EVALUATION OF CHEMICAL POLLUTANTS AND ASSOCIATED HEALTH-RISK FROM THREE WATER SOURCES IN BALI METROPOLIS, BALI LGA, TARABA STATE

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ABSTRACT

A pollutant is any substance that interacts with an environment and is capable of causing harm to both organisms and the environment itself. Examples of chemical pollutants include; heavy metals, pesticides residues etc. Three water samples were collected in a clean 750ml container from different sources (river, borehole and well) in different areas of Bali town, Bali local government area of Taraba State. Heavy metal concentration and physicochemical analysis was carried out. Results from analysis showed mean iron (Fe) concentration to be 24.52mg/L (river), 4.13mg/L (Well) and 3.12mg/L (borehole) which are higher in all the water samples when compared with the iron tolerable limits of 0.3mg/L by World Health Organization (WHO), United States Environmental Protection Agency (USEPA) and Nigerian Standard for Drinking Water Quality (NSDWQ) whereas, zinc (Zn) and cupper (Cu) are only higher in river water with a tolerable limit of 5.0mg/L, manganese was found to be higher in all the water samples analyzed with a tolerable limit of 0.1 mg/L which was slightly higher compared to those of standards. The Physicochemical parameters analyzed showed that river water was more turbid with a value of 6.4NTU which was above tolerable limit of 5.0NTU as contained in the standard. However, river water with a higher conductivity value of 344.15uS/cm was still below the tolerable limits of 1000μS/cm when compared with water samples from well and borehole. Proper water treatment was recommended to be carried out on the water from well, borehole and river sources before human consumption in order to prevent bioaccumulation which may lead to health-related problems associated with its consumption.

Key Words: Pollutants, Environment, Health, Risk, Evaluation, Chemical.

INTRODUCTION

Over the decades, environmental pollution has been of great concern largely due to increased industrialization and urbanization. Improvement in human living standards is on the steady rise owing to the production of goods, provision of employments as well as generation of waste. However, waste disposal stemming from these activities has constituted serious global environmental concern resulting in increased rate at which chemical pollutants are released into the atmosphere, soil, plants and water. Hence, affecting both human and the rest of biota. Environment can be considered as the general condition surrounding an organism or group of organisms i.e the combination of external physical conditions that affect and influence the growth, development and survival of organisms (Farlex, 2005). Environment consists of; flora, fauna and the abiotic, which includes; aquatic, terrestrial and atmospheric habitat. Environmental contaminants are substances that are present in the natural environment at levels higher than their permissible limits (Rahman and Singh, 2019). Pollutants can be defined as any substance(s) in the environment that poses the potential to cause harm and interferes with the integrity of the environment thereby reducing the quality of life and may eventually cause death. Such a substance has to be present in the environment beyond tolerance limit (Duruibe *et al.,* 2007). Examples of chemical pollutants include; heavy metals such as; arsenic (As), chromium (Cr), lead (Pb), cadmium (Cd) etc. other forms of chemical pollutants also exist as; oxides of carbon, nitrogen and sulphur (COx, NOx, SOx), chlorofluorocarbons (CFCs), chemical fertilizers (anhydrous ammonia etc.) and organochlorine compounds (polychlorinated biphenyls [PCBs]) (Tchounwou *et al.*, 2012).

Chemical pollutants are toxicants that cause acute illnesses in aquatic creatures, absorption of heavy metals in the food chain in aquatic creatures may result in occasional fever, cramps, kidney impairment, and hypertension in humans. Fish play an important role in chemical pollutant biomagnification since they are at the top of

the food pyramid and act as permitted transfer media to humans. Chemical pollutants may be extremely harmful to humans, causing toxic and carcinogenic effects as well as oxidative degradation of biological macromolecules (Taslima *et al*., 2022).
Heavy metal breakdown in water sources is a significant environmental hazard that negatively affects plants, animals, and human health (Briffa *et al.,* 2020). When heavy metal ions enter the human body, they initiate various processes in the body, for instance, Cr (VI), Pb (II), and As (III) interfere with metabolic pathways by inhibiting enzymatic activities. Some ions of heavy metal bond with sulfhydryl groups, to forms reactive oxygen species (ROS) in biological systems causing oxidative stress, leading to the inactivation of macromolecules and significant decrease in the glutathione levels of the body (Nita & Grzybowski, 2016). Consequently, both humans and animals suffer from a wide range of harmful effects including congenital disorders, immune system problems, and cancer, among many others (Ray *et al.,* 2014).
The utilization of natural resources at a careless rate creates disturbances in the environment and causes several related environmental and health problems. Environmental pollution stemming from chemical pollutants such as heavy metals and others come from different sources which include urban-industrial aerosols, solid and liquid wastes, mining activities, factory/industrial effluents, emissions, and agricultural chemicals (Jarup, 2003).

Statement of Problem

Human activities such as mining and bush burning results in the production of harmful substance which invariably gets into bodies of water. Similarly, trace metals arising from geographical processes such as weathering of rocks and volcanic eruptions leaches into rivers, lakes, oceans and underground water due to the action of water thereby causing water pollution leading to various human health challenges. These elevated levels of chemical pollutants present in water are of great environmental concern.

Aim and Objectives

The aim of the research was to assess chemical pollutant levels in three different water sources from Bali town, Bali LGA, Taraba State.
The objectives are:

1. to determine heavy metal contents in the water samples

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2. to determine some physicochemical parameters, present in the water samples

Significance of the Study

Bali town, endowed with mountains, rocks, rivers and land, made it possible for massive agricultural practices, mining and quarry activities. These practices contribute to the rate at which chemical pollutants are generated and transmitted into water bodies. Water been a major part of livelihood is used for various domestic purposes by the teaming population within Bali locality, in which little or no research was carried out in order to investigate its healthiness and risk associated with its usage. This research will investigate the heavy metal contents as well as physicochemical properties of the selected water samples so as to make the findings public and to create awareness about the findings.

Scope of the Study

The study was restricted to Bali town only, Bali local government area of Taraba State.

LITERATURE REVIEW

Chemical pollutants

Lenntech (2004) defined the term “chemical pollutant” to refer to any metallic element and or compounds that has a relatively high density and is toxic or poisonous even at low concentration. Chemical pollutants such as, heavy metal occur as natural constituents of the earth crust, and become persistent environmental contaminants because they cannot be degraded or destroyed. In rocky state, they exist as ores in different chemical forms from which they are obtained as minerals. Heavy metal ores include sulphides, such as iron, arsenic, lead, lead-zinc, cobalt, gold, silver and nickel sulphides. They also include oxides such as; aluminium, manganese, gold, selenium and antimony. Some exist as both sulphide and oxide ores for example, iron, copper and cobalt. Ore minerals tend to occur as a family, they exist naturally and occur together as sulphides, just like oxides. Hence, sulphides of lead, cadmium, arsenic and mercury would naturally be found occurring together with sulphides of iron (pyrite, FeS^{2+}) and copper (chalcopyrite, $CuFeS^{2+}$) as minors. They can be obtained

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as by-products of various hydrometallurgical processes or as part of exhaust fumes in pyrometallurgical and other mining processes involved in obtaining them.

During mining processes, some metals are left behind as tailings scattered in open and partially covered pits, some are transported through wind and flood thereby creating various environmental problems, heavy metals are basically recovered from their ores by mineral processing operations.

Generally, heavy metals (a chemical pollutant) are naturally occurring components of the earth's crust with large differences in concentrations. However, pollutions from human activities have contributed to the high occurrence of chemical pollutants in the ecosystem (Rasmussen *et al.,* 2007). The following are few examples of chemical pollutants (heavy metals); arsenic (As), chromium (Cr), lead (Pb), and cadmium (Cd). These chemical pollutants are toxic to humans (Tchounwou *et al.*, 2012).

Occurrence of chemical pollutants

Chemical Pollutants are everywhere in the environment as a result of both natural and anthropogenic activities. Basically, there are two main sources of chemical pollutants namely; Natural and Anthropogenic sources. The principal natural sources of these toxic chemical pollutants occur through; leaching, weathering, volcanic eruptions, etc. During the weathering process, rocks, soil, and minerals are broken down by interactions between elements for example, oxygen and water, living organisms and the atmosphere (Bundschuh *et al.,* 2021). Anthropogenic sources of heavy metal pollution involve agricultural activities, such as the application of pesticides and herbicides, contaminated irrigation water and utilization of municipal waste for fertilization purposes (Bakshi *et al.,* 2018). Additionally, anthropogenic sources of chemical pollutants include waste disposal in farmland, mining activities, smoking, traffic emissions, discharge of sewage, and building materials like paints (Su *et al.,* 2014).

Heavy metals may last long in the environment, remain undecomposed and enter the body through food, air, water and are accumulated biologically over a period of time. Meanwhile, pollution from the activities of humans has introduced chemical pollutants into the ecosystem (Rasmussen *et al.,* 2007).

The presence of chemical pollutants (heavy metals and others) in water bodies may come from both natural and man-made sources (anthropogenic). Volcanic eruptions, weathering of metal-containing rocks, sea-salt sprays, forest fires, and natural weathering processes can all lead to the release of metals from their native skies into various environmental sections (Nikiema and Asiedu, 2022). Heavy metals can be found in a variety of forms, including hydroxides, oxides, sulfides, sulfates, phosphates, silicates, and organic compounds.

Sources of chemical pollutants

Chemical pollutants are found naturally on the Earth's crust since the Earth's formation. Due to the astounding increase in heavy metals concentration, it has resulted in an imminent surge of metallic substances in both terrestrial and aquatic environment (Gautam *et al*., 2016).

Natural sources of chemical pollution include; volcanic activities, metal corrosion, metal evaporation from soil and water, sediment re-suspension, soil erosion and geological weathering. These produces chemical pollutants that results in the pollution of the ecosystem (aquatic environment) (Bradl, 2005).

Anthropogenic sources of chemical pollutants stem from human activities and is the major cause of chemical pollution in aquatic environment. Some anthropogenic activities leading to release of chemical pollutants are discussed below;

Volcanic Activities

Volcanic ash is a product of explosive volcanic eruptions and can be carried to a destination far away from the site at which the volcano erupted (Ma and Kang, 2022). Volcanic ash, spills into the aquatic environment leading to contamination as well as influence turbidity and acidity. Surface coatings on fresh volcanic ash are very acidic due to the action of aerosols containing strong mineral acids such as H_2SO_4, HCl, and HF in the plume. As a result, when freshly erupted ash comes into contact with aquatic environment, it can reduce the pH beyond safe levels for aquatic life preservation (Guffanti and Tupper, 2015).

Pesticides and Herbicides

Pesticides are chemicals used to kill pests such as insects, fungi and rodents. While herbicides are used to kill weeds (undesired grasses around farms). After the second world war, pesticides such as dichlorodiphenyltrichloroethane (DDT), which were highly toxic, persistent and bioaccumulating were commonly used in agriculture and for vector control (e.g. against the Anopheles mosquito, for malaria control). Chemicals that exhibit the characteristics of DDT (i.e. high toxicity, persistence and bioaccumulation) are termed persistent organic pollutants (POPs), and most of the POPs are pesticides. Pesticides have been found to be carcinogenic in experimental animals, and therefore are possibly carcinogenic to humans. POPs can be transported by wind (e.g. from combustion and high-temperature processes such as those in the iron and steel industry) and water, and as such can affect areas far from the point of their use. Their persistence in the environment, and their potential to move up the food chain, led to the Stockholm Convention of 2001, under which nations agreed to reduce or eliminate the production, use and/or release of POPs (Stockholm Convention, 2008).

Organophosphates (such as malathion, diazinon and chlorpyrifos) are insecticides containing phosphorus. Pyrethroids (synthetic versions of the short-lived natural pesticide pyrethrin, which is made from chrysanthemum flowers) are another category of insecticide, often used by householders to control pests such as leaf-eating insects and ants. Organophosphates and pyrethroids can attach to soil particles and get washed into rivers and streams, endangering aquatic life. Amongst the POPs are polychlorinated biphenyls (PCBs), which are a group of organic chemicals used in a variety of ways (e.g. as hydraulic fluids, plasticisers, fire retardants, heat transfer fluids, paint additives, lubricants and cutting oils), the main problem with manufactured substances such as pesticides is that most are unknown in nature and thus organisms have not evolved to deal with many of them (EPA, 2012).

Although the National Agency for Food and Drugs Administration and Control (NAFDAC) in Nigeria has enforced laws on the regulation, registration importation, manufacturing, formulation, advertising and distribution on these pesticide products. Despite all the stipulated laws, there are still evidence of their continuous usage in agriculture and public health sector in the country. This is as a result of inappropriate regulatory control on production, lack of enforcement and lack of logistic to monitor its importation and use of these chemicals. The distribution of pesticides in Nigeria lacks organization making it very difficult to access the market size and types of

pesticides used in the country together with the poor statistics on the amount of pesticide imported into Nigeria (Osinbajo, 2002).
Studies have shown the presence of high levels of dominant persistent organochlorine pesticides like aldrin, dieldrin, DDT, DDE, DDD, lindane, heptachlor and endosulfan in most water and sediments from major Nigerian rivers is generated from agricultural and industrial activities. Significant concentration of lindane and Aldrin which ranged from 0.4867-0.7731 ppb was detected in water samples from Ogba, Ikoro and Ovia rivers in Edo state. High concentrations of these OCPs observed was accrued to extensive use of Lindane marketed as gamalin 20 for fishing alongside with intense run-offs from agricultural farms due to high usage of Aldrex-40 for crop protection (Ize-iyamu *et al*., 2007).

Mining

Global industrialization and urbanization have increased the anthropogenic component of chemical pollutants in the atmosphere. Mining, smelting, power plant waste, and industrial and agricultural operations are all common anthropogenic sources of chemical pollutants. Certain metals are released into the environment through mining and the extraction of certain elements from their ores (Adnan *et al*., 2022). Heavy metals released into the atmosphere by mining, smelting, and other industrial activities are caused by dry and wet deposition. They are added to the environment via wastewater discharges such as industry effluents and residential faeces (Sharma and Agrawal, 2005). Elements commonly found in wind-blown dust come from industrialized areas. Vehicle exhaust, which emits lead; smelting, which liberates arsenic, copper, and zinc; pesticides, which emit arsenic; and the combustion of fossil fuels, which emit nickel, vanadium, mercury, selenium, and tin, are all substantial contributors to chemical pollution in the environment. Individual actions contribute to environmental degradation owing to the everyday creation of assets to meet the needs of consumers (Purves, 2012).

Emission of Chemical Pollutants

Chemical pollutants can be emitted into the environment by both natural and anthropogenic causes. The major causes of emission are the anthropogenic sources specifically mining operations (Nriagu, 1989). In some cases, even long after mining activities have ceased, the emitted metals continue to persist in the environment. Peplow (1999), reported that hard rock mines operate from 5-15 years until the minerals are depleted, but metal contamination that occurs as a consequence of hard rock mining persist for hundreds of years after the cessation of mining operations. Apart from mining operations, mercury is introduced into the environment through cosmetic products as well as manufacturing processes like making of sodium hydroxide. Heavy metals are emitted both in elemental and compound (organic and inorganic) forms. Anthropogenic sources of emission are the various industrial point sources including former and present mining sites, foundries and smelters, combustion by-products and traffics (UNEP / GPA, 2004). Cadmium is released as a by- product of zinc (and occasionally lead) refining, lead is emitted during its mining and smelting activities, from automobile exhausts (by combustion of petroleum fuels treated with tetraethyl lead antiknock) and from old lead paints, mercury is emitted by the degassing of the earth's crust. Generally, metals are emitted during mining and processing activities (Lenntech, 2004). Environmental pollution by heavy metals is very prominent in areas of mining and old mine sites and pollution reduces with increasing distance away from mining sites (Peplow, 1999). These metals are leached out and in sloppy areas, are carried by acid water downstream or run-off to the sea. Through mining activities, water bodies are most emphatically polluted (INECAR, 2000). The potential for contamination is increased when mining exposes metal-bearing ores rather than natural exposure of ore bodies through erosion (Garbarino *et al*., 1995), and when mined ores are dumped on the earth surfaces in manual dressing processes. Through rivers and streams, the metals are transported as either dissolved species in water or as an integral part of suspended sediments, (dissolved species in water have the greatest potential of causing the most deleterious effects). They may then be stored in river bed sediments or seep into the underground water thereby contaminating water from underground sources, particularly wells; and the extent of contamination will depend on the nearness of the well to the mining site. Wells located near mining sites have been reported to contain heavy metals at levels that exceed drinking water criteria (Garbarino *et al*., 1995; Peplow, 1999).

Chemical Pollutants and Chemistry of Pollution

Mining activities and other geochemical processes often result in the generation of acid mine drainage (AMD), a phenomenon commonly associated with mining

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activities. It is generated when pyrite (FeS^2) and other sulphide minerals in the aquifer and present and former mining sites are exposed to air and water in the presence of oxidizing bacteria, such as *Thiobacillus ferrooxidans*, and oxidised to produce metal ions, sulphate and acidity (Ogwuegbu and Muhanga, 2005).

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + 2H_2SO_4$$

$$2FeSO_4 + 2H_2SO_4 \rightarrow Fe_2(SO_4)_3 + SO_2 + 2H_2O$$

$$Fe_2(SO_4)_3 + 2FeAsS + 9/2O_2 + 3H_2O \rightarrow 2H_3AsO_4 + 4FeSO_4 + S$$

(Duruibe *et al.,* 2007).

Water

Water is one of the most important parts of the ecosystem. Living things exist because this is the only planet upon which water exist. Water is essential for the survival of all living things be it plant or animal life. Water is the most abundant commodity in nature, although the earth is a blue planet and 80% of earth's surface is covered with water, the hard fact of life is that about 97% is locked in oceans and sea which is too saline to drink and direct use for agricultural or industrial purposes. Again, due to increased human population the use of fertilizers in agricultural practices and other human activities on the natural aquatic resources cause heavy and varied pollution in aquatic environment leading to depletion of aquatic biota (Mahananda *et al.,* 2010). Quality drinking water is of paramount to human physiological cycle and man's continued existence depends on its availability (Laminkara, 2011).

Source of Chemical Pollutant Contamination in Water

Chemical pollutants present in water can be due to natural or anthropogenic activities. Natural activities include weathering of rocks containing heavy metals, volcanic eruptions and forest fires while anthropogenic sources include, the use of chemical for agriculture, mining, industrial waste and others. Through these activities, chemical pollutants enter different sections of the environment. Heavy metals can be found in the forms of sulfates, hydroxides, oxides, sulfides, phosphates, and silicates (Salgarello *et al*., 2013). A huge amount of accumulation of chemical pollutants in water is mainly due to anthropogenic and natural activities. Other natural source through which chemical pollutants contaminates water are; wet and dry deposition of atmospheric salts, water-rock interaction, or water interaction with the soil. While increase in the rate of urbanization and industrialization result in anthropogenic activities leading to generation of chemical pollutants and their subsequent transmission into water leading to contamination (Priti and Paul, 2016).

Table 1: Heavy metals and their common sources

Heavy metal ion	Common sources
Copper (Cu)	Fertilizers, tanning, and photovoltaic cells
Zinc (Zn)	Soldering, cosmetics, and pigments
Silver (Ag)	Refining of copper, gold, nickel, zinc, jewelry, and electroplating industries
Chromium (Cr)	Leather industry, tanning, and chrome plating industries
Arsenic (As)	Wooden electricity poles that are treated with arsenic-based preservatives, pesticides, fertilizers, the release of untreated effluents, oxidation of pyrite (FeS) and arsenopyrite (FeAsS)
Mercury (Hg)	Combustion of coal, municipal solid waste incineration, and volcanic emissions
Cadmium (Cd)	Paints, pigments, electroplated parts, batteries, plastics, synthetic rubber, photographic and engraving process, photoconductors, and photovoltaic cells
Lead (Pb)	PVC pipes in sanitation, agriculture, recycled PVC lead paints, jewelry, lead batteries, lunch boxes, etc.

Source: Gumpu *et al.* (2015).

How chemical pollutants enter into water bodies

Chemical pollutants enter water bodies through various ways, this includes entry into hydrosphere, lithosphere and atmosphere. Apart from entry through natural process as mentioned previously i.e. volcanic activity and weathering of rocks (Zhang *et al.,* 2023).

Anthropogenic activities leading to the introduction of chemical pollutants in water bodies can be due to release of shipwrecks, oil spills, mining and fire, or from the application of pesticides and herbicides for the control of pest and weeds in agricultural practices. Industrial effluents, sewage and waste disposal is also another means in which chemical pollutants enter into water bodies. Temperature, direction of movement of surface waters, circulation of air masses and wind speed are factors

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upon which movement of chemical pollutants into water depends on (Walker *et al.*, 2012).

Basically, there are two sources of chemical contamination in water namely; point sources and non-point sources. Point sources include surface water sources, like rivers, lakes, and ponds, which can be polluted by effluent discharged from a known point or direction i.e. overflow or drainage. Whereas, in non-point sources, contaminants get into water sources through rainwater runoff (surface runoff) (Yang *et al.,* 2022).

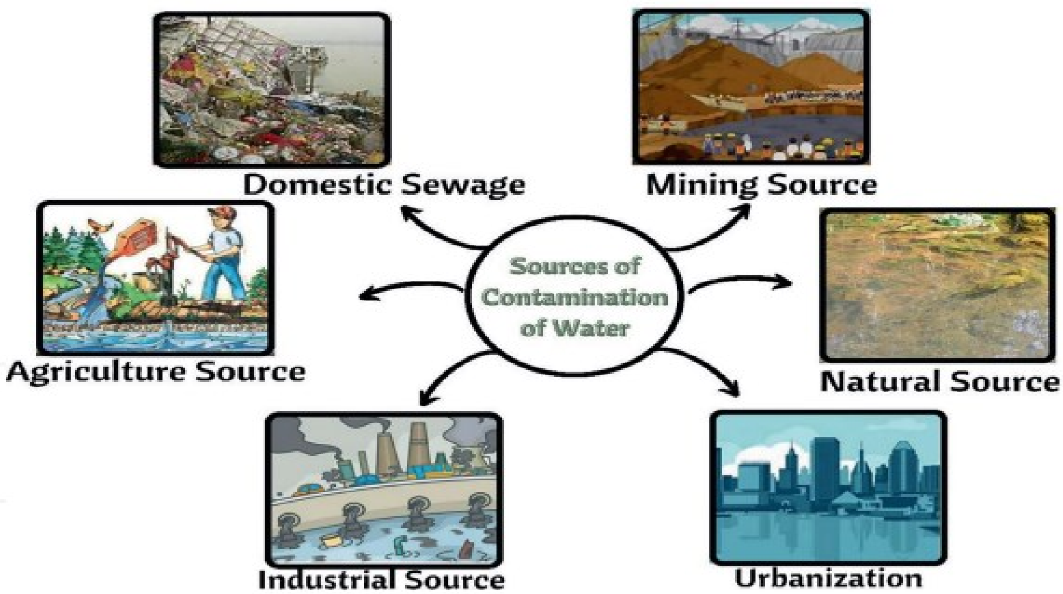

Fig. 1. Contamination of water through different sources. Anubhav *et al.,* (2022).

Chemical pollutants and health risk

Chemical pollutants enter the living systems through nutrition, drinking water, and air by inhalation. Although some of these chemical pollutants such as zinc, copper, and selenium in very low concentrations are essential for metabolism. However, at higher concentrations, they can cause poisoning. Poisoning due to chemical pollutants might occur as a result of tainted drinking water (lead pipes), high ambient air concentrations near emanation sources, or food chain consumption (Javed, 2012). Chemical pollutants bioaccumulate in the body and become dangerous to humans. Bioaccumulation refers to an increase in the absorption of a chemical in an organism that is proportional to the concentration of the chemical in the environment (Agarwal *et al*., 2010). Chemical pollutants are toxicants that cause acute illnesses in aquatic creatures, absorption of heavy metals in the food chain in aquatic creatures may result in occasional fever, cramps, kidney impairment, and hypertension in humans. Chemical pollutants may be extremely harmful to humans, causing toxic and carcinogenic effects as well as oxidative degradation of biological macromolecules (Taslima *et al*., 2022).

Biological systems produce reactive oxygen species (ROS) when heavy metal ions bond with sulfhydryl groups to form reactive oxygen species. This oxidative stress causes macromolecules to be inactivated, which results in oxidative stress, and the glutathione levels in the body decrease (Nita & Grzybowski, 2016). Consequently, both humans and animals suffer from a wide range of harmful effects as a result of these pollutants. Congenital disorders, immune system problems, and cancer are among the problems that can result (Ray *et al.,* 2014).

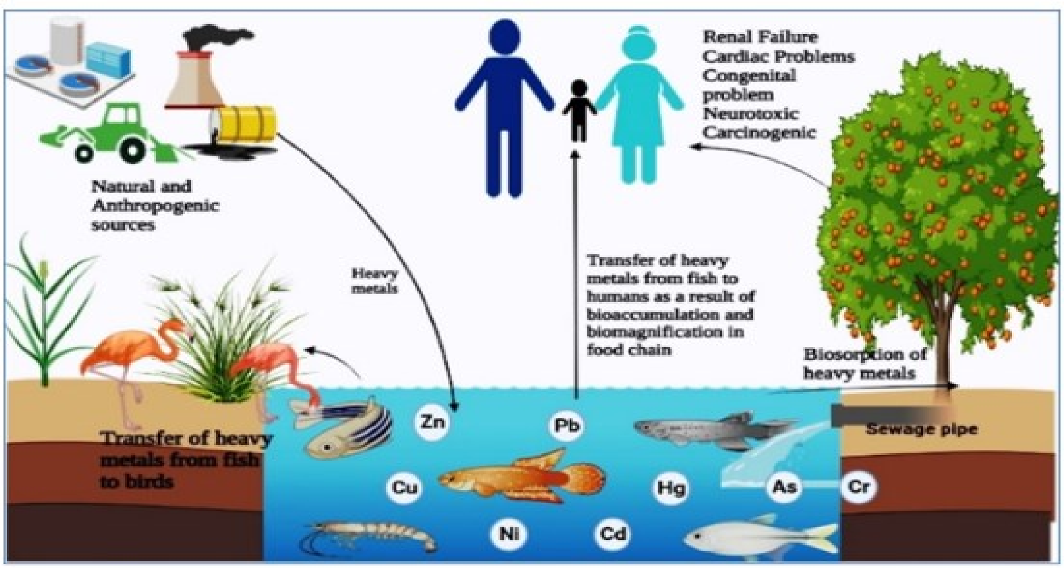

Fig. 2 Chemical pollutant intake via the food chain, Khushbu *et al.* (2022).

Chemical pollutants breakdown in water sources is a significant environmental hazard that negatively affects plants, animals, and human health (Ediagbonya *et al*., 2022).
Inhalation, ingestion, and dermal absorption are the three main pathways through which high concentrations of trace metals interact with humans. Human exposure to

contaminated water occurs through the ingestion of drinking water and food, as well as dermal contact (Rahman and Singh, 2019). When chemical pollutants enter the human body through water or food, they initiate various processes in the body. Heavy metals such as Cr (VI), Pb (II), and As (III) interfere with metabolic pathways or inhibit enzymatic activities (Witkowska *et al.,* 2021). Cr (VI) ions can easily cross the cell membrane and are reduced in intracellular space via their lower oxidative stage. The reduction process generates oxidative stress in the cell, which is responsible for damage to proteins, DNA, and RNA (Kumar and Garg, 2018).

Table 2. Summary of Nigerian and some International guideline values for drinking water samples

Parameter (element/substance)	Nigerian guideline value (mg/L)	WHO guideline value (mg/L)	USEPA guideline value (mg/L)	EU guideline value (mg/L)
Arsenic (As)	0.01	0.01	0.01	0.01
Barium (Ba)	0.7	0.7	2.0	NA
Cadmium (Cd)	0.003	0.003	0.005	0.005
Chlorine (Cl^-)	250	250	250	400
Chromium (Cr^{6+})	0.05	0.05	0.1	0.05
Chemical Oxygen Demand	NA	NA	NA	NA
Conductivity (µS/cm)	1000	NA	NA	NA
Cyanide (CN^-)	0.01	0.07	0.2	0.05
Hardness (as $CaCO_3$)	150	180	NA	NA
Iron (Fe^{+2})	0.3	0.3	0.3	0.2
Manganese (Mn^{2+})	0.2	0.4	0.05	0.001
Mercury (Hg)	0.001	0.006	0.002	0.001
Nitrate	50	50	10	50
Ph	6.5-8.5	6.5-8.0	6.5-8.5	5.5-9.5
Phosphate (PO_4^{3-})	NA	NA	NA	NA
Sodium (Na)	200	200	NA	150
Sulphate (SO_4^{2-})	100	250	250	250
Total Dissolved Solids	500	NA	NA	NA
Zinc (Zn)	3.0	3.0	5.0	NA

Source: Oyem *et al*. (2015).

Table 3: Nigeria Standard for Drinking Water Quality (NSDWQ) and World Health Organization (WHO) Drinking Water Quality Standard for the Parameters.

Parameter/unit	NSDWQ, 2017	WHO, 2017
pH	6.5-8.5	6.5-8.5
Turbidity(NTU)	5.0	
Conductivity(µS/cm)	1000	
TDS (mg/L)	500	
Temperature °C	Ambient	Ambient
Tot. hardness (mg/L)	150	100
Chloride (mg/L)	100	250
Fluoride (mg/L)	1.0	1.5
Nitrate (mg/L)	10	50
Sulphate (mg/L)	100	200
Manganese (mg/L)	0.1	0.05
Iron (mg/L)	0.3	0.05-0.3
Zinc (mg/L)	5.0	3.0
Copper (mg/L)	1.0	2.0
Lead (mg/L)	0.01	0.01
Chromium (mg/L)	0.01	0.05
Arsenic (mg/L)	0.01	0.01
Potassium (mg/L)	1.0	1-2
Nickel (mg/L)	0.01	0.07
TCC (CFU/L)	0	0
FCC(CFU/L)	0	0

Source: (NSDWQ 2007; WHO, (2017).

MATERIALS AND METHODS

Reagents

All reagent used were strictly prepared from chemicals of analytical reagent grade (AnalaR) and deionized water was used during the analysis. The plastic containers and the glass wares were thoroughly washed with detergent solution, after which it was rinsed thoroughly with tap water, then deionized water and finally rinsed with analytical sample.

Sample collection

Three water samples were collected from different sources (river, borehole and well) in different areas of Bali metropolis in Bali local government area of Taraba State and were labelled X, Y and Z. The water samples were collected in three (3) clean 750ml plastic containers, the sample containers were rinsed with the respective water samples before filling each with the sample according to method described by Said and Jimoh, (2012).

Laboratory analysis

Heavy metals analysis using AAS

Heavy metal analysis was carried out using methods adopted from Goodwill *et al*. (2015). Where 50ml of well mixed, acid preserved samples was measured into a beaker, 5ml Conc. HNO_3^+ and few glass beads was added. It was then slowly boiled and evaporated on a hot plate up to 20ml. Conc. HNO_3 was added in fewer drops until the completion of digestion (the sample was not allowed to dry). The beaker was washed down with deionized water 3 times. It was then filtered and poured in a 100ml volumetric flask and made up to 100ml and mixed thoroughly.

The filtrate was then taken to the AAS (Buck 230, Buck Scientific Las Vegas USA). A lamp for each desired metal was installed into the instrument and the wavelength characteristics of each heavy metal was set for the determination using air acetylene integrated flame mode (for all heavy metals). Standards of each metal in the samples was run with corresponding lamps and the concentration of each metal was obtained by extrapolation from the calibration curve of the standards.

Physicochemical parameters

A multiparameter photometer was utilized to ascertain the chemical parameters including nitrates (NO^-_3), sulphates (SO_4^{2-}), Chlorides (Cl^-), fluorides (F^-) and Bicarbonates (HCO_3^-). The pH measurements were carried out using the pH meter (AS ONE 2 -8140 -01 KR5E As Pro pH Meter, Singapore). The membrane was dipped into the samples and readings were taken. The turbidity readings were taken using the turbidimeter (Extech TB400 Turbidity Meter, USA) by using the methods described in the 23rd edition of standard methods for the examination of water and wastewater as reported by Rice e*t al*., 2017.

The conductivity otherwise referred to as Electrical Conductivity (EC) of the water samples was determined by electrochemical method. This was achieved by allowing the conductivity meter to stabilize for 30 minutes after it was switched on. 250ml of the water sample was measured into a beaker using a measuring cylinder, the conductivity meter probe was immersed into each of the samples in the beaker and the conductivity value was displayed on the digital readout in triplicates for each water sample after 10 minutes of steady reading before obtaining the average value for the readings. The experiments were carried out for all the samples and the readings recorded respectively according to method adopted from Kur *et al*. (2019).

RESULTS AND DISCUSSION

Samples was analyzed in triplicate, their mean values were obtained, presented and discussed below;

Table 4: Mean concentration of heavy metal contents of water (mg/L)

Heavy Metals	River water	Borehole water	Well water
Lead	0.00082	0.00024	0.00013
Cadmium	0.00091	0.00033	0.00016
Chromium	0.00032	0.00024	0.00011
Nickel	0.00044	0.00027	0.00015
Iron	24.52	4.13	3.12
Zinc	8.21	0.62	0.33
Manganese	41.32	2.15	1.95
Copper	4.33	0.36	0.25

Result from table 4 above showed that the mean concentrations of Lead (Pb), Cadmium (Cd), Chromium (Cr) and Nickel (Ni) in all the water samples were below the tolerable limits when compared with the standards specified by world health organizations (WHO) and others as published in table one above. However, iron (Fe), zinc (Zn), manganese (Mn) and copper (Cu) were detected in varying concentrations with the river water sample having higher mean value than those of borehole and well water respectively. Iron (Fe) for instance, has a concentration of 24.52mg/L which is way higher than those of borehole (4.13mg/L) and well (3.12mg/L) respectively. Iron is essential for biological systems; it is considered a secondary priority chemical contaminant according to United Nations International Children's Emergency Fund (UNICEF) (2008).

The concentrations of iron (Fe) in all the water samples are above tolerable limits according to standards published in Oyem *et al.* (2005). The concentration of iron from the sampled areas showed that the highest concentration of iron (24.52mg/L) was observed in river water from table 4, this may be due to the hydrogeological nature of the area. Iron is frequently found in groundwater due to large deposits in the earth's surface; however, a limit of 0–0.3mg/L is acceptable which is in tandem with similar work carried out by Edet *et al*. (2011). Corrosion of borehole casing and other pipes may also contribute to iron content in borehole water. According to Bassey and Akanimo (2022), bacterial activity can decrease or increase iron concentration in ground and surface water. When exposed, Fe^{2+} becomes oxidized to form the ferric state of Fe^{3+}, which is soluble and precipitates as ferric hydroxide, causing a brown discoloration of the water and the characteristic brown stains in sinks and laundered textiles, metal pipes for reticulation and scaling in pipes (Awalla and Ezeigbo, 2002).

Zinc (Zn) concentration was seen to be higher (8.21mg/L) in the river water sample as presented in table 4 above than those of the borehole (0.62 mg/L) and well water (0.33mg/L) respectively, this could be attributed to natural causes rather than human activities. High natural levels of zinc are associated with high concentrations of metals such as lead and cadmium. Anthropogenic sources are related to mining and metallurgic operations (Bassey and Akanimo, 2022). Zinc been a constituent of roofing sheets may be washed down by rainfall into the soil before ending up in the underground water by leaching over a long period within and around the study area. At concentrations higher than 3mg/L, zinc adds a characteristic taste to water. Since both the Nigerian and WHO guideline set 3.0mg/L for zinc in drinking water, the borehole and well water are seen to contain tolerable concentrations of zinc levels. Zinc is an essential nutrient for bone development, metabolism and wound healing. High zinc level in blood may cause mental illness referred to as metal fume fever (Okurnmeh, 1999).

The mean concentration of manganese (Mn) in the three samples analyzed gave 41.32mg/L for river water, 2.15mg/L for borehole water and 1.95mg/L for well water are all higher when compared to the tolerable limits by WHO (0.4mg/L), this may be due to the natural content of groundwater in the sense that Mn in water can come from natural sources in bedrock, specifically, water from deep wells as reported in a research conducted by Wendel *et al*. (2016). High concentration of manganese usually slightly above the WHO (0.4mg/L) and NSDWQ maximum permissible limit results in neurological and gastrointestinal disorder (NSDWQ, 2007).

The concentrations of copper (Cu) were also detected at varying levels from the samples analyzed, the presence of copper (Cu) in water may be attributed to mining activities, geological deposits, weathering and erosion of rocks. The mean concentrations of copper analyzed range from 4.33mg/L for river, 0.36mg/L for borehole and 0.25mg/L for well water respectively as presented in table 4 above. Chronic exposure to copper leads to alteration of brain functions and gastrointestinal disorders (NSDWQ, 2007).

Table 5. Mean physicochemical composition of water samples (mg/L)

Parameters	**River water**	**Borehole water**	**Well water**
Bicarbonate	162.11	123.80	88.42
Conductivity (uS/cm)	344.15	186.95	111.22
Turbidity	6.42	3.85	2.45
pH	6.20	6.00	5.60
Sulphates	72.75	24.60	10.35
Nitrates	8.95	2.56	1.15
Chlorides	23.00	8.60	3.15
Fluorides	3.02	0.85	0.52

Bicarbonates (HCO_3^-) are dominant anion in all the water samples. The HCO_3^- concentrations ranged from 88.42 for well water to 162.11 mg/L for river water as shown in Table 5 above. The presence of HCO_3^- ions gives water a pleasant odor and does not present any risk to human health (Lahcen *et al*., 2019).

The conductivity values range from 344.15μS/cm (river water), 186.95μS/cm (borehole water) and 111.22μS/cm (well water) (Table 5). All the values are below the permissible limit of 1000 μS/cm of NSDWQ. Conductivity in water is due to dissolved solutes.

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Turbidity is the degree of cloudiness in water caused by both dissolved and suspended solids. The turbidity values range from 6.42 NTU for river water sample, 3.85 NTU for borehole water sample and 2.45NTU for well water respectively as presented in table 5 above. The river water is the most turbid, this is due to dissolved and suspended solid.

The pH values for the water sample analyzed range from 6.20 for river water, 6.00 for borehole water and 5.60 for well water as presented in table 5 above. These values are lower than those of WHO and NSDWQ permissible limits of between 6.5 to 8.5 (see table 1 above). The low pH may be attributed to soil formation and composition and/or the formation of tannic acids by decaying plants. pH is the measure of acidity or alkalinity of an environment or substance, the pH of water varies naturally within water bodies owing to geology and nature of the soil. High acidity may lead to acidosis and promote disease conditions.

The sulfate concentrations range between 72.75mg/L (river water), 24.60mg/L (borehole water) and 10.35mg/L (well water) (see table 5 above). These values are below WHO's maximum permissible limit of 200 mg/L. Sulfates may be leached from the soil into water bodies (Bassey and Akanimo, 2022).

The concentrations of nitrates range between 8.95mg/L (river water), 2.56mg/L (borehole water) and 1.15mg/L (well water) as presented in table 5 above. The values were below the NSDWQ recommended value of 50 mg/L. Nitrates in water are from fertilizers, agricultural run-off and gun powder. High nitrates doses cause cyanosis and asphyxia (blue baby syndrome) in infants (NSDWQ, 2007).

The mean chloride concentrations in the water sample analyzed are shown in table 5, the result showed that river water contain 23.00mg/L, borehole water contains 8.60mg/L while well water contained 3.15mg/L. These values are below the permissible limit of 250 mg/L as stated by NSDWQ and WHO chloride standards for drinking water. Chlorides enter water bodies through weathering from rocks, salt-bearing geological formation and an intrusion of salty ocean water into fresh ground water sources.

Results from analysis showed that mean fluoride concentrations range from 3.03 mg/L (river water), 0.85 mg/L (borehole water) and 0.55mg/L for well water (see table 5 above). Values obtained for borehole and well water are below permissible limits of 1.50 mg/L by WHO and NSDWQ (Table 1). Fluorides occur in form of minerals and are found in hard rocks; hydrogeological conditions help in the mobilization of fluorides in ground water. High fluoride dose cause fluorosis and skeletal tissue morbidity (NSDWQ, 2007).

SUMMARY, CONCLUSION AND RECOMMENDATION

Summary

Water samples from three (3) different sources was obtained and analyzed. Results from analysis revealed that the concentrations of Ni, Fe, Zn, Cu and Cu are higher than the tolerable limits as contained in the Nigerian, WHO, USEPA and EU guideline values for domestic water usage. Again, physicochemical analysis indicated that chemical compounds such as sulphates, nitrates, chlorides and fluorides respectively which are important factors in ascertaining water quality were also analyzed respectively.

Conclusion

Findings from this research revealed the presence of chemical pollutants in the different water samples analyzed at different concentrations, it was concluded that water from these sources (well, river and borehole) should be properly treated before human consumption in order to prevent bioaccumulation which may lead to various health related illnesses.

Recommendation

The following recommendations was made based on the findings from the study;

1. The following heavy metals Ni, Fe, Zn, Cu and Cu are found to be in higher concentration in all the three water sources analysed, this makes it unsafe for human consumption. Hence, river, well and borehole water should be treated properly before human consumption.
2. pH moderation should be prioritized prior to consumption of water from the well source.
3. Further studies on the quality of water in Bali town should be carried out by researchers in order to provide more information that will be helpful to the general populace.

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REFERENCES

Adnan, M., Xiao, B., Xiao, P., Zhao, P., Li, R. & Bibi, S. (2022). Research Progress on Heavy Metals Pollution in the Soil of Smelting Sites in China. *Toxics.* 10(5): 231.

Agarwal, A., Pandey, S. R. & Sharma, B. (2010). Water pollution with special reference to pesticide contamination in India. Journal of Water Resource and Protection, 2(5): 432-448

Anubhav, S., Anuj, S., Rohit, K., V., Rushikesh, L., C., Pritam, P., P., V. N., Vinay, A., Sumit, K., C., Garima, A., Kumud, K., A. & Mahipal, S., S. (2022). Heavy Metal Contamination of water and Their Toxic Effect on Living Organisms. *Open Access Peer-reviewed chapter.* DOI:10.5772/intechopen. 105075.

Awalla, C.O & Ezeigbo, H.I. (2002). An appraisal of water quality in the Urbu-Okposi area, Ebonyi state, southeast Nigeria. Journal of the Nigerian Association of Hydrogeologists. 13,13-44.

Bakshi, S., Banik, C. & He, Z. (2018). The impact of heavy metal contamination on soil health, In: Managing soil health for sustainable agriculture (Reicosky, ed.). 2(8): 1–36.

Bassey, S.O. & Akanimo, N.E. (2022). Physicochemical, Spectroscopic and Bacteriological Analyses of Surface and Ground Water in Epenti Ekori, Yakurr Local Government Area, Cross River State- Nigeria. *J. Environ. Treat. Tech*.10(1): 67-75.

Bradl, H. (2005). *Heavy metals in the environment: origin, interaction and remediation*. Elsevier.

Briffa, J., Sinagra, E., & Blundell, R. (2020). Heavy metal pollution in the environment and their toxicologi cal effects on humans. *Heliyon*, *6*(9), e04691. https://doi.org/10.1016/j.heliyon.2020.e0469.

Bundschuh, J., Schneider, J., Alam, M.A.; Niazi, N.K.; Herath, I.; Parvez, F., Tomaszewska, B., Guilherme, L.R.G., Maity, J.P. & López, D.L. (2021). Seven Potential Sources of Arsenic Pollution in Latin America and Their Environmental and Health Impacts. *Sci. Total Environ*. 780:146-274.

Duruibe, J. O., Ogwuegbu, M. O. C., and Egwurugwu, J., N. (2007). Heavy metal pollution and human biotoxic effects. *International Journal of Physical Sciences*. 2(5):112-118.

Duruibe, J. O., Ogwuegbu, M. O. C., and Egwurugwu, J., N. (2007). Heavy metal pollution and human biotoxic effects. *International Journal of Physical Sciences* Vol. 2 (5), pp. 112-118.

Edet, A., Ukpong, A.J. and Ekwere, A.S. (2011) Impact of Climate Change on Groundwater Resources: An Example from Cross River State, Southeastern Nigeria. In: Proceedings of the Environmental Management Conference, Federal University of Agriculture, Abeokuta.

Ediagbonya, T. F., Ogunjobi, J. A., Odinaka, C. V., & Adenikinju, C. A. (2022). Bioaccumulation of Elemental Concentrations in Sediment and Frog (Pyxicephalus edulis) in Igbeebo River, Ondo State, Nigeria. Chemistry Africa. 1- 13.

Farlex Incorporated (2005). Definition: Environment, The Free Dictionary, Farlex Inc. Publishing, U.S.A. (www.thefreedictionary.com/).

Garbarino, J.R., Hayes, H., Roth, D., Antweider, R., Brinton, T.I., Taylor, H. (1995). Contaminants in the Mississippi River, U.S. Virginia, U.S.A. Geological Survey Circular 1133, (www.pubs.usgs.gov/circ/circ1133/).

Gautam, P. K., Gautam, R. K., Banerjee, S., Chattopadhyaya, M. C., & Pandey, J. D. (2016). Heavy metals in the environment: fate, transport, toxicity and remediation technologies. *Nova Sci Publishers*, *60*, 101-130.

Guffanti, M., & Tupper, A. (2015). Volcanic ash hazards and aviation risk. In Volcanic hazards, risks and disasters (pp. 87-108). *Elsevier*. Available on: https://doi.org/10.1016/B978-0-12- 396453-3.00004-6. Accessed 14th February, 2025.

Gumpu, M.B., Swaminathan,S., Krishnan, U.M. & Rayappan, J.B. (2015). A review on detection of heavy metal ions in water – An electrochemical approach. Sensors and Actuators B: Chemical. (213):515-533.

Institute of Environmental Conservation and Research (INECAR), (2000). Position Paper Against Mining in Rapu-Rapu, Published by INECAR, Ateneo de Naga University, Philippine (www.adnu.edu.ph/Institutes/Inecar/pospaper1.asp).

Ize-Iyamu, O., Asia, I.O. & Egwakhide, P.A. (2007). Concentration of residues from organochlorine pesticides in water and fish from some rivers in Edo state Nigeria. Int. J. of Physical Sci. 2(9):237-241.

Jarup L. (2003). Hazards of heavy metal contamination. Br. Med. Bull. 68: 167–182.

Javed, M. (2012). Effects of zinc and lead toxicity on the growth and their bioaccumulation in fish. *Pak. Vet. J*. 32(3):357-362.

Khushbu, Rachna, G., Sushama, Amik, K., & Pankaj, S. (2022). Ecological impact of heavy metals on aquatic environment with reference to fish and human health. *Journal of Applied and Natural Science*. 14(4): 1471 - 1484.

Kumar, P., Gacem, A., Ahmad, M.T., Yadav, V.K., Singh, S., Yadav, K.K., Alam, M.M., Dawane, V., Piplode, S., Maurya, P., Ahn, Y., Jeon, B.H. & Cabral-Pinto, M., M.S. (2022). Environmental and human health implications of metal(loid)s: Source identification, contamination, toxicity, and sustainable clean-p technologies. Front. *Environ. Sci*.10:949581.

Kur, A., Alaanyi, A.T. & Awuhe, S.T. (2019). Determination of quality of water used by students of college of education, katsina-ala through physical and electro-chemical parameters. *Science World Journal*. 14(1): 1-6.

Lahcen, B., Ahmed Z. & Othman, S. (2021). Hydrochemical characteristics and quality assessment of water from different sources in Northern Morocco. Elsevier, 261-274.

Lamikanra, A. (2011). Essential Microbiology for Students and Practitioner of Pharmacy, Medicine and Microbiology, Amkra Books Lagos. Rasyan Journal of Chemistry 4(2): 461-465.

Lenntech Water Treatment and Air Purification (2004). Water Treatment, Published by Lenntech, Rotterd mseweg, Netherlands. (www.excelwater.com/thp/filters/WaterPurification.htm).

Ma, C., J. & Kang, G., U. (2022). Effect of the Eruption of Nishinoshima Volcano in the Summer of 2020 on Air Quality in Fukuoka and Busan. *Asian Journal of Atmospheric Environment (AJAE), 16(1)*. Avaialble on: https://doi.org/10.5572/ajae.2021.120. Accessed 13th January, 2025.

Mahananda, M.R., Mohanty, B.P. & Behera, N.R. (2010). PhysicoChemical Analysis of Surface and Ground Water of Bargarh district, Orissa, India. International Journal of Research and Reviews in Applied Sciences 2(3): 284- 295.

Nigerian Standard for Drinking Water Quality, NSDWQ (2007). Nigerian Standard for Drinking Water Quality. Nigerian Industrial Standard. NIS: 554:13-14.

Nikiema, J., & Asiedu, Z. (2022). A review of the cost and effectiveness of solutions to address plastic pollution. *Environmental Science and Pollution Research, 1-27*. Available on: https://link.springer.com/article/10.1007/s11356-021-18038-5. Accessed 13th February, 2025.

Nita, M. & Grzybowski, A. (2016). The Role of the Reactive Oxygen Species and Oxidative Stress in the Pathomechanism of the Age-Related Ocular Diseases and Other Pathologies of the Anterior and Posterior Eye Segments in Adults. Oxidative Med. Cell. Longev. 31: 64-734.

Nriagu, J., O. (1989). A global Assessment of Natural Sources of Atmospheric Trace Metals, *Nature*. 338: 47-49.

Ogwuegbu, M., O., C., and Muhanga, W., (2005). Investigation of Lead Concentration in the Blood of People in the Copperbelt Province of Zambia, *J. Environ*. (1): 66 – 75.

Okurnmeh, O.K & Olashahinde, P.I. (1999). Ground water assessment in Okposi-Ebonyi state. Natural and Applied Sciences Journal. 2(1),33-34.

Osibanjo, O. (2002). Organochlorine in Nigeria and Africa, the handbook of environmental chemistry. 30:321 – 354.

Oyem, H. H., Oyem, I. M., & Usese, A. I. (2015). Iron, manganese, cadmium, chromium, zinc and arsenic groundwater contents of Agbor and Owa communities of Nigeria. *Springerplus*, *4*, 1-10.

Priti, P. & Paul, B. (2016). Assessment of heavy metal pollution in water resources and their impacts: A review. Journal of Basic and Applied Engineering Research. 3(8):671 675.

Purves, D. (2012). Trace-element Contamination of the Environment. *Elsevier*.

Rahman, Z. & Singh, V.P. (2019). The Relative Impact of Toxic Heavy Metals (THMs) (Arsenic (As), Cadmium (Cd), Chromium (Cr)(VI), Mercury (Hg), and Lead (Pb)) on the Total Environment: An Overview. Environ. Monit. Assess. 191, 419.

Rahman, Z. & Singh, V.P. (2019). The Relative Impact of Toxic Heavy Metals (THMs) (Arsenic (As), Cadmium (Cd), Chromium (Cr)(VI), Mercury (Hg), and Lead (Pb)) on the Total Environment: An Overview. Environ. Monit. Assess. 191, 419.

Rasmussen, P. E., Wheeler, A. J., Hassan, N. M., Filiatreault, A., & Lanouette, M. (2007). Monitoring personal, indoor, and outdoor exposures to metals in airborne particulate matter: Risk of contamination during sampling, handling and analysis. *Atmospheric Environment*, *41*(28), 5897-5907.

Ray, P.D., Yosim, A. & Fry, R.C. (2014). Incorporating Epigenetic Data into the Risk Assessment Process for the Toxic Metals Arsenic, Cadmium, Chromium, Lead, and Mercury: Strategies and Challenges. Front. Genet. 5.

Rice E.W., Baird, R.B. & Eaton A.D. (2017). Standard methods for the examination of water and wastewater. 23rd edition. American Public Health Association, American Water Works Association, Water Environment Federation, Washington, D.C.

Sa'id, M.D. & Jimoh, W.L.O. (2012) Trace metals concentration in drinking water supplies from some elected areas of Kano metropolis and it's environs, Kano state, Nigeria. *Biological and Environmental Science Journal for the Tropics, 9(3):*212-214.

Salgarello, M., Visconti, G. & Barone-Adesi, L. (2013). Interlocking circumareolar suture with undyed polyamide thread: A personal experience. Aesthetic Plastic Surgery. 37(5):1061-106.

Sharma, R., K. & Agrawal, M. (2005). Biological effects of heavy metals: an overview. *Journal of environmental Biology*. 26(2): 301-313.

Stockholm Convention (2008). About the Convention. www.chm.pops.int/Convention/tabid/54/Default.aspx

Su C, Jiang, L. & Zhang, W. (2014). A review on heavy metal contamination in the soil worldwide: Situation, impact and remediation techniques. Environ. Skept. Critics, 3(2): 24–38.

Taslima, K., Al-Emran, M., Rahman, M. S., Hasan, J., Ferdous, Z., Rohani, M. F. & Shahjahan, M. (2022). Impacts of heavy metals on early development, growth and reproduction of fish–a review. *Toxicology Reports*. https://doi.org/10.1016/j.toxrep.2022.04.013.

Tchounwou, P.B., Yedjou, C.G., Patlolla, A.K. & Sutton, D.,J. (2012). Heavy Metals Toxicity and the Environment. 101: 133–164.

United Nations Environmental Protection/Global Program of Action (2004). Why The Marine Environment Needs Protection from Heavy Metals, Heavy Metals 2004, UNEP/GPA Coordination Office. (http://www.oceansatlas.org/unatlas/uses/uneptextsph/wastesph/2602gpa.).

Walker, C. H., Sibly, R. M., Hopkin, S. P., & Peakall, D. B. (2012). *Principles of ecotoxicology*. CRC press.

Wendel, B.V., Joode D.B., Bouchard, B.M.F., María, A. & Quesada, R. (2016). Manganese Concentrations In Drinking Water from Villages Near Banana Plantations With Aerial Mancozeb Spraying in Costa Rica: Results from the Infants Environmental Health Study (ISA). Environ Pollut. 215:247–57.

Witkowska, D.; Słowik, J., Chilicka, K. (2021). Heavy Metals and Human Health: Possible Exposure Pathways and the Competition for Protein Binding Sites. *Molecules*. 26: 60-65.

World Health Organization,WHO (2017). Access to improved drinking water sources and improved sanitation.www.who.wt/2wst. Retrieved 7th December, 2024.

Yang, L., Zhang, M., Wei, J. & Qi, J. (2022). Pollution Load Estimation and Control Countermeasures of Zhangze Reservoir. Front. Environ. Sci. 10: 874124.

Zhang, P., Yang, M., Lan, J., Huang, Y., Zhang, J., Huang, S., Yang, Y. & Ru, J. (2023). Water Quality Degradation Due to Heavy Metal Contamination: Health Impacts and Eco-Friendly Approaches for Heavy Metal Remediation. Toxics 11: 828.