



My Academic Voyage in Water into the World of Heavy Metals

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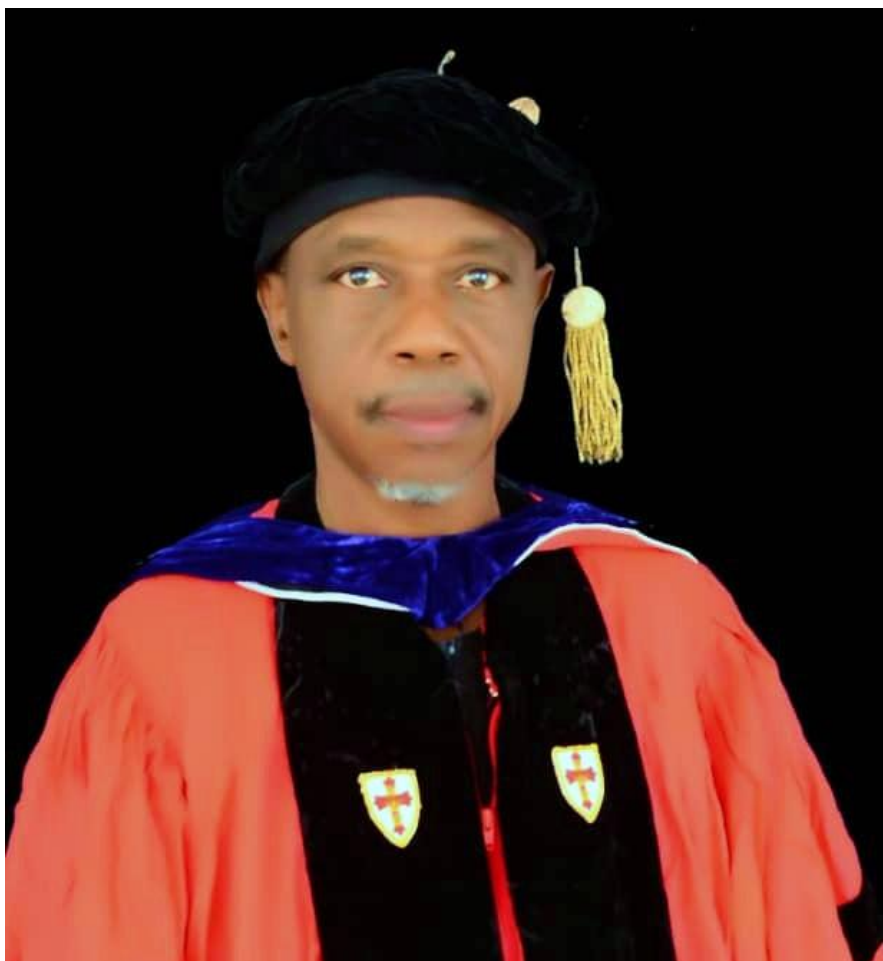
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SUMMARY OF PRESENTER'S BIODATA

AbdulRahman Abdul Audu is presently a Professor of Analytical Chemistry and teaches at both the undergraduate and postgraduate levels at the Department of Pure and Industrial Chemistry, Bayero University, Kano. He was promoted to this position in October, 2007 having moved through the various levels of the academic cadre of the University. He obtained his MSc and PhD (Analytical Chemistry) from Boston University, Massachusetts, USA in 1985 after his BSc (Hons) Chemistry degree at the University of Nigeria, Nsukka in 1978. Between 1989 – 90 he was awarded the Nuffield Foundation Fellowship of the Commonwealth Countries to undertake a Post-doctoral research at the University of Lancaster, England where he worked with Prof C.J Peacock.

AbdulRahman, in trying to enhance his knowledge of the industrial applications of Chemistry took a few years of industrial experience at the Unilever Plc (Nig.), Ikeja, Lagos and served as the Total Quality Manager and rose to the position of Company Development Manager. He also worked at the NASCO Group, Jos as the Group's General Manager (R&D) and rose to the position of General Manager, NASCO Household Products Ltd.

AbdulRahman has held several administrative positions in the University ranging from Pre-degree Admission Officer, Level Coordinator, Examination Officer, Head of Department, Dean of the Faculty and the First Coordinator of the Bayero University Central Laboratories Complex.

In 2004, he was awarded the British Council Award for training on Modern Instrumentation Techniques when he spent some time at the Colour Science Department, University of Leeds, U.K.

In 2006, he was awarded the British Council Research Grant under the African Knowledge Transfer Partnership (AKTP) on the Bayero University - God's Little Tannery Joint Research on the Environmentally-friendly Tannery Waste Management Project.

AbdulRahman has served as external examiner as well as Visiting Professor to many universities. He was Head of Department of Pure and Industrial Chemistry and Dean, Faculty of Natural and Applied Sciences, Umaru Musa Yar' Adua University, Katsina.

Abdulrahman has many scholarly peer-reviewed articles to his credit in both local and international journals. He is in the management team of the ChemSearch Journal, the Kano Chapter production of the Chemical Society of Nigeria (CSN) and serves as the Editor-in-Chief.

AbdulRahman is married with children.

My Academic Voyage in Water into the World of Heavy Metals

Introduction

What is Water?

Water is without doubt, the most abundant, the most accessible and the most studied of all chemical compounds. Its abundance, crucial importance for man's survival, and ability to transform so readily from liquid to solid and gaseous states has ensured its prominence in man's thinking from the earliest times.

Secular philosophers have also perceived the unique nature of water. Thales of Miletus who is generally regarded as the initiator of the Greek Classical tradition of philosophy, ca 585 BC, considered water to be the sole fundamental principle of nature. His celebrated dictum maintains, that: "It is water that in taking different forms, constitutes the earth, atmosphere, sky, mountains and men, beasts and birds, grass and trees and animals down to worms, flies and ants. All these are but different forms of water (Franks, 1982).

Though, this may sound quaint or even perverse to modern ears, we should reflect that some marine invertebrates are, indeed, 96 – 97% water, and the human embryo during its first month is 93% water by weight. As it is known today, approximately 70% of the human body is composed of water and we can survive only a few days without it.

Aristotle considered water to be one of the four elements, along-side earth, air and fire. This belief in the fundamental and elementary nature of water persisted until the epoch-making experiments of Cavendish and others in the second half of the eighteenth century which showed that water is composed of two elements hydrogen and oxygen (Mellor, W. (1922).

Distribution and Availability

Water is distributed very unevenly and with variable purity over the surface of the earth:

Table I: *Estimated world water supply*

Source	Volume in 10^3 Km^3	% of total
Salt water		
Oceans	1,348,000	97.33
Saline lakes/inland seas (e.g. Caspian sea)	105	0.008
Fresh water		
Polar ice and glaciers	28,200	2.04
Ground water	8.450	0.61
Lakes (Tanganyika and Nyassa)	125	0.009
Soil moisture	69	0.005
Atmospheric water vapour	13.5	0.001
Rivers	1.5	0.0001

Source: Greenwood and Earnshaw, 1986

Desert regions have little rainfall and no permanent surface waters whereas oceans, containing many dissolved salts, cover vast tracts of the globe. Oceans comprise over 97% of available water and cover an area of $3.61 \times 10^8 \text{ km}^2$ which is approximately 70.8% of the earth's surface. Only about 2.8% of the total water is fresh and most of this is locked up in the Antarctic and Arctic ice caps (Greenwood and Earnshaw, 1986).

Some Properties and Structure of Water

Water is a volatile liquid with many curious properties, most of which can be ascribed to the extensive H-bonding. In the gas phase the H_2O molecule has a bond angle of 104.5° giving it almost a tetrahedral structure. Liquid water has a molecular weight of 18.0151 gm/mol , melting point of 0.00°C and boiling point of 100°C .

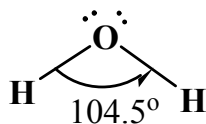


Fig. 1a *Structure of Water Molecule*

Water is often called the universal solvent for its ability to dissolve any material. It is usually said that “water has no enemy”. As such, natural water is far from being pure but exists as a natural solution containing many dissolved minerals and gases.

For instance the anomalously high melting and boiling points of water compared with the hydrides of other elements in groups V, VI and VII is as in Fig 1b, due to the presence of hydrogen-bonding as shown in Fig1c.

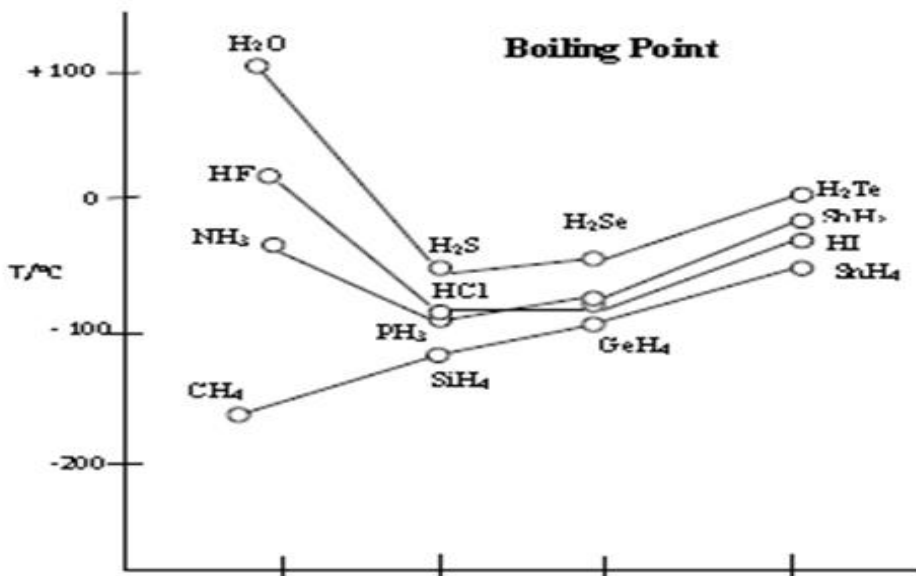


Fig 1b: Showing the anomalous behavior of Water

Although we generally take water for granted, it is a remarkable chemical compound with unique properties that account to its essential life-supporting role. If the hydrogen bonds in water were weaker, water would have a much lower boiling temperature and require less energy to boil.

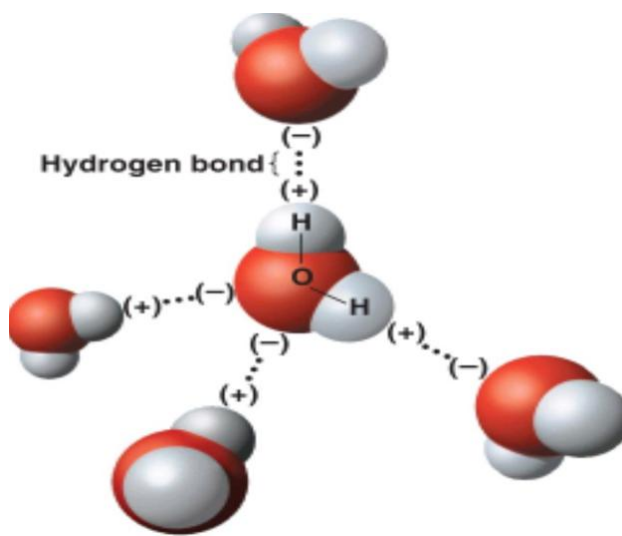


Fig 1c: *Showing the Hydrogen Bonding in Water*

If water had no hydrogen bonding at all, it would boil at about -75°C , making life as we know it very uncomfortable if not impossible. Because of the hydrogen bonding, almost all our body's water whether in cells, blood or other body fluids are well below the boiling point. Our existence depends on hydrogen bonding, without it, we would be a gas.

Chemical Formula and the Name, Water

The chemical formula of a compound reveals the elements that make it up, and the atom ratio of those elements. The name usually conveys similar information for instance; sodium chloride indicates a compound composed of the element sodium (Na) and chlorine (Cl) with formula NaCl. Using the same logic, the chemical compound hydrogen oxide indicate two hydrogen and one oxygen atoms; H_2O . Generally, H_2O is not referred to as hydrogen oxide but water. This is one of the peculiarities of water as a chemical compound. The name has nothing to do with the chemical composition of the compound. This is because the name predates the knowledge of its chemical compositions.

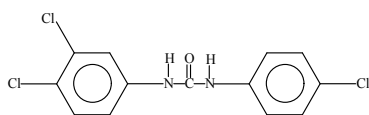
The Voyage in Water

Water, because of its peculiar nature of being able to dissolve most chemical substances, has been used extensively as a reaction medium in either mixed or in its pure state. This is because water can break down chemical compounds into their ionic

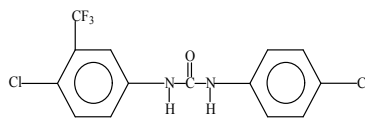
or molecular ion forms providing large surface areas for various forms of chemical reactions to take place. It has served as reaction medium, solubilizer and carrier of pollutants. Water also can be used in various forms by man in animal husbandry and agriculture. Water, because of its finite nature, has been continuously purified and also reclaimed.

Water as a Reaction Medium

My academic voyage in water began in 1980 at the Boston University, Massachusetts, USA with my doctoral research project titled: “The hydrolysis of 3, 4, 4¹-Trichlorocarbanilide [Trichlocarban] and 4, 4¹ - Dichloro - 3 - Trifluoromethyl carbanilide [Cloflucarban] in mixed Aqueous/Alcoholic Solution”; in which water, mixed with ethanol, was used as a reaction medium.



(N-(4-Chlorophenyl)-N'-(3,4-dichlorophenyl)urea phenyl]urea (Triclocarban, TCC)



(N-(4-Chlorophenyl)-N'-(4-chloro-3-(trifluoromethyl phenyl]urea (Cloflucarban, CFC)

Fig 2: Showing the Structures of TCC and CFC

These compounds were known to completely inhibit the growth of micrococcus pyogenes var. aureus (MPA) in dilutions of 1 to 30 million (Beaver et al, 1957) and were also effective against both gram positive bacteria – staphylococci and fungi. Thus have been commercially incorporated in soaps, cosmetic and healthcare personnel hand wash as bacteriostats (Heyn, et al, 1982). The study was carried out to investigate the fate and persistence of these carbanilides in mixed aqueous/alcoholic medium at acidic, neutral and alkaline conditions. Effects of light on the degradation of the compounds were also assessed using artificial and natural sunlight. They were discovered to be most unstable under normal daylight and alkaline conditions with half-lives ranging between 0.6 to 0.7 years (Audu, 1985).

Millions of tons of synthetic compounds are deliberately introduced into the environment for the control of weeds and pests. Most of these and their residues find their ways into surface waters of the environment and make it unfit for human/animal consumption as well as agriculture. We undertook a comparative study of the photohydrolysis of five commonly-used substituted ureas as herbicides and pesticides

using natural sunlight as the source of ultraviolet radiation. The photohydrolysis rate were found to be dependent on the substituents on the benzene rings and were up to six times higher in the dry seasons than the values obtained in the cloudy harmattan seasons. The results were explained to be as a result of the larger amount of uv radiations received during the dry season than those of the harmattan period (Audu and Heyn, 1988).

The reaction rates of ethanolsis of ionized phenyl Salicylate PS^- were studied in the presence of different concentrations of various inorganic and organic salts in ethanol – water solvent system of different compositions (Khan and Audu, 1990). The observed pseudo first order rate constant, k_1 , revealed non-linear increase with increase of the content of ethanol until it became Ca 85% v/v. The rate constants, k_1 , began to decrease with increase of ethanol content beyond 85% v/v. At ethanol content of <55%, the rate constant followed a relationship.

$$K_1 = K [EtOH]_T / (1 + K [EtOH]_T)$$

Where K is the second order rate constant and $(EtOH)_T$ is the total amount of ethanol in the mixture. Both the inorganic and organic cations were found to be preferentially solvated by the water molecules with EtOH contents <55% v/v.

We subsequently studied the effect of inorganic and organic salts on the rates of methanolysis of ionized phenyl Salicylate, PS^- , at 30°C in water – methanol solvent (Audu and Khan, 1992).

The observed pseudo-first-order rate constants, K_{obs} , for methanolysis of PS^- represented a non-linear increase with increase in methanol content in the mixed $H_2O - MeOH$ solvent system.

The rate constants, K_{obs} at $\leq 55\%$ v/v were derived from this relationship.

$$K_{obs} = K [MeOH]_T / (1 + K_A [MeOH]_T)^2$$

Where:

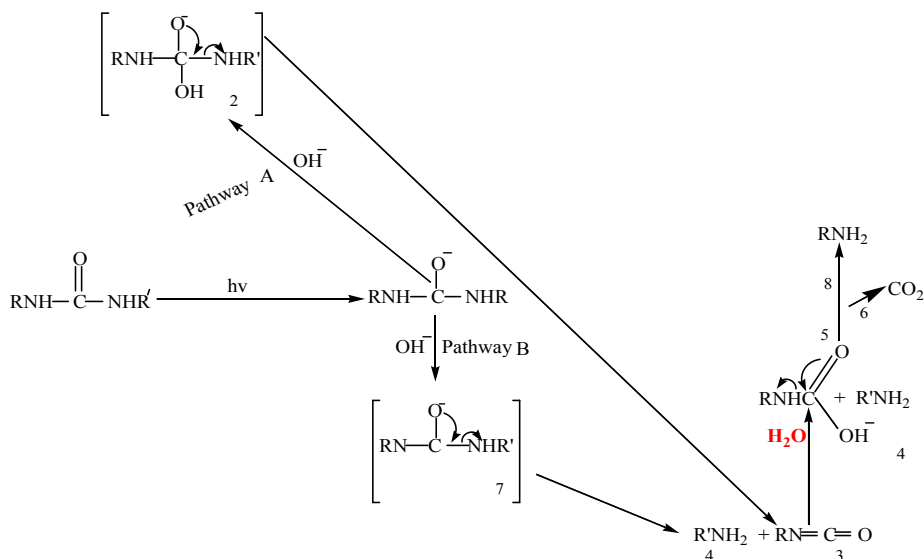
K = nucleophilic second order rate constant for the reaction of MeOH and PS^-

K_A = association constant for the dimerization of MeOH.

The rate constants, K , were independent of total concentration of inorganic salts while the value of K_A increased with increase in the total inorganic metal ion concentration in the order $\text{Li}^+ > \text{Na}^+ > \text{K}^+$. The observation drawn from the result was based on the great solvation ability of water and that at $\leq 55\%$ which is water – rich, the metal ions are preferentially solvated by water molecules only.

The photodecomposition of ten commonly-used agricultural chemicals, ranging from pre-emergence photosynthesis inhibition to post-emergence, herbicides and pesticides were studied in mixed aqueous solutions under natural sunlight in Pyrex glass containers. The parent compounds as well as the photodecomposition products were recovered from the reaction mixture using a macroreticular polystyrene-divinylbenzene cation exchange resin (XAD – 2) which gave high percentage recoveries. The extracts were quantified using temperature programmed gas chromatography. The compounds were found to have been decomposed into aromatic amines, primary and secondary aliphatic amides and N^1 , N -diphynylurea substituted products (Audu, 2001).

Substituted urea compounds which are used primarily as antimicrobial agents in cosmetic products have been photohydrolysed using 250 watts mercury arc lamp at 25°C . Since these compounds are not readily solubilized in water, a mixed aqueous-alcoholic system was used. The study was carried out using the initial rate method and the rate constants were found to increase with decrease in the alcoholic concentration in the reaction mixture. The mechanism, as shown in the scheme below, proposed for the photohydrolytic degradation is the initial $n \rightarrow \pi^*$ transition of the amide carbonyl functions followed by Zwitterionic state with the subsequent solvation by water molecules to form tetrahedral intermediate. It is this intermediate that collapsed to provide the degradation products (carbon dioxide and aromatic amines) (Audu, 2003).



Scheme Showing the Pathways for the Hydrolysis of Carbanilides

Heavy Metals in the Environment

Heavy metals are among the most common environmental pollutants and their occurrence in water and biota indicate the presence of natural or anthropogenic sources. The main anthropogenic sources are associated with mining, industrial and domestic effluents, urban storms and agricultural water run-offs as shown in Plates 1-4 below. Rivers in urban areas have been associated with water quality problems because of the practice of discharging untreated effluents from industries that have continuously led to increased metal load of the receiving water bodies.



Plate 1: *Showing local gold mining*

Millions of people around the world get exposed to high levels of heavy metals such as arsenic, chromium, nickel, lead and selenium unknowingly in their drinking water and food sources.



Plate 1b: *Showing the grinding of mined gold ore*

Trace amounts of these elements in the body can result in genetic and epigenetic alterations in different cancer-related genes of somatic and stem cells.



Plate 1c: *Showing the Gold Mining Settlement*

Half of the world's newly-diagnosed cancer cases and over 70% of all cancer deaths occur in developing and under-developed countries. In this regard, efforts should be made to quantify the levels of heavy metals in the ecosystem and assess their contribution to incidences of diseases in the communities.



Plate 2: *Showing Cows in dumps*

The concerns for water resources with contaminants such as arsenic, lead, chromium, nickel, and cadmiums that pose threats to health have increased worldwide (WHO, 2000) see Plate 5 below. Exposure to arsenic through drinking contaminated water, eating food irrigated with arsenic-rich water has been found to cause various forms of cancer (IARC, 2012). It has been reported that Nigerians who have been continuously exposed to lead are susceptible to inflammatory disorders and cancer (Adeniyi, 1998).



Plate 3: *Showing wastewater from industrial processing*

The strongest evidence of heavy metals in the environment adversely interfering with healthy reproductive function in women has been associated with lead (Ashiru, 2016). The report even noted that findings have shown that men have a lot more to worry about since sperm development and maturation are more sensitive to heavy metals than eggs.



Plate 4: *Showing contamination of meat by roasting*



Plate 5: *Showing the destructive effects of heavy metals on human organs*

The World of Heavy Metals

The levels (mg/kg) of some heavy metals, Cr, Co, Cu, Fe, Mn, Ni, Pb and Zn were determined in gardens irrigated with industrial waste water effluents in Sharada, Kwakwachi and Jakara areas of Kano metropolis. The vegetables analysed after tri-acid wet digestion with Atomic Absorption Spectrophotometer include spinach, lettuce, cabbage, okra, tomato, onion and carrot. Samples were collected directly from the identified farms during the dry and rainy seasons and the metal levels ranged widely from 0.34 ± 0.03 mg/kg (Cr) to 27.35 ± 0.12 mg/kg (Fe). The relative abundance of the metals in the vegetables followed the sequence Fe > Zn > Mn > Ni > Pb > Co > Cr. Reduction of metal levels were observed in the rainy season samples variously ranging from $8.25 \pm 0.14\%$ Fe in onion to about $45.19 \pm 0.15\%$ Ni in okra (Audu and Lawal, 2005). The vegetables analysed generally show higher retention capacity for essential metals (Zn, Mn and Cu) than for the toxic ones (Pb, Cr and Ni).

The accumulation of heavy metals in soils is of biotechnological concern because of their capacity to inhibit microbial activities. The Kaduna refinery (KRPC) soils which are traditionally subjected to remediation by natural processes were analysed for Cu, Fe, Pb, Mn and Zn using atomic absorption spectrophotometer after acid digestion.

The mean concentrations of the heavy metals were in μmg $0.9.80 \pm 0.67$, 3648.50 ± 0.22 , 134.50 ± 0.28 , 712.0 ± 0.01 and 472.30 ± 8.72 respectively; given the order as $\text{Fe} > \text{Pb} > \text{Zn} > \text{Mn} > \text{Cu}$ (Audu and Lawal, 2004).

Heavy metals that may be present as pollutant or natural components affect microbial metabolic activities, but natural microbial populations have been reported to be the most effective means to bio-degrade hydrocarbon pollutants in contaminated soils. Based on this, we studied the effect of metal amendment on the population density of naturally-occurring microorganism in oil refinery soil using BTX (Benzene/Toluene/Xylene) as the soil contaminant/substrate for the organisms.

The results of the metal ion-modulated microbial degradation of BTX in spilled refinery soils microorganisms show that colony (viable cells) count increased proportionately with experimental levels of Cu, Fe, Mn and Zn over the concentration ranges of 0 to $32 \times 10^3 \mu\text{g/gm}$. The metal supported microbial growth was also observed with Pb over a concentration range of 0 to $14.3 \times 10^3 \mu\text{g/gm}$ of soil, higher concentrations of Pb ($16 \times 10^3 \mu\text{g/gm}$) resulted in decreased mean colony count. The initial inhibition trend for the heavy metals as found in the soil amended to $32 \times 10^3 \mu\text{g/gm}$ was in the order of $\text{Pb} > \text{Zn} > \text{Fe} > \text{Cu} > \text{Mn}$.

Despite the similarity indicated in the general trend for heavy metal inhibition of the microbial degradation of BTX in the refinery and reference soils Cu, Fe, Mn and Zn indicated almost the same inhibition level in the reference as opposed to what was observed in the refinery soil.

The difference in levels of inhibition as observed in the refinery soil may be related to the nature of organic materials native in the soil since different metals have different modes of interaction with the organic pollutants in the refinery soil (Raiswell et al., 1980).

Water for Humans, Animals and Agriculture

The construction of dams and barrages to control natural river flows has been widespread in Nigeria. These dams have been developed primarily for irrigation and in some cases, for human and animal husbandry. The Tomas Dam, which is situated in the Dambatta Local Government Area was nurtured by the Kano State Ministry of Agriculture (WRECA, 1975). The storage of water permits the development of 600 acres of land through gravity irrigation and for supplying water to the Dambatta Municipal Water Treatment Plant. The dam receives an annual average rainfall of

38.5cm but owing to the sandy nature of the soils, the infiltration rate is high and the surface run-off at the dam is about 10%. From the result of the various chemical parameters situated, the Tomas Dam water can be termed fresh and fit for domestic use (Audu et al, 2003).

An all-year round nitrite (a known carcinogen) level determination of the Jakara Dam that receives waste effluents from Bompai Industrial Estate and the Abattoir was also carried out. The results showed that the highest level was observed during the rainy season with values ranging from 7.10 ± 0.06 ppm to 9.34 ± 0.12 ppm; the average of which was 1½ times above the WHO limit for potable water (Audu and Abdullahi, 1988).

Irrigation as a source of soil pollution in the Sudan – Sahel region of northern Nigerian was later studied due to the activities around the Jakara, Tiga and Tomas Dams of Kano State. The Jakara Dam receives its water from River Hadejia, household’s wastewater from the Kano city and industrial waste water from the Bompai Industrial Estate while the Tomas and Tiga Dams are reservoirs for water from the Hadejia River alone. Tiga Dam soils were found to contain the highest concentrations of lead, copper and chromium while Jakara gave the highest levels of cadmium and nickel as in Fig 3.

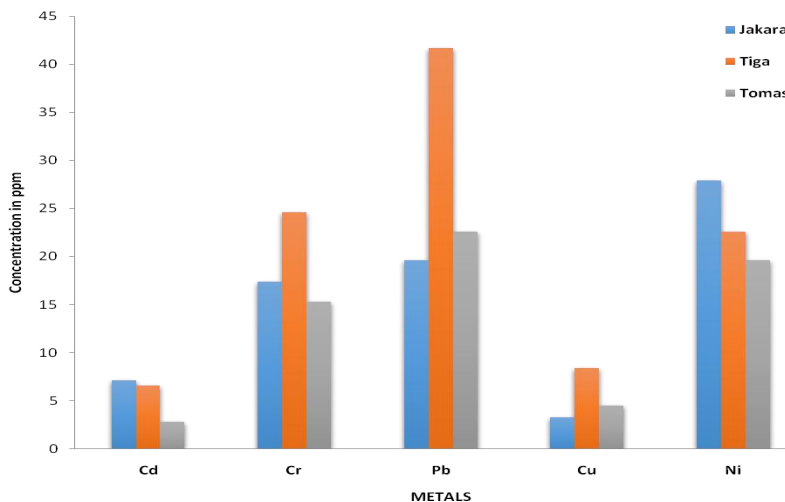


Fig 3: Showing the pattern of heavy metals distributions in the dams

From the results of the analysis, three metals show high pollution level viz lead, cadmium and copper. The levels of cadmium in the Jakara and Tiga soils are more than 20 times the highest levels in such soils. The lead levels in the Tiga soils are about twice the 20 mg/g obtained in soils of this nature. It was then recommended that the soils in these irrigation sites be regularly monitored to ascertain the cumulative pattern (Audu and Peacock, 2005).

The obstruction of the flow of Kumaduga – Yobe River in the north east of Nigeria was studied with respect to its contribution to the heavy metal load of the basin. The results indicated high level of metal pollution which was traced to the upstream which has direct contribution from industrial activities. It was observed that the concentrations of Fe and Pb in the sediment samples were appreciably higher than the WHO permissible levels (Audu and Waziri – 2012).

The assessment of the levels of some heavy metals in glass sand deposit in Kazaure was carried out and it was discovered that Cr and Cd are at pollutional levels in the area. The abundance of the metals quantified were in the order Zn > Fe > Pb > Ni > Cr > Cu > Mn > Cd (Audu et al., 2013).

The effect of the Challawa Industrial Estate on the physicochemical properties and heavy metal levels of potable water supply in Kano metropolis was also studied (Audu and Idowu, 2015).

It was earlier observed that the potable water quality obtained from various locations in Kano metropolis has shown greater variations. Attempts were made to ascertain the reasons for the variations even though the supplies were from only two treatments plants that obtain their raw water from the same source.

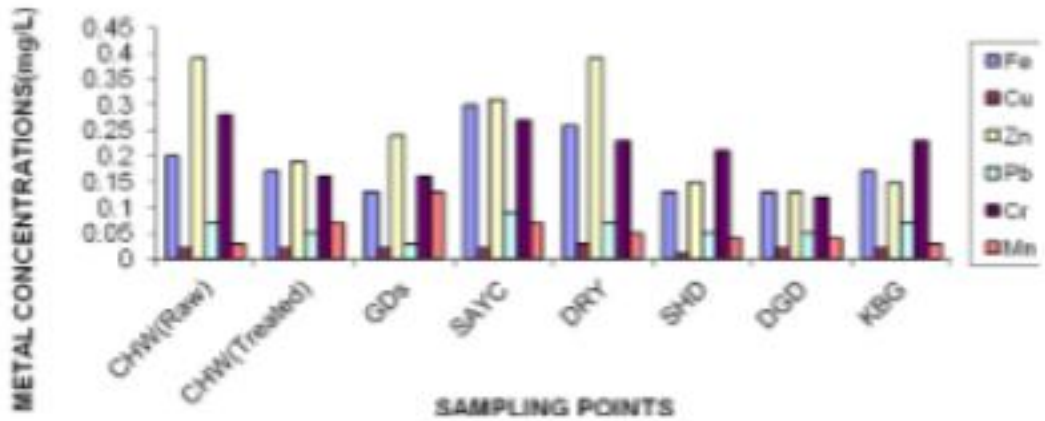


Fig 4: Showing the levels of metals at sampling points along challawa route

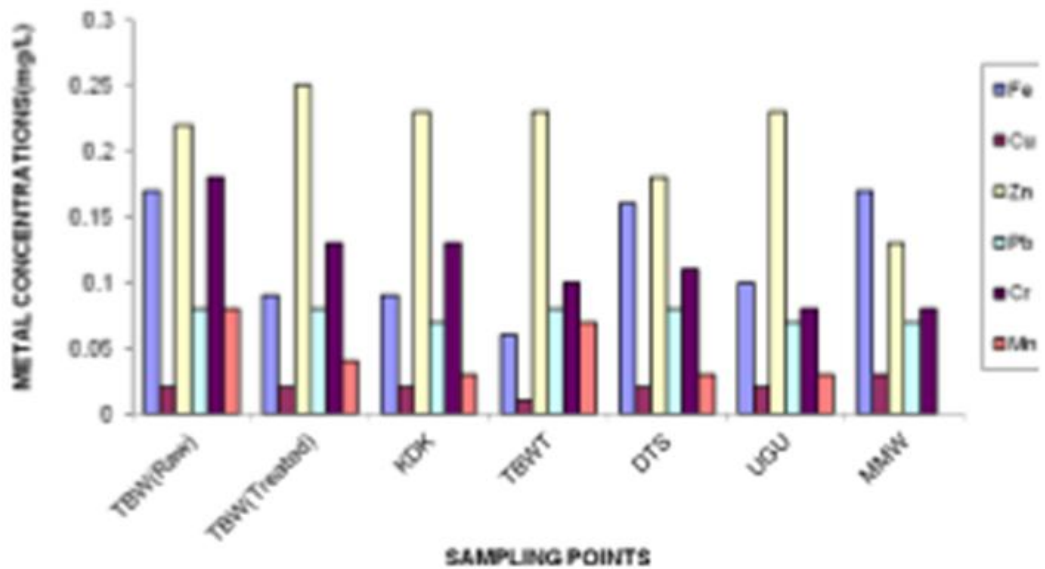


Fig 5: Showing the heavy metals levels at sampling points along tamburawa route

The highest values of Fe, Cu and Mn were recorded along the older distribution channel of Challawa as in Figs.4 and 5. The levels of Pb and Cr were generally high

in both routes which are also observed in the raw water used at the two treatment plants. The results obtained from heavy metal concentrations fell within the maximum allowable limit set by the World Health Organization for potable water except in the cases of Pb and Cr. The high Fe, Cu, Mn levels as obtained in the Challawa route were attributed to leaching from rusting in the old galvanised metal pipe-work in the distribution channel. The level of chromium and lead were similar in the two networks showing that the raw water used in both treatment plants were responsible for the high values obtained and were not effectively removed by the treatment processes.

The residual level of chromium in leather from skins processed through the use of chemicals and those of plant materials have been determined using instrumental Neutron Activation Analysis (NAA). The leather samples were all processed either in tannery companies in Kano or by traditional tanners at Kofar Mata. This is because high levels of residual chromium in leather products cause some health hazards. From the spectrum of the NAA, the mean chromium in the samples were 2.33 ± 0.3 , 2.23 ± 0.3 and $2.93 \pm 0.4\%$ for samples from the tannery, leather craft market and leather waste dumps. Chromium concentration samples collected from local tanners was below detection limit of the technique (Audu et al., 2012).

In the determination of metal levels in the Ajiwa Dam, Katsina State, water samples were collected in the rainy, dry and harmattan seasons and used for the analysis. The results indicated that Ni has its levels as 0.222 ± 0.024 mg/L (rainy season), 0.048 ± 0.002 mg/L (harmattan) and 0.052 ± 0.003 (dry season) and they were higher than the WHO permissible levels. Similar variations in metal levels with seasonal changes were also observed with manganese which was also higher than the WHO levels. Other metals such as cadmium, copper, chromium and zinc are within the allowed limits (Audu and Suleiman, 2016).

The concentrations of some heavy metals were seasonally determined in water samples from 35 sites from three wetlands in northern Nigeria as in Fig.6. The data obtained were subjected to the Turkey's test, principal component analysis and the Pearson correlation coefficient statistical evaluation as in Fig.7.

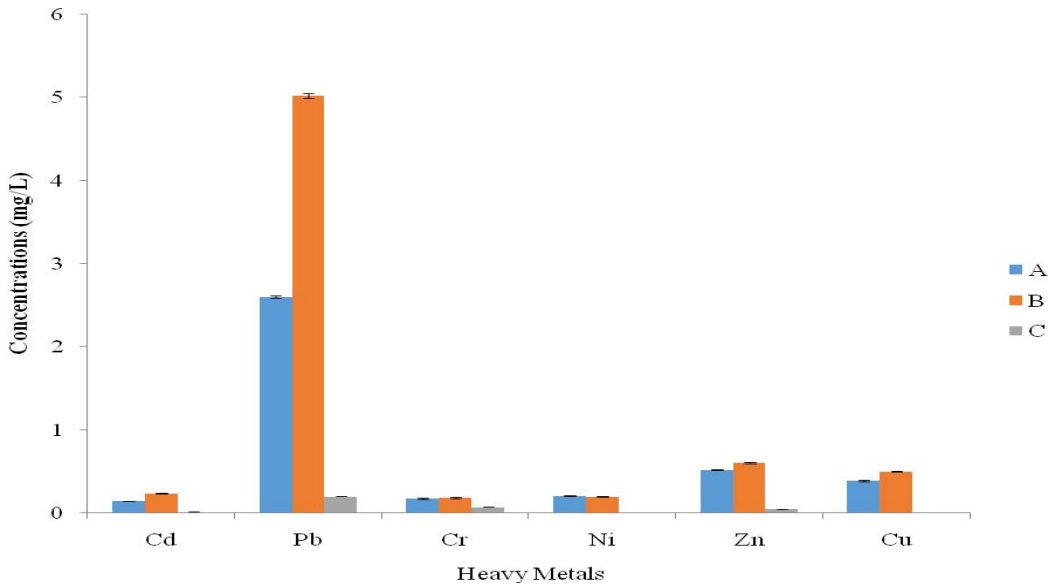


Fig 6: *Metals distributions according to study area*

Lead (Pb) was noted to have the highest mean concentration and the metal graduation order of $Pb > Cr > Zn > Cu > Cd$ in the rainy season but the order changed to $Pb > Cu > Zn > Ni > Cd > Cr$ in the dry season.

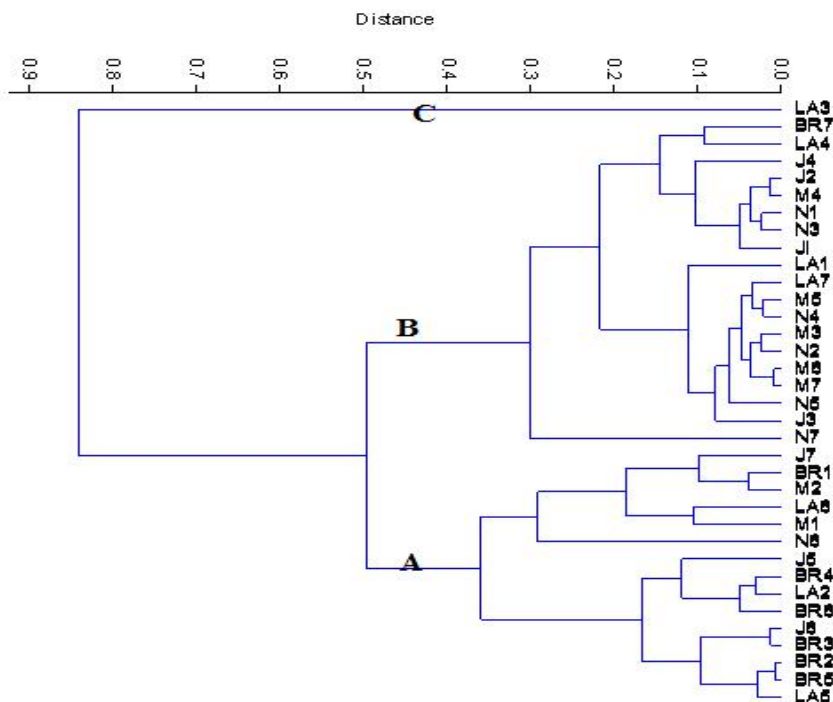


Fig 7: Cluster analysis of the heavy metal levels in the wetlands

The Pb and Cd in all the sites were higher than the WHO and NAFDAC guidelines, indicating that the wetlands water samples are unsafe for human consumption, thus relying on these wetlands as source of food would have serious public health implications. The PCA and CA indicate that the accumulations of metals in these wetlands are mainly caused by anthropogenic activities which were traced to the Challawa and Sharada Industrial Estates in Kano (Audu et al, 2018).

Conclusion

Water, because of its peculiar nature dissolves most chemical substances available on the earth's surface, thus ensuring that there is actually no such thing as *pure water*. Science has taken advantage of this singular nature of water to use it in various forms, ranging from being a reaction medium, heat transfer channel, agriculture and removal of wastes. In the above processes, the resultant water is either contaminated or seriously polluted.

Thus, water generally in the industry today is used as sink for pollutants. Since man cannot cheat Mother Nature, the pollutants are recycled to man through breathing, eating and drinking. This eventually makes the human body the sink for these pollutants with consequences of disease conditions in mankind.

The most serious threat to life on earth today is the increasing level of heavy metals in water and the situation is worse among the under-developed nations. This is due primarily to the non-enforcement of environmental regulations especially as these relate to industrial emissions in the forms of air, waste water and solid wastes.

As at the current situation, there is no water body in all our study area which is not contaminated with heavy metals, ranging from municipal potable water sources to river bodies and even the wetlands. This is because these water bodies are interconnected. Thus, their contents can easily be moved from one area to other unexpected locations. Unfortunately, such contaminants as heavy metals are non-degradable and thus, move around in cycles.

To avoid the future disaster of eventual pollution of the available water supply in Nigeria with heavy metals, sustainable efforts should be made on industrial waste water management. A joint waste water management scheme for cluster industries would be recommended. This would provide an economical solution to the problem due to economy of scale and concomitant equalisation. This system would provide a basis for rational cost sharing. This approach to the joint industrial waste water treatment would require classification, delineation of appropriate pre-treatment system for each class of industries, separate/joint recovery system for the heavy metals and provision of appropriate conveyance system. The effluents from the joint treatment plant can then be discharged into the municipal waste water and then ultimately treated for human use.

At this point, it is worthy to note that the available fresh water is less than 3% while the remaining 97% is a solution of minerals and other substances. This shows that water is a finite resource that needs conservation. Our existence depends on water and only a collective effort can ensure the provision of safe water.

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