RIVERS STATE UNIVERSITY
PORT HARCOURT

CONTENDING WITH RELIABILITY, AVAILABILITY, SUSTAINABILITY OF WATER AND INFRASTRUCTURAL PROTECTION USING CHEMICAL ENGINEERING MASS TRANSFER

AN INAUGURAL LECTURE

BY

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DEDICATION

This Inaugural Lecture is dedicated to Jehovah God My Refuge and Strength. You are worthy, Jehovah our God, to receive the glory and the honour, and the power, because you created all things and because of your will they came into existence and were created.

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PROTOCOL

The Pro-Chancellor and Chairman of Council
The Vice-Chancellor and Chairman of this Occasion
The Deputy Vice-Chancellor (Administration)
The Deputy Vice-Chancellor (Academics)
The Registrar and Secretary to Senate
The University Librarian
The Bursar
Provost College of Medical Sciences, Dean of Post Graduate School
Head of Campuses
Head of Faculties
Directors of Centres/Institutes
Heads of Departments
Emeritus Professors
Distinguished Professors and other Members of Senate All Academic, Administrative and Technical Staff Students of this Great University
Respected Guests, Friends, Admirers, Associates, and Well Wishers
My Lords, Spiritual and Temporal
Gentlemen of the Press
Distinguished Ladies and Gentlemen

1.0 PREAMBLE

Vice Chancellor, Sir and Distinguished audience, today is like a dream! For a son of a poor fisherman and a fisherman himself, standing in the midst of this creme de la creme audienceto deliver an Inaugural Lecture! This indeed is the mercy of God Almighty and His faithfulness. It came to a point that I could not continue Primary School Education because my parents could not afford the school fees of One Pound Thirteen Shillings Four Pence (£1. 13s.4p) for Primary Four per term. How I continued from Primary Five and concluded my Primary Six in 1973.

I was one of the pioneer students of Government Secondary School Ngo, Andoni in 1974 and I was one of those who graduated in 1979. I was also among the first batch of students who gained admission 1980, in the Faculty of Engineering, in the then College of Science & Technology; later Rivers State University of Science and Technology, Port Harcourt, and now Rivers State University and among those who graduated in 1985. Because of my background, and circumstances of life, I decided to marry during my NYSC. It was in 1997/98 I came back for M. Tech programme. In 1999 I concluded and Prof. M. F. N. Abowei saw my results and urged me to continue for PhD programme. He gave me a topic for the PhD and 2003 December, I faced the viva voce. This was when my knowledge of mass transfer in chemical engineering was consummated. At my undergraduate level, Prof. E. N. Wami introduced me to the trend when he gave the topic; 'Mass transfer between Oil Slick and Water and Methods for its Dispersion' as my first degree project topic. My M. Tech Dissertation was on 'Investigation into Coating Failure in the Marine Environment', while the PhD Thesis- 'Modeling Groundwater contaminants due to Transient Sources of Pollutants', are all centred on mass transfer phenomena. This shows the divine plan for today's inaugural lecture.

My industrial experiences started with International Paints West Africa Limited, Ikeja Nigeria with laboratory activities to production of heavy coatings for the protection of process plants/infrastructure. Later I was posted to marketing unit of the company to service and supervise the sales outlets to industries applying the coatings for sustenance of process units. The experience gained with this coating manufacturer opened way for me to be employed with Oil/Gas Servicing Company, Alusteel Nigeria Ltd as Corrosion Engineer of the Company. There, I had the opportunity to supervise projects on coating applications, cathodic protection design works on pipelines, storage tanks and other offshore facilities.

The rigors of offshore activities made me to look inwards and I prayed that God should provide another opportunity to serve Him in His vineyard and humanity. As at then I was an Accredited Lay Preacher and Steward in Methodist Church Nigeria, serving in Port Harcourt Diocese of Methodist Church. God indeed answered my prayers. In August 2005, I was employed as Lecturer II by The Rivers State University of Science & Technology, when Emeritus Prof. S. C. Achinewhu was the Vice Chancellor.

The background given above led me to focus my research into groundwater reliability (quality), availability and sustainability. I have observed how potable water has been scarce for citizens of Nigeria, especially those of us from Niger Delta region. I remember when I lived at Otokolomabie, a fishing settlement fishing with my parents, people were drinking from ponds and shallow wells. Even in my village Unyengala, Andoni, access to potable water is not made available by government. Besides, infrastructure decay couple with low level of maintenance culture has brought about littering of roads, sea with abandoned vehicles, ships indiscriminately. The adverse effects of these abandonments to the ecosystem is better imagined. My experience with Alusteel Nigeria Ltd, which took me to Duala Cameroun for the dry docking of offshore lay barge has shown that some of our excesses that cause infrastructure decay can be curtailed.

2.0 INTRODUCTION

2.1 MASS TRANSFER IN CHEMICAL ENGINEERING

Chemical engineers develop and design chemical manufacturing processes. They apply the principles of chemistry, biology, physics and mathematics and economics to solve problems that involve the production or use of chemicals, fuel, drugs, food, and many other products. Chemical engineers are involved in saving/protecting the environment, improving materials, generating energy, enhancing food production, advancing biomedicine and developing electronics.

However, in this inaugural lecture, areas of research over the years in mass transfer phenomenon in protecting water and infrastructure are presented. These have linkages in sustainability of food, energy and the environment.

2.2 Mass Transfer

The cause (driving force) of a mass transfer process-the transition of a component from one phase to another (for instance, from the liquid phase *x*f having a molar concentration of the transferring component of x to the gaseous phase *y*f having a molar concentration of y) is the lack of equilibrium between the phases in contact, their deviation from the rate of dynamic equilibrium. In chemical thermodynamics it has been established that the magnitude of this deviation with equal

temperatures and pressures of the phases is determined by the difference between the chemical potentials of the transferring components $(\mu_x - \mu_y)$.
In electrophoresis and in electrochemical processes, an electrical potential provides the motive force, in Clusins and Dickel column for the separation of gaseous isotopes, it is a thermal gradient. In most industrial applications activity or concentration gradient is employed to effect mass transfer between two phases (Ujile, 2014).

Mass transfer describes the transport of mass from one point to another and is one of the main pillars in the subject of Transport Phenomena. Mass transfer may take place in a single phase or over phase boundaries in multi-phase systems.

2.3 Types of Mass Transfer

Depending on the conditions, the nature, and the forces responsible for mass transfer, four basic types are distinguished: (i) diffusion in a quiescent (stagnant) medium, (ii) mass transfer in laminar flow, (iii) mass transfer in the turbulent flow, and (iv) mass exchange between phases.

Mass transfer by convection involves the transport of material between a boundary surface (such as solid or liquid surface) and a moving fluid or between two relatively immiscible, moving fluids.

2.4 Modes of Mass Transfer

Diffusion: Diffusion is the macroscopic result of random molecular motion on a microscopic scale.
Convection: Mass transfer by convection involves the transport of material between a boundary surface (such as solid or liquid

surface) and a moving fluid or between two relatively immiscible, moving fluids.

Another mode is the movement of mass caused by a chemical species simply being carried along in a fluid stream which is (advection). This mode has been applied in most of our researching activities over the years.

3.0 AREAS OF APPLICATION

3.1 Electrochemical Corrosion and Ionic Mass Transport

Evans Diagram and Corrosion Kinetics

Metallic surface in aqueous environment can corrode through anodic oxidation, with cathodic reaction (hydrogen evolution or oxygen reduction) taking place on the same surface in the region adjacent to anodic reaction site. Current flows through electrolyte next to the sites and the circuit is completed through the transfer of electrons in the metal.

Evans diagram is obtained by plotting the Tafel approximation of polarization curves (potential vs. current density) for both the cathodic and anodic reactions on one graph.Rather than using equations, a better way of visualizing the relationship between potential and current is by means of Evans diagrams (E-log i plots), where potential is plotted on the vertical (Y) axis and log current or log current density is plotted on the horizontal (X) axis (Figure 2).

Corrosion potential (Ecorr) and corrosion current density (icorr) are obtained from the intersection of the two curves. Cathodic protection involves introduction of another metal in the system that is polarized at lower potentials. On Evans diagram, this translates into another anodic polarization line closer to the current density axis (has lower potential) than the original metal.

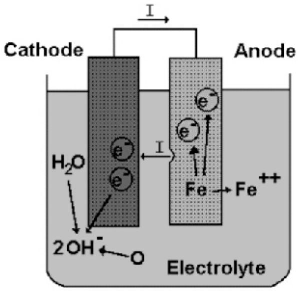

Figure 1. The corrosion cell (DEP, 2003)

At anodic areas, positively charged metal ions leave the metal surface, while at cathodic areas, electrons leave the metal surface. Thus, corrosion takes place at the anodic areas where metal ions react with the electrolyte to form the typical corrosion products. The basic electrochemical reaction is:

$$Fe \rightarrow Fe^{++} + 2e^- \quad (1)$$

At the cathodic areas, dissolution of metal does not take place, but reduction reactions occur in the electrolyte. Depending on the pH and presence of oxygen, the basic electrochemical reaction can be:

$$2H^+ + 2e \rightarrow H_2 \text{ or } \tfrac{1}{2}O_2 + H_2O + 2e \rightarrow 2OH^- \quad (2)$$

At the anode the electrochemical current leaves the metal surface and at the cathodic areas the current enters the metal surface. Because the reaction involves the flow of electrons, the reaction rate can be expressed as an electric current. When a potential of a metal electrode is shifted negatively, the metal tends to attract the Fe++ ions and the anodic reaction is slowed down. When the potential is changed in apositive direction, the Fe++ ions are more easily released and the corrosion accelerates. Similarly, the cathodic reaction rate is increased when the metal becomes more negative and the reaction slows down when the potential becomes more positive. Figure 1.(DEP 2003) explains the principles of the process.

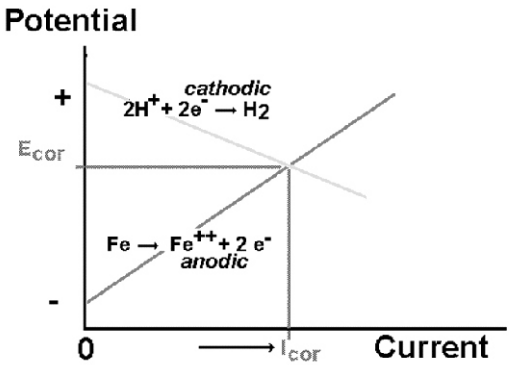

Figure 2 The Evans diagram (DEP, 2003)

The intersection of this line with the cathodic polarization line yields the new Ecorr and icorr See Fig. 2. At this new potential the original metal undergoes cathodic rather than anodic reaction and does not corrode (cathodic protection). If the corrosion potential is not lowered enough to prevent anodic oxidation of the original metal, the lowering of the potential greatly reduces the current density and hence rate of corrosion of the original metal.

Corrosion potential and current density can be calculated using equations (1) and (2) respectively Ujile & Ehirim2010 when the transfer coefficients are equal to 0.5 or equations (3)in more general case. Cathodic protection may be obtained by imposing a potential f (which is different from Ecorr) on the system, and in that case the current density can be obtained by a form of the Stern-Geary relation as shown in equation (3). Peabody, (2001).

$$i = i_{corr}\left[\left(\frac{\alpha_{ax}F}{RT} + \frac{\alpha_{cr}F}{RT}\right)(\phi - E_{corr})\right]$$

3.2 Ionic Mass Transport

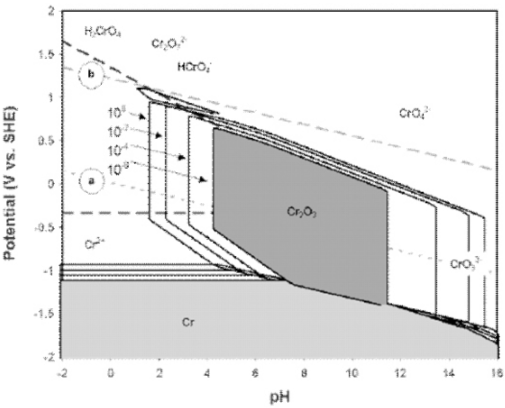

Fig 3: Corrosion Basics –Thermodynamics (Menendez and Hanson, 2000; Ujile, 2005)

Figure 3 is known as the Pourbaix diagram developed from the Nernst equation principles. It has been proven as a convenient way to summarize a situation in terms of its thermodynamics and provide a useful means of predicting electrochemical and chemical processes that could potentially occur in certain conditions of temperature, pressure and chemical make-up. The figure 3 shows region of immunity of chromium (metal); passivity (the surface film- when cathodic protection is required) and the upper section, corrosion (metal ions) is experienced. At potentials more positive than – 0.8 and at pH values below 7 chromium ion is the stable substance. Similarly, in figure 4, the intersection of the two curves in the Evans diagrams occurs at the corrosion current, icorr. It is observed that the wider the difference in equilibrium potentials (ie the bigger the value of ΔEtherm), the bigger the value of icorr (i e the greater the corrosion).

The above corrosion processes have been able to establish the following reaction mechanisms:

- Initiation step
- Propagation & growth steps

Where the initiation, propagation and growth steps are not attended to; by way of controlling or terminating, the facility in question will experience deterioration and failure. The adverse consequences of such failures are enormous economically, socially and environmentally.
Figure 3 was applied for corrosion processes on zinc roof top in three communities in Akwa Ibom on the effects of Petroleum hydrocarbon gas flares at QIT (Ujile & Ehirim, 2013).

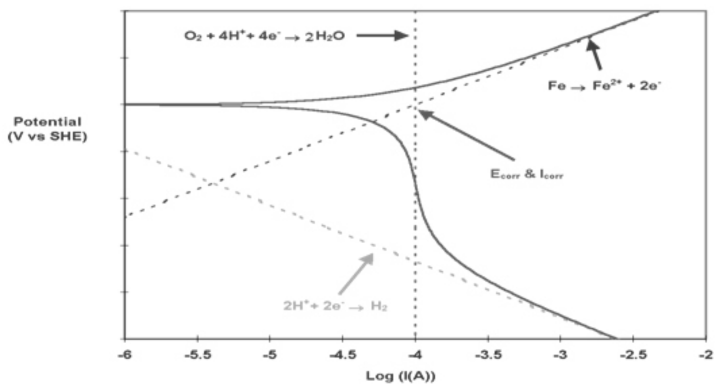

Fig 4: Corrosion Basics - Kinetics (Ujile, 2010)

Concentration gradient, potential gradient and convection contribute to the flux of an ionic species in an electrochemical system. The change in concentration of a species (from the bulk of the solution to the electrode surface) is assumed to occur in the Nernst diffusion layer. If δ_N the Nernst diffusion layer thickness, Co and Cos the concentrations in the bulk and on electrode surface respectively and D the diffusion coefficient, then the mass flux due to diffusion is given by the relation:

$$\frac{D}{\delta_N} = K_L\left(C_O - C_{OS}\right) \quad \textbf{(4)}$$

Frequently this is also expressed as a product of the mass transfer coefficient *(kL)* and driving force (the concentration difference, *Co – Cos)*.

The current density i is related to the flux N of the charged species ($i = F zN$, *z* being the charge on the species). If a cathodic (reduction) reaction is considered, the current density is due to the flux of cations, the flux of anions being zero at the surface of the electrode. In this case the potential gradient can be expressed in term of the concentration gradient and properties of the anion, and substituted in the flux equation for the cation (equation4) yielding the following equation for the current density:

$$i = -\frac{nFD}{l - t_+}\frac{\partial C}{\cap x} \quad \textbf{(5)}$$

The concentration gradient in the above equation can be expressed in terms of the bulk and surface concentrations and the Nernst diffusion layer thickness. The current density increases as the concentration gradient increases, reaching a limiting value when the surface concentration is reduced to zero. This is called the limiting current density (i_l).

Frequently a supporting electrolyte (that does not participate in the reaction) is added to the system to increase the conductivity and reduce Ohmic losses. If sufficient excess of the supporting electrolyte is added, the transference number t_+ for the cation of interest can be reduced to zero leading to the following expression for the limiting current density:

$$i_l = -nFD\frac{C_o}{\delta N} \quad \textbf{(6)}$$

The limiting current in absence of supporting electrolyte is almost twice that in presence of a large excess of the supporting electrolyte.

4.0 GROUNDWATER

Groundwater is by far the most abundant and readily available source of freshwater, followed by lakes, reservoirs, rivers and wetlands:

Groundwater represents over 90% of the world's readily available freshwater resource (Boswinkel, 2000). About 1.5 billion people depend upon groundwater for their drinking water supply (WRI, UNEP, UNDP, World Bank, 1998).

The amount of groundwater withdrawn annually is roughly estimated at ~600-700 km3, representing about 20% of global water withdrawals (WMO, 1997).

A comprehensive picture of the quantity of groundwater withdrawn and consumed annually around the world does not exist.

4.1 RELIABILITY OF WATER

Clean water supplies and sanitation remain major problems in many parts of the world, with 20% of the global population lacking access to safe drinking water. Water-borne diseases from faecal pollution of surface waters continue to be a major cause of illness in developing countries. Polluted water is estimated to affect the health of 1.2 billion people, and contributes to the death of 15 million children annually.

A wide variety of human activities also affects the coastal and marine environment. Population pressures, increasing demands for space and resources, and poor economic performances can all undermine the sustainable use of our oceans and coastal areas. Serious problems affecting the quality and use of these ecosystems include:

I) Alteration and destruction of habitats and ecosystems. Estimates show that almost 50% of the world's coasts are threatened by development-related activities.

ii) Severe eutrophication has been discovered in several enclosed or semi-enclosed seas. It is estimated that about 80% of marine pollution originates from land-based sources and activities.

iii) In marine fisheries, most areas are producing significantly lower yields than in the past. Substantial increases are never again likely to be recorded for global fish catches. In contrast, inland and marine aquaculture production is increasing and now contributes 30% of the total global fish yield.

iv) Impacts of climate change may include a significant rise in the level of the world's oceans. This will cause some low-lying coastal areas to become completely submerged, and increase human vulnerability in other areas. Because they are highly dependent upon marine resources, small island developing states (SIDS) are especially vulnerable, due to both the effects of sea level rise and to changes in marine ecosystems.

4.2 Sources of Contamination

The sources of groundwater contamination in the Niger Delta are both from natural and human activity. The Niger Delta Basin serves as the receptor of water and sediments generated upstream of the Niger and Benue catchment. Investigations carried out by Teme (2002), Ujile (2007) revealed the excess water and sediments generated during annual floods are released through the distribution network of rivers, creeks, rivulets, canals into the Atlantic Ocean. Groundwater contamination can occur by infiltration, recharge from surface water, direct migration and inter-aquifer exchange (Figures 5 and 6). In figures 5 and 6 one could see that in saturated zone, contaminants in the leachate spread horizontally in the direction of groundwater flow and vertically due to gravity.

Ibadan is the second largest city in Nigeria, and it is a major commercial, industrial and administrative centre. Open waste disposal sites have produced a negative effect on the quality of groundwater and soil. The data obtained from all the studies of the four sites indicate existence of pollution near the disposal sites. The closest well to the waste site showed higher contamination than the control sites. It was noticed by the investigators that that groundwater contamination spread horizontally Ujile, *et al* (2012).

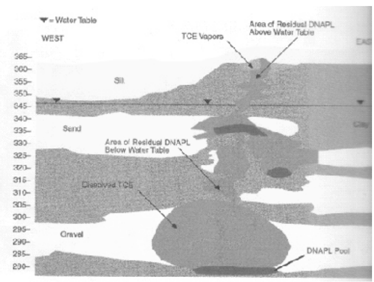

Fig. 5: Contaminant plume profile (Ujile, 2003)

Water scarcity and poor water quality impact virtually everyone, making water management a critical global issue. Water management strategies attempt to minimize water use; and a common water management strategy involves the 4Rs (UNESCO, 2017; Foo, 2019)

(I) Reduce pollution at the source; ii) Remove contaminants from wastewater; iii) Reuse wastewater; (iv) Recover by-products.

Many chemical process industries (CPI) facilities are faced with ever-tightening water discharge limits, rising cost of wastewater treatment, it becomes imperative for engineers and other stakeholders in water management process to focus efforts on the first R, ie, reduction of contamination at source. The emphasis has been on designing robust more and sustainable chemical processes that produce less wastewater (Ujile, 2020).

Groundwater is known to be an efficient perennial source of water and a much needed buffer during the times of drought Calow, *et al* (1997). A resource can be locally developed for in situ utilization Adepelumi, *et al* (2009). Groundwater is believed to be the ultimate source of potable water for rural population because of its incremental development at affordable cost and its relative stability than its surface counterpart Carter, (2003).

In developing mass transfer model for predicting concentration profiles of contaminants in groundwater resource, Ujile and Owhor (2018)concluded that sources of pollution are anthropogenic.

Their work involved experimental analyses on three abandoned dumpsites (Nkpolu, Oyigbo, and Elekahia) in Port Harcourt to determine the concentrations of lead, cadmium, and Iron in soil and existing tap water close to the dumpsites. Model for the prediction of lead (Pb), cadmium (Cd) and Iron (Fe) migration from abandoned dumpsite into groundwater has been developed. The model was solved and validated with experimental results. Statistical analysis was performed between the experiment and model result to determine the significant difference.The model validation showed goodness fit which was further validated by statistical analysis as there was no significant difference at $p<0.05$. The simulation performed to determine the quality of existing groundwater obtained from taps close to the abandoned dumpsites showed that the contaminants' concentration decreased as the depth from point source increased into the groundwater aquifer. At the 60 meters depth, the result obtained from predictive model showed that Pb (0.000182mg/L for Nkpolu, 0.000194mg/L for Oyigbo and 0.000482 mg/L for Elekahia dumpsites, Cd (9.77x10-6mg/L for Nkpolu and 6.98 x10-6mg/L for Oyigbo and Elekahia dumpsites and Fe (0.000347mg/L for Nkpolu, 0.00419mg/L for Oyigbo and 0.00415mg/L for Elekahia dumpsites. The concentrations were below the international standard limit for drinking water quality (0.01mg/L for Pb, 0.003mg/L for Cd and 0.3mg/L for Fe). However, the laboratory analysis showed that only water sample collected from Nkpolu abandoned dumpsite met the international standard limit. Results showed that the increase in seepage velocity would impact negatively on the contamination of groundwater.

Out of the 112 borehole analyses in some towns and villages in the Rivers and Bayelsa States, 42%, 8%, 10%, 77% and 54% of iron, chloride, salinity, hardness and pH respectively were found to be contaminated (Ujile, 2013). The Funiwa blowout of 1980 had adverse effects on groundwater at Fishtown in the Bayelsa State. An ecological investigation carried out 18 months later revealed extensive environmental degradation of the area (Oteri,1981). Presently, there are high levels of oil/gas exploration and exploitation in the region where the economy of Nigeria depends on.

The groundwater quality assessment carried out by Adesuyi, *et al*. (2015) on 20 boreholes in the Eliozu community of Port Harcourt has shown contamination of most of the parameters, like dissolved oxygen, biochemical oxygen demand, etc. Groundwater studies in some areas in the Rivers State have shown increased levels in Total Dissolved Solids (TDS), upto 2900mg/l; there was a high hydrocarbon content, with oil and grease at 71mg/l in 2006 compared to 1.8mg/l recorded 17 years earlier (Ayotamuno and Kogbara, 2007). Amajor (1991) and Ujile (2001) had reported iron and chloride elevation as groundwater issues, and this was corroborated by Ophori *et al.* (2007). Similar problems as reflected in the Bayelsa, Delta and Akwa Ibom States have also been reported (Amangabara and Ejenma, 2012); (Edet, 2004); (Amadi *et al*., 2010).

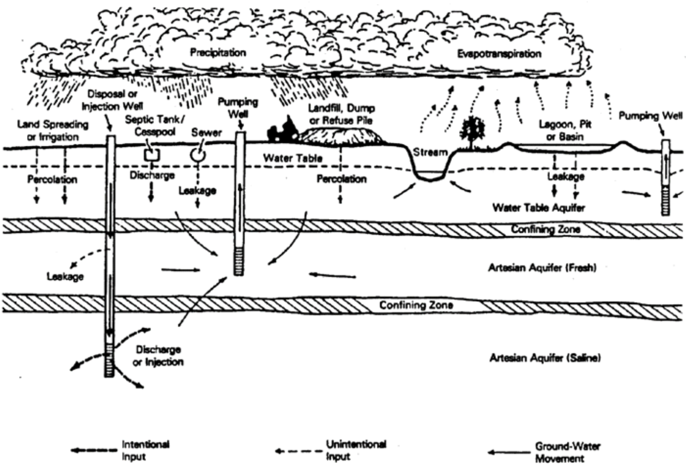

Fig 6: Sources of groundwater contamination (Geraghty and Miller, 1985; Ujile, 2003)

TABLE 1: POPULATION AND PER CAPITA WATER AVAILABILITY FOR SELECTED COUNTRIES

(Adapted from World Bank, 1992)

	Population				Annual renewable fresh water available (km^3)	Per capita freshwater availability ($1000m^3$)		
Countries	Millions			Growth Rate % per annum				
	1994	2025	2050	1985-1994		1994	2025	2050
Argentina	34.2	46.1	53.1	1.4	994	29.06	21.56	18.71
Bangladesh	117.8	196.1	238.5	2.0	2357	20.00	12.02	9.88
Brazil	150.1	230.3	264.3	1.8	6950	46.30	30.18	26.30
Canada	29.1	83.3	39.9	1.3	2901	99.69	75.74	72.70
China	1190.9	1526.1	1606.0	1.4	2800	2.35	1.83	1.74
Egypt	57.6	97.3	117..4	2.0	59	1.02	0.60	0.50
India	913.6	1392.1	1639.1	2.0	2085	2.28	1.50	1.27
Indonesia	189.9	275.6	318.8	1.6	2530	13.32	9.17	7.94
Japan	124.8	121.6	110.0	0.4	547	4.38	4.50	4.97
Mexico	91.9	136.6	161.4	2.2	357	3.88	2.61	2.21
Nigeria	**107.9**	**238.4**	**338.5**	**2.9**	**308**	**2.87**	**1.29**	**0.91**
Turkey	60.8	90.9	106.3	2.1	203	3.34	2.23	1.91
United Kingdom	58.1	61.5	61.6	0.3	120	2.07	1.95	1.95

Table 1 shows that for a country such as Nigeria, whose population is expected to increase significantly from about 108 million in 1994 to some 339 million by the year 2050, its per capita water availability is likely to decline from 2870 m3/year to only 910 m3/year by 2050.There are exceptions in few countries such as Japan. Availability and Sustainability become challenges for Nigeria from Table 1.

4.3 WATER QUALITY AND AVAILABILITY STATUS IN NIGERIA

Results of the water quality indices in some communities in Nigeria show that both surface and ground water status is unfit for drinking. For example the values of water quality indices of Okrika, Rivers State, in wet and dry seasons are 26240 and 42860 respectively (Ogolo *et al,* 2021).

DETERMINATION OF WATER QUALITY INDEX ON

GROUNDWATER IN OKRIKA AND ITS ENVIRONS

The quality of water is the degree of its safety and hygienic conditions. Drinking water is said to be potable when such conditions are attained and it is determined by the amount and level of physico-chemical, microbial and heavy metals (which included suspended and dissolved substances in the water, the degree of alkalinity (pH), temperature, appearance in terms of colour, taste, odour and the presence of non- desirable microorganisms). Water for domestic purposes should therefore be free from these substances in order to prevent waterborne diseases. The understanding and monitoring of sources of water used for water supply remains social, economic and conservational importance. This is necessary, since per capita water demand is increasing, while accessibility to freshwater availability has continued to decline. Water Quality Index (WQI) is a very useful and efficient method for assessing the suitability of water quality. It is also a very useful tool for communicating the information on overall quality of water (Jaji et al., 2007) to the concerned citizens and policy makers. It, thus, becomes an important parameter for the assessment and management of water quality (both surface and groundwater). WQI reflects the composite influence of different water quality parameters and is calculated from the point of view of the suitability of (both surface and groundwater) for human consumption. In general, water quality indices incorporate data from multiple water quality parameters into a mathematical equation that rates the health of waterbody with number (Akoteyon, et al 2011 https://www.researchgate.net/publication/279900384). The study assessed groundwater water quality for domestic use based on computed water quality index values as shown in equation (1).

$$Q_p = \sum_{p=1}^{n} \left(\frac{A_p - I_p}{S - I_p} \right) \subset 100 \quad \textbf{(7)}$$

Where Qp= quality of parameters
Ap= average values of parameters determined under laboratory conditions
S = standard permissible values obtained from recognized bodies
Ip= ideal values for the parameters.
All ideal values (Ip) are taken to be zero, except that of pH=7; DO =14.6; Fluorides = 1 (Dakhad, et al, 2008).
The water quality index is determined by aggregating the products of the parameter qualities and the unit weights dividing by the aggregate of the unit weights as in equation (7).

$$WQI = \frac{\sum_{p=1}^{n} Q_p W_p}{\uparrow_{p=1}^{n} W_p} \quad \textbf{(8)}$$

The water quality ratings assigned to assigned to water quality index values are shown in table 2

TABLE 2: WATER QUALITY INDEX AND WATER STATUS

Water Quality Index	Water Quality Status
0-25	Excellent
26-50	Good
51-75	Bad
76-100	Very bad
>100	Unfit for drinking

Source: Chatterji and Razuiddin(2002)

RESULTS OF WQI OF GROUNDWATER FROM OKRIKA AND ITS ENVIRONS

TABLE 3: WET SEASON

Parameter	Observed Value	Standard Value (WHO)	Unit Weight (W_p)	Quality Rating (Q_p)	WQI (W_pQ_p)
pH	5.59	6.5-8.5	0.011	282	3.102
Electrical Conductivity	1307	1000	0.0050	130.7	0.654
TDS	8118	600	0.052	1353	**70.356**
Salinity	14.8	200	0.0002822	7.4	0.0021
Turbidity	0.51	5	0.0004004	10.5	0.004204
Chlorine	8.92	5	0.006788	178	1.208
Bromine	0.01	0.05	0.0007627	20	0.015
DO	2.14	6	0.005525	144.884	0.80
BOD	0.48	0.002	0.915	24000	**21960**
Nitrate	0.92	50	0.0000702	1.84	0.0001292
Phosphate	0.47	0.5	0.003585	94	0.337
TOTAL				**26222**	**26240**

TABLE 4: DRY SEASON- WATER QUALITY RATING OF GROUNDWATER FROM OKRIKA AND ITS ENVIRONS

Parameter	Observed Value	Standard Value (WHO)	Unit Weight (W_p)	Quality Rating (Q_p)	WQI (W_pQ_p)
pH	6.3	7.5	0.003266	140	0.457
Electrical Conductivity	115.9	1000	0.0002706	11.6	0.00314
TDS	91.67	600	0.000357	15.3	0.005462
Salinity	1.09	200	0.00001272	0.545	0.0000070
Turbidity	0.01	5	0.0000047	0.2	0.00000094
Chlorine	0.01	5	0.0000047	0.2	0.00000094
Bromine	0.01	0.05	0.0000047	20	0.0094
DO	0.94	6	0.00371	158.84	0.590
BOD	0.85	0.002	0.992	42500	42160
Nitrate	0.41	50	0.00001913	0.82	0.0000157
Phosphate	0.08	0.5	0.0003733	16.0	0.005973
TOTAL				**42860**	

The analysis has shown that the water status for wet and dry season is unfit for drinking (Tables 2, 3 and 4).

The borehole and well water in Wukari Town, Taraba State has shown some levels of contamination (Oko, 2014). In Lagos, similar contamination problems are encountered (Akoteyon, *et al*. 2011).

Analysing the water management issues using Geospatial Information System (GIS) in Nigeria, Merem, *et al* (2017) recorded the critical state of Nigeria's water situation comprises of a whole range of additional challenges including changes in regional water balance projected for 2020 across multiple regions beginning with the north, central and southern regions. Among the regions, the North East and the North West have a projected demand of 1,650 to 2,896 while the Central West 1 and 2 share a projected demand level of 3,128 - 2,419. During the same period in the south, the South West and South East would see demand levels of 8,472 - 4,707. With the actual supply capacity volumes estimated mostly in the hundreds for all regions with exception of the south west with 1,012. Among the other regions (most notably North West, North East, the Central areas and South east), the volume of water supply capacity will stand at 275 -378 to 534-182 and 396. GIS assessment reveals a steady dispersion of socio-economic factors as well as diffusion of stressors in some areas. Despite current initiatives, Nigeria's water environment remains under stress with projected deficits. Figure 7 shows the percentage of population with access to potable water in 2001 (Okoye, 2007). The figure also shows the percentage of population in the 36 states in Nigeria.

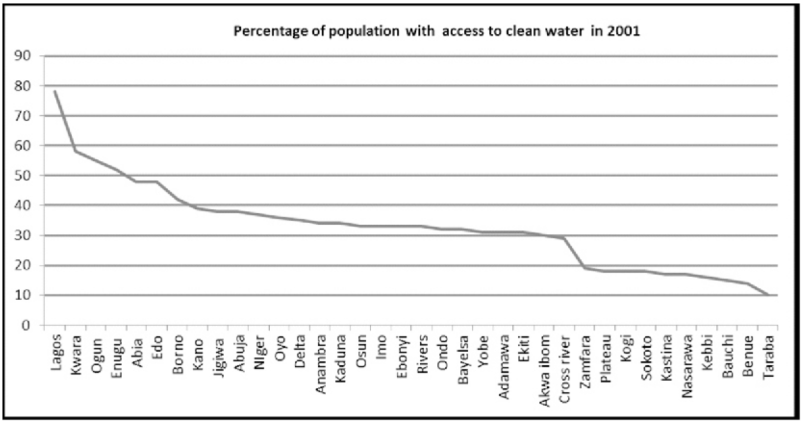

Fig.7: Percentage of Population with Access to Clean Water in 2001 (Okoye, 2007)

5.0 DEVELOPING MODELS OF GROUNDWATER CONTAMINATION AND SOLUTION TECHNIQUES

In modelling groundwater contamination, we obtained the following with water balance phenomenon, Ujile, 2003; Ujile 2007:

$$\left(D_x \frac{\partial^2 C}{\partial x^2} + D_y \frac{\partial^2 C}{\partial x^2} \right) - \left(V_x \frac{\partial C}{\partial x} + V_y \frac{\partial C}{\partial y} \right) = \mathrm{R} \frac{\partial C}{\partial t} + \mathrm{KC} \qquad \textbf{(9)}$$

5.1 Method of Solution to the Model Equation

There are two types of models used in most groundwater investigations: analytical and numerical. An analytical model is a very simplified equation that has an exact solution. A numerical model approximates the partial differential equations describing the groundwater flow and solute transport. Numerical models, though still simplifications of the actual

hydrogeology, are typically much more complex than analytical models. Each model may also simulate one or more of the processes that govern groundwater flow or contaminant migration rather than all the flow and transport processes .
However each model whether it is simple analytical or complex numerical has applicability and usefulness in hydrogeological and remedial investigations. It is on the basis of the applicability and usefulness of the two types of models that the conjunctive use of the two models is applied.
The method used for solving the model equation (9) incorporates the Taylor theorem using the grid system. The Neumann and Mixed problem principle associated with Euler method were used for the solution of the model equation.
Eq. (9) was solved using appropriate boundary conditions to yield approximate predictive model. The developed groundwater model equation in the x – y Cartesian plane is subject to the boundary conditions.

$$\text{In}\ \frac{C_{A\wp}}{C_o} = \text{In}\left[K_L\ (1+\rho_b\ Kd/\phi) + \frac{M}{h}\right] - \left\{\left[K_L\ (1+\rho_b\ Kd/\phi) + \frac{M}{h}\right]\Big/(1+\rho_b\ K_d/\phi)\right\}.t \qquad \textbf{(10)}$$

(10)

$$Where\ M = \left(\frac{2D_x}{h} - (1-a)V_x\right)\frac{1}{a} + \left(\frac{2D_y}{h} - (1-b)V_y\right)\frac{1}{b} \qquad \textbf{(11)}$$

(11)

$$\mathrm{C_A}` = \frac{C_A}{h}\ (\mathrm{A + B + P + Q})$$

$$\mathrm{A} = \left(\frac{2D_x}{h} - V_x\right)\frac{1}{a(a+1)}$$

$$\mathrm{B} = \left(\frac{2D_y}{h} - V_y\right)\frac{1}{b(b+1)}$$

$$P = \left(\frac{2D_x}{h} + V_x a \right) \frac{1}{a(a+1)}$$

$$Q = \left(\frac{2D_y}{h} + V_y b \right) \frac{1}{(b+1)}$$

(Ujile, 2003)

5.2 Application of the Model Equations

Area Description: Yenagoa in Bayelsa State

Niger Delta is one of the largest wetlands in the world; and produces crude oil, which accounts for about 85% of the total Nigerian Government revenue. The states within the region are: Edo, Delta, Bayelsa, Rivers, Akwa Ibom, Ondo and Cross River State. Yenagoa is the headquarters of one of these States, was taken as the study area. The groundwater iron distribution map of part of the region is shown in Fig. 8. The figure shows that Yenagoa has very high iron concentration of 1 to 8 mg/l. The River Niger deposits all loadings from the upper Niger at the Deltaic zones. It bifurcates at some 130 km south of the apex into the rivers Nun and Forcados. Yenagoa is located east of the confluence of River Nun and Ekole River. Niger Delta Environmental Survey Report NDES asserted that the River Niger carries iron loadings from the deposits of Itakpe Iron Ore and perhaps through the processes of dispersion, advection, inter aquifer exchange move the pollutants to the groundwater aquifer. The recent flood (2022) in Bayelsa, Rivers and Delta States would exacerbate the groundwater contamination in the affected States. Therefore the reliability, availability, and sustainability of the only source of potable water is not guaranteed.

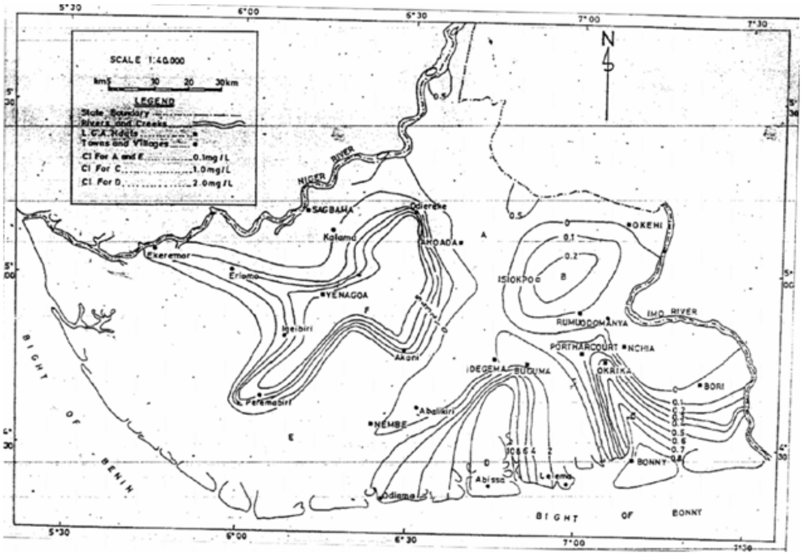

Fig.8: Groundwater Iron distribution map of Bayelsa and Rivers State in Niger Delta, (Ujile et al., 2007)

The application of the second order partial differential equations for groundwater flow to determine the concentration profile of iron has been carried out. The application of the model equation has provided simple results that are similar to works carried out by other researchers with complex results.
The variation of porosity values has caused significant changes in the concentration of groundwater contaminant.
This analysis can be applied for the design of natural attenuation landfill for both municipal and industrial wastes. Materials of construction at the bottom of the landfill can be based on the principle of attenuation of groundwater contaminants. The determination of concentration profile gives a guide to the treatment method(s) that is/are applicable.

6.0 RELATION TO LIFE: WATER-ENERGY-FOOD NEXUS

Countries have challenges of providing water, energy and food for the growing human population within the limits of its environment. These three are closely connected in a nexus in the sense that it requires water and energy to produce food, it requires water and possibly biomass to produce energy and it requires energy to produce usable water, Xie, *et al* (2018). Abraham, (2018) stated that the global challenges for meeting the human needs for food, water and energy are inter-connected in a complex way. The standpoint of these linkages shows that they are treated together as a unit Ujile, (2021).

Chemical engineering practice involves the use of both renewable and non-renewable materials, energy and exergy (available energy) resources and water for the production of chemicals, value added goods, food and wastes in form of pollution. It therefore becomes imperative that engineers, chemists and experts in other disciplines who are involved in production processes should incorporate the idea of pollution prevention into process and product designs, manufacturing, and value - chain management Das and Cabezas, (2018). Here, consideration of the availability of water, energy and food supply with the prevailing population growth index and correlations with the consumption rates in Nigeria is made. This could establish deficiencies that might inform stakeholders the management framework of the resources to maintain high standard of healthy living in the country as to sustain the Millennium Development Goal (MDG).

6.1 MASS TRANSFER PHENOMENON ON ADSORPTION OF CONTAMINANTS.

In liquid-solid systems the volume changes in the liquid phase are small, and because of the difficulty of distinguishing between the adsorbed phase and liquid clinging to the surface that is removed from solution; the amount adsorbed is calculated from the changes in concentration of the known contaminants.

The precise way in which adsorption and regeneration are achieved depends on the phases involved and the type of fluid-solid contacting equipment employed. Of the three known types of contacting the only one relevant in this work is (Richardson, et al 2003):

Those in which the adsorbent and contacting vessel are fixed while the inlet and outlet positions for process and regenerating streams are moved when the adsorbent becomes saturated. The fixed bed adsorbent is an example of this arrangement. If continuous operation is required, the unit must consist of at least two-beds, one of which is on-line, while the other is being regenerated.

Adsorption processes may be classified as purification or bulk separation, depending on the concentration in the feed fluid of the components to be adsorbed (Seader and Henley, 2006). In adsorption process, there is higher concentration of materials at the surface or interface between the two phases, it is called interphase accumulation. The substance which is being adsorbed on the surface of another substance is called adsorbate. The substance, present in bulk, on the surface of which adsorption is taking place is called adsorbent. The interface may be liquid–liquid, liquid–solid, gas–liquid or gas–solid. Of these types of adsorption, only liquid–solid adsorption is widely used in water and wastewater treatment. The following four steps are considered, in which solute (adsorbate) is moved toward the interface layer and attached into adsorbent.

(I) **Advective transport:** solute particles are moved from bulk solutions onto immobile film layer by means of advective flow or axial dispersion or diffusion,

(ii) **Film Transfer:** Solute particle is penetrated and attached in immobile water film layer,

(iii) **Mass Transfer:** Attachment of solute particle onto the surface of the adsorbent and finally

(iv) **Intraparticle Diffusion:** Movement of solute into the pores of adsorbent (Vasanth et al. 2004).

6.2 Design Process

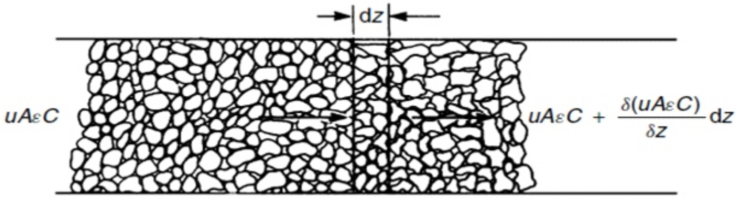

Fig. 9: A mass balance of adsorbate in the fluid flowing through an increment dz of bed

A mass balance of adsorbate in the fluid flowing through an increment dz of bed gives:

Input – Output = Accumulation + loss by adsorption (12)

Equation (1) can be expressed mathematically as

$$uA\varepsilon C - [uA\varepsilon C + \frac{\partial(uA\varepsilon C)dZ}{\partial Z}] = \frac{\partial(\varepsilon ACdZ)}{\partial t} + loss \qquad (13)$$

where u = interpellet velocity of fluid, m/s

ε= interpellet void fraction, -

A= superficial cross-sectional area of bed, m2

C= concentration of adsorbate in the fluid, kmol/m3

Z = distance along a bed, m

The rate of loss by adsorption from the fluid phase equals rate of gain in the adsorbed phase

Rate of adsorption = $\frac{\partial[(1-\varepsilon)AC_s dZ]}{\partial t}$ (14)

$$\left(\frac{\partial(uC)}{\partial Z}\right)_t + \left(\frac{\partial C}{\partial t}\right)_Z = -\frac{1}{m}\left(\frac{\partial C_s}{\partial t}\right)_Z \qquad (15)$$

$$m = \frac{\varepsilon}{1-\varepsilon}$$

This work shows that iron, hardness, etc are considered to be the constituents in the borehole water to be adsorbed by the adsorbent, based on the analysis and characterization of the water samples.

When the adsorbate content of the inlet stream is small, fluid velocity virtually remains constant along the bed column. Equation (15) becomes:

$$u\left(\frac{\partial(C)}{\partial Z}\right)_t + \left(\frac{\partial C}{\partial t}\right)_Z = -\frac{1}{m}\left(\frac{\partial C_s}{\partial t}\right)_Z \qquad (16)$$

Equation (16) includes explicitly the interpellet voidage. The intra-pellet voidage α contributed by the pores is subsumed in the terms Cs, which is the mean adsorbate content on the pellet. Cs may vary along the bed although it is assumed to be constant at any radius at a particular distance from the inlet. This is peculiar at the second stage, where the velocity is under control.

Substituting $\chi = \frac{Z}{mu}$ and $t_1 = t - \frac{Z}{u}$ into equation (16) we have:

$$\frac{\partial C}{\partial \chi} = -\frac{\partial C_s}{\partial t_1} \qquad (17)$$

Equation (17) defines the adsorption process of iron removal from borehole water. The concentration of iron and other contaminants are adsorbed on the adsorbent, depending on the adsorbent bed (distance), velocity of flow, voidage of adsorbent, (surface area) with respect to time.

7.0 WATER-ENERGY-FOOD NEXUS

Our countries have challenges of providing water, energy and food for the growing human population within the limits of its environment. These three are closely connected in a nexus in the sense that it requires water and energy to produce food, it requires water and possibly biomass to produce energy and it requires energy to produce usable water Ujile, (2020). Climate change could affect the amount of water available to produce electricity or extract fuel. In areas where water is already scarce, competition for water between energy production and other uses could increase Ujile, (2021).

7.1 ENERGY

Energy is a vital input for the techno-industrial development and economic growth for any country. Despite the enormous endowments of renewable and non-renewable primary energy resources, Nigeria is still faced with many electricity problems; ranging from generation, transmission to distribution and marketing. This has hampered its economic development. The total installed capacity of power generation in Nigeria as at August 2015 is 12, 522 MW, but 7141 MW is said to be available [Nigeria Power Baseline Report, 2016].

As at (2020) Nigeria was battling with 3500 MW for over 180 million people. The available energy is on a very low side. Nadabo, (2010) expressed that the persistence of the problem is due to the government's adaptation of short term, hasty policies and carrying out energy projects which are detrimental to long term energy policies that will help the nation to achieve sustainable energy and energy efficiency.

Table 5: Nigeria's Energy Situation compared with Selected Countries (Onyekena, *et al.* 2017)

Country	Population (Million)	Generation Capacity (GW)	Energy Consumption (billion kwh)	Energy Consumption per Capita (kwh)
USA	321,368,864	1,053	3,883	12,083
Germany	80,854,408	178	583	7,204
UK	64,088,222	76	304	4,740
South. Africa	53,675,563	44	234	4,363
China	1,367,485,388	1,505	5,523	4,039
Brazil	204,259,812	119	479	2,344
Egypt	88,487,396	27	129	1,462
Indonesia	255,993,674	41	156	609
India	1,251,695,584	223	758	605
Ghana	26,327,649	3.0	11	403
Nigeria	178,562,056	7.6	23	129

Moss and Portelance (2017) stated that Nigeria is 80% below its energy use, based solely on income levels- this is the lowest in the world. Table 5 represents the appalling state of energy consumption in Nigeria relative to selected developed and developing countries.

Nigeria's economic growth is also constrained by insufficient electricity generation capacity, which results in a lack of a reliable and affordable supply of power. At the same time, Nigeria flares considerable amounts of associated gas, a by-product of offshore crude oil extraction. Flaring generates significant greenhouse gas emissions and wastes a considerable amount of energy. To reduce gas flaring and increase generation of clean energy generally through greater private sector participation, we support the Government of Nigeria's efforts to better manage the sector https://www.usaid.gov/nigeria/economic-growth.

TABLE 6: ELECTRICITY GENERATION PROFILE (SOURCE: NERC, 2015)

Year	Ave. Gen. availability (MW)	Maximum peak generation (MW)	Maximum daily energy generated (MWh)	Total energy generated (MWh)	Total energy sent out (MWh)	Per Capita Energy Supply (kWh)
2007	3,781.3	3,599.6	77,322.3	22,519,330.5	21,546,192.2	155,3
2008	3,917.8	3,595.9	86,564.9	18,058,894.9	17,545,382.5	120,4
2009	4,401.8	3,710.0	82,652.3	18,904,588.9	18,342,034.7	122,0
2010	4,030.5	4,333.0	85,457.5	24,556,331.5	23,939,898.9	153.5
2011	4,435.8	4,089.3	90,315.3	27,521,772.5	26,766,992.0	165.8
2012	5,251.6	4,517.6	97,781.0	29,240,239.2	28,699,300.8	176.4
2013	5,150.6	4,458.2	98,619.0	29,537,539.4	28,837,199.8	181.4
2014	6,158.4	4,395.2	98,893.8	29,697,360.1	29,013,501.0	167.6

7.2 FOOD

The country is a leader in various types of agricultural production, such as palm oil, cocoa beans, pineapple, and sorghum. It is the largest producer of sorghum in the world just after the United States, and ranks fifth in the production of palm oil and cocoa beans. Nigeria is also a large global nuts exporter.

Agriculture is a key activity for Nigeria's economy after oil. Agricultural activities provide livelihood for many Nigerians, whereas the wealth generated by oil reaches a restricted share of the population. According to a recent survey, some 70 percent of households in Nigeria participate in crop farming activities, while about 41 percent own or raise livestock. In rural areas more people participate in agricultural activities than in urban areas. Fishing is a less popular activity than farming. With a coastline of 850 kilometers, and many lakes, creeks, and rivers, fishing is practiced by about three percent of households. In the South-South states, fishing is more common than in others.

Among households, the most common crops in Nigeria are maize and cassava, which are grown by almost 50 percent of households. In addition, other widespread crops are Guinea corn, yam, beans, and millets. In quite a few plot-growing maize crops, households used to apply herbicides, while about half use inorganic fertilizers. Among all major crops grown by Nigerian households, herbicides, inorganic fertilizers, animal tractions, and organic fertilizers are the most common farming inputs. Apart from household farming activities, Nigeria is a global leader in agricultural production, as mentioned before. In large production, palm oil crops experienced a significant increase in the past two decades, reaching over one million metric tons in the last three years. Similarly, milled rice and soybean production has been growing as well. On the other hand, some of Nigeria's largest agricultural productions dropped, such as millet crops (Simona Varrella, 2021).

Water, land and energy are critical components of the food system. Energy type, price and availability are key factors that influence growers and manufacturers. The use of food and agricultural waste and solar power as energy will be a boon to overall environmental and social health. Better use of food waste supports environmental and social sustainability by reducing associated economic losses and climate impact, Schmitz and D'Cruz, (2019). Water for example, is fundamental to the production, manufacture and distribution of food. Its availability and application will shape the way farms, homes and people operate, Kachergis, (2014).

People around the world are living longer and consumers are becoming increasingly interested in improving their physical and mental performance as well as their ageing process Marsman, (2018). In 2016, food production index for Nigeria was 124.6 index. Food production index of Nigeria increased

from 27.4 index in 1967 to 124.6 index in 2016 growing at an average annual rate of 3.32%.The description is composed by our digital data assistant.
What is food production index? Food production index covers food crops that are considered edible and that contain nutrients. Coffee and tea are excluded because, although edible, they have no nutritive value. Knoema, (2020). Innovation in the food sector is, as in many other sectors, rooted in the interaction among universities, government research institutes, policy makers as well as industry itself.

Table 7: Global Hunger Index IFPRI (2018) over Years

# (0-119)	Country/Year	2000	2005	2010	2018
22	Mexico	10.8	9.1	7.7	6.5
77	Kenya	36.5	33.5	28.0	23.2
80	Benin	37.5	33.5	28.1	24.3
103	Nigeria	40.9	34.8	29.2	31.1
119	CAR	50.5	49.6	41.3	53.7

Table 7 shows that Nigeria ranks 103 out of 119 countries on the Economist's Global Food Security Index (GFSI 2018). This Index considers the core issues of affordability, availability, and quality across a set of 119 countries, with a score of 0-100, whereby 100 is the best. The situation in Nigeria improved slightly in 2010 compared to 2005. The index is only available at the national level, so regional figures cannot be extracted.

Chemical engineers and experts in food technology should borrow a leaf from China. Established companies will need to look for innovation opportunities in emerging markets to drive innovation in other areas. China has a fertile innovation ecosystem with many rising professionals interested in innovation, a large consumer base with disposable income, inexpensive resources and favourable government policies. Overall government support encourages entrepreneurship and innovation allowing university-enterprise collaborations to thrive and maintain a talent base (World Economic Forum White Paper, 2016).

Boss, *et al* (2018), carried out a study on global agriculture as an energy transfer system and the energy yield of world agriculture. Their study established the fact that systematic energy losses from wastes, diversion of energy output as feed for livestock and poultry, and appropriation of energy output for biofuels synthesis may reduce the available energy for human consumption to levels consistently less than the human metabolic requirements. In figure 10 there are economic opportunities in the rural areas as a result of post-harvest losses. Figure 10 depicts the main drivers and causal processes in the Nigerian agri-food system. Negative feedback loops between a weak enabling environment, lack of incentives and finance for investment and low agricultural productivity keep the agri-food sector locked into underperformance. Poor energy and unavailability of process water have constituted weak environment that have resulted Nigeria to be among the national food deficit country.

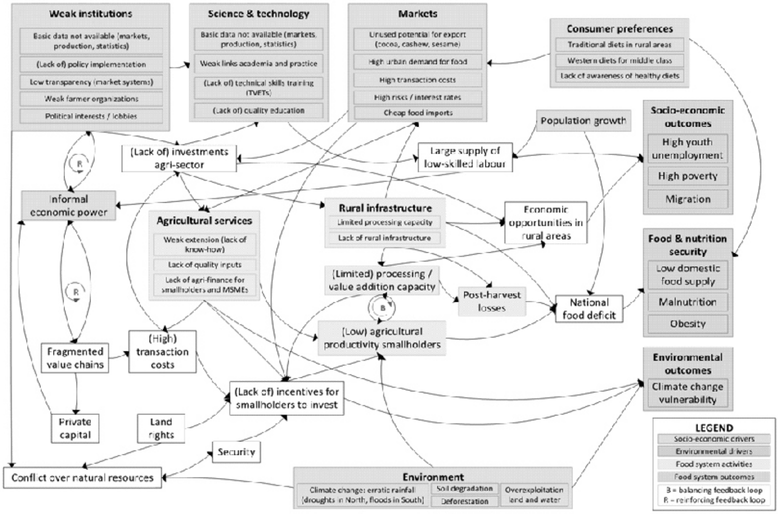

Fig.10: Causal diagram Nigerian agri-food system (Posthumus, et al, 2019)

Table 8: Energy and water uses for food handling, post farm to consumer (source: Zimmerman, *et al*, 2018)

RESOURCE	HANDLING	RETAILING	CONSUMER
Water	**Input as an ingredient in processed food;** **Cleaning food products** **Sanitation of food handling areas, processing facilities, and preparation equipment** **Sterilization of packaging materials,** **Hand, water, clothing sanitation**	**Cleaning retail display space** **Sanitizing freezer, cooler** **Operating freezing and cooling systems**	**Preparation, cleaning, cooking** **Cleaning tools, pans, refrigerator, oven** **Sanitation of cooking and food preparation area**
Energy	Operating processing, sorting, grading , cleaning facilities Operating of water movement systems (pumps, wastewater disposal) Lighting, heating, cooling, ventilation of work areas Distribution and transportation Disposal of solid waste (food) through municipal waste stream (MWS)	Storage: freezing, cooling Lighting, heating, cooling retail stores Distribution and transportation Disposal of food and packaging waste through MWS	Food preparation: heating, cooking, preparation Storage: freezing, cooling Lighting, heating, and cooling of cooking areas Transporting food home Disposal of food and packaging waste, MWS

A generalized model could be obtained by selecting energy and water connectivity with food system. Table 8 depicts a conceptual network-based model capturing fundamental components for a typical urban food system. For processing, freezing uses the most energy, followed by baking Masanet, et al (2012). Many other processes for food preservation exist, for example, vacuum packing produce. As the table shows, water and energy are critical inputs to food processing, distribution, retailing and consumption.

8.0 MASS TRANSFER APPLICATION IN CORROSION KINETIC STUDIES/ PROTECTION

8.1 Electrochemical Corrosion and Ionic Mass Transport

Mathematical correlations were developed to predict the behavior of iron roofing sheets on exposure to different environmental conditions. The analytical results from Atomic Absorption Spectroscopy (AAS) of chromium, iron oxide and zinc contents for the locations considered were fed into the developed equation. Corrosion rates were determined by weight loss method and model equation, and the results from the two methods are in agreement. The rate constants for location A is 0.36/hr; and location B = 0.174/hr; location C = 0. Corrosion rates by weight loss method were 0.514mpy and 0.221mpy for locations A and B respectively within the first five years; while corrosion effects on roofing sheet were noticed to be 0.0068mpy at location C from 5 – 10 years. The developed model provides solutions which have direct application to the prediction of corrosion rates on iron roofing sheets.

8.2 Results obtained from the developed model are presented in Tables 9 and 10

Table 9:Concentration levels of active ingredient considered in roofing sheets in the study locations.

Sample Location	Sample identification	g/100g		(mg/kg)		
Esit Urua	A_{11}	6.45	0.022	32.95	<1.0	25
	A_{21}	1.67	0.019	26.07	<1.0	30
	A_{31}	1.48	0.009	31.93	<1.0	20
	A_{41}	0.98	0.015	22.14	<1.0	35
	A_{51}	1.80	0.024	30.90	<1.0	28
Ibaka	B_{11}	2.56	0.019	26.66	<1.0	36
	B_{21}	1.56	0.013	13.97	<1.0	52
	B_{31}	1.14	0.011	14.81	<1.0	56
	B_{41}	0.92	0.008	15.90	<1.0	49
	B_{51}	1.25	0.014	18.61	<1.0	46
Ikono	C_{11}	1.39	0.013	26.89	<1.0	51
	C_{21}	1.43	0.014	17.37	<1.0	49
	C_{31}	2.08	0.021	15.59	<1.0	45
	C_{41}	1.18	0.015	17.60	<1.0	40
	A_{51}	1.29	0.024	19.47	<1.0	38
(Conc) new zinc roofing sheet		10.2	0.035	41.56	<1.0	<1.0
		zinc	chromium	Iron oxide	sulphate	chloride

Table 10: Estimated corrosion on samples of zinc coated steel from the study areas

Sample Location	Sample identification	Surface area (cm^2)	Surface area ($inch^2$)	Initial weight (g)	Final weight (g)	Weight loss (g)	Duration* (Years)	Corrosion rate (mpy) (wt loss x 22300) / a.d.t.
Esit Urua	A_{11}	407	65.12	48	35	13	1-5	0.514
	A_{21}	38	60.8	50	48	2	5-10	0.034
	A_{31}	220.73	35.32	55	48	7	10-15	0.1225
	A_{41}	364.64	58.34	50	37	13	15-30	0.091
	A_{51}	385.2	61.63	50	48	2	<1	0.501
Ibaka	B_{11}	363.5	58.16	40	35	5	1-5	0.2214
	B_{21}	208.52	33.36	30	25	5	5-10	0.1544
	B_{31}	208.52	33.36	30	25	5	10-15	0.093
	B_{41}	284.2	45.47	37.5	25	12.5	15-30	0.0965
	B_{51}	418	66.88	50	48	2	<1	0.462
Ikono (control)	C_{11}	440	70.4	50	50	0	1-5	0
	C_{21}	473	75.68	50	49.5	0.5	5-10	0.0068
	C_{31}	404	64.64	75	74	1.0	10-15	0.00543
	C_{41}	409	65.5	62.5	62	0.5	15-30	0.00268
	A_{51}	517.5	82.8	55	55	0	<1	0

*Final weight was taken after mechanical cleaning of the corrosion product by mild abrasive cleaning, Density = 7.909g/cm3, thickness, t = 0.015cm (for most areas); Surface area considered are those exposed to the atmosphere. = 7.14g/cm3 *as given by home owners; Loss/unit area was calculated for the zinc.

The kinetic processes of corrosion rates established in this work are applicable in any environment similar to the one considered (coastal/industrial). The correlations of rate constants to corrosion rates are innovations that should be studied further for baselines to determine corrosion rates. This should override the weight loss method that most times gives low precision and

unreliable data.
The research has shown clearly that corrosion of the iron/zinc roofing sheet is more pronounced in the industrial/coastal environment when compared to the city of Ikono in the hinterland of Akwa-Ibom state. That is to say in the minimum, that the industrial activities in these regions have brought about an accelerated corrosion rates.

9.0 COMMUNITY SERVICE CONTRIBUTIONS

Vice Chancellor Sir, my career in Chemical Engineering started as Technical Sales of coatings, Corrosion Engineer, Process Engineer, Project Manager and in 2005 as a Lecturer in Rivers State University of Science & Technology, now Rivers State University.

9.1 Infrastructural Protection

Vice Chancellor Sir, while working with Oil/Gas servicing company as Corrosion Engineer, I was consulted to be involved on Air Quality, Precipitation and Corrosion Studies of Qua Ibo Terminal (QIT) flare and the Environs. September 2001 pp 90-98. Client: Mobil Producing Nigeria Unlimited. Ujile, A. A. and Ehirim, E. O. (2014)

(a) The results of the studies indicted QIT flares, which cause the re-injection of the flare to Idoho reservoir, and have brought a boost to crude oil production output. Today the flares are no more in existence.
(b) Design, formulation/production and application of glass- fibre epoxy reinforced coating on gas risers at Edikan and Afia fields OML 100 ELF. Petroleum Nig. Ltd. (TOTAL). Mass transfer phenomenon was applied in the design and application.

9.2 Water Reliability, Availability and Sustainability

(a) Vice Chancellor, Sir, The Inaugural Lecturer has carried out the design and fabrication processes of a typical packed bed water treatment unit for a household. The process is energy saving. Plate 1 shows that the process is operational and has been replicated for Rivers State Government for ten other communities in Andoni Local Government Areas in October – November, 2014 during cholera outbreak. The Communities are: Ngo, Okoloile, Ajakajak, Ebukuma, Oyorokoto, Asukoyet, Asukama, Ikuru Town, Dema, and Anyamboko. The adsorbents used presently are imported. However, we have carried out laboratory production of activated carbon from bamboo, palm bunch and other sources (kaolin rice husk, etc).

(b) Evaluating Water-Energy-Food-Nexus for Sustainability of Healthy Living in Nigeria

This evaluation has contributed immensely to the fact that availability of potable water, energy and food supply with the prevailing population growth index correlates the consumption rates in Nigeria. Deficiencies established in the studies, inform stakeholders and managers of the resources to work on so as to maintain high standards of heathy living in Nigeria Ujile, (2020).

(c) Water-Energy-Food Nexus and Climate Change: The Challenges and Opportunities for Chemical Engineers, Plenary Session Paper. Ujile, (2021)

Agencies and Institutions in charge of water, energy and food and climate monitoring, measurement and forecast should have a synergy as to effect control in the area of pollution. An entrepreneur who intends to produce paper (in paper mill). To ensure a regular supply of raw material, the company sets up a sugar mill. Bagasse, a waste from the sugar mill will serve as raw material for paper making. Another waste product, molasses, could be used as in a distillery for the production of ethyl alcohol. To guarantee a regular supply of sugarcane, the entrepreneur considers the cultivation of this crop by organizing the farmers in the area. Long term agreements with farmers could be reached; to buy their produce and, in turn, take the responsibility of supplying them water. Part of the water for irrigation may be treated wastewater from the paper production plant. The company can also use bagasse pith (a waste after the paper making) and other combustible agricultural wastes in the area as energy sources.

The two scenarios presented should be as guide for chemical engineers and other allied professionals to take up the challenges to converting waste to energy and possibly other useful substances.

Plate 1: A typical packed bed water treatment unit for a household at Unyengala, Andoni

10.0 CONCLUSIONS

This Inaugural Lecture has been able to establish the application of chemical engineering mass transfer phenomenon to identify sources of groundwater contamination. The Nigeria per capita potable water availability is low and this has affected energy generation and consumption per capita. The evaluation of the water-energy-food nexus has placed Nigeria among the third world countries from the standpoint of global food security Index. The lecture has further proffered solutions to dearth of potable water in the rural setup/areas. A typical two-stage packed-bed water treatment column for a household was presented that had served communities in rural areas. The adsorbents being used are imported, however, research is going on to establish locally based adsorbents for water treatment.

Everyone seated here should be conscious of sources of potable water into his/her home. The sources of contamination points, landfill sites, grave yards, burial inside our compounds (where borehole water is located), etc highlighted should be of serious food for thought for all of us.

Mass transfer was applied in corrosion studies. The modeling of Corrosion Rates on Corrugated Iron Roofing Sheets in three locations in Akwa Ibom State, Nigeria has great impact for the removal of four flare stacks that polluted the QIT environment. There are more areas of application of mass transfer to bringing about reliability, availability, sustainability of water and protection of our national infrastructure. Maintenance and the use of professional personnel are the key points we should take home.

Lay not up for yourselves treasures upon earth, where moth and rust doth corrupt, and where thieves break through and steal: But lay up for yourselves treasures in heaven, where neither moth nor rust doth corrupt, and where thieves do not break through nor steal: (St. Matthew 6:19-20). And Jesus said unto them, 'I am the bread of life: he that cometh to me shall never hunger; and he that believeth on me shall never thirst' (St. John 6:35). Jesus Christ is reliable, available to us at all times and sustains us in all things.

10.1 RECOMMENDATIONS TO GOVERNMENT, INDUSTRIES, and ACADEMIA ON WATER AND INFRASTRUCTURE POLICIES

(i) Federal and State Ministries of Environment should consider groundwater protection an issue of paramount importance. Enabling laws should be put in place for waste disposal systems, and these regulations should be enforced.

(ii) A regulatory framework integrating certain entities should be identified and utilized by Federal and States Government for the purpose of groundwater management for quality and sustainability in our communities for the citizens.

(iii) Activities of process industries should be monitored by relevant Agencies to determine compliance to regulations on water policies and protection of infrastructure. Figure 11 should be used as a minimum guide.

(iv) Managers of Industries should ensure that ethics of engineering relating to environmental protection vis- a-viz waste management and treatment, disposal comply with regulations.

(v) Managers and Head of Higher Institutions of learning should engage relevant Faculties and Department to researching into preserving our groundwater resources and protection of available infrastructure. There is a lack of understanding in many important physical processes and system dynamics in groundwater environments. Processes in the unsaturated zone – those associated with the flow of immiscible contaminants, coastal aquifers, salt water intrusion, and complex chemical interactions and phase changes have received little or no attention in the Niger Delta region.

(vi) Consequently, engineers, scientists, hydrogeologists and water resources ministries both in the state and federal governments have limited the ability to predict the effect of remediation on the fate and transport of a contaminant in an aquifer; the effect of changes in pesticide and fertilizer applications for crop yields, and the effect of salinity build up on crop losses and human health are also unpredictable to an extent. The initial need for research lies in understanding the physical and chemical processes taking place in different sub-surface environments, and in developing mathematical representations of these processes.

(vii) The reaction that is simulated by the Inaugural Lecturer is non-linear equilibrium adsorption of a single dissolved species. However several different zones with different sorptive and reactive properties are required: e.g distribution coefficient, decay coefficient, yield coefficient. It is therefore recommended that further analysis/ research on the model equations developed by the Inaugural Lecturer be carried out as to determine the impact of soil bulk density, chemical decay rates and other hydro geological parameters on groundwater contamination.

A proper understanding of a system's dynamics in place can bring about the formulation and application of management models. There is also the need to expand our understanding of the criteria by which alternative management programs should be judged, and the types of constraints that need to be applied to obtain the objective function of systems. There is a research need in this area.

The PhD students carrying out such research activities, I say laborare est orare, and God will prosper the work of your hand.

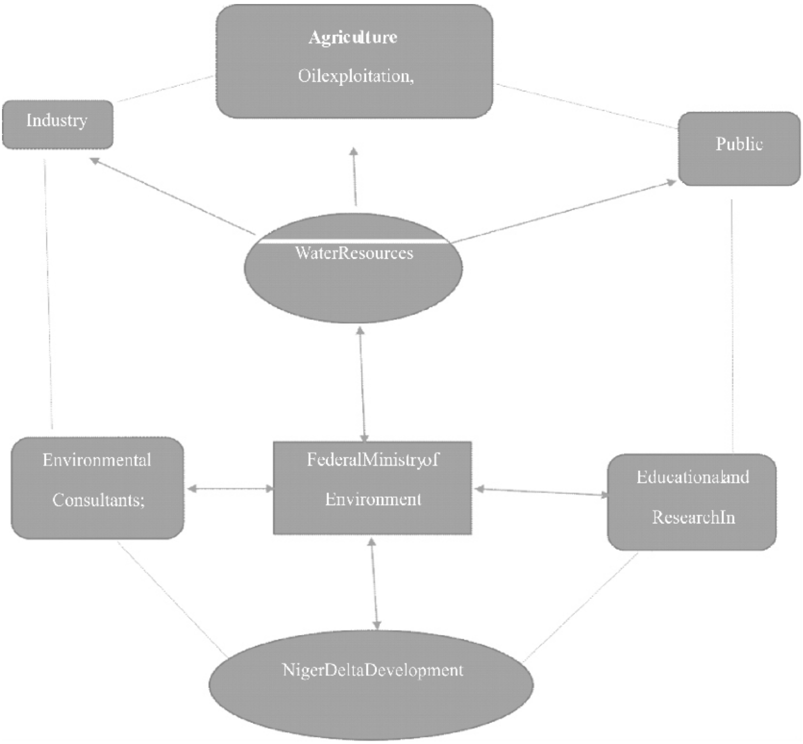

Figure11. Developed components of an integrated approach to ground water management in the Niger Deltaregion (Ujile, 2017a)

NOMENCLATURE/GREEK SYMBOLS

A – Superficial cross-sectional area of bed, m2

Ap – average values of parameters determined under laboratory conditions

C – Concentration

Co- Initial concentration; Co, Cos, concentration in the bulk and

on electrode surface respectively
CA'- Concentration at time t
Cs - Concentration of adsorbed phase, kmol/m3
D – Diffusion coefficient$_N$δ- Nernst diffusion layer thickness
Dx, Dy, - directional hydrodynamic dispersion coefficients, m2/s
Ecor- Potential
Icor- corrosion current
F – Faraday's constant
h- Distance of flow model by pollutants, m$_p$*i*- ideal values for the parameters
Qp- Quality of parameters/rating
M – Individual mass transfer coefficient of pollutants in groundwater flow in x-y direction, m/s
R – Gas constant; Retardation factor $R = 1 + \rho_b \frac{k_d}{\phi}$

ϕ - Porosity of aquifer$_b$ρ- bulk density of soil, kg/m3$_d$*k* - Distribution coefficient$_L$*k*- mass transfer coefficent
S – Standard permissible values obtained from recognised bodies*t* - time, s
u – inter-pellet velocity of fluid, m/s
Vx, Vy, - directional seepage velocity components, m/s
Wp- Unit weight
WQI – Water Quality Index
x - cordinateh orizontald irection
y - cordinatev erticaldir ection
Z – Distance along a bed, m

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