Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 8, Issue, 06, pp.32801-32814, June, 2016

INTERNATIONAL JOURNAL
OF CURRENT RESEARCH

ISSN: 0975-833X

REVIEW ARTICLE

GROUNDWATER POLLUTION AND REMEDIATION: TRENDS AND PRACTICES

*Nnabuihe, I. K., Okeke, O. C., Israel, H. O., Obioha, Y. E. and Ikoro, D. O.

Department of Geology, Federal University of Technology, Owerri, Nigeria

ARTICLE INFO

Article History:
Received 17th March, 2016
Received in revised form
21st April, 2016
Accepted 06th May, 2016
Published online 15th June, 2016

Key words:

Groundwater,
Pollution,
Remediation,
Health Hazards,
Ecosystem.

ABSTRACT

One of the major environmental problems today is groundwater pollution. Pollutants originating from both anthropogenic and natural activities classified into point sources and non-point sources tend to threaten groundwater. This polluted groundwater in turn threatens both human and environmental health through acute and chronic exposures. In order to provide protection to both human and environmental health, there is need to prevent groundwater pollution in the first place by ensuring the elimination of pollutants at their sources. However, If pollution eventually occurs, the polluted groundwater can be remedied using a wide variety of techniques categorized into ex-situ methods (i.e. pumping out of water from aquifer and treating on the surface, e.g. steam stripping, carbon adsorption, chemical oxidation, thermal treatment, bioremediation, etc) and in-situ methods (i.e. in-place treatment of water, e.g. air-sparging, permeable reactive barriers, nanoremediation, monitored natural attenuation, bioremediation, etc). Common remedial measures such as boiling, filtration, sedimentation and chlorination should be adopted for treatment of water before consumption on the home front. A typical case of groundwater pollution is that of Ogoniland, Niger-Delta, Nigeria, contaminated with petroleum hydrocarbons but yet to be given any adequate remedial attention. Remediation as an option may not be feasible, hence, prevention is always the best option.

Citation: Nnabuihe, I. K., Okeke, O. C., Israel, H. O., Obioha, Y. E. and Ikoro, D. O., 2016. "Groundwater pollution and remediation: trends and practices", *International Journal of Current Research*, 8, (06), 32801-32814.

INTRODUCTION

One of the major environmental problems today is groundwater pollution. Development in agriculture and industry, including urbanization, has led to the production of numerous chemicals and consumables, and generation of enormous wastes (Forster *et al*., 1998; Kehinde, 1998; Adelana *et al*., 2003; Adelana *et al*., 2004; Adelana *et al*., 2005; Ajala, 2005; Ocheri, 2006; Adelana *et al*., 2008; Govt. of Canada, 2010; Longe and Balogun, 2010; Eni *et al*., 2011). The improper handling and disposal of these hazardous chemicals and wastes poses a threat to groundwater, and constitutes a major source of anthropogenic pollution of groundwater (Ogunbajo and Kolajo, 2004; Adelana *et al*., 2008; Akinbile and Yusoff, 2011). Todd (2004) defined groundwater pollution as the artificially induced degradation of natural groundwater quality. In other words, any addition of undesirable substances to groundwater caused by human activities is considered to be pollution (Tchobanoglous and Schroeder, 1987; Govt. of Canada, 2010).

Corresponding author: Nnabuihe, I. K.
Department of Geology, Federal University of Technology, Owerri, Nigeria.

Besides resulting from human activities, groundwater pollution can also emanate from natural processes, as water (a universal solvent) tends to dissolve substances that degrade its quality as it moves through rocks and subsurface soil (National Academy of Sciences, 1984; Sajad *et al*., 1998; Adeniran and Ajamu, 2004; Akinbile and Yusoff, 2011; Hassan, 2012). Hence, groundwater pollution occurs when pollutants released to the ground find their way into the groundwater and degrade the natural quality of the water or due to the dissolution of minerals or chemicals or elements that constitutes the rocks of the earth, by groundwater in motion. In Nigeria to be precise, where there is huge environmental degradation (Olokesusi, 1987), the groundwater is under serious threat by various pollutants as indicated by numerous research (Ibe, 1999; Musa *et al*., 2004; Adekunle *et al*., 2007; Iwegbue, 2007; Alexander, 2008; Ilemobayo and Kolade, 2008; Ipeaiyeda and Dawodu, 2008; Edet and Worden, 2009; Ufoegbune *et al*., 2009; Alichi *et al*., 2010; Dan-Hassan *and Olasehinde,* 2010; Garba *et al*., 2010; Nwankwoala and Udom, 2011; Adelowo *et al*., 2012; Adamu *et al*., 2013; Omono *et al*., 2013). Comprehensive studies and findings on groundwater pollution have been carried out in different parts of the country and documented by various authors including, Olayinka and Olayiwola, 2001; Abimbola *et al*., 2005; Obase *et al*., 2009, and Ocheri *et al*., 2014 among many others. Most of these findings were above the prescribed limits for drinking water by the Nigerian Standard and WHO – guidelines. On the other hand, polluted groundwater constitutes human and environmental health hazards, and should be given adequate attention to prevent its occurrence or be properly remedied when it occurs. Groundwater remediation therefore, refers to the removal of pollutants or contaminants from groundwater to provide protection to both human and environmental health. Research has shown that groundwater pollution can occur instantly, but remediation of the same groundwater is usually slow, difficult, expensive and sometimes impossible (Akujieze, 2006; Akujieze and Ezomo, 2010).

Landfills: (Fig. 2) are, essentially, holes in the ground filled with wastes (Younger, 2007). A percolating rainwater finds its way into the landfill dissolving the landfill materials (household chemicals, paints, car battery acid, solvents, etc) to form a solution known as *'leachate'*. Several studies confirmed the potential toxicological risk of landfill leachates (Cameron, *et al.,* 1980; Atwater, et. al; 1983; Ikem *et al*., 2002; Mohd *et al*., 2011). This leachate from old unlined landfills or lined but leaking landfills might leach or migrate into the groundwater, thereby, polluting the groundwater.

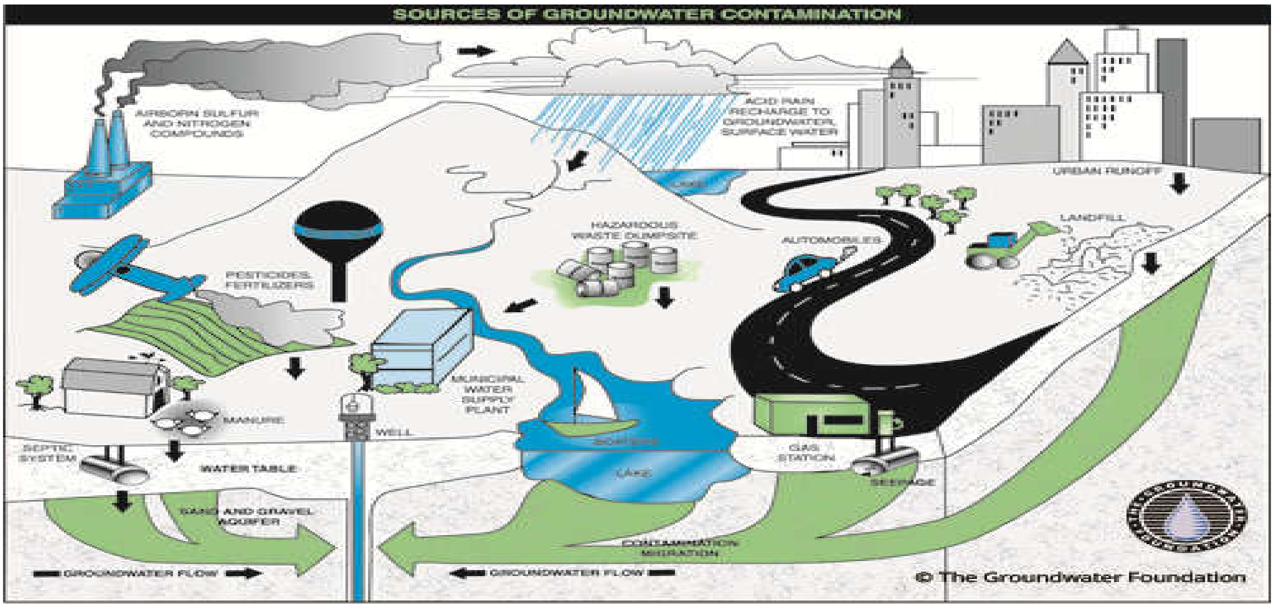


Fig. 1. Sources of groundwater pollution. Source: USEPA (2002)

SOURCES AND IMPACTS OF GROUNDWATER POLLUTION

Sources of Groundwater Pollution

There are many different sources of groundwater pollution (Fig. 1). Groundwater becomes polluted when natural and anthropogenic substances from septic disposal systems, leaking underground storage tanks and piping, salt water intrusion, landfills and dumpsites leachates, agricultural activities, naturally occurring heavy metals, mining and industrial activities, radioactive decay of Uranium, etc. are dissolved or mixed in waters recharging the aquifer (Biswas, 1997; Aremu *et al*., 2002; Glenn, 2002). Though pollutants may reach groundwater from a variety of sources as indicated in fig. 1 above, they are categorized into two main sources: point sources and non-point sources (Krueger, et. al. 1998; Suzuki, *et al.,* 1998; Schwarzbauer, J., 2006).

Point sources of pollution

Point sources of pollution refer to pollutant sources that originate from a single or specified location or point. Among these are municipal landfills, industrial waste disposal sites, septic tanks, leaks or spills of petroleum products, acid mine drainage, etc. and of which few are further considered below.

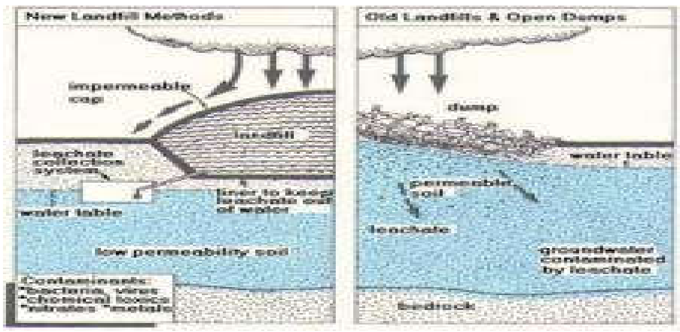


Fig. 2. Landfill. Source: Lyle (2015)

Septic Systems: Leakage of effluents and solid wastes from septic tanks and cesspools resulting from improperly sited, designed, constructed, or maintained septic system (fig. 3) may find its way into the groundwater and contaminate it with bacteria, viruses, nitrates, phosphorous, detergents, oil, household chemicals, and other contaminants causing serious problems. Also, untreated or inadequately treated solid wastes from sewage plants can also leak these contaminants into the groundwater.

Acid Mine Drainage: Mines can produce a variety of groundwater pollution problems (Todd, 2004; Ezekwe *et al*., 2012). Acid mine drainage from coal and metal mines can contaminate both surface and groundwater (Plummer *et al.*, 2005). Coal deposits are often associated with pyrite ($FeSO_4$), so also some metals are associated with pyrite and other sulfide minerals. The oxidation of sulfur in these minerals due to exposure to air results in the formation of sulfuric acid which contaminate the groundwater. Groundwater pollution can also result from the leaching of soluble minerals from the mine wastes (tailings) into the groundwater.

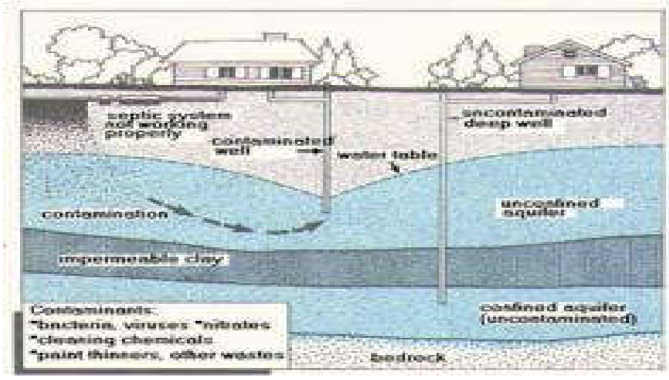


Fig. 3. Septic System. Source: Lyle (2015)

Tank and Pipeline Leakages: Leakage of petroleum and petroleum products due to structural failure in surface and underground tanks, including pipelines abounds worldwide. Storage tanks containing gasoline (fig. 4), oil, chemicals, or other types of liquids (including liquid radioactive wastes) can corrode, crack and develop leaks which migrate into the groundwater causing a serious pollution problem (Borden and Kao, 1992; Govt. of Canada, 2010).

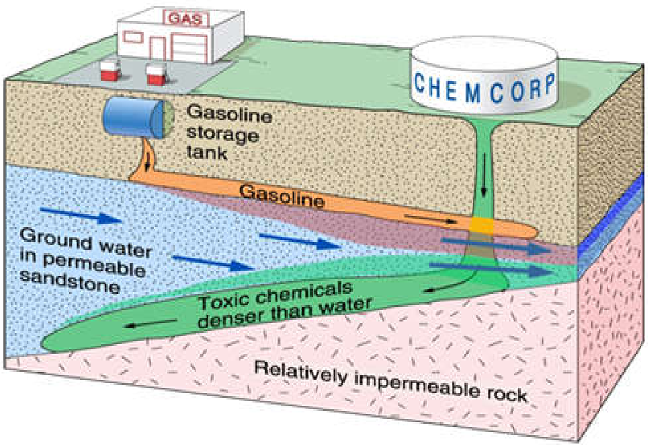


Fig. 4. Underground Storage Tank. Source: Plummer *et al.* (2005)

Non-point sources of pollution

Non-point sources of pollution refer to pollutant sources that cannot be traced to specific point. These sources are diffused or scattered rather than originating from a single discrete source or location. Examples of non-point sources include agricultural chemicals, such as fertilizers, herbicides, pesticides (insecticides, fungicides, rodenticides, and avicides), and animal wastes. Similarly, contaminants in rain and snow, and run-off from urban areas are non-point sources of pollution. Non-point sources are further considered below.

Fertilizer

The extensive or excessive use of nitrogen fertilizers in agricultural fields (fig. 5), forests, golf courses and lawns tends to deposit large amount of nitrate in the soil. This nitrate can easily be leached by rain or irrigation water into the groundwater, especially when the groundwater is shallow and unprotected (unconfined), thereby causing groundwater pollution.

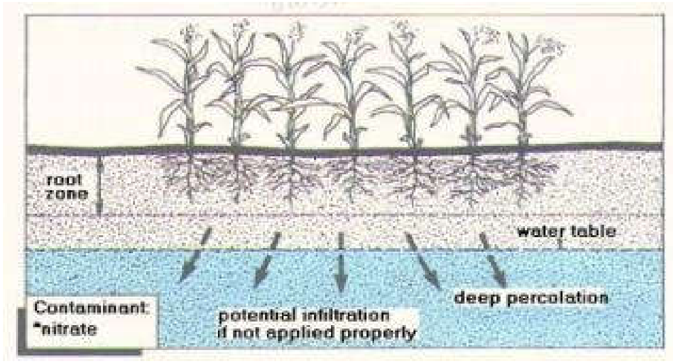


Fig. 5. Fertilizer Application on plants. Source: Lyle (2015)

Pesticides and Herbicides

Pesticides and herbicides (such as DDT and 2, 4 –D) applied to agricultural crops (fig. 6) can find their way into groundwater when rain or irrigation water leaches the poisons downward into the soil (Plummer et al, 2005). In addition to agriculture, homeowners, businesses (eg. Golf courses), use these chemicals which seep into the ground and eventually into the water.

Fig. 6. Pesticides application on plants. Source: Plummer *et al.* (2005)

Animal Waste

The raising of animals normally results in the generation of large quantities of waste (fig. 7). These wastes from animal feedlots may contain bacteria and viruses which percolates into the ground, thereby, contaminating the groundwater. The spreading of these wastes on the land as fertilizers, and their storage, also constitute a source of contamination. Research has shown that groundwater contamination goes unnoticed for a long time in most cases, and becomes recognized only after the users have been exposed to potential health risks. Pollution of groundwater can result in poor drinking water quality, loss of water supply, degraded surface water systems high cleanup costs, high costs for alternative water supplies, and/or potential health problems (EPA, 2002).

Fig. 7. Diagram of animal feedlots. Source: Plummer *et al.* (2005)

Impacts of Groundwater Pollution

Polluted groundwater can hurt animals, plants, or humans when it is removed from the ground by man-made or natural processes and can pose a serious threat to lives either directly by ingestion or dermal contact with polluted groundwater or indirectly through the food chain or web.

Impacts on the ecosystem

Ecosystem can be severely affected by pollution (Begum *et al*., 2009) via groundwater, as the local flora and fauna may be relying on it. Interaction between surface and underground water indicates that surface water (losing stream) seeps through the soil and becomes groundwater. Conversely, groundwater can also feed surface water sources (gaining stream). Hence, surface water bodies can be degraded by a polluted groundwater, which upsets their ecological balance (Govt. of Canada, 2010).

The deposition of heavy metals and hazardous chemicals in the soil through polluted groundwater, can lead to soil infertility (Akinbile and Yusoff, 2011). This in turn has a devastating effect on vegetation as many plants have a limited tolerance to specific metals and organic substances. It can also lead to poisoning of crop irrigated with polluted groundwater, which in turn affects herbivorous animals (especially ruminant animals) that feed on agricultural plants (Abolude *et al*., 2009; Akinbile and Yusoff, 2011), and also affects microbial population.

Impact on human health

The occurrence of polluted groundwater constitute a risk to human health. Polluted groundwater may contain disease carrying organisms such as bacteria, viruses, protozoa, and parasitic worms. These agents can cause diseases like hepatitis, cholera, dysentery, poliomyelitis, and typhoid (USEPA, 2002), which are generally known as water-borne diseases. Exposure to polluted groundwater can cause diarrhea, skin irritation, respiratory problems, stomach irritations, ulcers and intestinal disorders which can lead to more severe health effects. Accumulation of heavy metals and some organic pollutants can lead to cancer, reproductive abnormalities, neurological disorder and other more severe health effects. These health problems could be permanent and irreversible (Greenberg and Bederman, 2015). However, health effects from groundwater pollution depend on the types of chemicals or specific pollutants in the water. Hence, there is need for the individual consideration of these typical pollutants or chemicals. These pollutants are tolerated to a certain level but become threatening when they exceed the Maximum Allowable Limits (Nwachukwu, *et al.,*2014).

Lead

Lead is extremely toxic to humans and other mammals. Its accumulation in the body can have serious effects on the central nervous system, kidney, liver; and cause pregnancy risks, with hearing and learning disabilities in children (USEPA, 2002). Lead can also cause slight increase in blood pressure in adults, and probably carcinogenic.

Mercury

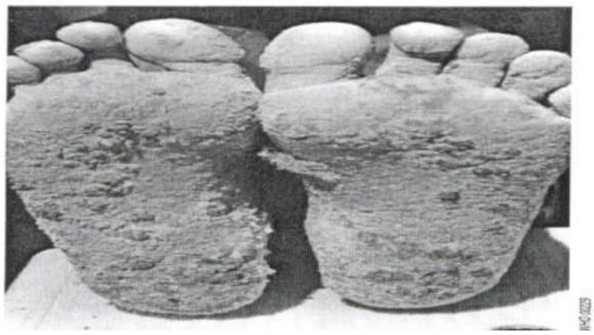
Mercury causes acute and chronic toxicity. It can damage the nervous systems and brains of humans, including the interference with nervous systems development in fetuses and young children.

Barium

Low exposure to barium via groundwater can cause stomach irritation, swelling of the brain and liver, cardiac disorders, and breathing difficulties but can cause serious paralyses at high exposure or dosage.

Arsenic

Arsenic pollution has been reported to occur in many parts of the world (Allan *et al*., 2000; Gbadebo, 2005;). Arsenic poisoning causes acute and chronic toxicity. It causes serious liver, kidney and nervous system damage, cardiovascular damage, and skin, lung and bladder cancer, and arsenicosis (fig. 8), (Chakraborti *et al*; 2002).



Berylium

Exposure to berylium causes acute and chronic toxicity. It can cause damage to lungs and bones. Berylium is possibly carcinogenic.

Cadmium

Cadmium tends to replace zinc biochemically in the body. It causes high blood pressure, liver and kidney damage, deformities, anaemia, and cardiovascular problems (Goyer and Clarkson, 2001). Cadmium also destroys testicular tissue and red blood cells.

8a

8b

8c

Fig. 8. Skin Lesions/Arsenicosis.Source: Allan, *et al.* (2000)

Chromium

Although chromium III is a nutritionally essential element, Chromium VI tends to cause liver, brain, nervous system, and kidney damage, internal hemorrhaging, respiratory damage, dermatitis, and ulcers on the skin.

Cyanide

Exposure to water polluted with cyanide can result in a damage to spleen, brain, and liver.

Copper

Long-term exposure to copper may cause stomach and intestinal distress, dizziness, liver and kidney damage, and anaemia.

Zinc

Zinc is an essential element in human body. However, in higher dose, zinc can cause vomiting, skin irritations and anemia, and can lead to damage in pancreas , and respiratory problems in very high doses.

Iron

Iron is an essential element for the blood in a moderate amount, but may cause conjunctivitis and retinitis if it comes in contact with the tissue.

Sodium

Sodium is required by the body in low level, but in excess, sodium can lead to high blood pressure and kidney damage.

Sulfur

Exposure to sulfur in water can lead to heart damage, reproductive failure, immune system damage, and eye problems.

Fluorine

Exposure to fluorine in water can cause damage to the kidney, nerves, muscles, and bones.

Fluoride

This is an essential chemical containing fluorine that is often added to toothpaste and sometimes to drinking water to protect teeth from decay. High doses of fluoride can cause yellowing of the teeth, damage to the spinal cord and crippling bone disorders.

Petrochemicals

Benzene and other petrochemicals have shown to cause leukemia and neuromuscular, kidney, liver and nervous system damage even at a low exposure levels (Bako *et al*., 2008). These chemicals are also known to cause cancer, anemia, gastrointestinal disorder, skin irritation, blurred vision, headache, nausea, fatigue, rashes, weight loss, and eye and respiratory tract irritation (USEPA, 2002). Excessive or long term exposure can lead to death.

Chlorinated Solvents

These can cause cancer, and damage to nervous system, reproductive system, kidney, stomach and liver.

Pesticides

The organo-chemicals present in pesticides can poison the human body systems and cause cancer, gastrointestinal disturbance, numbness, weakness, dizziness, headaches, and can destroy the nervous system, thyroid, reproductive system, liver, endocrine and kidneys.

Nitrates

Exposure to nitrates can cause cancer, shortage in vitamin A, and tends to decrease the functional capacity of thyroid glands. It can also inhibit the capacity of blood to carry oxygen leading to decreased oxygen level (USEPA, 2002; USEPA, 2009).

Coliform Bacteria

The presence of pathogenic bacteria, viruses and parasites in drinking water can cause polio, cholera, typhoid fever, dysentery, and infectious hepatitis.

Socio-economic impacts

Social stigmatization: Research has shown that most people who suffer from dreaded skin-related diseases such as arsenicosis are ostracized by the general public with the fear that such disease is communicable and could be contracted. There are existing cases of married women being divorced or employees losing their jobs due to arsenicosis, which subjects them to serious trauma.

High costs of medical treatment: People who are affected by any of the life-threatening diseases including cancer, anemia, and kidney, liver and heart damage resulting from exposure to high doses of pollutants usually find it difficult to foot their medical bills, due to high charges involved in the diagnoses and treatment of such diseases.

High clean-up costs: As noted earlier, once polluted, the cost of remediating an aquifer is usually too high (USEPA, 2002). This would constitute the cost of remediation and that of hiring the equipment for remediation depending on the technique involved.

High costs for alternative water supply: Exploring for a pollution free aquifer as an alternative could be very expensive depending on the geologic setting and its proximity to the affected community (USEPA, 2002). Where there is no alternative aquifer, resorting to bottled water or other sources (e.g. tanker supply) could be a temporary option, but could cost enormously.

GROUNDWATER REMEDIATION PRACTICES

Preventing Groundwater Pollution as an Aspect of Remediation Practice

Considering the slow movement of groundwater that prolongs the manifestation of its problems, and the high cost of aquifer clean up (if it can be done at all), it is preferable by far to prevent pollution from happening in the first place (Govt. of Canada, 2010; Hassan, 2012). Preventing contaminants from reaching the groundwater is the best way to reduce the health risks associated with poor drinking water quality (USEPA, 2002). The above statements tend to support the usual axiom that *"prevention is better than cure",* hence we can conclude that prevention is the best remedy to groundwater pollution. Prevention as the perfect solution to groundwater pollution can be achieved by adopting effective groundwater management practices by all concern – governments, industries and every individual. Prevention as a solution to pollution aims at the elimination of pollutants at their source. This elimination can be achieved by:

Protection of sensitive aquifers: the physical properties of an aquifer are by large essential parameters to determining the possibility and degree to which pollutants on the land surface will reach the groundwater. Unconfined aquifers (water table) are more sensitive to pollution than confined aquifer due to the absence of impermeable layer which inhibits contaminants movement. With the vulnerability map in place, which identifies areas that are more or less prone to pollution due to human activities on the land overlying the aquifer. relevant agencies, including water supply agencies can establish landuse practices that can be allowed over a shallow aquifer and at the watershed, including proper identification and adequate monitoring of potential pollution sources (Akinbile and Yusoff, 2011; Ocheri *et al*., 2014).

Minimizing the use of chemicals: minimizing the use of hazardous household chemicals, agro-chemicals, and hazardous industrial chemicals and raw materials will go a long way to reducing the amount of pollutants released into the environment. These chemicals should be used only when it is the last alternative. Better still, hazardous chemicals can be substituted with sustainable substances.

Effective waste management practices: effective and efficient waste management system should be implemented (Ocheri *et al*., 2014). This can be accomplished by providing efficient waste collection, transportation and disposal systems; proper locations and appropriate use of landfills, injection wells, and other waste disposal options; treatment of point sources to remove pollutants prior to disposals; discouraging the disposal of hazardous wastes in landfills and injection wells; storing of hazardous liquids in aboveground tanks with leak detection and collection systems; recycling of wastes, and reporting any incidents of pollution or unauthorized dumping or collection points to the appropriate quarter.

Adoption of good engineering practices: good engineering practices can be adopted in the design and installation of storage tanks and waste disposal systems. This can be accomplished by installing corrosion-free tanks with spill or leak detecting and collecting systems, and installing landfills with double impervious liners (Nadim *et al*., 2000; Ocheri *et al*., 2014).

In addition, to ensure the integrity of good engineering work, good quality construction materials should be used while ensuring efficient and effective monitoring and repair systems.

Implementation of monitoring programmes: it has been made clear that the groundwater is under constant threat by human activities. Hence, there is need for the constant and continuous monitoring of the underground water and potential sources of pollution to checkmate and arrest any incidence of pollution (Ocheri *et al*., 2014). This can be accomplished by installing groundwater monitoring wells especially near underground storage tanks and waste disposal systems such as landfill leachate collection systems.

Effective public enlightenment programs: going by the popular axioms, *"knowledge is power"* and "*if you are not informed you will be deformed",* there is need to create awareness to the general populace on the dangers of groundwater pollution resulting from man's activities. Industries and the general public should also be educated on proper waste management to regulate the release of pollutants into the environment.

Effective legislation: preventing groundwater pollution requires effective groundwater rules. Relevant government agencies should implement strict regulations against the use, handling, storage, and disposal of hazardous chemicals to ensure a more environmentally safe waste management, including an efficient and effective legislation to handle cases of pollution after occurrence.

Groundwater Remediation Methods

Research has shown that groundwater pollution can occur instantly, but remediation of the same groundwater is usually slow, difficult, expensive and sometimes impossible. Groundwater remediation methods involve biological, chemical and physical treatment technologies which are often used in combination to achieve this abatement. However, Hassan (2012) stated that the selection of a remedial method depends upon several parameters grouped into the following categories:

- Contaminant profile;
- Aquifer profile; and
- Feasibility profile.

There are diverse remediation methods which can be categorized into ex-situ and in-situ methods.

Ex-situ remediation methods

Ex-situ remediation methods refer to water treatment methods or technologies involving the pumping out of water (dewatering) from polluted aquifers and the subsequent treatment of such water on the surface, after which it may be re-injected back into the aquifer (Hassan, 2012). There are quite a number of ex-situ cleanup methods or technologies, some of which include:

Steam stripping

This involves the introduction or injection of steams into extracted polluted groundwater to remove the contaminants, usually volatile organic matter from the water. Stripping process can be accomplished by the use of a steam stripper which functions by transferring the pollutant (Volatile Organic Carbons) from dissolved phase to vapour or gaseous phase (vaporization) via steam injection (Hassan, 2012).

Carbon adsorption

This method involves the passage of extracted polluted groundwater through series of columns containing activated carbon in which contaminants get absorbed (Fig.9) (Khraisheh *et al*., 2004; Ayotamuno *et al*., 2006; Hassan, 2012). The degree of adherence of contaminants to the surface of the activated carbon is a function of surface area to mass ratio. Activated carbon is effective in adsorbing chlorine, fluorides and dissolved organic solutes but expensive (Khraisheh *et al*., 2004), and ineffective in removing heavy metals, nitrates, microbial contaminants, and other inorganic contaminants. However, adsorption efficiency can be hampered due to saturation of the carbon materials. Hence, this material should be replaced periodically.

Ex-situ chemical oxidation

Ex-situ chemical oxidation process involves the introduction of strong oxidizing compounds or agents such as hypochlorite, hydrogen peroxide, ozone gas, potassium permanganate, etc into a vessel containing polluted groundwater, to chemically convert the toxic contaminants to less toxic compounds (fig. 10) (Hassan, 2012). The oxidizing agents aim at converting most organic compounds to carbon dioxide, water, and salts. However, the use of certain oxidizing agents for certain contaminants may result in incomplete oxidization or formation of intermediate contaminants. For instance, chloromethane may form as substitution products when chlorine is used as the oxidizing agent.

Ex-situ thermal treatment

This process involves the exposure of an extracted polluted groundwater to high temperature in treatment plants which aims at separating, destroying or immobilizing the contaminants (Hassan, 2012).

Ex-situ bioremediation

This simply involves the use of microorganisms to destroy or remove pollutants from extracted polluted groundwater. Bioremediation process is based on the principle that microorganisms feed on the contaminants as food (biodegradation) thereby detoxifying or removing the

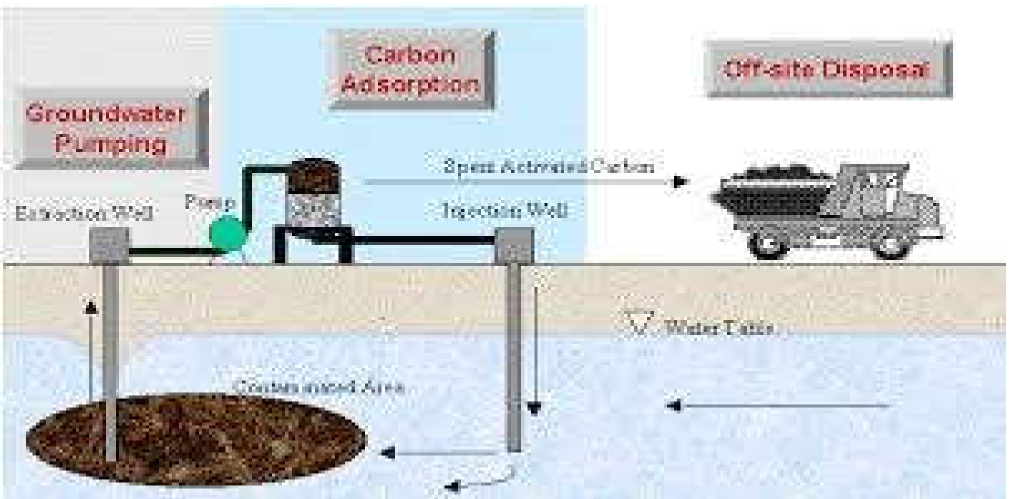


Fig. 9. Carbon Absorption Process. Source: Hyman and Dupoint (2001)

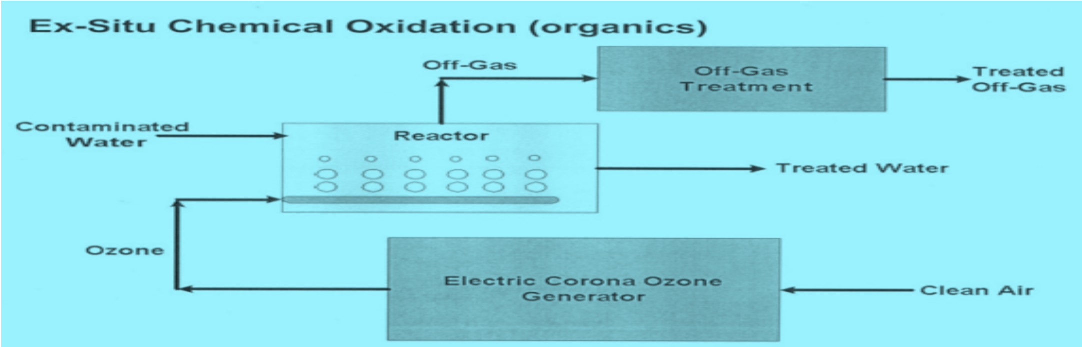


Fig. 10. Ex-situ chemical oxidation process. Source: USEPA (2009)

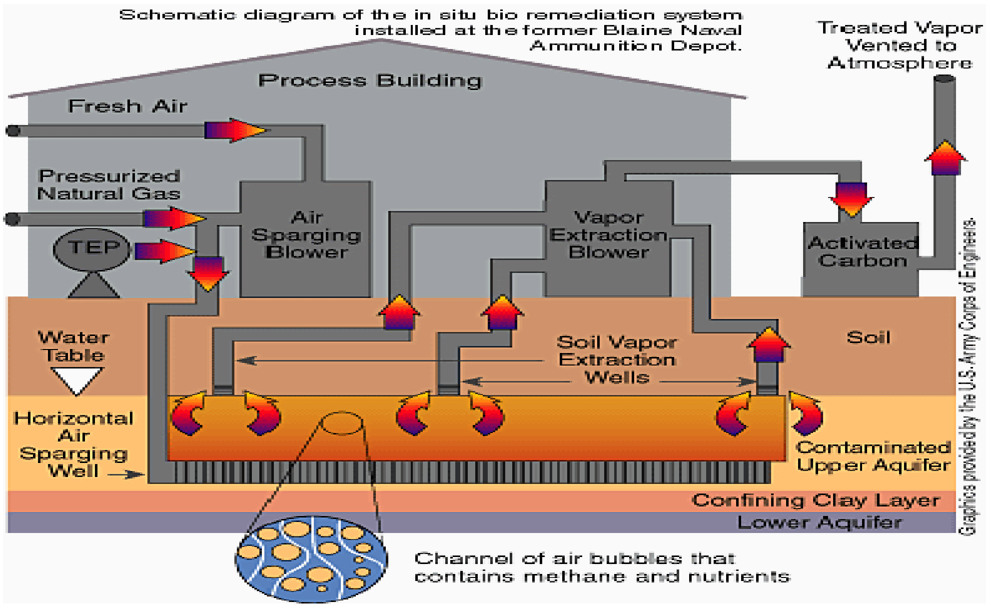


Fig. 11. Air-Sparging. Source: Stewart (2008)

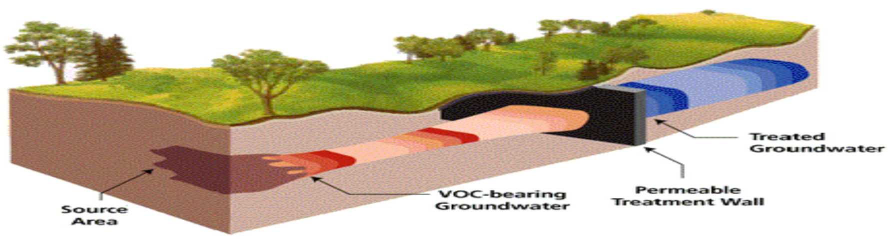


Fig. 12. Permeable Reactive Barriers (PRBS). Source: Reddy (2008)

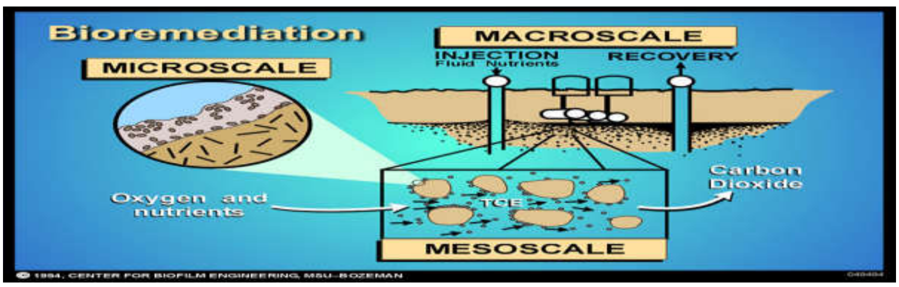


Fig. 13: In-situ bioremediation. Source: Stewart (2008)

pollutants, with carbon dioxides or methane as the end-product of degradation. The productivity of these organisms can be enhanced by the addition of nutrient (in the form of nitrogen and phosphorus), oxygen, and moisture, while creating favourable conditions by the careful monitoring of the pH and temperature of the systems. Bioremediation is effective in the removal of contaminants such as petroleum hydrocarbons, solvents, pesticides, wood preservatives, and other organic chemicals from groundwater.

In-Situ Remediation Methods

In-situ remediation methods refer to water treatment methods or technologies which tend to treat groundwater without extracting it from the aquifer (Kavanaugh *et al*., 2003; Stroo *et al*., 2003; Geosyntec Consultant Inc., 2004; McGuire *et al*., 2006; Krembs, 2008). It is otherwise known as in-place treatment of groundwater as the required processes are carried out while the water remains in its in-ground setting.There are also quite a number of in-situ cleanup methods or technologies, some of which include:

Air sparging

Air sparging which is sometimes referred to as in-situ air stripping is an environmental remediation technique involving the injection of air into a “polluted media” (in this case, aquifer) to remove contaminants especially Volatile Organic Compounds (VOCs) from groundwater by transforming them (VOC) from a dissolved state to a vapour phase which is removed through vacuum extraction systems (Fig. 11) (Nadim *et al*., 2000; Reddy, 2008; Hassan, 2012). .Air sparging can also promote biodegradation of contaminants in the media through oxygen in the injected air, which acts as a nutrient for bacteria. It can also be used in combination with soil vapour extraction for the efficient removal of contaminants that migrate from groundwater to the overlying sediment. However, air sparging is known to be effective in relatively shallow aquifers, as it is difficult operating below 9m (30 ft).

Permeable Reactive Barriers (PRBs)

This is an in-situ remediation technique which involves the use of a trench made across the direction of polluted groundwater flow and backfilled with porous reactive medium such as activated carbon, iron filings, or peat to absorb contaminants, including nutrients, pesticides, volatiles, and metals as the water passes through the barrier resulting to the flow of cleaned groundwater beyond the barrier (Fig.12). Numerous researchers, including Benner *et al*., 1997; Gavaskar *et al.,* 1998; Mulligan *et al*., 2001; Amos, and Younger, 2003; PIRAMID Consortium, 2003; Robertson *et al*. 2005; Reddy, 2008; Anna, 2014, Cruden, 2015, have contributed immensely to the development of this technique. Meanwhile, the use of PRBs has shown to be effective only in relatively shallow aquifers (Stewart, 2008).

Nanoremediation

Nanoremediation is an environmental remediation technique involving the use of nanoscale materials or nano-sized reactive agents (nanopraticles) such as zero-valent iron, calcium carbonate, graphene, carbon nanotubes, titanium dioxide, and iron oxide to degrade organic contaminants or immobilize heavy metals (e.g lead and arsenic) in a polluted media (e.g groundwater, wastewater, soil, and sediment) by redox reactions or adsorption respectively. Generally, nanoparticles have very high surface area per unit mass resulting in very high reactivity. Being highly reactive, nanoparticles are easily attracted to non-target components thereby limiting their dispersal rate and extent. However, this limitation can be averted by coating the nanoparticles with surfactants, polyelectrolyte coatings, emulsification layers, and protective shells made from silica or carbon.

Natural attenuation

This involves the removal, degradation or reduction in concentration of contaminants from a polluted groundwater (aquifer) through natural processes such as dilution, filtration, sorption, microbiological decomposition, and chemical reactions, with no human intervention. The rate and effectiveness of this cleanup approach is a function of the type of pollutant and the local hydrogeologic setting (USEPA, 2002). Natural attenuation can be a better approach of groundwater remediation than the Pump-and-Treat method. However, for natural attenuation to qualify as a remedial “technology”, it must be carefully monitored (ASTM, 1998; USEPA, 1998a; Younger, 2007; Cruden, 2015). Hence, Monitored Natural Attenuation (MNA) should be adopted to ensure the efficacy of the natural processes.

In-situ bioremediation

This involves the injection of air (oxygen), nutrients, and sometimes degrading bacteria into polluted aquifer to stimulate or enhance the biodegradation of carbon-based contaminants to simpler and less toxic organic compounds by microbial organisms (fig. 13) (Nadim *et al*., 2000; Hassan, 2012; Cruden, 2015). Bioremediation is effective in the treatment of groundwater polluted with hydrocarbons. However, it should be noted that in bioremediation process, more toxic compounds may be produced as by-products of degradation (e.g. TCE to Vinyl chloride). Ex-Situ bioremediation mentioned above controls this situation by containing the hazardous by-products in the treatment unit for further decomposition to ensure a non-toxic end-product. The efficacy of this technique is dependent on parameters such as contaminant of concern, temperature, oxygen supply, nutrient supply, pH, availability of contaminant to microbes, and contaminant concentration.

Water Treatment on the Home Front

The water treatment techniques outlined above are mostly required for the treatment of large scale or public supply. However, there are other popular methods for purifying water, especially at the home level, even though some of them are also used for large scale treatment. Galadima *et al.,*(2011) reported that many villages in Nigeria have never seen the so called “treated tap water” in their communities. Hence, there is need to advocate water treatment at the home front. In Nigeria, water management is yet to be given adequate attention (Akujieze *et al.,*2003). This is indicated by the high dependency on untreated groundwater abstracted through hand dug wells and borehole systems (Ocheri, 2006; Ocheri, 2010). Major treatment of water from these wells would be required before its domestic consumption or before meeting the WHO drinking water standard (Yusuf, 2007). Depending on the type of contaminants, adequate and appropriate measures should be taken to treat the water by way of disinfection, chlorination, sedimentation, filtration, reverse osmosis, and boiling to make the water potable and fit for domestic use (Ogedengbe and Akinbile, 2007; Akinbile and Alatise, 2011; Nwachukwu, *et al.,*2014; Ocheri, *et al.,*2014).

Abandonment

It has been noted earlier that the cost of cleaning up a polluted aquifer is usually extremely high. In the course of remediating or treating a polluted aquifer, all available methods are considered in order to come up with the most appropriate and feasible method. However, if the pollution is so severe or the available remediation methods are considered too difficult or expensive, then abandoning the aquifer's groundwater and securing an alternative source of water would be the last resort (USEPA, 2002).

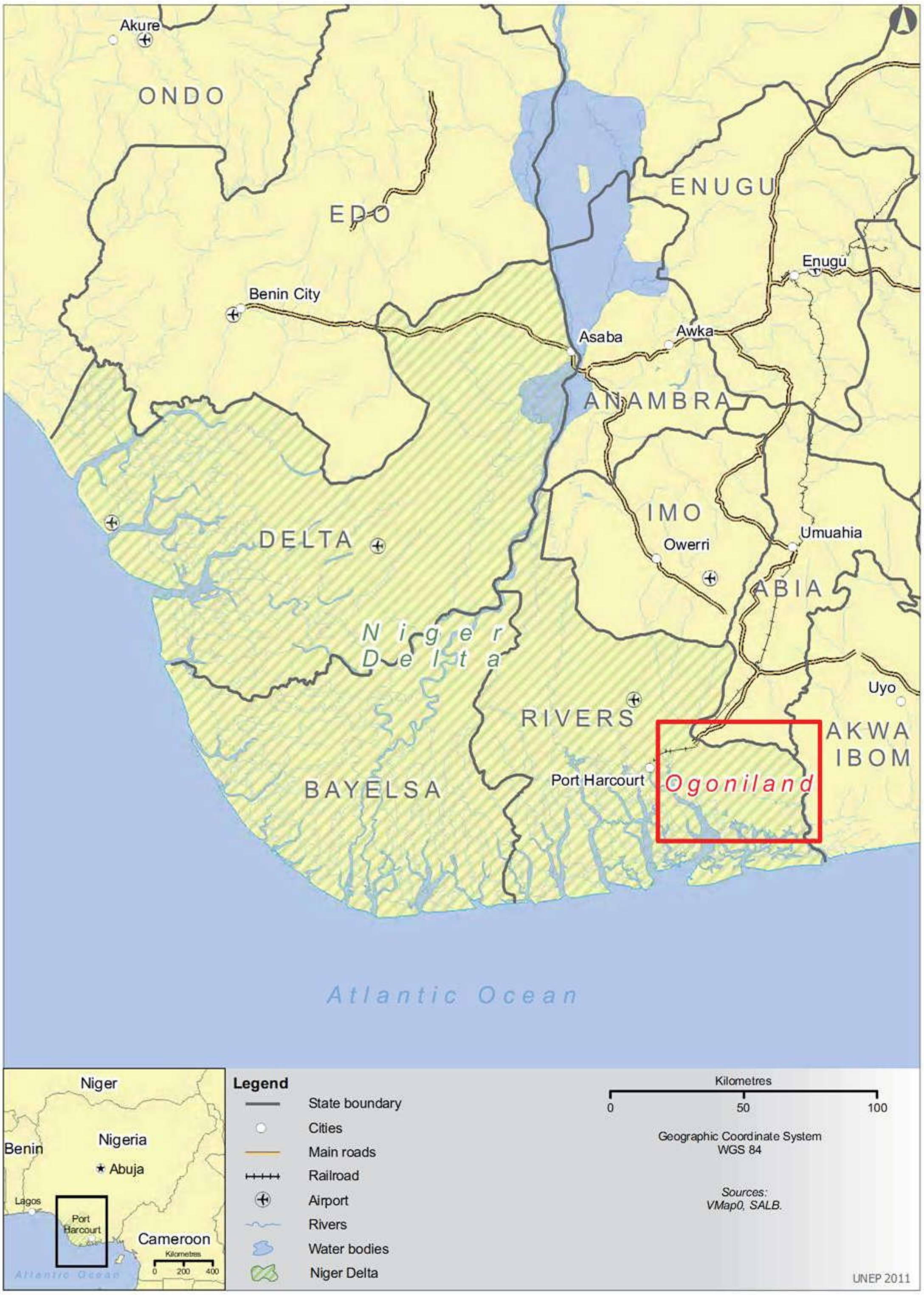


Fig. 14. Map of Niger-Delta showing Ogoniland. Source: UNEP (2011)

CASE HISTORY OF GROUNDWATER POLLUTION IN NIGER-DELTA, NIGERIA

Ogoniland is a large community in the Niger Delta region of Nigeria (fig.14), and remains one of the several localities that have been seriously affected by the activities of multinational oil companies. These companies have operated in the region for over fifty years with cases of oil spillage, leakage and environmental degradation (Ayodele, 1985; Krist, 2000; Akujieze *et al*., 2003; Ayotamuno *et al*., 2006; Bolaji, 2008;). In 2010, the United Nations Environmental Programmes (UNEP) undertook an assessment of Ogoniland to ascertain the level of environmental degradation in the area. The study involved the collection and analysis of water and soil samples from 142 groundwater monitoring wells and 780 boreholes respectively. It lasted for a period of fourteen (14) months and had the report released on August 4, 2011. According to the UNEP report, groundwater resources in Ogoniland are heavily polluted with petroleum hydrocarbons. A case cited was Nisisioken Ogale, near a Nigerian National Petroleum Company (NNPC) pipeline, where some families were drinking water from wells polluted with benzene, a known carcinogen, at levels over 900 times above World Health Organization (WHO) guidelines.

Also, five highest concentrations of Total Petroleum Hydrocarbons detected in groundwater in the region, exceeded 1 million micrograms per litre against the Nigerian Standard of 600 micrograms per litre. UNEP reported that the total cleanup of Ogoniland and water resources would require modern technology and could take up to 25 to 30 years, and could also cost several billions of dollars. Ogoni case has been a source of concern to Nigerians and the world at large as the level of degradation tends to threaten human and environmental health. This necessitates an urgent call for a collaborative effort from all concern – the government, multinationals, communities and every individual, to finding a lasting solution to the problem, which should incorporate the solutions proffered by UNEP.

Conclusion

Groundwater is susceptible to pollution by pollutants such as nutrients, pathogens, heavy metals, household chemicals, petroleum hydrocarbons etc grouped into two main categories: point sources and non-point sources. The dangers of polluted groundwater cannot be overemphasized. It can have diverse effect on both human and environmental health, ranging from common water-borne diseases to more severe health problems such as cancer, reproductive abnormalities, neurological disorders, and so on. Plants, animals, and humans alike, all get their shares of the "spoils". Man should strive for pollutant free groundwater, either by preventing the water from being polluted in the first place or by treating it with appropriate remediation technique, when it is polluted. Local communities and private well owners should be encouraged to adopt and adhere to point of use or home level (small scale) treatment techniques such as boiling, chlorination, sedimentation and filtration. However, it is important to note that remediation as an option may be too expensive, difficult or even impossible. Hence, always remember that it pays to prevent than to remediate, and this prevention is in our hands.

REFERENCES

Abimbola, A.F., Laniyan, T .A., Okunola O. W., Odewale, A. A., Ajibade, M. and Kolawole, T.. 2005. Water quality test of areas surrounding selected refuse dumpsite in Ibadan southwestern Nigeria. *Journal of Water Resources,* Vol.16.pp.39-48.

Abolude, D.S., Davis, O. A. and Chia, A. M. 2009. Distribution and concentration of trace elements in Kubani Reservoir in Northern Nigeria. *Research Journal of Environment and Earth Sciences,* Vol.1, No.2, pp.39-44.

Adamu, G.K., Tukur, R. and Kankara, .A. I. 2013. Groundwater assessment in the basement complex of Kano state, Nigeria., *American Journal of Engineering Research,* Vol.2,Issue 7, pp.171-175.

Adekunle, I. M., Adetunji, M. T., Gbadebo, A. M. and Banjoko, O. B. 2007. Assessment of Groundwater Quality in a Typical Rural Settlement in Southwest Nigeria. *International Journal of Environmental Research and Public Health,* 4(4), 307 – 318.

Adelana, S. M. A.; Olasehinde, P. I.; Bale, R. B.; Vrbka, P., Edet, A. E. and Goni, I. B. 2008. An overview of the geology and hydrogeology of Nigeria. In A. M. M. Segun, M. A. Adelana (Ed.), Applied Groundwater studies in Africa. London, UK: CRC Press/Balkema.

Adelana, S.M.A., Bale, R.B. and Wu, M. 2003. Quality of assessment of pollution vulnerability of groundwater in Lagos metropolis, SW Nigeria in: proceedings of the aquifer vulnerability Risk Conference AURO3 Salamenia Mexico, 2, pp.1-17.

Adelana, S.M.A., Bale, R.B. and Wu, M. 2004. Water quality in a growing urban centre along the coast of South western Nigeria In: Seilder, K, P.W and XI, R (eds). Research Basic and Hydrological planning, Balkama, The Netherlands, pp.83-92.

Adelana, S.M.A., Bale, R.B., Olasehinde, P. I. and Wu, M.. 2005. The impact of anthropogenic activities over groundwater quality of coastal aquifer in Southwestern Nigeria. Proceedings on Aquifer vulnerability and Risks. 2nd International Workshop and 4th Congress on the Protection and Management of Groundwater. Raggia di Colornoparma.

Adelowo, O. O, Akinlabi, I. A. and Fagade, O. E. 2012. Environmental Impact assessment of Attenda abattoir, Ogbomosho Southwestern Nigeria on surface and groundwater quality using geoelectrical imaging and microbiological analysis. *Environmental Monitoring and Assessment*, 184 (7), 4565 – 4575.

Adeniran, K. A. and Ajamu, S. O. 2004. Effectiveness of the Drastic Model to Predict Agrochemical-Induced Groundwater Pollution. Water Resource – *Journal of the Nigerian Association of Hydrogeologists (NHA)*, Vol. 15, No. 2, Pp. 1 – 5.

Ajala, O. 2005. Environmental impact of urbanization, culture and the Nigeria in: Fadare et al. (eds) Globalisation, Culture and Nigerian built Environment, *Faculty of Environmental Design and Management*, OAU, pp.192-199.

Akinbile , C. O. and Alatise, M. O. 2011. Qualitative Analysis of Bored Groundwater for Agricultural and Municipal uses in Ondo State, Nigeria, *Journal of Agricultural Science and Technology*, Makurdi (in press).

Akinbile, C. O. and Yusoff, M. S. 2011. Environmental impact of leachate pollution on groundwater supplies in Akure, Nigeria. *International Journal of Environmental Science and Development*, Vol. 2, No. 1, Pp. 81 – 86.

Akujieze, C. N. 2006. Remedies of soil and groundwater pollution: An overview. *Afri. Sci*., 7(2): 61 – 68.

Akujieze, C. N. and Ezomo, F. O. 2010. Permeable reactive and Aquifer Remediation. *J. Civ. Environ. Syst. Eng*., 11(2): 48 – 63.

Akujieze, C. N.; Coker, S. J. L. and Oteze, G. E. 2003. Groundwater in Nigeria – A millennium experience – Distribution, practice, problems and solutions. *Hydrogeology Journal*, 11(2), 259 – 274.

Alex, C. 2015. Groundwater remediation, IWA Publishing.

Alexander, P. 2008. Evaluation of groundwater quality of Mubi town in Adamawa State, *Nigeria. African Journal of Biotechnology,* Vol.7 (11), pp.1712-1715.

Alichi, A.U., Asana, I.O., Aghomishe, M.A., Ozoade, V.U and Aiyegbusi, S. 2010. Hydrogeochemical characteristics and groundwater quality assessment in Aba Metropolis, Southeastern Nigeria. *Proceedings, Annual Conference of the Nigerian Association of Hydrogeologists on Water Resources Development and Climate Change*. P. 30.

Allan H. Smith; Elena O. Lingas and Mahfuzar Rahmar 2000. Contamination of drinking-water by arsenic in Bangladesh: a public health emergency. Special Theme – Environment and Health. Bulletin of the World Health Organization, 78(9), Pp. 1093 – 1103.

Amos, P. W. and Younger, P. L. 2003. Substrate characterization for a subsurface reactive barrier to treat colliery spoil leachate. Water Research, 37 : 108 – 120.

and Remedial Techniques as on 27-05-2012 –NewDesign.

Anna, A. 2014. A review of the hydrogeological conditions in Nigeria – Occurrence, contamination and remediation of groundwater. Department of Earth Sciences University of Gothenburg. Report 2014 C108, Pp 10 – 14.

Aremu, D. A.; Olawuyi, J. F.; Meshitsuka, S., Sridhar, M. K. and Oluwande, P. A. 2002. Heavy metal analysis of groundwater from Warri, Nigeria – *International Journal of Environmental Health Research*, 12(3), 261 – 267.

ASTM 1998. Standard Guide for Remediation of Groundwater by Natural Attenuation at Petroleum Release Sites, E – 1943 – 98, West Conshohocken, Pennysylvania.

Atwater, J. W., Jasper, S., Mavinic D. S. and Koch F. A. (1983). Experiments using daphnia to measure landfill leachate toxicity. Wat Res., 17, 1855 – 1861.

Ayodele, A. S. 1985. The conflict in the growth of the Nigerian petroleum industry and the environmental quality. *Socio-Economic Planning Sciences*, 19 (5), 295 – 301.

Ayotamuno, M. J.; Kogbara, R. B.; Ogaji, S. O. T. and Probert, S. D. (2006). Petroleum contaminated groundwater: Remediation using activated carbon. *Applied Energy*, 83 (11), 1258 – 1264.

Bako, S. P.; Chukwunonso, D; and Adamu, A. K. 2008. Bio-Remediation of refinery effluents by strains of pseudomonas aerugenosa and penicillium janthinellum. *Applied Ecology and Environmental Research*, 6 (3), 223 – 299.

Begum, A.; Ramaiah, M.; Harikrishna, Khan, I; Veena, K. (2009). Analysis of heavy metals concentration in soil and litchens from various localities of Hosar Road, Bangalore, India. *E. J. CHEM*, 6(1) : 13 – 22.

Benner, S. G., Blowes, D. W. and Ptaceck, C. J. 1997. A full-scale Porous reactive wall for prevention of acid mine drainage.

Biswas, A. K. 1997. Water Resources: Environmental Planning Management, and Development. McGraw-Hill, New York. 135 – 150.

Bolaji, G. A. 2008. A remedial approach for soil and groundwater impacted by crude oil in the Niger Delta. In S. M. A. M. A. M. Adelana (Ed), Applied Groundwater studies in Africa (Pp. 115 – 123). London, UK: CRC Press/Balkema.

Borden, R. C. and Kao, C. 1992. Evaluation of Groundwater Extraction for Remediation of Petroleum-Contaminated Aquifers. *Water Environment Research*, Vol. 64, No. 1. Pp. 28 – 36.

Cameroon R. D., Koch F. A. 1980. Toxicity of landfill leachates. *J. Wat. Pollut Control. Fed*., 52, 760 – 769.

Chakraboti, D., Rahman, M., Paul, K., Chowdhury, I., Sengupta, M., Lodh, D., Chanda, C.; Saha, K.; Mukherjee, S. 2002. Arsenic calamity in the Indian Subcontinent. What lessons have been learned? Talanta 58, Pp. 3 – 22.

Dan-Hassan, M.A. and Olasehinde, P. I. .2010. Seasonal variations in physic-chemical properties of groundwater from central part of the Federal Capital Territory, Abuja, Nigeria. *Proceedings, Annual Conference of the Nigerian Association of Hydrogeologists on Water Resources Development and Climate Change*, P.10.

Edet, A. E. and Worden, R. H. 2009. Monitoring of the physical parameters and evaluation of the chemical composition of river and groundwater in Calabar (Southeastern Nigeria). Environmental Monitoring and Assessment, 157 (1 – 4), 243 – 258 .

Eni, D.V., Obiefuna J., Oko, C. and Ekwok, I.. 2011. Impact of urbanization on sub-surface water quality in Calabar municipalty, Nigeria. *International Journal of Humanities and Social Sciences,* Vol.1, Issue 10, pp.167-172.

Ezekwe, I. C., Odu, N. N., Chima, G. N. and Opigo, A. 2012. Assessing regional groundwater quality and its health implications in the Lokpaukwu, Lekwesi and Ishiagu mining areas of Southeastern Nigeria using factor analysis. *Environmental Earth Sciences*, 67(4), 971 – 986.

Forster, D., Lawrence, A. R. and Morris, B. B. 1998. Groundwater in urban development. World Bank Technical Paper No.390, Washington D.C, 121.

Galadima, A., Garba, Z. N., Leke, L., Almustapha, M. N. and Adam, I. K. 2011. Domestic water pollution among local communities in Nigeria – causes and consequences, *European Journal of Scientific Research*, Vol. 52, No. 4, Pp. 592 – 603.

Garba, Z. N., Hamza, S. A. and Galadima, A. 2010. Arsenic Level Speciation in Freshwater from Karaye Local Government Area, Kano State Nigeria. *International Journal of Chemistry*, India. Vol. 20, No. 2 : 113 – 117.

Gbadebo, A. M. 2005. Arsenic pollution in aquifers located within limestone areas of Ogun State, Nigerian. Natural Arsenic in Groundwater: Occurrence, Remediation and Management, 85 – 92.

GeoSyntec Consultants Inc. 2004. Assessing the feasibility of DNAPL source zone remediation: Review of case studies. Contract Report CR-04-002-ENV for NAVFAC.

Glenn, L. 2002. Pesticides and Groundwater Contamination. The Ohio State University Bulletin 820.

Government of Canada, 2010. "Groundwater Contamination in Canada" Canadian Bulleting of Environmental Sciences: Environment Canada, Ottawa, 2010. Pp. 12 – 16.

Goyer, R. A. and Clarkson, T. W. 2001. Toxic effects of metals, in Casarett and Doullis Toxicology: The Basic Sciences of Poisons, Sixth Edition (C. D. Klaassen, ed.) Mc-Graw-Hill, New York, PP. 811 – 867.

Greenberg and Bederman 2015. Health Effects of groundwater and soil contamination, Silver Spring, MD 20910, (310) 589 – 2200. PP. 68 – 100.

Hassan, N. U. 2012. Groundwater Contamination, Prevention and Remedial Techniques as on 27-05-2012 – New Design

Hyman, M. and Dupont, R. 2001. Groundwater and soil remediation: Process Design and cost estimating of proven technologies. *American society of Civil Engineers Press*, Pp. 109 – 135.

Ibe, K. M. 1999. Migration of contaminants into groundwater at a landfill site: A case study of the Avu landfill site Owerri, SE, Nigeria. *International Journal of Environmental Health Research,* 9(1), 55 – 66.

Ikem, A., Osibanjo, O., Sridhar, M. K. C. and Sobande, A. 2002. Evaluation of Groundwater Quality characteristics near two waste sites in Ibadan and Lagos, Nigeria, water, air and soil poll, 140 : 307 – 333. Kluwer Academic Publishers, the Netherlands.

Ilemobayo, O. and Kolade, I. 2008. Profile of Heavy Metals from Automobile Workshops in Akure, Nigeria. *Journal of Environ. Sci. Technol*., 1: 19 – 26.

Ipeaiyeda, A. R. and Dawodu, M. 2008. Heavy Metals Contamination of Topsoil and Dispersion in the Vicinities of Reclaimed Auto-repair Workshops in Iwo, Nigeria. Bull. Chem. Soc. Ethiopia, 22(3): 339 – 348.

Iwegbue, C. M. 2007. Metal Fractionation in Soil Profiles at Automobile Mechanic Waste Dumps around Port Harcourt. *Waste Manage Res*., 25(6) : 585 – 595.

Kavanaugh, M. C., Rao, S. C., Abriola, L., Cherry, J., Destouni, G., Falta, R., Major, D., Mercer, J., Newell, C., Sale, T., Shoemaker, S., Siegrist, R., Teutsch, G. and Udell, K. 2003. The DNAPL remediation challenge: Is there a case for source depletion? U. S. EPA/600/R – 03 /143. Ada, Oklahoma: National Risk Management Research Laboratory, U.S. EPA.

Kehinde, M.O. 1998.The impact of industrial growth on groundwater quality and availability in: Osuntokun, A(eds) Current Issues in Nigerian Environment, Ibadan Danidan Press.

Khraisheh, Majeda, A. M.; Al-degs, Yahya, S.; and McMinn, Wendy, A. M. 2004. Remediation of wastewater containing heavy metals using raw and modified diatomite. *Chemical Engineering Journal*, 99(2), 177 – 184.

Krembs, F. J. 2008. Critical analysis of the field scale application of in-situ chemical oxidation for the remediation of contaminated groundwater. M. S. Thesis, Environmental Science and Engineering Diasion, Colorado School of Mines.

Krist, A. O. 2000. Environmental Problem in the Oil Rich Niger-Delta in Nigeria. Newsline at GREEN AFRICA.

Krueger, C. J., Barber, L. B. and Metge, D. W. 1998. Fate and transport of linear alkylbenzensulfonates in sewage, contaminated aquifer: a comparison of natural-gradient pulsed tracer tests. *Environ Sci. Technol*., 32, 1134 – 1142.

Longe, E. O. and Balogun, M. R. 2010. Groundwater Quality Assessment near a municipal landfill, Lagos, Nigeria, *Research J. of applied Sci, Engineering and Technology*, 2(1): Pp. 39 – 44.

Lyle, S. R. 2015. "Groundwater Contamination" Bulletin, New York State Water Resources Institute, Cornell University, New York.

McGuire, T. M., McDade, J. M. and Newell, C. J. 2006. Performance of DNAPL source depletion technologies at 59 chlorinated solvent-impacted sites. *Groundwater Monitoring and Remediation*, 26, No. (1): 73 – 84.

Mohd, R. T., Wan, W. Y., Abd, R. S. and Jasni, Y. 2011. Groundwater quality at two landfill sites in Selangor, Malaysia, *Bulletin of the Geological Society of Malaysia*, 57 : 13 – 18.

Mulligan, C. N., Yong, R. N. and Gibbs, B. F. 2001. Remediation technologies for metal-contaminated soils and groundwater: an evaluation. *Engineering Geology*, 60 (1 – 4), 193 – 207.

Musa, H., Yakasai, I. A., and Musa, H.H.. 2004. Determination of lead concentration in well and boreholes in Zaria, Nigeria. *Chemical Class Journal,* Vol. pp.14-18.

Nadim, Farhad, Hoag, George, E.; Liu, Shili, Carley, Robert, J. and Zack, Peter 2000. Detective and remediation of soil and aquifer systems contaminated with petroleum products: an overview. *Journal of Petroleum Science and Engineering*, 26(1 – 4), 169 – 178.

National Academy Sciences, 1984. Groundwater Contamination. National Academy Press, Washington, D. C. Pp. 179.

Nwachukwu, J. C., Udoka, U. P. and Okeke, AUG (2014). Health Hazards of Water pollution and water treatment techniques (edited by Okeke O. C. and Udoka U. P. in Handbook of Geologic Methods, Vol. II). Platinum Global Ventures Press, Port Harcourt, Pp. 71 – 135.

Nwankwoala, H.O., and Udom, G. J. .2011. Hydrochemical evaluation of groundwater in parts of eastern Niger Delta, Nigeria, *Journal of Academic and Applied Sciences*, Vol.1, No.2,pp.33-58.

Obase, K., Olurunfemi, M. O. and Akintonwa, 2009. Geophysical and Hydrochemical investigation of the area around a waste dumpsite in Ile-Ife, Southwestern Nigeria. *Global Journal of Geological Science,* Vol. 7(1), pp.47-54.

Ocheri, M. I. 2006. Analysis of water consumption pattern in Makurdi metropolis. *Journal of Geography and Development*, Vol.1, No.1, 71-83.

Ocheri, M. I., Odoma, L. A.., and Umar, N. D. 2014. Groundwater Quality in Nigeria Urban Areas: A Review. *Global Journal of Science Frontier Research (H): Environment and Earth Science*, Vol. 14, Issue 3. Version (1), Pp. 35 – 45.

Ocheri, M.I., Mile, I. I., and Obeta, M. C. 2010. Seasonal variation in nitrate levels in hand dug wells in Makurdi metropolis. *Pakistan Journal of Nutrition,* Vol.9, pp.539-542.

Ogedengbe, K. and Akinbile, C. O. 2007. Wellwaters Disinfection by Solar Radiation in Ibadan, Nigeria, *Nigerian Journal of Technological Development*, 2007. 5(1): 39 – 47. Ilorin, Nigeria.

Ogunbajo, M. I. and Kolajo, O. A. 2004. The Impact of Solid Waste Disposal on the Chemical Quality of Surface and Sub-surface Water Resources in Parts of Ibadan

Metropolis, South-Western Nigeria. *Water Resources – Journal of the Nigeria Association of Hydrogeologists (NAH),* Vol. 15, No. 2. Pp. 26 – 32.

Olayinka, A., and Olayiwola, M. A. .2001. Integrated use of geoelectrical imaging and hydrochemical method in delineating limit of polluted surface and groundwater at a landfill site in Ibadan area southwestern Nigeria. *Journal of Mining and Geology,* Vol.37, No.1, pp.53-68.

Olokesusi, A. 1987. Characteristics of environmental problems in Nigeria and Management prospects. Environmentalist, 7(1), 55 – 60.

Omono, O.V., Onwuka, O. S. and Okogbue, C. O. 2013. Characterisation of groundwater in three settlement areas of Enugu metropolis, Southern Nigeria. Environmental Monitoring and Assessment, www.ncbi.nih.gov/pubmed/ 24037228.

PIRAMID Consortium 2003. Engineering Guidelines for the Passive Remediation of acidic and/or Metalliferous mine drainer and similar wastewaters. European Commission 5th Frame work RTD Project no. EVKI – CT-1999-000021 "Passive in-situ remediation of acidic mine/industrial drainage" (PIRAMID). University of Newcastle Upon Tyne, Newcastle Upon Tyne, UK.

Plummer C. C., McGeary, D., and Carlson, D. H. 2005. Physical Geology (Tenth Edition), McGraw-Hill, New York. 264 – 277

Reddy, K. R. 2008. Physical and Chemical groundwater Remediation technologies, Department of Civil and Materials Engineering, University of Illinois at Chicago, IIL 60607, USA. Pp. 263 – 271.

Robertson, W. D.; Blowes, D. W.; Ptacek, C. J. and Cherry, J. A. L. 2005. Long-term performance of in-situ reactive barriers for nitrate remediation. Groundwater, 38 (5), 689 – 695.

Sajad, M. M., Rahim, S. and Tahir, T. .1998. Chemistry of groundwater of Rawalpinli/Isalama, 24th Conference, Islamba.

Schwarzbauer, J. 2006. Organic Contaminants in riverine and Groundwater Systems: Aspects of the Anthropogenic Contribution, Springer Verlag Berlin, 33 – 40.

Stewart, R. 2008. "Groundwater Remediation", Department of Geosciences, Texas A & M University, Texas, U. S. A.

Stroo, H. F., Unger, M., Ward, C. H., Kavanaugh, M. C., Vogel, C., Leeson, A., Marqusee, J. A. and Smith, B. P. 2003. Remediating chlorinated solvent source zones. *Environmental Science and Technology*, 37: 224A – 231A.

Suzuki, T., Kondo, H., and Yaguchi, K. 1998. Estimate of the leachability and persistence of pesticides at golf courses from point-source monitoring and model to predict pesticides leaching to groundwater. *Environ Sci. Technol*., 32, 920 – 929

Tchobanoglous, G. and Schroeder, E. D. 1987. "Water Quality Characteristic Modelling Modification" Edition, Pp. 418 – 419.

Todd, D. K. 2004. Groundwater hydrology (Second Edition). John Wiley & Sons, Canada. 314 – 316.

Ufoegbune, G. C., Lamidi, K. I., Awomeso, J. A., Eruola, A. O. Idowu, O. A. and Adeotun, C. O. 2009. Hydrochemical characteristics and groundwater assessment of some selected communities in Abeokuta southwestern, Nigeria. *Journal of Environmental Chemistry and Exotoxicology,* Vol.1, No.1, pp.10-22.

UNEP 2011. Environmental Assessment of Ogoniland (Edited by Tim Davis and Tim Jones). United Nations Environment Programmes, Nairobi, Kenya. ISBN: 978 – 92 – 807 – 3130 – 9. Pp. 108 – 200

USEPA 1998a. Monitored Natural Attenuation for Groundwater, EPA/625/K-98/001.

USEPA 2002. Getting up to speed "from Section C, Groundwater Contaminants" Wellhead protection: A guide for small communities. Chapter 3. EPA/625/R – 93/002.

USEPA 2009. Correction Measures Selection process: Remedial Technologies Overview. Session 3. P. 20.

Younger, P. L. 2007. Groundwater in the Environment: An Introduction, Blackwell, Australia. 01 – 257.

Yusuf, K. A. 2007. Evaluation of Groundwater Quality Characteristic in Lagos-City. *Journal of Applied Science,* 7(13): 1780 – 1784.

****