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MODELLING FOR ENVIRONMENTAL RISK ANALYSIS OF POLLUTANTS FROM HUMAN ACTIVITIES

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ABSTRACT

The current environmental predicament has two recognizable components: natural pollution and pollution problems due to industrialization. Industrial pollution phenomena involve man-made organic chemicals such as pesticides, plastics and other synthetics that persist and degrade slowly. Man is responsible for introducing hydrocarbon and heavy metals at problem levels into the environment. The principles that govern the distribution and effect of some of these pollutants in the environment show similarities regardless of the origin of the pollutant. Using experimental and complex mathematical models, it is possible to simulate the affected ecosystem. This requires the developments of a framework for the understanding ecosystem functions. This paper seeks to illustrate the models developed for environmental risk analysis of petroleum production effluent and pesticides with a view to predicting their behaviour and the consequences of their output into the ecosystem and environment.

1.0 INTRODUCTION

Human activities, in recent times, have resulted in the release of a variety of environmental pollutants into our environment. Such human activities may range from industrial activities like crude oil production to agricultural activities like pesticide production and application. The ultimate is the accumulation and subsequent exposure of man to such concentrations of the pollutants that can cause serious environmental risks. The characterization of the probability of potentially adverse health effects from human exposures to environmental hazards constitutes risk assessment (NAS. 1985).

The principles that govern the distribution and fate of some of these environmental pollutants in the ecosphere show similarities regardless of the origin of the pollutants (Atlas and Bartha 1998). The environmental fate, risk / hazard and subsequent behaviour of the environmental pollutants can therefore be successfully modeled. Models of ecosystems are simpler than real ecosystems; to be useful though, models must accurately reflect real systems.

There are two major approaches to ecosystems modelling:

(i) Experimental approach to ecosystem modeling. attempt to simplify and simulate real ecosystems, or subsystems within complex ecosystems, by limiting the numbers of variables being examined and by controlling environmental conditions. The insights obtained by the use of such simplified models are protected to the complex natural ecosystems.

(ii) Mathematical approach to ecosystems modeling may analyze results of experimental models or actual field studies in an attempt to explain the data and interrelationship within the systems by predictable mathematical formulae. This approach also may examine theoretical aspects of functioning within ecosystems and project the expected results, with later verification by field or experimental observations (Atlas and Bartha, 1998).

There is paucity of information on evaluating environmental risks arising from vast human activities in recent times. This paper is aimed at evaluating the environmental risks of petroleum production effluent (PPE) and pesticides using a tested and verified model developed by the authors.

2.0 HUMAN HEALTH RISKS FROM PETROLEUM PRODUCTION EFFLUENT (PPE).

Environmental contamination from PPE and petroleum hydrocarbon has become an important human and environmental health issues in the United States of America over the last two decades (Kostecki and Calabrese, 1990). Yet this contamination has probably occurred globally since the increased production and use of petroleum became widespread during the last decade (Sullivan, 1991). The situation is worse in Nigeria considering the complete dependence of the Nigerian economy on petroleum production activities. Potentials exist for humans to be exposed to petroleum constituents in the environment through various pathways. Potential pathways of exposure to petroleum hydrocarbon in the environment depend on the environment, type of soil, petroleum type and petroleum constituents presents (Sullivan, *et al.* 1990).

Potential human exposures to petroleum in the environment can be evaluated through the use of formal quantitative risk assessment (QRA). This method incorporates information about the toxicity of the petroleum and its constituents, the environmental behaviour of these agents to evaluate the possible health risks to humans exposed to petroleum in the environment.

Crude oil is the naturally occurring liquid phase of petroleum. Natural crude oil seeps are common in regions of petroleum – bearing formations. This natural contamination may result in human exposures to crude oil and subsequent associated health risk. Health risks associated with exposures resulting from accidental releases of chemical into the environment are referred to as additional or incremental risks. QRAs are used to evaluate incremental health risk from accidental releases of petroleum products into the environment (Sullivan, 1991).

2.1 Use of Quantitative Risk Assessment (QRA)

Petroleum Exploration and Production companies use formal health – based risk assessment for a number of reasons, including the need to understand risks and to prioritize the remediation and prevention of risk.

According to Sullivan (1991), the QRA internally provides information that can answer a variety of internal questions. For example, how can one company with multiple sites contaminated with variety of chemical prioritize remediation alternatives? How can a remediation of chemical contaminants that pose the highest risk to the exposed population be handled? How can a company develop a structured environmental programme to remedy each of those sites when the given fiscal reality does not permit remediation of all sites in a given time? Companies therefore, can use QRA to prioritize the sites and clean up the most risky sites first. QRA can also be used to prioritize the remediation within a given site. The chemical with the highest concentration may not be the chemical with the highest risk. Use of QRA within a site allows, first, for the remediation of chemical contaminant that posed the highest risk to the exposed population with subsequent remediation of the remaining chemical contaminants having lower risk (Sullivan *et al*, 1990).

Externally, QRA is used in a variety of situations, including regulatory responses and dealings with the public and media. QRA can provide alternative contamination levels or remediation goals at a given site and can be used to convey the conditions at the site to the public and media. QRA is a scientifically defensible document, based on the best and most current understanding of the toxicity and exposure data base that provide a logical documented transition from site - specific exposure and toxicity data to the estimated risk. As a legal document, QRA is used in liability cases and in the defense of product liability suits, amongst others (Sullivan, 1991).

2.2 Components of Quantitative Risk Assessment

The principle of risk assessment, according to Sullivan (1991) can be summed up as:

Hazard x Exposure = Risk.

Hazard is a measure of the chemical toxicity; exposure is a measure of the dose being received by the population: while risk is the probability that an adverse effect will occur in the exposed population.

Risk assessment process is usually divided into four steps:

(a) Hazard identification,

(b) Dose – response assessment,

(c) Exposure assessment, and

(d) Risk characterization (NAS, 1985; USEPA, 1986b)

Hazard identification is a qualitative review of relevant biological and chemical information to determine whether exposure to an agent may pose a hazard or increase the incidence of a health condition or effect (cancer, birth defects, etc) (NAS, 1985; USEPA, 1986a). Also available information is melded into a weight of evidence determination. Often in this step, indicator or candidate chemicals will be chosen from contaminants present at the site.

According to (Sullivan, 1991), candidate chemicals are determined by reviewing:

(i) the list of chemicals present at the site,

(ii) the matrix in which those chemicals exist,

(iii) the opportunity for receptor exposure (based on environmental mobility), and

(iv) the toxicity of the chemicals.

Chemicals having the greatest potential for causing an adverse effect in receptors would be chosen as indicator chemicals. The logic is that the chemicals that pose less risk and have similar environmental fates would be remedied along with the indicator chemicals. It is possible that a given chemical may be present in high concentrations but not be mobile in the environment, resulting in low exposure and toxicity and therefore low potential for harm. A QRA would identify the second chemical as a candidate chemical.

The toxicity of complex inorganic/organic chemical mixtures like crude oil can be evaluated by investigation of the whole mixture or its individual components. For example, the toxicity of NO_2 from oil has been evaluated with component toxicity (Kostecki and Calabrese, 1990). In the case of crude oil, information is available on both whole crude oil and components toxicity. Component toxicity has been analyzed for both distillate fractions (i. e. those chemical components that separate from the crude during distillation within a set temperature range) and for individual components (e.g. polynuclear aromatic hydrocarbons). Animal and human toxicity to crude oil is evaluated with both crude oil and composite–toxicity information. In addition to the toxicity information considered, chemical and physical properties and environmental fate. Both of which affect the toxicity of crude oil, should be reviewed.

Dose–response assessment characterizes the relationship between the dose of agent and the incidence of adverse health effects in exposed populations (NAS, 1985). The result of this assessment is a probability estimate of the incidence of the adverse effect as a function of human exposure to the chemical. Two endpoints are evaluated separately: carcinogenic and non-carcinogenic effects.

An allowable exposure level called the reference dose models human exposure to carcinogenic chemicals. The reference dose is the maximum daily dose of chemical to which a human may be exposed and not be adversely affected and in most cases, is based on non – toxic exposure levels in animals extrapolated to humans with safety factors. This method assumes that these exposures have a threshold; i.e. some exposure level exists below which an adverse effect will not occur in the exposed individual (Sullivan, 1991). Human exposure to carcinogenic chemicals is modeled mathematically with either animal or, when available, human data. Often these models predict a no–threshold, linear dose–response curve that passes through the origin (i.e. a theoretical risk exist at all exposure levels). According to United States Environmental Protection Agency (USEPA, 1986a) and the National Research Council (NAS, 1985), the dose–response estimate should be describe and justify the methods of extrapolation used to predict incidence and should also describe the uncertainty inherent in these methods.

Exposure assessment measures or estimates the magnitude, duration, timing and route of exposure, the size and nature of the populations exposed, and the uncertainties in all estimates. The goal is to estimate accurately both the dose of the chemical reaching the target tissue in the receptor (target dose). Human exposures are reported as maximum daily doses (MDD) for carcinogens (Sullivan, 1991).

Three routes of exposure are typically investigated in QRA: ingestion, inhalation and dermal absorption. Receptor populations do not have to be humans. USEPA (1986b) have been involved in many QRA where both humans and wildlife were exposed populations. For some chemicals, wildlife exposures were higher than human exposures, and compared with human risk, the risk to wildlife was the limiting factor in assessment.

Environmental exposure to crude oil and/or its components may have occurred through all three exposure routes. Human may be exposed by inhaling the volatile organic contained in the lower–boiling point fractions expected to result in inhalation exposure unless contaminated soil become airborne as dust. Exposure to heavier fractions typically occurs through ingestion of and dermal contact with:

(i) soil containing crude oil residue, or
(ii) pure crude oil (Sullivan, 1991).

Risk assessment calculations can be performed in several ways. First, the risk from a given activity and exposure may be calculated and compared to a deminimus risk. Second, beginning with a given acceptable risk level, the exposure associated with that risk and the chemical concentration that would have to be present at the site to result in that exposure level can be calculated. Finally, some parameter of the exposure assessment can be estimated if an acceptable risk level and contaminant concentrations are known. For example, the percentage of a chemical that would be allowed to migrate off site and not exceed a given risk level in the exposed populations can be estimated. In all these assessments, the uncertainties and assumptions associated with them need to be presented to provide the public with an understanding of their limitations (Sullivan, 1991).

Although QRA provides health–based information to those making environmental decisions, there are limitations associated with performing a QRA. It is important that the effect of the QRA address these limitations in terms of the effect of the risk estimates. A few of the limitations encountered in QRA on crude oil are discussed.

According to Sullivan (1991), data limitations (divided into toxicity and exposure categories) associated with crude oil QRA often exist. Currently, data on the toxicity of crude oil as a substance are limited. Crude oil and other petroleum streams are evaluated as mixtures of toxicologically active compound i.e. as having effects equal to the summation of the effects of the individual compounds. This conservation assumption generally over estimates toxicity because it ignores the matrix effects of these mixtures.

Also, limited exposure data affect the calculation of the dose received by the population. Because the exposure assessment has multiple components, data limitations may exist in many places. Some common limitations include exposure – point concentrations when migration from the source must be modeled, exposure parameters (i. e. Amount of soil that contacts the skin each day), and the amount of compound absorbed into the body. When data are not available. Conservative estimates are used, resulting in over – estimated human risk.

Another impediment to the successful completion and use of QRA on crude oil is that the projects can be large and therefore costly, which before is viewed as negative by the parties commissioning the QRA. When QRA is fully documented and referenced, however, they can provide a valuable evaluation of the potential health risks that can be used to control current and future liability (Sullivan, 1991).

3.0 HEALTH RISK FROM PESTICIDES

The success of modern agricultural crop and forestry production was reported by (Pell *et al.* 1998) to be largely dependent on the use of chemicals (pesticides) to control various pest and weeds. The use of these pesticides has been on the increase and yielded good results but potential environmental hazards culminating from pesticide use is imminent where no efficient monitoring systems exists. These pesticides are designed to affect only specific target organisms or processes but most of them are know to have general toxic effects, causing interactions with the biological soil ecosystem.

Pesticides entering the soil will not always remain there. Rundgren *et al* (1998) reports that owing to sorption/desorption phenomenon they may be transported, transformed or not, through the soil profile and finally appear in surface waters and groundwater. The environmental fate of pesticides and other chemicals in soil is viewed with great concern today due to the problems that are resulting from use mobile and persistent molecules such as deterioration of surface water and groundwater quality (Hall, 1998; Richard and Baker, 1993; Lunbergh *et al*; 1995). Bergstrom and Stenstrom (1998) reported that when pesticides are applied on field, they can meet a variety of fates, some may be lost to the atmosphere through volatilization, and others are carried away by surface run-off or are photodegraded by sunlight. Chemicals use in agriculture have been found to contaminate soil and water and that their resistance to biodegradation can lead to their accumulation to toxic levels Dzyadevic *et al* (1998) states that crops grown on polluted soils concentrate these compounds in their tissues, creating greater hazard humans and animals. The pesticide residues penetrate via the food chain into products consumed by humans and livestock and cause various diseases because many pesticides are carcinogenic.

Forges (1989) has recorded the incidence of pesticide-related health problems to be 13 times higher in the third world than in the industrialized countries. Stewart (1996) reported that the use of pesticides and contaminated drinking water were ranked as the number one cause of health problem by 27% of farmers in Egypt. Thirty five percent of the farmers reported knowing of cases in which animals died as a result of pesticide poisoning.

3.1 Environmental Risk Analysis of Pesticides

Conway (1982) states that environmental risk analysis is the process of making predictions of where in the environment a pesticide is transported, the rate of transportation, degree of transformation and the effect of pesticides on organisms and environmental processes at ambient levels. It is also reported that the establishment of risks is done by first using simple screening tests to guide decision having small potential impact and then applying tests of increasing complexity and accuracy as decisions having large impact are reached. The pursuance of process changes in pesticide manufacturing using a new operation while construction of a manufacturing plant with large environmental impact potential, at a site are reported by Conway (1982), to constitute early decisions to be made. The assessment of risk according to Sanders (1979) involves an evaluation of both scientific data and the social, economic and political factor that must be considered in reaching an ultimate decision on the prohibition, control or management of chemical (pesticides) in the environment. This includes efficacy of the operation or products, which is a measure of the probability and intensity of beneficial effects as stated by Daniel (1978). The final decision making involves the scientific measurement of risk and then political judgement of the acceptability of the risk in view of the benefits from the operation (Conway, 1982)

Four major approaches to environmental risk analysis of pesticide can be outlined as follows:

(i) The model ecosystems (Microcosm) – This involves the construction of a physical model of a given environmental situation with the application of a pesticide and observation the fate and effects of the pesticides.

(ii) The Stochastic – Statistical approach – This involves obtaining large amounts of data under various conditions and establishing correlation between pesticides input, its observed concentrations and its effect in various environmental compartments.

(iii) The base-line approach – This approach relies on the prior full characterization of pesticides as to transport, persistence and effects in the soil environment. When screening tests are carried out with new pesticides understudy, the results obtained are compared with those of the baseline/constituents and a decision made as to probability and severity of adverse effect.

(iv) The deterministic approach – This involves the use of a simple mathematical model to describe the rates of individual transformations and transports of the pesticide in the environment. an estimate of Expected Environmental Concentration (EEC) is obtained from the study of only dominant mechanisms. The use if indicator organisms or microbial processes for determination of pesticide toxicity is also carried out.

3.2 Screening the Ecological Impact of Pollutants

The various analyses that can be employed in the screening of ecological impact of pollutants in the environmental include:

(I) Chemical fate
- (a) Transport – (i) Biological assimilation, leachability
  - (ii) Volatility
- (b) Persistence – (i) Biodegradation (using CO_2 respiration)
  - (ii) Chemical degradation
    - (a) Oxidation,
    - (b) Hydrolysis,
    - (c) Photochemical transformation on soil surface.

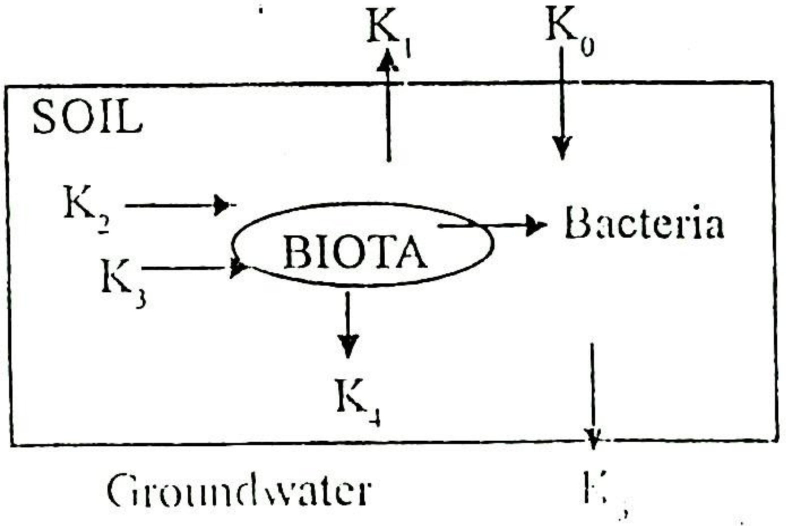
(II) Ecological Effects
- (a) Microbial effects – (i) N – mineralization
  - (ii) Nitrification
  - (iii) Phospholipid fatty acid composition in soil
- (b) Plants effects – (i) Seed germination and early growth
- (c) Animal effects - (i) Fish acute toxicity
  - (ii) Fish bioconcentration/ bioaccumulation test

The screening test can provide a basis for yes–no decisions regarding likely fate of the pollutant in the various compartments without constructing a mathematical model.

3.3 Modelling for Distribution of Pollutants in the Soil

A model for estimating the compartment (air, water, sediment, and fish) distribution of materials was described by Neely (1979) as reported by Conway (1982). Donagian and Rao (1986) reported that models are used to analyze the behaviour of an environmental system under both current (or past) conditions and anticipated (or future) conditions. Mathematical model provides a tool for integrating degradation and partitioning processes with site/soil–and wastes–specific characterization. This can be used to predict the behaviour of organic constituents in a contaminated soil and for predicting the pathways of migration through the contaminated area, and therefore pathways of exposure to humans and to the environment (Sims *et al.* 1989). Models may also be used to approximate and estimate the rates and extent of treatment that may be expected at the field scale under varying conditions. Modelling allows for the determination of contaminant requirements for pollutants of interest at the site.

The Compartmental model for distribution of pollutants in the soil environment can be described or represented as shown (Fig. 1.0) below:



Where:

K_0 = Input
K_1 = Volatilization
K_2 = Degradation
K_3 = Biota uptake
K_4 = Biota death
K_5 = Leaching

Fig. 1.0: Compartmental model showing the movement and distribution of pesticides in the soil environment.

The following equation has been developed from the above model as modification from Branson (1978).

$$C_B \frac{dP_S}{dt} = K_0 - K_1 AP_S - K_2 C_B P_B - K_3 BP_S + K_4 BP_S - K_5 VP_W$$

Where :

C_B	=	Concentration of active bacteria in soil
P_S	=	Pesticide concentration in soil
K	=	Rate constants
A	=	Surface area of soil
B	=	Mass of bacteria
P_B	=	Pesticides concentration in soil biota
V	=	Volume of groundwater
P_W	=	Pesticide concentration in ground water

A critical and cost – effective use of modeling is in the analysis of proposed or alternative future conditions, i.e. the model is used as a management or decision making tool to help answer "what if" type questions (Donag... and Rao, 1986). Results of modelling, according to Sims *et al.* (1982) can aid in the identification of constituents that will require treatment in the air (volatile) phase, in the leachate phase and in the solid (soil) phase.

3.4 Institution and Legal Framework for Pesticide Management

Sound pesticide management requires availability of reliable information and an accurate database with respect to type, nature, quantities of imports, exports, usage and effects of pesticide within the country. In Nigeria, environmental protection is the concern of all tiers of government and the Ministries and Agencies involved in protecting the environment from pesticide induced risk include:

(a) Federal Environment Protection Agency, FEPA (now Federal Ministry of Environment, FMENV.) - charged with the responsibility of regulating all classes of pesticides.

(b) National Agency for Food, Drug Administration and Control (NAFDAC) - responsible for the determination and management of pesticides risks in relation to goods, humans and animals.

(c) The factory Inspectorate Division of the Federal Ministry of Labour and Productivity – responsible for identifying and controlling hazards to workers (Adewoye, 1998).

These bodies set up national regulatory/ legal instruments such as:

- FEPA Decree 58 of 1988; Amended by FEPA Decree 59 of 1992 Sections 15, 16, 17, 18, 19, 20 on agrochemical, enacted to achieve the following objectives: Environmental Protection pollution abatement and control, human health, enforcement of FEPA regulations.
- Pesticides registration regulation of 1996;
- S. I. 15 National Environmental Protection Management of solid and hazardous wastes) Regulation of 1996;
- FEPA Decree 59 of 1992; NAFDAC Decree 15 of 1993 on importation of pesticides;
- FEPA S. I. 9 (1991) NAFDAC Decree 15 of 1993 on production and storage of pesticides;
- FEPA S. I. 9. Of 1991 on transportation of pesticides;
- NAFDAC Decree 15 of 1993 on distribution / marketing of pesticides;
- FEPA S. I. 9 1991, NAFDAC Decree 15 of 1993 on use / handling of pesticides and
- FEPA S. I. 15, 1991 NAFDAC Decree 15 of 1993 on disposal of pesticides;
- Food and Agricultural Organization (FAO) international code of conduct on use/distribution of pesticides.

The level of enforcement of these Decrees by government authority in Nigeria has not been satisfactory due mainly to financial constraints and lack of resources.

4.0 CONCLUSION

Human activities have been shown to be responsible for the release of vast environmental pollutants to the environment. During the second half of the 20th century man made pollution problems have become more acute than ever before.

In Nigeria in recent times, petroleum exploration and production and agriculture are the two major sectors whose activities release enormous pollutants into the environment. Humans are exposed to these pollutants through various pathways. Quantitative risk assessment (QRA) and models have been used to evaluate the environmental risks arising from these pollutants.

Modelling has assumed an important role in ecological investigations. Experimental and mathematical model provide a tool for developing an understanding of ecosystems function and of the factors that control the flow of energy and matter through an ecosystem and that they allow for the development of predictive capability. The predictive capability developed in such models is especially useful in proper management of ecosystems.

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