

Sources and Effects of Polycyclic Aromatic Hydrocarbons to Man and Its Environment: A Review

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ABSTRACT

Polycyclic aromatic hydrocarbon (PAHs) are a class of unique compound that consist of fused conjugated aromatic rings and do not contain heteroatoms or substituents carrier. They include naphthalene, phenanthrene, anthracene, pyrene, fluoranthene, chrysene etc. these compounds have varieties of uses such as its use in the manufacture of dyes, pigments, fumigants, insecticides, pesticides, resins, pharmaceuticals and agrochemicals, irrespective of its varieties of uses and applications, it poses great threat to man and the environment. These compounds can be point source (e.g., oil spill) or non-point source (e.g.; atmosphere deposition) and are one of the most widespread organic pollutants. Some of them are known or suspected carcinogens and are linked to other health problems. They are primarily formed by incomplete combustion of carbon-containing fuels such as woods, coal; diesel; fat, tobacco or incense etc. PAHs exert their toxicity following biotransformation to toxic metabolites, which can be bound covalently to cellular macromolecules such as protein, DNA and RNA, which causes cell damage, mutagenesis and carcinogenesis. Some health effects of polycyclic aromatic hydrocarbons according to the research includes; decrease immune function, cataract, kidney and liver damage (e.g. jaundice), breathing problems, asthma like symptoms and lung function abnormalities and repeated contact with skin may induce redness and skin inflammation. However, during biological and chemical degradation of PAHs, another toxic compound may be formed. If these transformation products are sufficiently persistent, they could potentially accumulate during remedial processes. This will provide the background information and rationale for the derivation of distribution behaviour, environment contaminations, sources,

types, the effect of PAHs on the environment and the recommendations.

I. INTRODUCTION

A polycyclic aromatic hydrocarbon (PAH) is a hydrocarbonchemical compound containing only carbon and hydrogen that is composed of multiple aromatic rings. The group is a major subset of the aromatic hydrocarbons. The simplest of such chemicals are naphthalene, having two aromatic rings, and the three-ring compounds anthracene and phenanthrene. The terms polyaromatic hydrocarbon or polynuclear aromatic hydrocarbon are also used for this concept (Alexander, 2000).

PAHs are uncharged, non-polar molecules, with distinctive properties due to the delocalizedelectrons in their aromatic rings. Many of them are found in coal and in oil deposits, and are also produced by the thermal decomposition of organic matter for example, in engines and incinerators or when biomass burns in forest fires (Band et al., 2002).

Polycyclic aromatic hydrocarbons are discussed as possible starting materials for abiotic syntheses of materials required by the earliest forms of life

PAHs belong to the group of persistent organic pollutants (POPs). These are organic pollutant contaminants that are resistant to degradation, can remain in environment for a long period and have the potential to cause adverse environmental effects. As a pollutant, they are at concern because some compounds have been identified as carcinogenic, mutagenic and teratogenic(Behymer and Hites, 1988). PAHs usually occur naturally, but they can be manufactured as individual compounds for research purposes, however, not as the mixtures found in

combustion product. PAHs also occur in oil, coal, and tar deposits, and are produced as by product of fuel burning (whether fossil fuel or biomass).

Naphthalene is the simplest example of a PAH. They can have a faint, pleasant odour. A few PAHs are used in medicines and to make dyes, plastic and pesticides (Behymer and Hites, 1988).

Environment

Environment is defined as the totalling of circumstance surrounding an organism or group of organisms especially, the combination of external physical conditions that affect and influence the growth, development and survival of an organism (Bjørseth and Olufsen, 1983). It consists of flora, fauna and the abiotic and includes the aquatic, terrestrial and atmospheric habitats. The environment is considered in terms of the most tangible aspects like air, water, soil and food. The less tangible, though no less important the communities we live in (Bolset al., 2009).

II. LITERATURE REVIEW

Polycyclic Aromatic Hydrocarbons (PAHs)

The major environmental concerns in urban and industrial areas are Polycyclic aromatic hydrocarbons. They have a relatively low solubility in water, but are highly soluble in lipids. PAHs can undergo photodecomposition when exposed to ultraviolet light from solar radiation (Borosky, 2014). In the atmosphere, PAHs can react with pollutants such as ozone, nitrogen oxides and sulphur dioxides. PAH may also be degraded by some microorganisms in soil. PAHs pollutants have high molecular mass, PAHs of 4 and more condensed aromatic rings are considered to be more dangerous than 2 and 3 rings PAHs in view of their potentials (Li et al., 2010).

The movement of PAHs in the environment depends on properties such as how easily they dissolve in water and how easily they evaporate in the air. As persistent organic pollutants (POPs), some of them are susceptible to dispersion on a global scale because in addition to having environmental persistence, they move between the atmosphere and earth's surface in repeated, temperature-driven cycles of deposition and volatilisation. POPs are truly multimedia contaminants which occur in all parts of the environment: atmosphere, inland and sea water, sediments, soil and vegetation (Han et al., 2004; Li et al., 2010). They are mainly of anthropogenic origin (caused by human activity) and have no significant natural sources. PAHs (which are known for their strong mutagenic, carcinogenic and toxic properties) are composed of carbon and

hydrogen atoms arranged in the form of fused benzene rings (Zhang et al., 2013). There are thousands of PAHs compounds in the environment but in practice PAHs analysis is restricted to the determination of 6 to 16 PAHs as priority pollutants, while some of these, e.g. benzo (a) pyrene, chrysene, benzo (a) anthracene are considered to be potential human carcinogens. PAHs are the most toxic among the hydrocarbon families. Individual PAHs differ substantially in their physical and chemical properties. The widespread occurrence of PAHs is largely due to their formation and release in all processes of incomplete combustion of organic materials (Zhang et al., 2013).

As defined by the international union of pure and applied chemistry (IUPAC), the simplest PAHs are phenanthrene and anthracene. PAHs may contain four-, five-, six-, or seven- membered rings, but those with five or six are most common. PAHs comprised only of six-membered rings are called alternant PAHs. Certain alternant PAHs are called benzenoid PAHs. PAHs containing up to six fused aromatic rings are often known as small PAHs and those containing more than six aromatic rings are called large PAHs (Tsapakis and Stephanou, 2005).

Sources of PAHs

Polycyclic aromatic hydrocarbons are lipophilic, meaning they mix more easily with oil than water. The larger compounds are less water soluble and less volatile (i.e. less prone to evaporate). Because of these properties, PAHs in the environment are found in soil, sediment and oily substances, as opposed to in water or air. Natural crude oil and coal deposits contain significant number of PAHs, arising from chemical conversion of natural product, molecules such as steroids to aromatic hydrocarbons (Sin et al., 2003; Tsapakis and Stephanou, 2005). They are also found in processed fossil fuel, tar and various edible oils. Smoke has a lot of PAH. Indoor household source of PAHs includes cigarette/tobacco smoke, smoldering fire places, wood stoves, unwanted gas burning appliances, kerosene space heaters, and the charring or burning of food. PAHs are one of the most widespread organic pollutant, in addition to their presence in fossil fuel they are also formed by incomplete combustion of carbon-containing fuel such as wood, coal, diesel, fat and incense (Hayakawa, 2016).

Natural source include release in forest fire and from volcanic eruptions. Most environmental PAHs are products of incomplete combustion or pyrolysis of fossil fuel. The

stationary fuel sources are responsible for over 97% of PAHs emissions. The study of this compounds is due mainly to their carcinogenic and widespread occurrence in environmental components, including surface soil (Hayakawa et al., 2014). Other potential sources of PAHs in environment include disposal from public sewage treatment, irrigation with coke oven effluent, leachate from bituminous coal storage sites, and use of soil compost and fertilizers (Hayakawa et al., 2014).

PAHs are produced in all processes of incomplete combustion of organic substance. Their production is favored by an oxygen deficient flame, temperature in the range of 650°C – 900°C and fuel which are not highly oxidized. Natural sources of pyrogenic PAHs such as volcanic activity and forest fire do not significantly contribute for the present to overall PAHs emissions (Kong et al., 2010; Hirose et al., 2011). Anthropogenic source can be divided into two categories: combustion of material for energy supply (e.g. coal, oil, gas, wood etc.) and combustion for waste minimalization (e.g. waste incineration). The first category include stationary source like industry (mainly coke and carbon production, petroleum processing, aluminum sintering etc.), residential heating (furnaces, fire places and stoves, gas and oil burner), power and heat generation (coal, oil, wood and peat power plant) and mobile sources like (car, lorries, trains, air planes) and sea traffic (gasoline and diesel engines) (Hirose et al., 2011). Second category covers incineration of municipal and industrial waste. Other miscellaneous sources contain unregulated fire such as agricultural burning, recreational fire, crematoria, etc.

1. Stationary sources

❖ Domestic sources

Heating and cooking are dominant domestic sources of PAHs. The burning and pyrolysis of coal, oil, gas, garbage, wood, or other organic substances are the main domestic sources. Domestic sources are important contributors to the total emissions of PAHs in the environment. Differences in climate patterns and domestic heating systems produce large geographic variations in domestic emissions (Hayakawa et al., 2007). PAH emissions from these sources may be a major health concern because of their prevalence in indoor environments. According to a recent World Health Organization (WHO) report, more than 75% of people in China, India, and South East Asia and 50-75% of people in parts of South America and Africa use combustion of solid fuels, such as wood, for daily cooking. Cigarette smoke is also a dominant source of PAHs in indoor environments.

In many studies, PAHs in the indoor air of smoking residences tend to be higher than those of non-smoking residences (Motoyama et al., 2009).

❖ Industrial sources

PAH emissions from industries are produced by burning fuels such as gas, oil, and coal. PAHs can also be emitted during the processing of raw materials like primary aluminum. Sources of PAHs include emissions from industrial activities, such as primary aluminum and coke production, petrochemical industries, rubber tire and cement manufacturing, bitumen and asphalt industries, wood preservation, commercial heat and power generation, and waste incineration (Kumagai et al., 2002).

2. Mobile sources

Mobile sources are major causes of PAH emissions in urban areas. PAHs are mainly emitted from exhaust fumes of vehicles, including automobiles, railways, ships, aircrafts, and other motor vehicles (Ukaogo and Igwe, 2015). PAH emissions from mobile sources are associated with use of diesel, coal, gasoline, oils, and lubricant oil (Nishikawa et al., 2011). One of the major influences on the production of PAHs from gasoline automobiles is the air-to-fuel ratio. It has been reported that the amount of PAHs in engine exhaust causes leaner mixtures (when there is higher concentration of air to fuel than there should be). A main contributor to PAH concentrations in road dust as well as urban areas is vehicle exhaust (Nishikawa et al., 2011).

3. Agricultural sources

Open burning of brushwood, straw, moorland heather, and stubble are agricultural sources of PAHs. All of these activities involve burning organic materials under suboptimum combustion conditions. Thus, it is expected that a significant amount of PAHs are produced from the open burning of biomass. PAHs emitted from biomass burning are LMW PAHs, including naphthalene, acenaphthylene, phenanthrene, fluoranthene and pyrene (Hayakawa et al., 2016).

4. Natural sources

Accidental burning of forests, woodland, and moorland due to lightning strikes are natural sources of PAHs. Furthermore, volcanic eruptions and decaying organic matter are also important natural sources, contributing to the levels of PAHs in the atmosphere. The degree of PAH production depends on meteorological conditions, such as wind, temperature, humidity, and fuel characteristics and type, such as moisture content,

green wood, and seasonal wood(Loibner et al., 2004).

Types of PAH

❖ Naphthalene

This is an organic compound with formula $C_{10}H_8$. It is the simplest polycyclic aromatic hydrocarbon, and is a white crystalline solid with a

characteristic odor that is detectable at concentrations as low as 0.08 ppm by mass. As an aromatic hydrocarbon, naphthalene's structure consists of a fused pair of benzene rings. It is best known as the main ingredient of traditional mothballs(Ravindra et al., 2008).

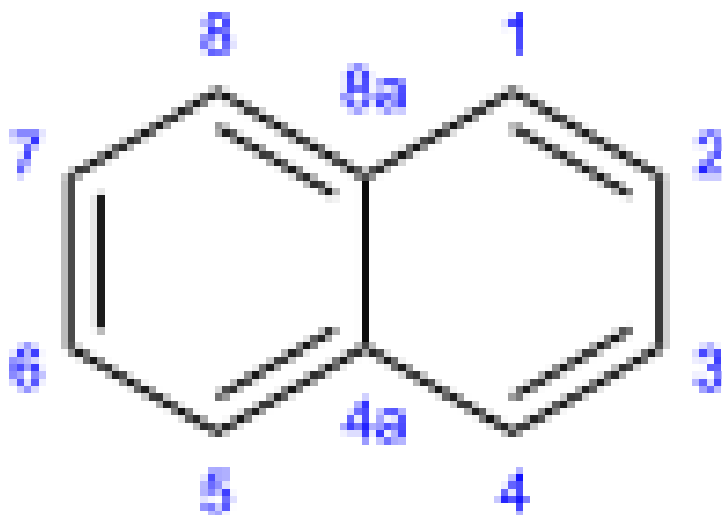


Fig 1: Chemical structure of Naphthalene

Production

Most naphthalene is derived from coal tar. From the 1960s until the 1990s, significant amounts of naphthalene were also produced from heavy petroleum fractions during petroleum

refining, but today petroleum-derived naphthalene represents only a minor component of naphthalene production. Naphthalene is the most abundant single component of coal tar(Ravindra et al., 2008).



Fig 2: Image of Naphthalene

Uses

Naphthalene is used mainly as a precursor to other chemicals. The single largest use of naphthalene is the industrial production of phthalic

anhydride, although more phthalic anhydride is made from o-xylene. Many azo dyes are produced from naphthalene, and so is the insecticide 1-

naphthyl-N-methylcarbamate (carbaryl)(Li et al., 2016).

As a fumigant

Naphthalene has been used as a household fumigant.

It is used to create artificial pores in the manufacture of high-porosity grinding wheels. In the past, naphthalene was administered orally to kill parasitic worms in livestock(Yunkeret al., 2002).

Naphthalene is used to make mothballs, PVC, insecticides (insect killing chemicals), dyes, toilet deodorant blocks, and phthalic anhydride.

The latter, among many other things, is used to make pharmaceutical and resins. Naphthalene is flammable and potentially explosive(Li et al., 2016).

Health effects

Exposure to large amounts of naphthalene may damage or destroy red blood cells, most commonly in people with the inherited condition known as glucose-6-phosphate dehydrogenase (G6PD) deficiency, which over 400 million people suffer from. Humans, in particular children, have

developed the condition known as hemolytic anemia, after ingesting mothballs or deodorant blocks containing naphthalene. Symptoms include fatigue, lack of appetite, restlessness, and pale skin. Exposure to large amounts of naphthalene may cause confusion, nausea, vomiting, diarrhea, blood in the urine, and jaundice (yellow coloration of the skin due to dysfunction of the liver). (Yunkeret al., 2002).

The US National Toxicology Program (NTP) held an experiment where male and female rats and mice were exposed to naphthalene vapors on weekdays for two years. Both male and female rats exhibited evidence of carcinogenesis(Shi et al., 2009).

❖ Phenanthrene

Phenanthrene a polycyclic aromatic hydrocarbon (PAH) with formula $C_{14}H_{10}$, consisting of three fused benzene rings. It is a colorless, crystal-like solid, but can also appear yellow. Phenanthrene is used to make dyes, plastics and pesticides, explosives and drugs. It has also been used to make bile acids, cholesterol and steroids(Shi et al., 2009).

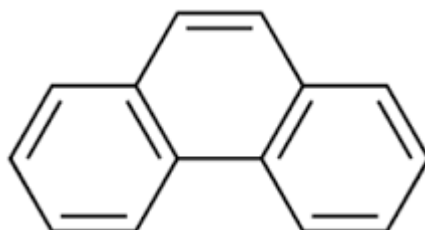


Fig 3: Chemical structure of Phenanthrene

Phenanthrene occurs naturally and also is a man-made chemical. Commonly, humans are exposed to phenanthrene through inhalation of cigarette smoke but there are many routes of exposure. Animal studies have shown that

phenanthrene is a potential carcinogen. However, according to IARC, it is not identified as probable, possible or confirmed human carcinogen(Liu et al., 2007).



Fig 4: Image of Phenanthrene

Applications of Phenanthrene

Phenanthrene is used to make dyes, plastics and pesticides, explosives and drugs. It has also been used to make bile acids, cholesterol and steroids. Phenanthrene occurs naturally and also is a man-made chemical(Liu et al., 2007).

❖ Anthracene

Anthracene is a solid polycyclic aromatic hydrocarbon (PAH) of formula $C_{14}H_{10}$, consisting of three fused benzene rings. It is a component of coal tar. Anthracene is used in the production of the red dyealizarin and other dyes. Anthracene is colorless but exhibits a blue (400–500 nm peak) fluorescence under ultraviolet radiation(Li et al., 2013).

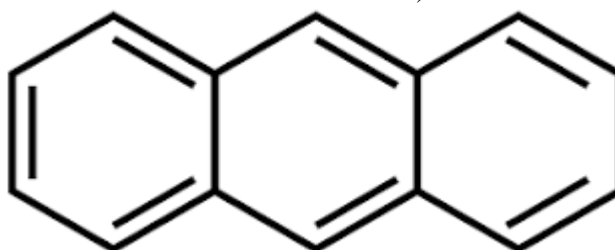


Fig 5: Chemical structure of Anthracene

It is a colourless crystalline aromatic hydrocarbon obtained by the distillation of crude oils and used in chemical manufacture.



Fig 6: Image of Anthracene

Occurrence

Anthracene, as many other polycyclic aromatic hydrocarbons, is generated during combustion processes. Exposure to humans happens mainly through tobacco smoke and ingestion of food contaminated with combustion products(Li et al., 2013).

Toxicology

Many investigations indicate that anthracene is non-carcinogenic: "consistently negative findings in numerous in vitro and in vivo genotoxicity tests". Early experiments suggested otherwise because crude samples were

contaminated with other polycyclic aromatic compounds. Furthermore, it is readily biodegraded in soil. It is especially susceptible to degradation in the presence of light(Ravindra et al., 2008).

❖ Pyrene

Pyrene is a polycyclic aromatic hydrocarbon (PAH) consisting of four fused benzene rings, resulting in a flat aromatic system. The chemical formula is $C_{16}H_{10}$. It is a yellow solid and forms during incomplete combustion of organic compounds(Ravindra et al., 2008).

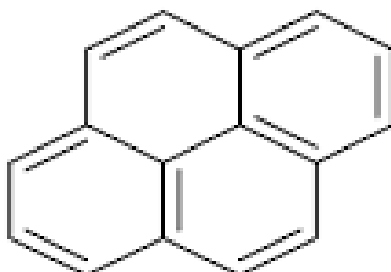


Fig 7: Chemical structure of Pyrene

Like most PAHs, pyrene is used to make dyes, plastics and pesticides. It has also been used to make another PAH called benzo(a)pyrene.

Although it is not as problematic as benzopyrene, animal studies have shown pyrene is toxic to the kidneys and liver. It is now known that pyrene affects several living functions in fish and algae (Cerniglia, 2012).

❖ **Fluoranthene**

Fluoranthene is a polycyclic aromatic hydrocarbon (PAH). The molecule can be viewed

as the fusion of naphthalene and benzene unit connected by a five-membered ring. Although samples are often pale yellow, the compound is colorless. It is soluble in nonpolar organic solvents. It is a member of the class of PAHs known as non-alternant PAHs because it has rings other than those with six carbon atoms. It is not as thermodynamically stable as pyrene (Cerniglia, 2014).

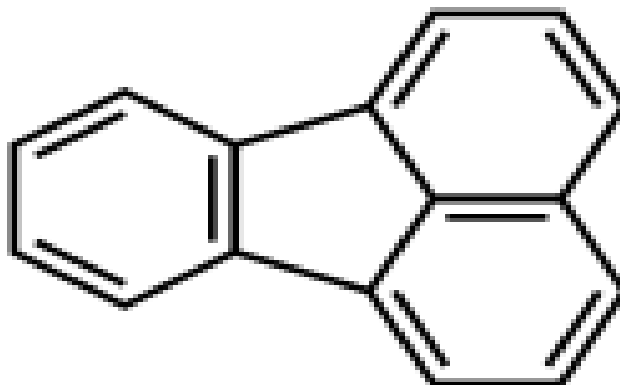


Fig 8: Chemical structure of Fluoranthene

Occurrence

Coal tar

Fluoranthene was originally isolated from coal tar pitch. It is still obtained from the high boiling fraction of coal tar, representing a few percent by weight (Cerniglia, 2014).



Fig 9: Image of Fluoranthene

Fluoranthene is found in many combustion products, along with other PAHs. Its presence is an indicator of less efficient or lower-temperature combustion. Fluoranthene is one of the U.S. Environmental Protection Agency's 16 priority pollutant PAHs (Collins et al., 2008). Fluoranthene has been classified by the International Agency for Research on Cancer as a group 3 carcinogen, "not classifiable as to its carcinogenicity to humans", however it was found to possess carcinogenic properties in case of newborn mice according to short-term lung tumor assay. In 2019, fluoranthene was added to the Candidate List of Substances of Very High Concern (SVHCs) due to its persistent, bio-accumulative and toxic (PBT) properties (Collins et al., 2008).

❖ **Chrysene**

Chrysene is a polycyclic aromatic hydrocarbon (PAH) with the molecular formula $C_{18}H_{12}$ that consists of four fused benzene rings. It is a natural constituent of coal tar, from which it was first isolated and characterized (De-Wiest, 2011).

The name "chrysene" originates from Greek (chrysos), meaning "gold", and is due to the golden-yellow color of the crystals of the hydrocarbon, thought to be the proper color of the compound at the time of its isolation and characterization. However, high purity chrysene is colorless, the yellow hue being due to the traces of its yellow-orange isomer tetracene, which cannot be separated easily (De-Wiest, 2011).

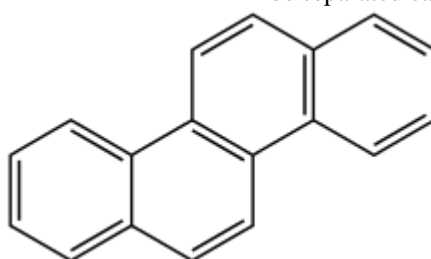


Fig 10: Chemical structure of Chrysene

Occurrence

Chrysene is a constituent of tobacco smoke

Safety

As with other PAHs, chrysene is suspected to be a human carcinogen. Some evidence suggests that it causes cancer in laboratory animals, but chrysene is often contaminated with more strongly carcinogenic compounds (Grifollet al., 2013).

Uses of PAHs

PAHs are not synthesized chemically for industrial purposes. Rather than industrial sources,

the major sources of PAHs are the incomplete combustion of organic material such as coal, oil and wood. However, there are few commercial uses of many PAHs. They are mostly used as intermediaries in pharmaceutical, agricultural product, photographic products, thermosetting plastic, lubricating materials, and other chemical industries (Grifollet al., 2013). General uses are: -

Table 1: Summary of some PAHs and their uses(ATSDR, 2009).

PAHs	Uses
Acenaphthene	Manufacturing of dyes, plastic, Diluents, pharmaceuticals and pesticides and processing of certain foods.
Anthracene:	Manufacture of dyes, pigments, and diluents for wood preservatives.
Chrysene	It is used in the manufacture of some dyes and the wood preservation creosote
Fluorene	Manufacture of dyes, pharmaceuticals, and agrochemicals
Naphthalene.	It is used as a fumigant in households, soil museum etc to repel moths/insects' attacks
	Manufacture of Pesticides, and resins
	Manufacture of pigments
Phenanthrene	
Pyrene:	

Other PAHs may be contained in asphalt used for the construction of roads, as well as roofing tar. Precise PAHs, specific refined products are used also in the field of electronics, functional plastic and liquid crystals (Grimmer et al., 2016).

Effects of PAH

1. Environmental effects

PAHs are usually released into the air, or they evaporate into the air when they are released to soil or water. PAHs often adsorb to dust particles in atmosphere, where they undergo photo oxidation in the presence of sunlight, especially when they are adsorbed to particles (Gurol and Singer, 2012). This oxidation process can break down the chemical over a period of days to week. Since PAHs are generally insoluble in water, they are generally found adsorbed on particulate and precipitated in the bottom of lakes and rivers, or solubilized in any oily matter which may contaminate water. Sediments, and soil, mixed microbial population in sediment/water system may degrade some PAHs over a period of weeks to months (Harrison et al., 2015; Grifollet al., 2013). The toxicity of PAHs is affected by metabolism and photo-oxidation, and they are generally more toxic in the presence of ultraviolet light. PAHs have moderate to high acute toxicity to aquatic life and birds. PAHs in soil are unlikely to exert toxic effect on terrestrial invertebrates, except when soil is contaminated (Herbes and Schwall, 2017).

Adverse effects on these organisms include tumors, adverse effects on reproduction, development and immunity, mammals can absorb PAHs by various routes e.g. inhalation, dermal contact and ingestion (Herbes and Schwall, 2017).

Plant can absorb PAHs from soils through their roots and translocate them to other plant parts. Uptake rates are generally governed by concentration, water solubility and their physicochemical state as well as soil type. PAH induced phytotoxic effect are rare. Certain plant contains substances that can protect against effect, whereas other can synthesize PAH that act as growth hormones (Kanaly and Harayama, 2000). PAHs are moderately persistent in the environment, and can bioaccumulate. The concentration of PAHs found in fish and shell fish are expected to be much higher than in the environment from which they are taken. Bioaccumulation has been also shown interrestrial invertebrates, however PAHs metabolism is sufficient to prevent biomagnification (Miller and Miller, 2011; Kanaly and Harayama, 2000).

2. Health effects

➤ Acute or short-term health effects.

The effects on human health will depend mainly on the length and extend of exposure, the amount or concentration of PAHs one is exposed to, and of course the innate toxicity of the PAHs, and whether exposure occurs via inhalation ingestion or skin contact. A variety of other factors can also affect health impacts, including subjective facts such as pre-existing health status and age (Portella et al., 2005).

The ability of PAHs to induce short-term health effects in human is not clear. Intake of PAHs from contaminated soil occur via ingestion, inhalation or dermal (skin) exposure to contaminated soil/dust and from inhalation of PAH vapours. Tilling the dry soil can result in ingestion of small but measurable amount of soil. Occupational exposure to high level of pollutant mixture containing PAH has resulted in symptoms such as eye irritation, nausea, vomiting, diarrhea and confusion (Rivas et al., 2000; Santioet al., 2009).

However, it is not known which components of the mixture where responsible for the effect and other compounds commonly found with PAHs may be the cause of these symptoms (Rivas et al., 2000).

➤ Chronic or Long-term Health Effects

Health effect from chronic or long-term exposure to PAHs may include decrease immune function, cataract, kidney and liver damage (e.g. jaundice), breathing problems, asthma like symptoms and lung function abnormalities and repeated contact with skin may induce redness and skin inflammation. Naphthalene, a specific PAH, can cause the breakdown of red blood cell if inhaled or ingested in large amounts. If exposed to PAHs, the harmful effect that may occur largely depend on the way people are exposed (Santioet al., 2009).

➤ Carcinogenicity

Although unmetabolized PAHs can have toxic effect, a major concern is the ability of the reactive metabolites, such as epoxides and dihydrodiols, of some PAHs to bind to cellular proteins and DNA. The resulting biochemical disruption and cell damage leads to Mutations, developmental malformation, tumors, and cancer. Evidence indicates that mixtures of PAHs are carcinogenic to humans (Wild et al., 2014). The evidence came primarily from occupational studies of workers exposed to mixtures containing PAHs and those long-term studies have shown an increase in risk of predominantly skin and lung, but as well as bladder and gastrointestinal cancers. However, it

is not clear from these studies whether exposure to PAHs was the main cause as workers were simultaneously exposed to other cancer-causing agent (e.g. aromatic amines) (Miller and Miller, 2011).

Animals exposed to level of some PAH over long period in laboratory studies have developed lung cancer from inhalation, stomach cancer from ingesting PAHs in food and skin contact. Benzo(a)pyrene is the most common PAH to cause cancer in animal and this compound is notable for being the first chemical carcinogen to be discovered (Rivas et al., 2000). Based on the available evidence the International Agency for Research on cancer classified a number of PAHs as carcinogenic to animal and some PAH-rich mixture as carcinogenic to humans. The IARC has classified seven PAH compound as probable human carcinogens and according to various research conducted it was found to be true: benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz(ah)anthracene, and indeno(1,2,3-cd)pyrene (IARC, 1983).

➤ **Teratogenicity**

Embryotoxic effect of PAHs have been described in experimental animal exposed to PAH such as benzo(a)anthracene, benzo(a)pyrene and

naphthalene. Laboratory studies conducted on mice have demonstrated that ingestion of high level of benzo(a)pyrene during pregnancy resulted in birth defects and decreased body weight in the offspring. It is not known whether these effects can occur in human (Gurol and Singer, 2012). However, the center for children’s Environmental Health reports studies demonstrate that exposure of PAH pollution during pregnancy is related to adverse birth outcomes including low birth weight, premature delivery, heart malformations. High prematal exposure to PAH is also associated with lower IQ at age three, increased behavioral problems at ages of six and eight and childhood asthma cord blood of exposed babies shows DNA damage that has been linked to cancer (De-Wiest, 2011).

➤ **Genotoxicity**

Genotoxic effects for some PAH been demonstrated both in rodents and in vivo tests using mammalian (including human) cell lines. Most of the PAHs are not genotoxic by themselves and they need to be metabolized to the diol exposed which react with DNA, thus inducing genotoxic damage. Genotoxicity plays important role in the carcinogenetic process and maybe in some forms of developmental toxicity as well (Ravindra et al., 2008).

Table 2: Summary of the environmental effects of some polycyclic Aromatics Hydrocarbons(ATSDR, 2009).

PAHs	Effects
Anthracene	Toxic, skin sensitizer, eye irritation, nausea, vomiting, diarrhoea and confusion.
Acenaphthylene	Toxic, eye irritation.
Benzo(a)anthracene	Toxic, Carcinogenic, heart malformations, childhood asthma, skin irritations.
Benzo(a)fluoranthene	Toxic
Pyrene	Toxic, eye irritation
Benzo(a)pyrene	Carcinogenic, mutagenic, birth defects, decrease in body weight, toxic, skin irritants, leukaemia, heart malformations, childhood asthma, eye irritation, nausea, vomiting, diarrhoea and confusion.
Chrysene	Toxic, Carcinogenic, kidney and liver damage and jaundice cataracts.
Benzo(k)fluoranthene	Toxic, Carcinogenic, Tumours of the gastrointestinal tract and lungs
Benzo(j)fluoranthene	Toxic, Carcinogenic.
Benzo(b)fluoranthene	Toxic, Skin irritants, Breakdown of red blood cell, heart malformations, childhood asthma, eye irritation, nausea, vomiting, diarrhoea and confusion.
Naphthalene	Carcinogenic, toxic, cataracts, kidney and liver damage and jaundice cataracts.
Dibenz(a,h)anthracene	Carcinogenic, toxic, increase in mammary tumours in rat kidney and liver damage and jaundice cataracts.
Indeno(1,2,3-cd)pyrene	

Degradation of PAHs

Degradation of PAHs in the environment occurs through biological, chemical and photochemical processes. These processes may also be utilized for remedial purposes. However, the degradation may result in a variety of transformation products some of which could potentially accumulate (Band et al., 2002).

1. Biological degradation

Biological degradation appears to be the main process responsible for the removal of PAHs in soil. Microorganisms, such as bacteria and fungi, may transform the PAHs to other organic compounds or to inorganic end products such as carbon dioxide and water. The latter process has been referred to as mineralization (Borosky, 2014). Some PAH-degrading microorganisms, primarily bacteria, are capable of using the PAHs as a carbon and energy source, and may thus transform the contaminants into molecules that can enter the organisms' central metabolic pathways. Other microorganisms have the capacity to degrade PAHs, while living on a widely available substrate. Such co-metabolism does not always result in growth of the microorganism, and sometime the co-substrate, i.e. the PAH, is only transformed into another compound without any apparent benefit for the organism (Zhang et al., 2013).

2. Microbial degradation pathways

PAH-degrading bacteria generally use the PAHs as a carbon and energy source while fungi metabolize the PAHs to more water-soluble compounds, thereby facilitating their subsequent elimination. Bacteria and fungi therefore have different metabolic pathways. The general fungal pathway is quite similar to the transformation pathways found in humans and other mammals (Hayakawa, 2016). The bacterial degradation of PAHs generally begins with a dioxygenase attack on one of the aromatic rings to form a cis-dihydrodiol, which is subsequently dehydrated to catechol. Catechol is a key intermediate from which ring cleavage degradation of PAHs can occur. The aromatic ring is cleaved between the hydroxyl groups (ortho fission) or adjacent to one of the hydroxyl groups (meta fission). Successive ring degradation may then occur, so that the structure is ultimately degraded to molecules that can enter the central metabolic pathways of the bacteria (Hirose et al., 2011).

3. Chemical degradation of PAHs

PAHs in soil are also degraded through abiotic processes. Oxidation reactions are the most important in this context, although photochemical

reactions may contribute significantly to the degradation on the surface of soils. However, some can also be produced from inorganic salts and oxides, especially those of iron and manganese (Hayakawa et al., 2016). Chemical oxidation reactions involving hydroxyl radicals, generated from hydrogen peroxide, and ozone, have been most widely studied. Hydroxyl radicals are strong, relatively unspecific oxidants that react with aromatic compounds, such as PAHs, by abstracting hydrogen atoms or by addition to double bonds (Hayakawa et al., 2016).

III. CONCLUSION

Polycyclic aromatic hydrocarbon (PAH) are ubiquitous environmental contaminants. PAHs reveal their toxicity following biotransformation to toxic metabolite which can bound covalently to cellular macromolecules as DNA, RNA and protein. PAHs are released to the environment through natural and synthetic sources with emissions largely to the atmosphere. Natural sources include emissions from volcanoes and forest fires. Synthetic sources provide a much greater release volume than natural sources; the largest single source is the burning of wood in homes. Automobile and truck emissions are also major sources of PAHs. Environmental tobacco smoke, unvented radiant and convective kerosene space heaters, and gas cooking and heating appliances may be significant sources of PAHs in indoor air. PAHs can enter surface water through atmospheric deposition and from discharges of industrial effluents (including wood-treatment plants), municipal waste water, and improper disposal of used motor oil. Several of the PAHs have been detected at hazardous waste sites at elevated levels. In air, PAHs are found adsorbed to particulates and as gases. Particle-bound PAHs can be transported long distances and are removed from the atmosphere through precipitation and dry deposition. PAHs are transported from surface waters by volatilization. In soil and sediments, microbial metabolism is the major process for degradation of PAHs, PAHs have a potential effect on the environment.

IV. RECOMMENDATION

From the above research conducted it can be seen that polycyclic aromatic hydrocarbons have been found to be highly toxic to man and the environment, ranging from minor health issues to chronic diseases like cancer, therefore the government should devise means to reduce the exposure of this PAH to man and the environment

as this would increase the life expectancy of the residing citizens.

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