bayero University Kano, Nigeria. Pb was the most common pollutant, according to analytical results, with amounts ranging from 0.013 to 0.333 mg/L, frequently surpassing the 0.01 mg/L WHO recommendation limit. While chromium remained largely undetectable, with a highest value of 0.038 mg/L, cadmium amounts varied from 0.008 to 0.020 mg/L. Children's lower body weight and higher water intake rates put them at a much higher risk than adults, according to health risk evaluations based on Average Daily Dose (ADD) and cancer risk estimates. For a number of samples, the cancer risk (CR) values were higher than the permitted limit of 1.0×10^{-4} set by the US Environmental Protection Agency (USEPA), suggesting possible health risks. Significantly, due mainly to higher lead concentrations, samples M4 (0.333), J5 (0.200), M1 (0.254), and K5 (0.203) posed the greatest health concerns. In order to safeguard children and other vulnerable groups, these findings emphasize the critical need for prompt remediation of the impacted water sources, limitations on their use, and the provision of safe substitute drinking water.

Keywords: Borno State, Nigeria. Kidney Disease, Heavy Metals, Health Risk Assessment, Water Contamination.

1. INTRODUCTION

In order to maintain life and promote good health, both humans and animals must have access to enough clean water [1]. The two main sources of water in the world are surface water, which includes rivers and lakes, and groundwater, which includes wells and boreholes [2]. Even though water makes up around 75% of the Earth, many people still lack access to clean drinking water. According to reports, 450 million people in 29 countries, mostly in Africa, lack access to safe drinking water, and around 1.1 billion people do not have access to an upgraded water supply [3]. The local population of Maiduguri, northeastern Nigeria, is mostly dependent on groundwater sources, such as hand-dug wells and boreholes, for their daily water needs due to the lack of surface water [3].

Protecting public health depends heavily on the quality of the water. Serious health issues like cancer, neurological impairments, organ damage, and waterborne illnesses can result from drinking tainted water [4]. Water contamination is a worldwide issue that is caused by both natural and man-made factors. Water quality is seriously deteriorated by contaminants such heavy metals, medications, and microplastics [5]. Through natural leaching, agricultural runoff, and industrial processes, heavy metals—which are harmful even at trace amounts due to their high density—enter the environment [6]. Human exposure happens when a person breathes in polluted air or consumes tainted food or drink [7]. Due to the nephrotoxic effects of metals like arsenic (As), lead (Pb), chromium (Cr), mercury (Hg), and cadmium (Cd), studies have connected exposure to heavy metals to a number of kidney conditions, including acute kidney injury (AKI) and chronic kidney disease (CKD) [8-10].

The quantities of lead (Pb), cadmium (Cd), and chromium (Cr) in water sources from a few chosen local governments in Borno State, northeastern Nigeria, are examined in this study along with any possible effects they may have on the prevalence of kidney disease. The Atomic Absorption Spectroscopy (AAS) method was used to determine the amounts of these metals in water samples. It is anticipated that the results will emphasize how urgently water quality problems must be resolved in order to lessen the prevalence of renal illnesses in the area. Additionally, the results of this study will guide the development of infrastructure, community education initiatives, and public health policies that aim to lower the prevalence of kidney-related diseases (Sustainable Development Goal 3: Good Health and Well-Being) and improve water quality (Sustainable Development Goal 6: Clean Water and Sanitation).

2. MATERIALS AND METHOD

2.1 Study Area

Borno State is located in the North-East geopolitical zone of Nigeria. It shares borders with Yobe State to the west for approximately 421 km, Gombe State to the southwest for 93 km, and Adamawa State to the south. To the east, Borno borders Cameroon for about 426 km (265 miles), with portions of the boundary running along the Ebedi and Kalia Rivers. The state's northern boundary forms part of Nigeria's national border with Niger Republic, extending approximately 223 km, mostly along the Komadougou-Yobe River. Its northeastern border, measuring about 85 km (53 miles), forms Nigeria's entire border with Chad, making Borno the only Nigerian state to share international borders with three different countries.

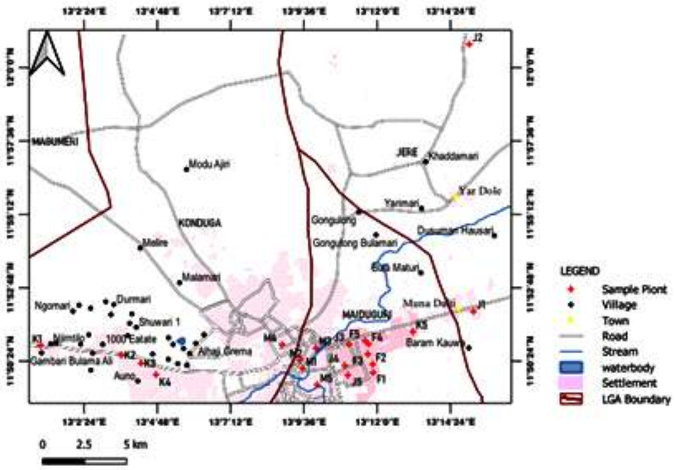

Figure 1: Map showing the location of the study area and   sampling points

The state derives its name from the historic Borno Emirate, with Maiduguri, the former capital of the emirate, serving as the modern capital city of Borno State. Established in 1976 following the dissolution of the former North-Eastern State, Borno originally included the territory now designated as Yobe State, which became a separate administrative entity in 1991 [11]. Maiduguri is the capital and largest city of Borno State, located in north-eastern Nigeria, on the African continent. Established in 1907 by British colonial administrators for governance and trade facilitation, Maiduguri has since evolved into the dominant urban center in the north-eastern region of Nigeria. Geographically, the city is situated within the Sudan-Sahel transition zone, lying between latitude 11°27′30″N and 11°33′1″N, and longitude 13°21′3″E and 13°91′10″E, covering a total land area of approximately 550 square kilometers [2].

Maiduguri is traversed by the Ngadda River, a seasonal watercourse that eventually disperses into the Firki swamps located near Lake Chad [12]. As of 2022, the city's metropolitan area was estimated to have a population of nearly two million residents. Maiduguri serves as the headquarters of the Maiduguri Metropolitan Council and is bordered by Jere Local Government Area to the north, Konduga Local Government Area to the south-west, and Mafa Local Government Area to the east. These surrounding areas constitute the broader study area for this research.

Table 1: Sampling locations with their corresponding coordinates

Name of location	**Sample ID**	**Coordinates**	
		Longitude	**Latitude**
Maiduguri			
Bulabulin	M1	13^{0}9’33.768’’ E	11^{0}50’9.912’’ N
Shehuri South	M2	13^{0}9’29.394’’ E	11^{0}.50’26.502’’N
kalari	M3	13^{0}9’59.7’’ E	11^{0}50’49.248’’N
Mafoni	M4	13^{0}8’53.178’’ E	11^{0}50’56.652’’N
Gwange	M5	13^{0}10’2.112”E	11^{0}49’37.602”N
Jere			
Dalakaleri	J1	13^{0}15’9.198”E	11^{0}52’1.746” N
Muna	J2	13^{0}15’0.936” E	11^{0}51’59.586” N
Mashamari	J3	13^{0}11’4.878” E	11^{0}50’57.714” N
London Ciki	J4	13^{0}10’56.538”E	11^{0}50’15.276”N
Ngomari	J5	13^{0}11’2.538” E	11^{0}49’56.652”N
Konduga			
Njimtilo	K1	13^{0}0’58.86” E	11^{0}50’54.834” N
Moromti	K2	13^{0}3’37.17” E	11^{0}50’36.114” N
Old Airport	K3	13^{0}4’16.326’’E	11^{0}50’19.74” N
Ngomari Airport	K4	13^{0}4’45.702” E	11^{0}49’57.432” N
Usmanti	K5	13^{0}13’1.326” E	11^{0}51’21.738” N
Mafa Local government			
Kaleri	F1	13^{0}11’52.284” E	11^{0}50’1.698” N
Zannari	F2	13^{0}11’51.288” E	11^{0}50’18.07” N
Fulatari	F3	13^{0}11’41.91” E	11^{0}50’37.848” N
Simari	F4	13^{0}11’43.338” E	11^{0}50’57.714” N
Simari Borehole	F5	13^{0}11’36.198” E	11^{0}51’4.14” N

2.2 Sample Collection

Water Samples: sample collection was carried out in twenty different locations across the four selected local government areas within Borno State. While taking the water samples, the boreholes were allowed to run for about 2 minutes before the water is taken and put into well-labeled 500ml plastic bottles thoroughly washed and rinsed with distilled water. The samples were acidified with Nitric acid (NHO_3) to prevent them from biological and chemical interactions.

2.3 Sample Preparation and Digestion

To determine the level of concentrations of heavy metal in the water sample, the samples were digested. This was done by taking 100cm^3 of each of the water samples and put them into beakers and 5ml of concentrated HNO_3 were added. The beaker together with the content was heated continuously until it got evaporated and reduced to 20ml. The beakers were allowed to cool before another 5ml of the concentrated HNO_3 was added. The beaker was covered with watch glass and placed on the hot plate again. The heating continued with addition of small amount of HNO^3 until the solution appeared light and clear. This marked the end of the digestion process. The watch glass and beaker walls were washed with distilled water and filtered to remove insoluble materials that could clog the atomizer. The filtrates were transferred to 100cm^3 volumetric flask and diluted to the mark with distilled water. These solutions were then used for the analysis in order to obtain the concentration of each of the targeted heavy metal [13].

2.4 Sample Analysis

Analysis of the digested water samples were determined for the heavy metals (Pb, Cd, Cr) using Atomic Absorption spectrometry (AAS) and this analysis aims to assess the quality of drinking water sources in Borno state. A State-of-the-art laboratory facility was used to analyze water samples to determine the level of concentrations of the selected heavy metals (Pb, Cd, Cr) at the Central Laboratory, Bayero University Kano, Nigeria. . Employing the above mentioned standard analytical technique, the samples were analyzed to determine the concentrations of heavy metals in the collected samples. This meticulous sampling and analysis approach aims to provide a comprehensive insight into the environmental conditions of Borno State and its potential correlation with kidney disease prevalence in the region.

2.5 Data Analysis

This evaluates the data obtained in quantifying heavy metals present in the study area. Perform statistical analyses to identify correlations between environmental contaminants and kidney function parameters. Utilize Geographic Information System (GIS) tools to spatially analyse contamination patterns and their potential impact on health.

2.6 Data Analysis and Validation

Here a comprehensive review and validation of collected data was done to ensure its accuracy and usability for decision-making.

Estimation of Average Daily Dose (ADD)

The Average Daily Dose (ADD) in mg/kg/day of selected heavy metals in the water samples, through ingestion of the water, was calculated for both adults and children using the relation from the World Health Organization [1]:

$$ADD = C_m \times IR_w \times \frac{EF \times ED}{BW \times AT} \tag{1}$$

where ADD is the average daily dose in *mg/kg/day*, C_m is the average heavy metal concentration in water measured in is *mg/L*, IR_w is the ingestion rate of water (*L/day)*, taken as 2.2 *L* for adults and 1.8 *L* for children, *EF* the exposure frequency, set to 365 days, *ED* is the exposure duration, which is 70 and 6 *years* for adults and children, respectively, *BW* is the average body weight, 70 *kg* for adults and 15 *kg* for children and *AT* is the average exposure time for the mean life expectancy, calculated as 365 multiplied by 70 for adults and 365 multiplied by 6 for children [14].

Carcinogenic Rirks (CR): Edokpayi, et al [14] also used this equation to estimate the carcinogenic risk (CR) through ingestion and this was also adopted in this research:

$$CRing = \frac{Exping}{SFing} \tag{2}$$

Where, CR_{ing} is the carcinogenic risk via ingestion route and SF_{ing} is the carcinogenic slope factor where Pb is 8.5E, Cd is 6.1E+03 and Cr is 5.0E+02 µg/kg/day.

3. RESULTS AND DISCUSSION

Cadmium (Cd), chromium (Cr), and lead (Pb) contents in the water samples varied, according to the study of heavy metal concentrations. From table 2, the average concentration of cadmium in all samples was 0.01275 mg/L, with a range of 0.008 to 0.020 mg/L. it was observed that the concentration in all the sampling areas exceeded the maximum permissible limit of 0.003 mg/L set by the Nigerian Standard for Drinking Water Quality (NSDWQ, 2007) [15] and the world health organization (WHO, 2022) [1] indicating that the water is not safe for consumption. The distribution of cadmium was fairly consistent across the samples, indicating possible widespread contamination. Contamination of water by cadmium and its compounds causes adverse health effects in human beings. This is because of incapability of the body to discharge cd. The metal is re-absorbed by the kidney, accumulating in the proximal tubular cells causing renal dysfunction and kidney disease [7].

Table 2: Concentrations of Heavy Metals (*Cd, Cr, Pb*) and Estimated Average Daily Dose (mg/kg/day) for Adults and Children in the Water Samples.

sample ID	Concentration (mg/L)			Average DailyDose for Adults			Average DailyDose for Children		
	Cd	**Cr**	**Pb**	**Cd(10^{-4})**	**Cr(10^{-4})**	**Pb**	**Cd**	**Cr(10^{-3})**	**Pb**
F1	0.013	BDL	0.013	4.086	BDL	0.0004	0.00156	BDL	0.00156
F2	0.012	0.038	0.017	3.771	11.94	0.0005	0.00144	4.56	0.00204
F3	0.014	BDL	0.066	4.400	BDL	0.0021	0.00168	BDL	0.00792
F4	0.013	BDL	0.076	4.086	BDL	0.0024	0.00156	BDL	0.00912
F5	0.012	BDL	0.027	3.771	BDL	0.0008	0.00144	BDL	0.00324
J1	0.013	BDL	0.066	4.086	BDL	0.0021	0.00156	BDL	0.00792
J2	0.014	BDL	0.062	4.400	BDL	0.0019	0.00168	BDL	0.00744
J3	0.014	BDL	0.076	4.400	BDL	0.0024	0.00168	BDL	0.00912
J4	0.014	BDL	0.137	4.400	BDL	0.0043	0.00168	BDL	0.01644
J5	0.02	0.023	0.2	6.286	7.23	0.0063	0.0024	2.76	0.024
K1	0.011	0.02	0.091	3.457	6.29	0.0029	0.00132	2.4	0.01092
K2	0.012	BDL	0.159	3.771	BDL	0.0050	0.00144	BDL	0.01908
K3	0.01	BDL	0.153	3.143	BDL	0.0048	0.0012	BDL	0.01836
K4	0.01	BDL	0.173	3.143	BDL	0.0054	0.0012	BDL	0.02076
K5	0.012	BDL	0.203	3.771	BDL	0.0064	0.00144	BDL	0.02436
M1	0.014	BDL	0.254	4.400	BDL	0.0080	0.00168	BDL	0.03048
M2	0.01	BDL	0.151	3.143	BDL	0.0047	0.0012	BDL	0.01812
M3	0.011	BDL	0.22	3.457	BDL	0.0069	0.00132	BDL	0.0264
M4	0.018	BDL	0.333	5.657	BDL	0.0105	0.00216	BDL	0.03996
M5	0.008	BDL	0.2	2.514	BDL	0.0063	0.00096	BDL	0.024
Average	**0.01275**	**0.027**	**0.13385**	**4.007**	**8.49**	**0.0042**	**0.00153**	**3.24**	**0.016062**
Maximum	**0.02**	**0.038**	**0.333**	**6.286**	**11.94**	**0.0105**	**0.0024**	**4.56**	**0.03996**
Minimum	**0.008**	**0.02**	**0.027**	**2.514**	**6.29**	**0.0008**	**0.00096**	**2.4**	**0.00324**

In Table 2, we can see that the majority of the samples had very low chromium contents; in fact, some samples had no measurable chromium at all. The average chromium concentration for all samples was 0.027 mg/L, with the maximum value recorded being 0.038 mg/L .This implies that chromium contamination in the studied area is either sporadic or confined. Even if the average concentration is low, isolated cases of detectable chromium are worth looking into further, especially to determine the source of the pollution and determine whether the chromium is in its known carcinogenic hazardous hexavalent form (Cr VI).

Among the metals examined, lead showed the greatest concentration and fluctuation, ranging from 0.013 to 0.333 mg/L with an average of 0.13385 mg/L. The World Health Organization's (WHO) recommended drinking water guideline of 0.01 mg/L is greatly exceeded by this level of contamination, making it noteworthy. The most common and worrisome contaminant in the study area is lead, which was continuously detected in the majority of samples and in significantly higher quantities than cadmium or chromium. The pervasiveness of lead in these water samples is a major public health danger that requires immediate treatment due to the well-established neurotoxic consequences of lead, particularly in children.

Because of their smaller bodies and comparatively higher water intake, children are more likely than adults to be exposed to heavy metals, according to the health risk assessment based on the computed Average Daily Dose (ADD). The lead (Pb) ADD readings are especially alarming, with estimations that are much higher in samples like M4, M1, and K5. These high ADD scores point to the possibility of prolonged exposure, especially in susceptible groups like youngsters. Despite having relatively lower ADD values, cadmium (Cd) and chromium (Cr) have cumulative health consequences that cannot be disregarded over time, especially for cadmium.

According to the Incremental Cancer Risk evaluation, the main causes of carcinogenic risk are lead (Pb) and, to a lesser extent, chromium (Cr). Cadmium is classified as a toxicant that is predominantly non-carcinogenic but nonetheless detrimental through other pathways since its cancer risk values are very low or nonexistent. Interestingly, when taking into account the cumulative effects of several pollutants, the cancer risk (CR) estimations for many samples approach or surpass tolerable risk thresholds. Given Pb's substantial correlation with neurological and developmental issues, this emphasizes the necessity of taking prompt mitigation actions to lower exposure levels.

Table 3: Carcinogenic Risk Assessment (CR_{ing}) of Cd, Cr and Pb for Adults and Children

sample ID	***Carcinogenic risk(CR_{ing}) for Adults***			***Carcinogenic risk(CR_{ing}) for Children***		
	Cd(10^{-8})	**Cr(10^{-6})**	**Pb**	**Cd(19^{-7})**	**Cr (10^{-6})**	**Pb**
F1	6.698	BDL	0.048	2.557	BDL	0.184
F2	6.183	2.389	0.063	2.361	9.12	0.240
F3	7.213	BDL	0.244	2.754	BDL	0.932
F4	6.698	BDL	0.281	2.557	BDL	1.073
F5	6.183	BDL	0.100	2.361	BDL	0.381
J1	6.698	BDL	0.244	2.557	BDL	0.932
J2	7.213	BDL	0.229	2.754	BDL	0.875
J3	7.213	BDL	0.281	2.754	BDL	1.073
J4	7.213	BDL	0.507	2.754	BDL	1.934
J5	10.304	1.446	0.739	3.934	5.52	2.824
K1	5.667	1.257	0.336	2.164	4.8	1.285
K2	6.183	BDL	0.588	2.361	BDL	2.245
K3	5.152	BDL	0.566	1.967	BDL	2.160
K4	5.152	BDL	0.640	1.967	BDL	2.442
K5	6.183	BDL	0.751	2.361	BDL	2.866
M1	7.213	BDL	0.939	2.754	BDL	3.586
M2	5.152	BDL	0.558	1.967	BDL	2.132
M3	5.667	BDL	0.813	2.164	BDL	3.106
M4	9.274	BDL	1.231	3.541	BDL	4.701
M5	4.122	BDL	0.739	1.574	BDL	2.824
Average	**6.569**	**1.697**	**0.495**	**2.508**	**6.48**	**1.890**
Maximum	**10.304**	**2.389**	**1.231**	**3.934**	**9.12**	**4.701**
Minimum	**4.12**	**1.257**	**0.100**	**1.574**	**4.8**	**0.381**

Table 3 presents the Carcinogenic Risk Assessment (CR_{ing}) for the water samples and figures 2 and 3 present the carcinogenic profiles for adults and children. The average values of cancer risk for Cd, Cr and Pb computed for adults are: 6.569 x10^{-8}, 1.697 x 10^{-6} and 0.495 respectively. The average computed for Cd and Cr are higher than 10^{-6} which is an indication that the water could pose serious health issue to an individual consuming the water. The average values obtained for children are: 2.508 x 10^{-7}, 6.48 x 10^{-6} and 1.890 respectively. All the values computed for children are higher than the recommended limits of 10^{-6} which could pose serious carcinogenic health problem for children. Children's heightened susceptibility is reflected in this persistent rise in risk. Samples J5, M4, M1, and K5, which correspond to samples with high lead contents, had the highest overall hazards. According to these results, a number of water sources are extremely dangerous for human health, especially for young people, and prompt repair is necessary to avoid long-term negative health effects in the impacted communities.

The health risks associated with the examined water samples are a significant cause for worry when compared to established safety criteria. Guidelines from the US Environmental Protection Agency (USEPA) state that a Cancer Risk (CR) of more than 1.0×10^{-4} is considered possibly unacceptable and calls for public health measures. Several samples in the current study exceed or come close to this crucial threshold, especially when evaluating children whose physiological and behavioral traits make them more susceptible to harmful exposures.

Children's cancer risk estimations are highest in samples like J5 (2.824), M4 (4.701), M3 (3.106) and M1 (3.586). The high lead (Pb) contents found in these samples are highly correlated with these heightened risk levels. Even though adult danger levels are often lower than those of children, some samples nevertheless show values that are close to the USEPA threshold, suggesting that prolonged exposure may have long-term health effects. These samples persistent overabundance of allowable limits points to ongoing water source contamination, most likely caused by human activities such industrial discharge, inappropriate waste disposal, or plumbing material deterioration.

The necessity of taking corrective action is highlighted by the discovery of water samples that are above the USEPA cancer risk limit. Limiting the use of tainted water sources for drinking and food preparation, offering substitute safe water sources, and tracking sources to determine and lessen contamination sources are all examples of public health initiatives. To guarantee the long-term safety of the impacted communities, regular monitoring and health risk assessments should also be put in place, with an emphasis on safeguarding vulnerable subpopulations like youngsters and expectant mothers.

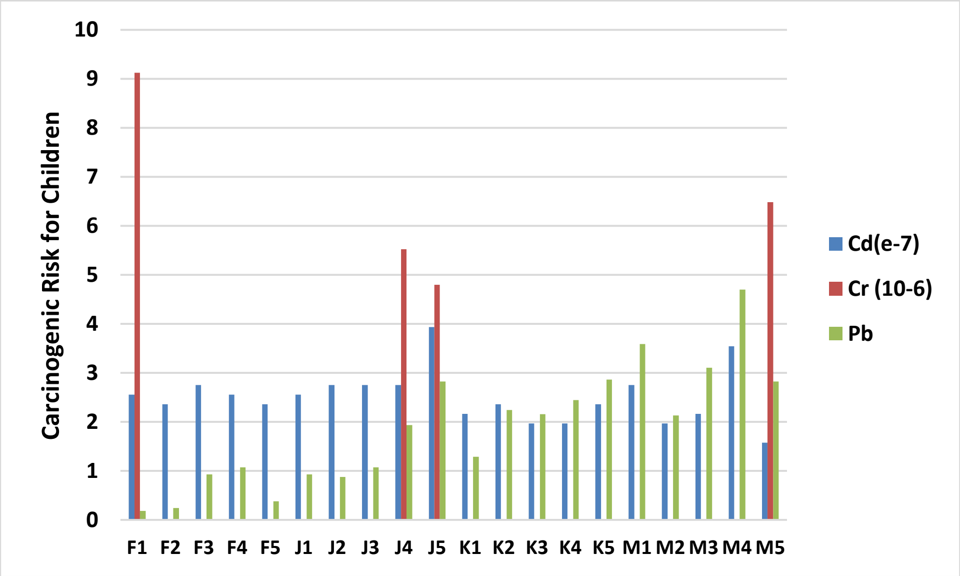

Figure 2: Profile of the Carcinogenic Risk for Children

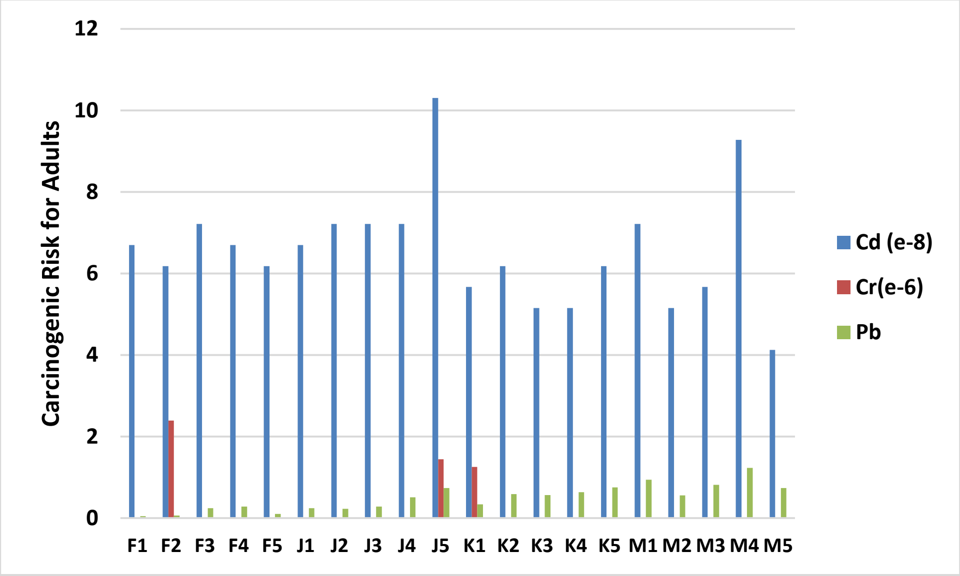

Figure 3: Profile of the Carcinogenic Risk for Adults

The carcinogenic risk (CR) of heavy metals in water for adults and children is shown in Figures 2 and 3, respectively. Across all studies, a distinct pattern shows that children routinely have higher CR values than adults. Children's smaller body mass, higher water intake per kilogram, and developmental sensitivity to toxic exposures all contribute to their increased vulnerability, highlighting the importance of taking age-specific risk assessments into account in environmental health research.

In both populations, lead (Pb) is the primary cause of carcinogenic risk. The greatest CR values are seen in samples J5, M4, M1, and K5. Children's risk in sample M4 is 4.701, significantly higher than the USEPA threshold of 1×10^{-4}. This highlights the serious health risks posed by lead pollution in these water sources, especially for young people, and emphasizes how urgent remediation and public health measures are.

The occasional contribution of chromium (Cr) to CR is in line with the modest quantities seen in Table 2. Certain samples have CR values that are marginally above the 10^{-6} limit, while other samples have undetectable Cr levels and negligible presence. Due to extremely low concentrations in the water samples under study—the majority of CR values are considerably below the suggested threshold—cadmium (Cd), despite its toxicity, has no effect on the risk of cancer.

Pb-rich samples are the most dangerous, and the spatial distribution of risk shows localized contamination hotspots. Anthropogenic activities like industrial discharge, poor waste management, and plumbing material deterioration are probably the cause of these hotspots. Children are at non-negligible risk from cumulative exposure to many metals, even from samples with lower levels of contamination.

The data show that adults typically stay below or close to the USEPA CR level, indicating moderate risk, when compared to youngsters. Chronic exposure, however, may still have long-term negative health impacts. On the other hand, CR values for children in several samples are higher than acceptable bounds, suggesting potentially intolerable health risks and the need to give younger populations priority for solutions.

The study's important public health implications are further supported by the combined findings from Figures 2 and 3. Limiting the use of tainted water, offering substitute clean water sources, and carrying out routine monitoring are all urgent steps that must be taken to reduce exposure. To avoid long-term health effects, targeted interventions should concentrate on high-risk locations and vulnerable populations, especially youngsters and expectant mothers.

All things considered, the data showed that lead is the main cause of carcinogenic risk, with chromium and cadmium playing a smaller role. A number of water sources surpass safe risk criteria, and children are disproportionately impacted, underscoring the study area's ongoing contamination. In order to protect vulnerable groups, these findings highlight the necessity of prompt repair, ongoing health risk assessments, and community-focused public health initiatives.

4. CONCLUSION

In conclusion, the evaluation of heavy metal contamination in the examined water samples points to a serious public health issue, especially in light of the high levels of lead (Pb) and the health hazards that go along with it. Both adults and children, particularly the latter, are exposed to potentially hazardous levels of these pollutants, according to the projected average daily doses and cancer risk values. The urgent need for action is highlighted by the fact that several samples, most notably M4, J5, M1, and K5, exceed the USEPA's tolerable cancer risk threshold.

The results highlight the need for prompt corrective measures to limit the use of tainted water sources and to offer safe substitutes for household and drinking usage. Additionally, preventing future exposure requires addressing the underlying sources of contamination through source control and environmental assessment. In order to reduce hazards and promote community health protection, stakeholder participation and public awareness will be crucial.

In the end, maintaining long-term safety requires consistent work in risk assessment, infrastructure upgrades, and water quality monitoring. Public health officials and environmental regulators in the area should continue to place a high premium on shielding vulnerable groups, especially children, from long-term exposure to dangerous chemicals in drinking water.

5. RECOMMENDATIONS

To protect public health, a number of crucial suggestions are put forth in light of the levels of contamination that have been discovered and the health hazards that are linked to them. First and foremost, priority should be given to urgent remediation operations or limiting the use of water from high-risk samples, especially M4, J5, M1, and K5. These water sources present serious health dangers due to lead concentrations and overall cancer risks that are higher than allowable limits. The use of these water sources for drinking and food preparation should be stopped until remediation is finished, and temporary substitute water sources should be made available.

Second, in order to determine and address the causes of lead contamination in the impacted areas, a thorough assessment ought to be carried out. Agricultural runoff, rusted plumbing systems, industrial discharges, and inappropriate waste disposal techniques are a few examples of potential causes. Finding these origins is crucial to putting into practice long-term pollution control strategies and averting recurrence in the future. Campaigns for public awareness should also be carried out to inform the public about possible exposure routes and measures to avoid them.

Finally, to identify any new trends in contamination, long-term plans should involve routine water quality monitoring in these and nearby locations. To eliminate heavy metals from the water supply, suitable water treatment equipment, including filtration or chemical precipitation units, may also need to be installed. A safe and sustainable water environment will require ongoing cooperation between environmental health organizations, water management authorities, and the community, especially to shield vulnerable populations like children from long-term exposure hazards.

REFERENCES

[1] WHO. (2022). Guidelines for Drinking Water Quality: Fourth Edition incorporating the first and second addenda. World Health Organization.

[2] A. Musa, B. M. Mala; L.K.Bukar and N. A. Wakil (2023). Quality assessment of borehole water in terms of selected physicochemical parameters in Maiduguri urban areas, Borno State, Nigeria. Journal of Applied Science and Environmental Management, 27(1), 5–8. https://www.ajol.info/index.php/jasem

[3] Y. M. Mshelia, D. M. Lawan, M. Arhyel and J. Inuwa (2023). Physicochemical analysis and water quality assessment of selected locations in Maiduguri metropolis using weighted arithmetic water quality index.

[4] M. O. Ezugwu, F. O. Akhimien (2022). Review of the effects of water characteristics and quality on human health. International Journal of Current Science Research and Review, 5(3). https://doi.org/10.47191/ijcsrr/v5-i3-09

[5] P. Babuje, S. Thirumalaisamy & K. Duraisamy (2023). Human health risks due to exposure to water pollution: A review. Water, 15(14), 2532. https://doi.org/10.3390/w15142532

[6] W. Jadaa, & H. Mohammed (2023). Heavy metals—Definition, natural and anthropogenic sources of release into ecosystems, toxicity, and removal methods: An overview study. Journal of Ecological Engineering, 24(6), 249–271. https://doi.org/10.12911/22998993/162955

[7] A. H. Sani, A. Musa and M. D. Achimugu (2023). Assessment of heavy metal pollution of drinking water sources and staple food cultivars around artisanal mining site in Igade–Mashegu, Niger State, Nigeria. World Journal of Biology Pharmacy and Health Sciences, 14(2), 306–319. https://doi.org/10.30574/wjbphs.2023.14.2.0162

[8] E. Iwunze, C. Kanu, C. Tobin-West, & B. Ordinioha (2023). Heavy metal exposure and renal impairment: A systematic review of observational studies. The Nigerian Health Journal, 23(3), 717–733.

[9] E.M. khalaf, M. Taherian., S. G. Almalki, P. Asban, A. K. Kareem, F. R. Alhachami, A. F. Almulla, R. M. Romero-Parra, Z. H. Jawhar, F. Kiani, I. N. M & M. J. Mohammadi (2023). Relationship between exposure to heavy metals and the increased health risk and carcinogenicity of the urinary tract (kidney and bladder). Reviews on Environmental Health. https://doi.org/10.1515/reveh-2022-0245

[10] H. M. Hussein & M. S. Aljashamy (2023). Investigation of some heavy metals on parameters of blood and oxidative enzymes in CKD in Iraq-Al-Qadisiyah. IOP Conference Series: Earth and Environmental Science, 1215, 012058. https://doi.org/10.1088/1755-1315/1215/1/012058

[11] R. Kawka (2002). The physiognomic structure of Maiduguri. In R. Kawka (Ed.), From Bulamari to Yerwa Metropolitan Maiduguri: Interdisciplinary studies on the capital of Borno State, Nigeria (pp. 22–33). Rudiger Koppe Verlag, Köln.

[12] M. M. Daura (2001). The physical environment and development: A study of Borno region. In M. M. Daura, O. Ogunnika, D. Irefin, & D. Balami (Eds.), Environment and development: Issues in sub-Saharan Africa (Seminar series Vol. 1, pp. 35–47). Faculty of Social and Management Sciences, University of Maiduguri.

[13] S. Nasiru. A. Aliyu, M. H. Garba, S. M. Dambazau, A. Nuraddeen, A. Babandi, & M. Ya'u (2021). Determination of some heavy metals in groundwater and table water in Tudun Murtala, Nassarawa Local Government Area, Kano, Nigeria. https://doi.org/10.4314/dujopas.v7i4b.13

[14] J. N. Edokpayi, A. M. Entina, N. Mutileni & J. O. Odiyo (2018). Evaluation of water quality and human risk assessment due to heavy metals in groundwater around Muledane area of Vhembe District, Limpopo Province, South Africa. Chemistry Central Journal, 12(2). https://doi.org/10.1186/s13065-017-0336-9

[15] Nigerian Standard for Drinking Water Quality (NSDWQ). (2007). Nigerian Industrial Standard, NIS 554:2007 ICS 13.060.20.

Bayero Journal of Physics and Mathematical Sciences / Vol. 17, No. 1 / Feb., 2026. ISSN: 1597 – 9342, Online ISSN: 2795 - 3866

BAJOPMAS JOURNAL 17(1): 14 – 25
Printed in Bayero University, Kano - Nigeria.

COMPARATIVE ANALYSIS OF PROPORTIONAL INTEGRAL DERIVATIVE (PID) AND MODEL PREDICTIVE CONTROL (MPC) CONTROLLERS FOR SHUNT DC MOTOR SPEED REGULATION

Abdullahi, B.; Gaya, M. S. and Shehu, N. M.
Department of Physics, Bayero University Kano, Nigeria

ABSTRACT

Conventional controllers such as Proportional Integral Derivative (PID) are simple and easy to design and implement, but often compromise control quality under varying conditions. In contrast, intelligent controllers offer superior adaptability at the cost of design and tuning complexity. Hence, a comparison is necessary to achieve a suitable trade-off between simplicity and control quality in systems like Direct Current (DC) shunt motor speed control. A shunt DC motor has its field windings connected in parallel (shunt) with the armature windings. This configuration gives the motor numerous advantages, such as ease of control, low armature reaction, quick response and durability, among others. This paper presents a comparison of Model Predictive Control (MPC), PID tuned using Ziegler Nichols, and PID-based Internal Model Control (IMC) approaches for speed control of the shunt DC motor. The controllers are tested through simulation under three distinct input scenarios, namely unit step, variable step, and random integer generator signals. Their performances are evaluated using standard control measures, including Rise Time, Settling Time, Overshoot, Integral of Absolute Error (IAE), and Control Effort. In each case, MPC records the lowest overshoot of 0%, 143% and 15.3% thereby demonstrating greater efficiency by minimizing control effort. However, PID_IMC achieves the lowest IAE, ranging from 0.3 to 12.3 (rad/s) and maintains the fastest settling time of 1.5 seconds, though all the controllers settle at the same time (15 seconds) for the random integer generator input. These results highlight the trade-off between accuracy and robustness: PID_IMC provides better accuracy in terms of tracking error, while MPC ensures robustness, lower overshoot, and reduced actuator demand, making it more suitable for systems operating under unpredictable conditions. The findings aim to assist control engineers in selecting where and when to choose between conventional PID and modern control techniques.

Keywords: Internal Model Control (IMC), Model Predictive Control (MPC), Overshoot; Proportional Integral Derivative (PID), Shunt DC motor.

1.0 INTRODUCTION

PID controller is a classic feedback controller that computes the corrected control signal *u*(*t*) as a combination of proportional, integral, and derivative terms of the error e(t). It is one of the famous and widely used conventional controllers, due to its simple and easy design and implementation process, but often compromises control quality under varying conditions. MPC, on the other hand, is an optimization-based control strategy that solves a finite-horizon control problem at each sampling instant, predicting future behavior to minimize a cost function. MPC is known for various advantages that include robustness, disturbance rejection, explicit constraint handling and adaptability despite its complex design and tuning process.