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A REVIEW OF ORGANIC AND INORGANIC CHEMICALS, THEIR SOURCES, METHODS OF MOBILIZATION AND ATTENUATION IN GROUNDWATER.

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ABSTRACT
Tens of thousands of man-made chemicals are put to use and are dispersed into the environment especially the water resources. There are varieties of pathways by which these contaminants make their way into the water resources, organic contaminants like Volatile organic compounds (VOC) enter the groundwater when used to make plastics, dyes, rubbers etc, Pesticides enter when used as herbicides, insecticides, fungicides, rodenticides and algaecides. Plasticizers and chlorinated solvent enter the groundwater through improper waste disposal. If the groundwater is the drinking water resources, it will be potentially dangerous on human health. Pharmaceuticals and other organic contaminants are a set of compounds that are receiving an increasing amount of public and scientific attention because of their hydro-chemical constituents. Inorganic chemicals are usually present in natural waters at much higher concentration than their organic counterparts. Many studies have been conducted since 1970 to characterize concentrations of organic compounds in groundwater. In 1977, 16 drinking water wells were closed in Gray town of Maine State in the United State of America (USA) because there were at least 8 synthetic organics that were detected in them. And in 1985, there were at least 33 organics that were detected in drinking water wells in USA. Some of these inorganic contaminants such as Barium, Arsenic, Aluminium, chloride, chromium, copper, fluoride and Fe Can cause a variety of effects such as gastrointestinal effects, acute and chronic toxicity, liver and kidney damage; decreases blood haemoglobin, Alzheimer's disease and possibly other Neurotoxic effects, deteriorates plumbing, water heaters, and municipal water-works equipment at high levels, Chromium V1 which is much more toxic than Chromium 111 causes liver and kidney damage, internal haemorrhaging and intestinal distress, liver and kidney damage, anaemia in high doses, decreases incidence of tooth decay but high levels can stain or mottle teeth, crippling bone disorder. Some of these chemical contaminants may become less harmful after undergoing attenuation. This review becomes imperative because of the essential nature of groundwater as it pertains to its use for drinking, irrigation and industrial purposes.

KEYWORDS: *Groundwater, Organic Contaminants, Inorganic Contaminants, Attenuation.*

INTRODUCTION

Organic and inorganic chemicals, their sources, mobilization and attenuation is of utmost importance in the study of groundwater and its quality.

Tens of thousands of man-made chemicals are put to use and are dispersed into the environment especially the water resources. There are a variety of pathways by which these organic contaminants make their way into the water resources (Heberer, 2001). If the groundwater is the drinking water source, it will be potentially dangerous on human health. Pharmaceuticals and other organic contaminants are a set of compounds that are receiving an increasing amount of public and scientific attention because of their hydrochemical constituents.

Inorganic chemicals are usually present in natural waters at much higher concentration than their organic counterparts. Many of these chemicals are naturally occurring and may be considered as an integral part of those particular water, e.g calcium, carbonate and Bi-carbonate in hard waters, rather than as "contaminants". Some of these major inorganic constituents make the differences in taste and even colour of various waters, when they occur in high or excessive concentration.

Groundwater, simply stated is the water which is located underground, below the water table. Water in soils and other geologic formations is stored in a complex network of pores and voids between the solid matrix, which consist of clay, sand, gravel, fissured rocks and other similar materials (Hornsby, 1986).

Groundwater is, but one component of the hydrologic cycle. Groundwater quality is very much influenced by surface-water conditions and vice versa. Contamination of any surface water body that recharges the groundwater system is a source of groundwater contamination. This include "natural" recharge sources such as lakes and rivers as well as "man-made" recharge sources such as artificial ponds/injection wells and infiltration of urban runoff.

In Nigeria, the rate of urbanization characterized by high population concentration increasing industrial and agricultural activities coupled with environmental pollution/degradation and indiscriminate disposal of all kinds of wastes are perceived to make groundwater vulnerable to pollution with all its concomitants health hazards on groundwater quality especially in rural areas (Kehinde,1998; Adelana *et al.* 2003;, Adelana *et al.,* 2004; Adelana *et al.,* 2005; Ajala, 2005; Ocheri, 2006; Adelana *et al.,* 2008; Eni *et al.,* 2011).

SOURCES OF GROUNDWATER ORGANIC CONTAMINANTS

There are several sources of organic contaminants in groundwater. These chemicals, which are found in groundwater, come from rain, organic action in the soil. Suburban areas have groundwater with high levels of nitrate due to the use of lawn fertilizers as well as septic tank discharges (Flipse *et al.* 1984). Agricultural areas have not only high levels of fertilizers found in groundwater (Pionke & Urban 1985), but also have specialized synthetic organic agricultural chemicals (Rothschild, Manser, & Anderson 1982). Landfills in urban and rural areas are known sources of contamination (Noss & Johnson 1984; McLeod 1984).

Naturally formed waters such as ocean water and connate brines can be sources of groundwater contamination under certain circumstances. Changes in pumping rates can cause fresh-water aquifers to be contaminated by intrusion of seawater in coastal areas. Similarly, changes in the groundwater flow field or leakage through imperfectly sealed wells can cause contamination of groundwater supply by naturally occurring brines or other poor-quality waters. Generally, trace amount of natural organic compounds exist in groundwater in most regions.

There are three important attributes that distinguish sources of groundwater contamination, these include: (a) their degree of localization, (b) their loading history and (c) the kind of contaminants emanating from them. Given the large number of ways of contaminating groundwater, there is a spectrum of source sizes ranging from an individual well to areas of 100 Km^2 or more. There are two terms that describe the degree of localization of the source of contamination of groundwater, (a) point and (b) nonpoint sources. A point source is characterized by the presence of an identifiable, small scale source, such as a leaking storage tank, one or more disposal ponds, or a sanitary landfill. Usually, this source produces a reasonably well-defined plume. While a nonpoint source refers to larger scale, relatively diffuse contamination originating from many smaller sources, whose locations are often poorly defined. Examples of nonpoint contaminants could include; herbicides or pesticides that are used in farming, nitrates that originate as effluents from household disposal systems, salts derived from highways in winter, and acid rain. These sources of organic contaminants are discussed in the following order:

1.Agrochemicals: Among all the agricultural concerns, agro-chemicals have given rise to grave environmental contamination. An unthoughtful use of chemicals may render agricultural land, water and air inefficient for supporting life. Most of the public environmental protection programs are urban-oriented; whereas the pollution and its effects in the local sectors are ignored as much as 50%to 70% of the water resources are polluted due to contamination from agricultural activities (Lal and Stewart, 1994). The nitrate concentration of well water has shown rising trends in many countries within the last 30 years (Guarda *et al.,* 2004). Application of nitrogen-based fertilizers such as NPK (nitrogen, phosphorus and potassium), urea together with organic manure like cow dung, decomposed vegetative waste, in more than required quantities, could lead to the percolation of nitrate into subsurface water bodies.

2. Fertilizers: The use of fertilizers in agriculture is recognized as a potential source of water pollution. High Nitrate-Nitrogen (NO_3-N) concentrations found in surface and groundwater is currently receiving attention. A certain portion of (NO_3-N) pollution comes from the use of agricultural fertilizer which can enter directly from the fields into the streams or underground sources. Report on groundwater resources in Lake Biwa (Japan) showed that the drainage from agricultural land contributed to 47% and 23% of the total nitrogen and phosphorus respectively (Misawa and Kondoh, 1992). Pollution of drinking water supplies is being reported frequently.

3. Household Chemicals: Household pollutants are contaminants that are released during the use of various products in daily life. Studies indicate indoor air quality is far worse than that outdoors because homes, for energy efficiency, are made somewhat airtight. Moreover, pollutants are trapped in houses causing further deterioration of indoor air quality. Hazardous household products which fall into six broad categories release toxic chemicals into the groundwater resources probably by neglect or accident.

4. Industrial Effluents: Contamination of drinking water supplies from industrial waste is a result of various types of industrial processes and disposal practices. Industries that use large amounts of water for processing have the potential to pollute waterways through the discharge of their waste into streams and rivers, or by run-off and seepage of stored waste into nearby water sources. Other disposal practices which cause water contamination include deep well injection and improper disposal of wastes in surface impoundments.

It has also been observed that large scale and long-term application of waste water on soils may lead to danger of insect infestation, pollution of groundwater and built up of metals, salts and other toxicants (Maddady and Gbasemi 2001, Matos, Fontes, da Costa and Martinez (2001), Samaila, 2005 and Sharma *et al.,* 2007).

5. Petrochemicals: Nigeria has a vast crude oil and gas deposits and attempts to explore it have left the country with unique vulnerabilities (Nduka and Orisakwe, 2009). Refinery and petrochemical plants generate solid waste and sludge composed of organic, inorganic compounds including heavy metals. Waste water released by petrochemical industries are characterized by the presence of large quantity of polycyclic and aromatic hydrocarbons, phenols, metal derivatives, surface active substances, sulphides, naphthylenic acids and other chemicals (Suleimonov, 1995).

6. Sewage: Sewage by itself is one of the major sources of groundwater contaminant. Contamination of drinking water resources by sewage can occur from raw sewage overflow, septic tanks, leakage of sewer lines, land application of sludge and partially treated waste water. Sewage is a complex mixture and can contain many types of contaminants.

The greatest threat pose to water resources arises from contamination by bacteria, nitrates, metals, trace quantities of toxic materials and salts. Seepage overflow into drinking water sources can cause disease from the ingestion of microorganisms such as E coli, Giardia, Cryptosporidium, Hepatitis A, and helminthes.

7. Radioactive Contaminants: The nuclear industry is the main generator of radioactive contaminants. Potential sources occur throughout the nuclear fuel cycle, which involves the mining and milling of uranium, uranium enrichment and fuel fabrication, power plant operation, fuel processing, and waste disposal.

2.1 Organic Chemicals and Types

Organic chemical is a broad class of substances containing carbon and its derivatives. Many of these chemicals will frequently contain hydrogen with or without oxygen, nitrogen, sulphur, phosphorus and other elements. They exist in either carbon ring or carbon ring form. Organic chemicals are pollutants that are made up of primarily of carbon and hydrogen atoms and similar amounts of various other atoms such as chlorine, nitrogen, sulphur, and phosphorus. There are about 70,000 chemicals in commercial use. The U.S Environment protection Agency (USEPA) has designated 654 of these chemicals as being hazardous (DER).

It has been reported that trace organic pollutants have been detected in all the 50 States of America.

The U.S. Geological Survey (USGS) collected and assorted the test data from the 1926 drinking water wells in the nation's rural areas from 1986 to 1999: And at least one volatile organic chemical (VOCs) were detected from 232 wells and the positive rate was 12% and the highest positive rates were Chloroform, tetrachloroethylene, etc. (Moran, 2002). According to Environmental Protection Agency list of priority pollutants, organic compounds are subdivided into FOUR GROUPS according the method of analysis: these include; Base-Neutral Extractable, Acid Extractable, Volatiles and Pesticides.

i) **Base-Neutral Extractables:** Base-neutral extractables include; Acenaphthene, Acenaphthylene, Anthracene, Benzidine, 1,2-Dichlorobenzene, 1,3-Dichlorobenzene, fluoranthene, naphthalene, etc.

ii) **VOLATILE ORGANIC COMPOUNDS (VOCS):** Volatile organic compounds (VOCs) are organic compounds with chemical and physical properties that allow the compounds to move freely between water and air. VOCs have been used extensively in industry, commerce, and households in the United States since the 1940's. Products containing VOCs including fuels, solvents, paints, glues, adhesives, deodorizers, refrigerants, and fumigants. In general, these compounds have low molecular weights, high vapour pressures, and low-to-medium water solubilities (Rathbum, 1998). Many of these compounds show evidence of animal or human carcinogenicity, mutagenicity, or teratogenicity.

iii) **Acid Extractables**: Acid Extractables include; p-Chloro-m-cresol, 2-Chlorophenol, 2-Nitrophenol, Pentachlorophenol, 2,4-Dinitrophenol, etc.

iv) **Pesticides:** Pesticides consist of a large group of chemicals that are used in agriculture and residential settings to control plants and animal infestation. Pesticides are commonly applied on farms, Fruit orchards, golf course, and residential lawns and gardens. There are several different kinds of pesticides: herbicides, insecticides, nematocides, fungicides. Some pesticides do not break down easily in water and can remain in the groundwater for a long period of time.

Table 1 shows the classes of organic contaminants found in water.

Table1. Important Families of Organic Contaminants Found in Groundwater

CHEMICAL FAMILY	EXAMPLES OF COMPOUNDS
Hydrocarbons and derivatives	
Fuels	Benzene, toluene, o-xylene, butane,
PAHs	Phenolantracene, phenanthrene
Alcohols	Methanol, glycerol
Creosote	m-Cresol, o-cresol
Ketones	Acetone
Halogenated aliphatics	Tetrachloroethane, trichloroethane, dichloromethane
Halogenated Aromatics	Chlorobenzene, dichlorobenzene
Polychlorinated biphenyls	2,4'-PCB, 4,4'-PCB

Source: Physical and chemical hydrogeology (By Schwartz Dominique Patrick)

Figure 1 is a schematic diagram showing the sources of Organic and inorganic chemicals and their mobilization in groundwater.

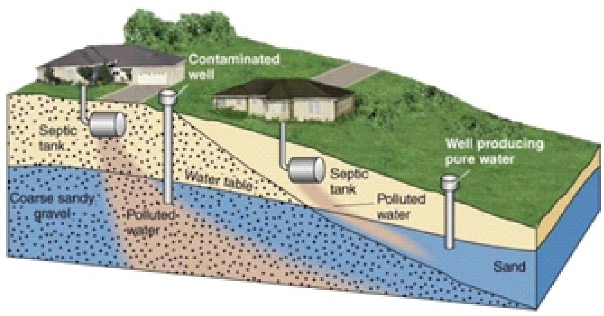

FIGURE 1: Sources of Organic and inorganic chemicals and their mobilization in groundwater (Foundation for Water Research, 2012).

Table 2 provides a summary of source and effect of inorganic contaminants in groundwater.

Table 2: Summary of inorganic contaminants found in groundwater, their sources, and effects on human health.

CONTAMINANT	SOURCES TO GROUNDWATER	EFFECTS ON HUMAN HEALTH
Aluminium	Occurs naturally in some rocks and drainage from mines	May cause Alzheimer's disease and possibly other Neurotoxic effects.
Arsenic	From natural processes, industrial activities, pesticides, and industrial waste, smelting of copper, lead, and zinc ore.	Causes acute and chronic toxicity, liver and kidney damage; decreases blood haemoglobin.
Barium	Occurs naturally in some Limestone, Sandstones, and soils in the eastern United States.	Can cause a variety of cardiac, gastrointestinal, and neuromuscular effects.
Chloride	May be associated with the presence of Sodium in drinking water when present in high concentrations. Often from saltwater intrusion, mineral dissolution, industrial and domestic waste.	Deteriorates plumbing, water heaters, and municipal water-works equipment at high levels. Above secondary maximum contaminant level, taste becomes noticeable.
Chromium	From old mining operations runoff and leaching into groundwater, fossil-fuel combustion, cement plant emissions, mineral leaching, and waste incineration.	Chromium V1 is much more toxic than Chromium 111 and causes liver and kidney damage, internal haemorrhaging, respiratory damage and dermatitis.
Copper	From metal plating, industrial and domestic waste, mining, and mineral leaching.	Can cause stomach and intestinal distress, liver and kidney damage, anaemia in high doses.
Fluoride	Occurs naturally or as an additive to municipal water supplies; widely used in industry.	Decreases incidence of tooth decay but high levels can stain or mottle teeth.
Iron	Occurs naturally as a mineral from sediment and rocks or from mining, industrial waste, and corroding metal.	Causes crippling bone disorder (calcification of the bones and joints) at very high levels.
Lead	Enters groundwater from industry, mining, plumbing, gasoline, coal, and as a water additive.	Impacts a bitter astringent taste to water and a brownish colour to laundered clothing and plumbing fixtures.
Manganese	Occurs naturally as a mineral from sediment and rocks or from mining and industrial waste.	Affects red blood cell chemistry; delays normal physical and mental development in babies and young children. Causes slight deficits in attention span, hearing, and learning in children.

Nitrate (as nitrogen)	Occurs naturally in mineral deposits, soils, seawater, freshwater systems, the atmosphere, and biota. More stable form of combined nitrogen in oxygenated water. Found in the highest levels in groundwater under extensively developed areas. Enters the groundwater from fertilizer, feedlots, and sewage.	Causes aesthetic and economic damage, and impacts brownish stains to laundry. Affects taste of water, and causes dark brown or black stains on plumbing fixtures.
Nitrite (combined nitrate/nitrite)	Enters environment from fertilizer, sewage, and human or farm-animal waste.	Toxicity results from the body's natural breakdown of nitrate to nitrite. Causes "bluebaby disease," or methemoglobinemia, which threatens oxygen-carrying capacity of the blood
Selenium	Enters groundwater from naturally occurring geologic sources, sulphur, and coal.	Nutritionally essential element to human at low doses but toxic at high doses.
Sodium	Derived geologically from leaching of surface and underground deposits of salt and decomposition of various minerals. Human activities contribute through de-icing and washing products.	Can be a health risk factor for those individuals on a low-sodium diet.
Sulphate	Elevated concentrations may result from saltwater intrusion, mineral dissolution, and domestic or industrial waste.	Can change the taste of water, and has a laxative effect in high doses.
Zinc	Found naturally in water, most frequently in areas where it is mined. Enters groundwater from industrial waste, metal plating, and plumbing, and is a major component of sludge.	Aids in healing of wounds. Causes no ill health effects except in very high doses. Impacts an undesirable taste to water.

2.2 Methods of Mobilization of Organic and Inorganic Chemicals in Groundwater.

The behaviour of organic contaminants in soils is generally governed by a variety of complex physical, chemical and biological processes. These processes directly control the transport of contaminants within the soil and their transfer from the soil or rocks to water, air or into the food chain. Both the direction and rate of these processes depend on the chemical nature of the organic contaminant and the physical, chemical and biological properties of the soil. Persistence of contaminants in soils increases the potential for environmental consequences while their mobility in soil environments is a key factor in assessing the environmental risk. Some compounds are strongly absorbed on the surface of the soil particles and remain in the soil, in some cases being inaccessible for microbial degradation. Some research results showed that the extent of mobilization for the organic compounds was a function of the source rock. In fate and transport sand column experiments, moisture content was found to have an important influence on the transport of the organic compounds.

In broad terms, there are three processes that govern the extent to which chemical constituents migrate in groundwater.

a. Advection, movement caused by the flow of groundwater
b. Hydrodynamic Dispersion, movement caused by irregular mixing of waters during advection
c. Density/viscosity differences (NAPLs)

2.2.1 Density/Viscosity Differences (NAPLS)

Contaminants having a density lower than groundwater tend to concentrate in the upper portions of an aquifer, while those having a higher density concentrate in the lower portions. The viscosity (tendency to resist internal flow) of specific contaminants affect their rate of migration from different portions of the aquifer. Contaminants with these properties may be non-aqueous phase liquids (NAPLs), or groundwaters with different salinities (fresh and salt water).

The viscosity of water decreases as temperature increases. Sneigocki, (1963) found that viscosity differences resulting from surface water at 66 ^{0}F injected into groundwater at 43 ^{0}F reduced the specific (gallons per minutes per foot of drawdown) of an artificial recharge well in the Grand Prairie Region of Arkansas by 30 percent. Kaufman and McKenzie, (1975) observed that the apparent hydraulic conductivity of an injection zone in the Floridan aquifer receiving hot organic wastes increased about 2.5 times because of temperature differences alone. Figure 3 Shows the effect of density on migration of contaminants (from Miller, 1985).

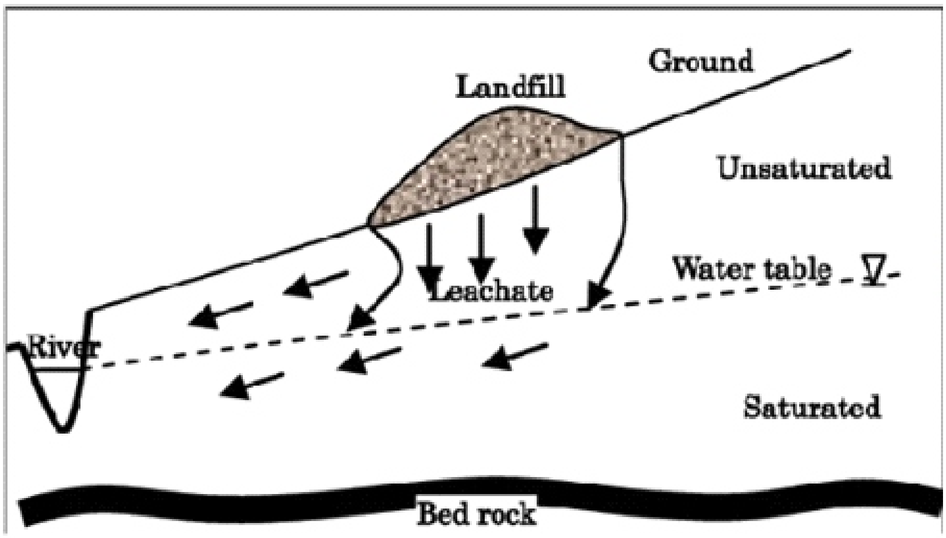

Figure 2: EFFECT OF DENSITY ON MIGRATION OF CONTAMINANTS (FROM MILLER, 1985).

2.3 Contaminant Plume and its Behaviour in Groundwater

A contaminant plume is an elongated body of groundwater containing contaminants, emanating and migrating from a point source within a hydrogeologic unit. The physical mechanisms of advection and dispersion, as well as a variety of chemical and microbial reactions, interact to influence the movement of contaminants in groundwater.

Groundwater contamination from landfills typically form a "plume" that moves outward and downward into surrounding and underlying aquifers, as shown in Figure 3. These plumes may contain dissolved carcinogens such as heavy metals (e.g., lead, mercury, chromium, cadmium, arsenic, etc.), volatile organic compounds (VOCs: benzene, ethylbenzene, toluene, etc.) and less harmful ions (sodium, calcium, iron, sulphate, chloride, etc.)

Figure 3 illustrates a plume of contaminants released from a point source at ground level migrating downwards to groundwater and carried downstream.

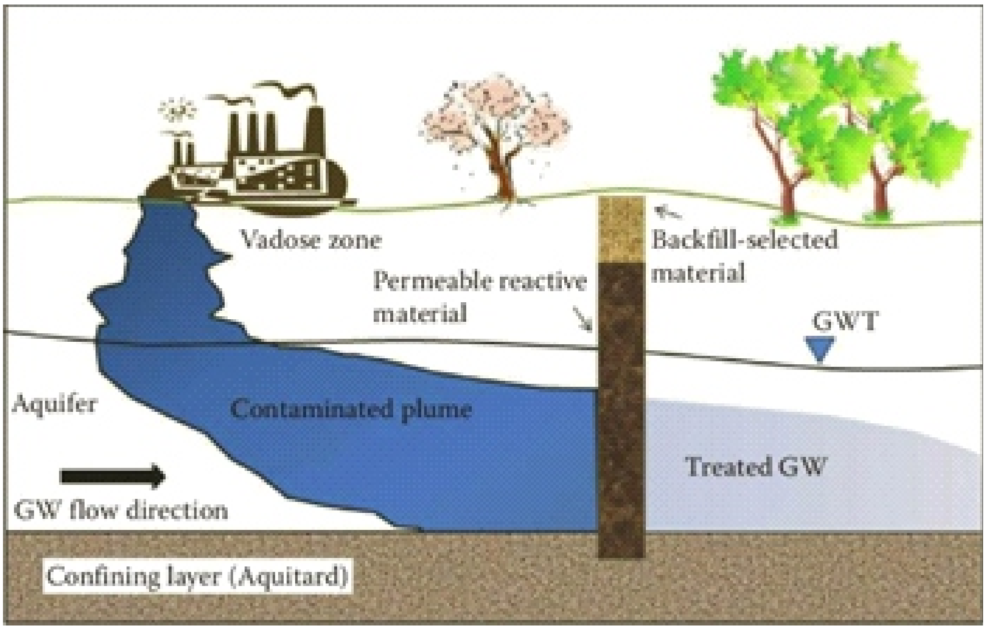

Figure 3: A Sketch showing plume of Contaminants (Ravi Naidu, *et al.*, 2014)

Figure 4 also shows the concentration of contaminants as they migrate from the point source into groundwater.

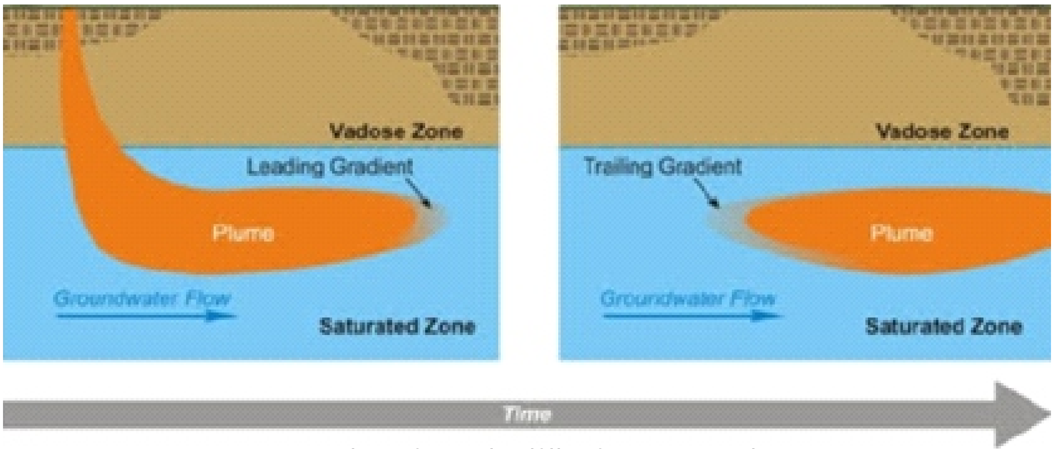

Figure 4: Source: Contaminant plume from a landfill (After UK Groundwater Forum).

2.4 Attenuation of Organic and Inorganic Chemicals/Contaminants in Groundwater.

Attenuation is simply to reduce in force, intensity, effect, quantity or value of something that is naturally toxic. Natural attenuation relies on natural processes to clean up or attenuate pollution in soil and groundwater as a cost-effective technology. It means dilution, dispersion, bio-degradation, irreversible sorption, and /or radioactive decay of contaminants in soils and groundwaters. It causes a net reduction of contaminant toxicity, human and ecological risk but rarely taken advantage of environmental remediation. Most contaminants in soils and groundwaters are naturally attenuated rapidly, and much faster than they can be removed by engineering remediation measures.

However, the right condition must exist underground to clean the sites properly. A science-based approach to remediation would be to ignore those contaminants which are naturally attenuated and remediate those which are not. Use of unenhanced natural processes as part of a site remediation strategy is called "natural attenuation”. Some processes that occur during natural attenuation can transform contaminants to less harmful forms or immobilize them to reduce risks. Such transformation and immobilization processes result from biological, chemical, and physical reactions that take place in the subsurface.

2.4.1 Natural Attenuation

Natural attenuation is the combination of naturally occurring processes that act without the need of human intervention or enhancement, and result in reduced risks posed by contamination in soil and groundwater. A good working definition is that of US Environmental Protection Agency (USEPA) Office of Solid waste Emergency Response:

The 'natural attenuation processes' that are at work in such a remediation approach include a variety of physical, chemical and biological processes that, under favourable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume and concentration of contaminants in soil and water.

2.5 Contaminant Retardation Process

In groundwater contamination transport, a number of chemical and physical mechanisms retard or slow the movement of constituents in groundwater. Three general mechanisms of retardation are; Filtration, Partitioning and Transformation.

i. **Filtration:** Filtration is the entrapment of solid particles and large dissolved molecules in the pore spaces of the soil and aquifer media. The figures 5 below show the major mechanisms of filtration: surface filtration, straining, and physical interactions. Surface filtration results from biological activity, as in the clogging mat that develops in the septic tank absorption trenches.

Filtration resulting from physical-chemical interaction has to do with the precipitation reactions, in which geochemical reactions in the aquifer result in a contaminant moving from a dissolved form to an insoluble form and may be an important retardation process for inorganic contaminants. Figure 5.

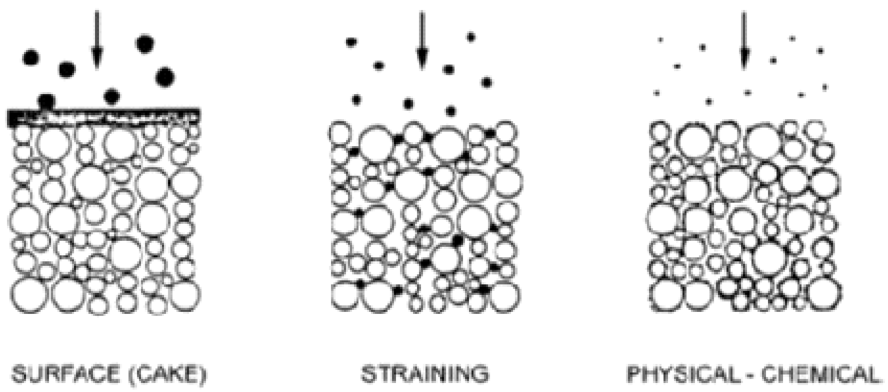

Figure 5: The three filtration mechanisms that limit particle migration through porous media (From Mc Dowell-Boyer et al., 1986)

ii. **PARTITIONING:** Retardation of dissolved contaminants in an aquifer can result from two major processes that change the form, but not necessarily the toxicity of the contaminant. These include; (a) Sorption, including both ion exchange and physical absorption and (b) precipitation. Ion exchange involves the replacement of a cation attached to a negatively charged site on a mineral surface by another cation. The mineralogy of its effectiveness in retarding cationic contaminants.

iii. **TRANSFORMATION OR DEGRADATION:** Transformation in contaminant retardation process refers to all the processes that transform a contaminant retard transport in that the original contaminant is no longer present. Unless the contaminant's reaction products are non-toxic inorganic elements, however, contamination may still persist. Complexation reactions involving heavy metals may even increase toxicity and mobility.

REMEDIATION OF CONTAMINANTS

The mechanism of natural attenuation can be classified as destructive and non-destructive. Destructive processes include; biodegradation and hydrolysis. Biodegradation is by far the most prevalent destructive mechanisms, such as yeast, fungi, and bacteria, break down target substances, such as fuels and chlorinated solvents, into less toxic or non-toxic substances. Certain microorganisms digest fuels or chlorinated solvents found in the subsurface environment, Non-destructive attenuation mechanisms include volatilization, sorption, dispersion and dilution, with dispersion and dilution being generally the most important.

3.1 Non-Destructive Mechanisms

There are four principal non-destructive mechanisms that cause a decrease in measurable contaminant concentrations.

i. **Dispersion** is the spreading of a chemical in groundwater outward from its expected path. As groundwater moves through different soil types and geological features, it travels at different velocities. This creates mechanical mixing, so groundwater spreads away from source areas into wider plumes.

ii. **Dilution** is simply a decrease in the chemical concentration in a fluid caused by mixing with a fluid containing a lower concentration. Dilution is an effect of dispersion, and it also takes place in most groundwater flow systems.

iii. **Sorption** occurs when contaminants attach to soil particles. This occurs in large part because they either dissolve into the organic matter in the soil or are attracted by electrical charge.

iv. **Volatilization** occurs when dissolved chemicals change from a liquid phase to a gaseous phase. For example, when water evaporates, it changes from a liquid to a vapour. In general, factors affecting volatilization from groundwater include concentration, change in concentration with depth, and temperature. Different chemicals have different propensities to volatilize. Volatilization is usually a minor element in natural attenuation.

3.2 Presence of Organic and Inorganic Contaminants in Groundwater as Earlier Documented

Records show that inorganic contaminants pose a major problem at many waste sites. While organics/VOCs are the most frequently reported contaminants, heavy metals and inorganic chemicals are the second and third most frequently reported categories of hazardous substances. A survey records of decision (RODs) from 1982 until December, 1986 (Booz-Allen and Hamilton, 1987) demonstrates that inorganic contaminants are a potential threat or problem at 56% of waste sites for which a ROD has been filled. These contaminants include acids, arsenic, asbestos, chromium, heavy metals, inorganics and radioactivity.

The presence of toxic metals in soil can severely inhibit the biodegradation of organic contaminants (Maslin and Maier, 2000). The establishment of maximum contaminant levels for tri-halomethanes is an example of the difficulty of health risk assessment. Their presence, caused by the chlorination of organic materials in the raw water, has caused great controversy, promoting the synthesis of mutagens and carcinogens (Zaki, *et al.,* 1982). Of the 33 organic contaminants found most frequently in groundwater, 14 were selected by the National Cancer Institute for animal carcinogenicity experiments. Eleven of the 14 were carcinogenic in at least one species of animal, while this method provides only a crude measure of the human risks, the findings justify a conservative approach when confronted with organic contaminants.

Due to their lipophilic nature, organic chemicals with high molecular mass tend to accumulate in the adipose tissues of living organisms. Thus, even though they are commonly present at low concentrations, adverse effects associated with chronic exposure are of a particular concern (UN/EP, 2001).

Conclusion

The presence of organic and inorganic chemicals in groundwater poses significant threats to human health and the environment. This review highlights the diverse sources of these contaminants, including agricultural activities, industrial processes, and wastewater disposal. The methods of mobilization, such as leaching, runoff, and atmospheric deposition, further exacerbate the problem.

Fortunately, various attenuation strategies, including bio-degradation, adsorption, and chemical treatment, can mitigate the impact of these contaminants. However, effective management of groundwater quality requires a comprehensive understanding of the complex interplay between contaminant sources, mobilization mechanisms, and attenuation processes.

Further research efforts should focus on developing innovative, cost-effective, and sustainable solutions for preventing and remediating groundwater contamination. Moreover, policy makers and stakeholders must work together to implement and enforce regulations that protect groundwater resources and ensure access to safe and clean water for future generation. By synthesizing the current state of knowledge on organic and inorganic chemicals in groundwater, this review aims to inform and inspire continued efforts to safeguard this vital resource.

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