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Ecotoxicology & Impact on Biodiversity.

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Ecotoxicology can be defined as the 'study of impacts of pollutants on the structure and function of ecosystems' it can be by manmade poisonous chemicals and their effect on the environment, it does not include the study of naturally occurring toxins or it is a scientific discipline combining the methods of ecology and toxicology in studying the effects of toxic substances and especially pollutants on the environment. Ecotoxicology is a mix of various discipline ecology, toxicology, analytical chemistry, physiology, molecular biology, and mathematics. Ecotoxicology looks at the impacts of contaminants including populations, pesticides on individuals, natural communities, and ecosystems. Communities of living things and the environments they live in form ecosystems.
Ecosystems include rivers, ponds, deserts, grasslands, and forests, and they too can be affected by pesticides. Ecotoxicologists also study what happens to the pesticides themselves, where they go in the environment, how long they last, and how they finally break down.
Herein we review what is ecotoxicology, different kinds of toxicants their impact on biodiversity, assessment of toxicity of environmental toxicant.

Keyword: Ecotoxicology, Biodiversity, Toxicology, Environment

1. Introduction

The discipline 'toxicology' is as old as medicine – many toxic plant chemicals have been used as therapeutic agents in medicine. The term 'ecotoxicology' appeared in the literature in 1969. Ecotoxicology can be defined as the 'study of impacts of pollutants on the structure and function of ecosystems' it can be by manmade poisonous chemicals and their effect on the environment, it does not include the study of naturally occurring toxins, for example cholera toxin, or brevitoxin. In the 1940s and 1950s, environmental toxicology is a new discipline that grew out of studies on the environmental fate and transport of pesticides, it may directly affect something far from the site of application. Pesticides that are bound to soil particles may be carried into streams with runoff. Pesticide drift may travel many miles in the wind. Sunlight, water, microbes, and even air can break down pesticides. Environmental toxicology is an important discipline (e.g., single-species testing for screening purposes). Still, ecological toxicology (ecotoxicology – more realism in tests, test species and exposures) is required for predicting real world effects and for site-specific assessments[1]. Dr. Rene Truhaut was first used the term ecotoxicology around 1969[2]. Further, this field of ecotoxicology studies the effects of anthropogenic chemicals on ecosystems at different levels of biological organization, from the molecular and cellular level to entire ecosystems. Ecotoxicology is somewhat different from stress ecology, where stress ecology considers a broader range of natural stressors such as oxygen depletion on individuals or the effects of temperature, populations and communities; however these parameters directly impact on toxicity. There is further separation between environmental toxicology and ecotoxicology, which is often rather artificial, with a tendency of ecotoxicology being more focused on the level of communities and ecosystems and environmental toxicology being more focused on the level of individual organisms, including humans, or cells. One of the core missions of ecotoxicology is to understand the mechanisms by which contaminants perturb normal biological performance (their mode of action), in order to develop appropriate measures to prevent adverse outcomes resulting from environmental contaminants. There is a wide range of possible contaminant effects that can compromise the ecological fitness of individual organisms or populations. Ultimately, the impact of a toxic contaminant or contaminant mixture depends on the relative sensitivity of a species, community or ecosystem, and the intensity and timing of exposure. Pesticides and contaminants may affect more than just the populations of animals and plants that make up a community. They may affect basic processes like nutrient cycling or the formation of soil. For example, nitrogen cycling may be affected if pesticides impact the bacterial and fungal communities in soil though undervalued for a long time, is a major issue in applied ecotoxicological research[3]. Ecotoxicology faces the challenge of predicting and assessing the effects of an increasing number of chemical stressors on aquatic species and ecosystems. With increasing ecological relevance the reproducibility, specificity and thus suitability for standardisation of methods tends to diminish.

Ecotoxicological study is a multi-step process which involves:

- The entry, distribution and fate of pollutants within the environment;
- The entry and fate of pollutants in living (biota) organisms within an ecosystem;
- The harmful effects of the chemical pollutants on the constituents (biotic & abiotic) of ecosystems (which include man).

1.1 Types of Toxicant

- **Carcinogens**: cause cancer
- **Mutagens:** cause mutations in DNA
- **Teratogens:** cause birth defects
- **Allergens:** cause unnecessary immune response
- **Neurotoxins:** damage nervous system
- **Endocrine disruptors:** interfere with hormones

The drug thalidomide, used to relieve nausea during pregnancy, turned out to be a potent teratogen, and caused thousands of birth defects before being banned in the 1960s. Some chemicals, once inside the bloodstream, can "mimic" hormones. If molecules of the chemical bind to the sites intended for hormone binding, they cause an inappropriate response. Thus these chemicals disrupt the endocrine (hormone) system.

Studies toxicants that come from or are discharged into the environment affects as:

Health effects on humans
Effects on animals
Effects on ecosystems

1.2 Factors Affecting Toxicity

Not all people are equal. Sensitivity to toxicant can vary with sex, age, weight, etc. Babies, older people, or those in poor health are more sensitive.

1.3 Type of Exposure

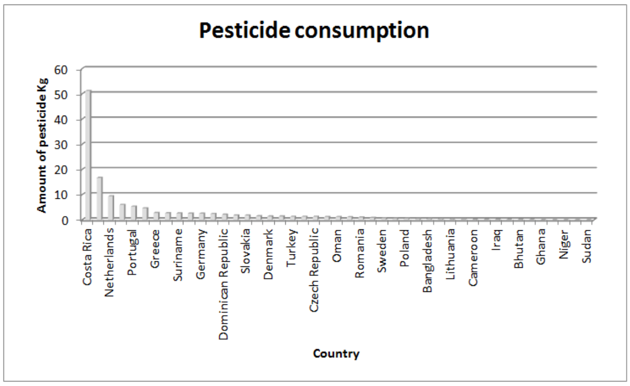
There are two key issues specific to ecotoxicology: acute and chronic responses; and, criteria for species selection.

Acute = high exposure in short period of time

Chronic = lower amounts over long period of time

Toxicological testing with acute and chronic responses often involves many individual species and endpoints. The results are used in some form of weight of evidence assessment, but without clear guidance as to how to interpret deferential responses and intensities of response. The standard toxicity testing is routinely based on concentrations (e.g., LC=EC50 determinations) in the external medium (e.g., water, sediment). However, increasingly it is becoming apparent that the dose, that is, the material associated with biological tissues, is a much better predictor of effects[1].

Pesticide usage by different countries



1.4 Dose Response Analysis

Method of determining toxicity of a substance by measuring response to different doses of test compound Lab animals is used. Mice and rats breed quickly, and give data relevant to humans because they share mammal physiology with us. Responses to doses are plotted on a dose-response curve (Fig.1); dose-response curves allow us to predict effects of higher doses. The goal of dose response analysis is to gather all information useful in establishing relationship between the extent of contamination and the likelihood or magnitude of an adverse effect.

By extrapolating the curve out to higher values, we can predict how toxic a substance may be to humans at various concentrations. In most curves, response increases with dose. But this is not always the case; the increase may not be linear. With endocrine disruption, it may decrease.

Threshold- dose at which response begins and LD 50- dose lethal to 50% population.

1.5 Points to Consider for Specie Selection

Normally, an organism is chosen that is economically or ecologically important. While the latter criterion is necessary, it does not go far enough if we are doing more than screening. In order to get better predictions and for site-specific assessments, there is need to test the equivalent of ‘‘keystone’’ species, ideally for the area being assessed. Test species should be identified by community-based studies.

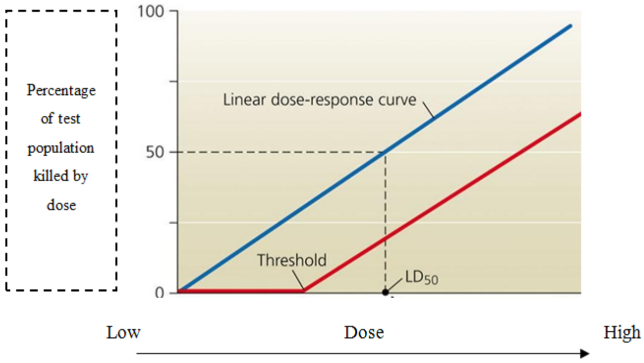


Fig 1: Dose response curve

1.6 Policy on Toxicants

Environmental toxicology can be mostly characterized by toxicological studies of environment (1).

Key agencies and products they regulate:

Food and Drug Administration (FDA): food, additives, cosmetics, drugs, medical devices

Environmental Protection Agency (EPA): pesticides, industrial chemicals, and any synthetic chemicals not covered by other agencies

Occupational Health and Safety Administration (OSHA): workplace hazards

1.7 International Policy on Toxicants

There is little or no effective regulation in most developing nations. Europe follows a policy closer to the precautionary principle than does the U.S. The EU is now considering a still-tougher policy.

Stockholm Convention, 2001: international treaty to phase out 12 persistent organic pollutants (POPs), “the dirty dozen”

1.8 Environmental Health:

The scope of ecotoxicology includes populations, organism, ecosystem and communities[4]. It is the science of contaminants in the biosphere and their effect on constituents of the biosphere including humans. Ecotoxicology started to play a key role in providing knowledge that allows controlled sustainable development connected with simultaneous preservation of sustainability and productivity of environment[2]. It assesses environmental factors that influence human health and quality of life. Further seeks to prevent adverse effects on human health and ecological systems Fig.2.

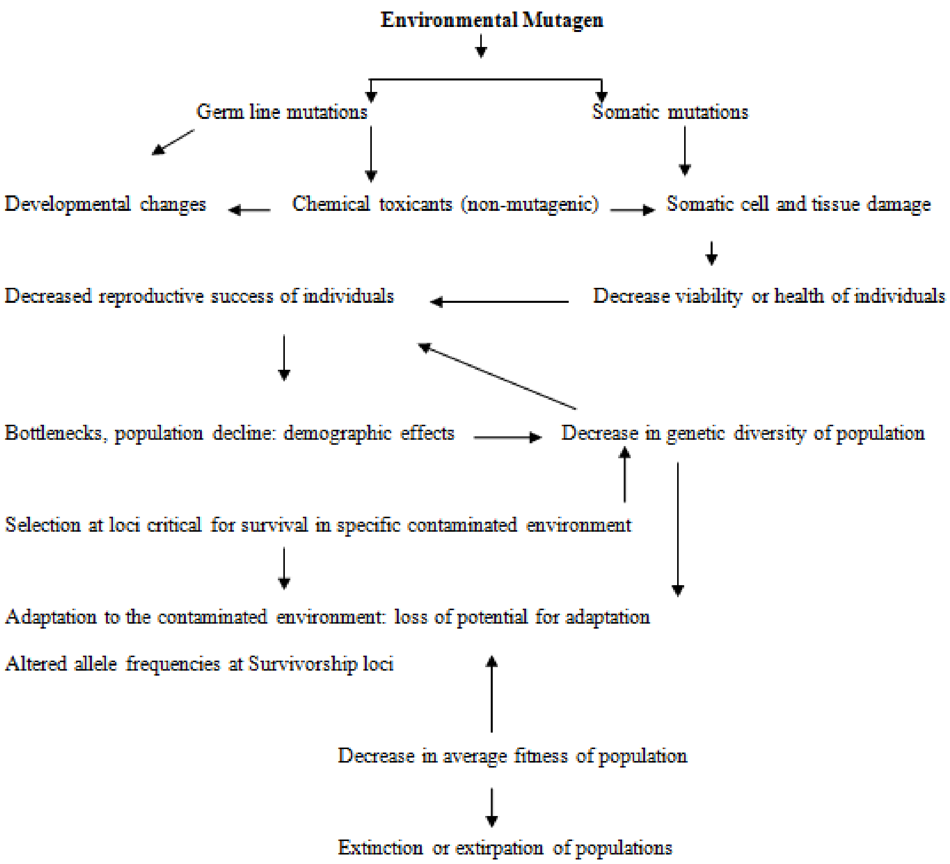


Fig 2: Flow chart to demonstrate the inter relationships among factors related to chemical contamination of the environment with decreased genetic diversity of populations.

1.9 Persistence

Some chemicals are more stable than others, persisting for longer in the environment.
DDT and PCBs are persistent.
Bt toxin in GM crops is not persistent.
Most toxicants degrade into simpler **breakdown products**. Some of these are also toxic.
(DDT breaks down to DDE, also toxic.)

1.10 Environmental Health Hazard

Loss of biodiversity is one of the major environmental concerns worldwide. In order to review a chemical's impact on biodiversity, a reference system is needed that represents natural, undisturbed conditions[5,6]. Monitoring of possible threats to biodiversity appears to be an overly difficult, if not impossible task. New substances like compounds, impurities, elements, additives must be notified to the regulatory authorities before they are marketed, and the amount of information required depends on the apparent potential hazard and the amount to be produced. There are various other environmental impacts that are associated with the use of natural resources, such as pesticides used in the production of food and acidification triggered by the combustion of fossil fuels[7].
Some threats are:

- Physical or climatic hazards (floods, blizzards, landslides, radon, UV exposure)

- Biological hazards (viruses, bacteria, pathogens)
- Cultural or lifestyle hazards (drinking, smoking, bad diet, crime in neighborhood)

1.11 Some Environmental Hazards

Chemical contamination may cause population reduction by the effects of heritable and somatic mutations as well as non genetic modes of toxicity[8].

- **Indoors**
    - Toxicants in consumer products and in plastics
    - Radon
    - Lead in paints and pipes
    - Asbestos
- **Water**
    - Fertilizer and Nitrates runoff
    - Herbicides and pesticides runoff
    - Arsenic, mercury and other heavy metals in groundwater and surface water
- **Food**
    - Herbicides and pesticides residue
    - Toxins that are of natural origin
- **Air**
    - Dust and particulate matter
    - Pesticide drift
    - Chemicals from automotive exhaust and from industrial pollution
    - Smoking and second hand smoke
    - Troposphere ozone

Table 1: Overview of environmental impacts from the use of natural resources

	Direct impacts of extraction And distribution	Disturbance to material cycle
Use of mineral reserves	large local/regional impacts On the landscape and ecotoxico Logical pollution	Use on non-ferrous metal in particular e.g. Zn, Pb and Cd is responsible for steep rise in metal fluxes
Use of fossil fuels	large local/regional impacts On the landscape and ecotoxico	Carbon cycle is greatly enlarged (greenhouse effect) Metal fluxes are enhanced (metal acts As contaminants) Sulphur cycle is enlarge
Fisheries	Shrinkage of fish stocks, loss of Biodiversity	Disruption of nutrient cycles
Use of wood fibers as fuel	loss of forest area, biodiversity in In plantations and secondary forest	Carbon storage function reduced
Use of agricultural products	Loss of forest area, soil, consumption Of groundwater reserves	Greenhouse gas affected, eutrophication disruption of nutrient cycles
Use of water	falling water tables, exhaustion of Groundwater reserve, falling water tables	

1.12 Ecological basis of Ecotoxicology

Ecology can be incorporated into toxicology either extrinsically (separately, e.g., providing information on pre-selected test species) or intrinsically (e.g., as part of test species selection) – the latter is preferable[1]. The term ecotoxicology comprises the integration of ecology and toxicology (9 and 10 Fig. 3a and 3b). Its objective is to understand and predict effects of chemicals on natural communities under realistic exposure conditions[1]. A few species were exposed to environmental pollution and genetic studies were carried on them and it was demonstrated that chemical exposures can cause genetic damage[8]. Aquatic species are used for ecotoxicological tests because release via sewage into rivers is a main and major pathway for many chemicals. The basis for determining the effects of contaminants on ecosystem is at organism level

At organism level, response can be:

- Acute toxicity causing mortality

- Chronically accumulating damage ultimately causing death
- Sub lethal impairment of various aspects of physiology and morphology
- Sub lethal behavioral effects

Ecology
Population function → Field observations → Planned field observations
Experimental
Organism interactions
Manipulations

Progress through time → **Ecotoxicology**
Ecology in presence of toxicants

Environmental Toxicology → lab exposures → Investigations Complex in situ
experiments
Toxicant effects on biota

Fig 3a: Development of ecology, ecotoxicology and environmental toxicology (Modified after Peter M. Chapman., 2002)

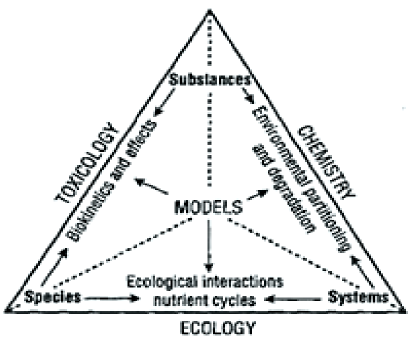


Fig 3b: Relation between ecology, toxicology and chemistry.

1.13 Measurable Biochemical Changes (Fig 4)

At population level, response can be:

- Size and dynamics (based on birth rates, death rates, gains, from immigration and losses from emigration)
- Cause a reduction or an increase in the natural flowchart of numbers, in the biomass, sex ratio, etc.

At community level, response can be:

- species diversity
- predator prey relationship, etc

Change in ecosystem

- nutrient cycling rates, patterns of nutrient flow,
- Physicochemical conditions etc.

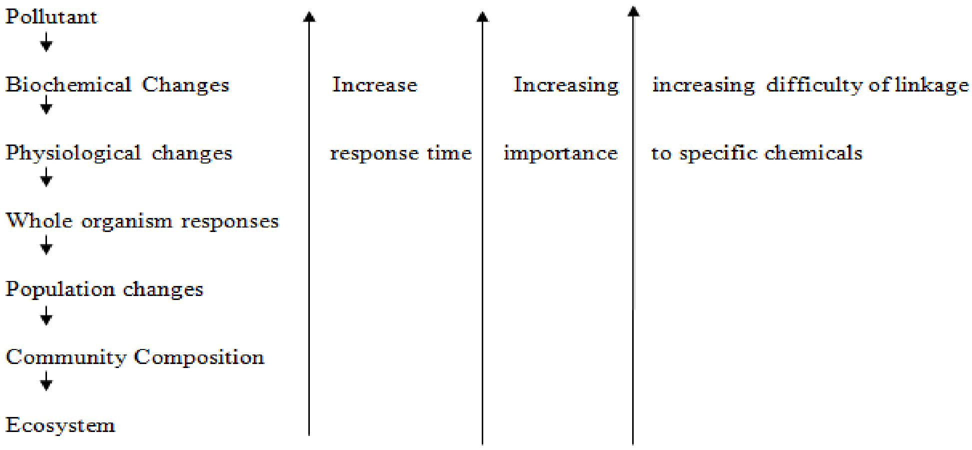


Fig 4: Flow chart for effect of pollutant on ecosystem.

1.14 Assessment of Structural Changes

A pollutant can be defined as a substance that occurs in the environment at least in part as a result of man's activities and which has a deleterious effect on living organisms. It is different from the contaminant; a contaminant is a substance that is released by man's activities. A pollutant can be classified in many ways: by chemical or physical, source, use, nature, place of occurrence in the environment, choice depends on the purpose[12].

1. Changes in species / population structure
   - appearance/disappearance of an indicator species
   - number of individuals of a species
   - biomass of a species
   - presence or absence of a species

Biomass-a quantitative estimate of the total mass of living plant or animal materials

2. Changes in community/ecosystem structure
   - biomass
   - abundance
   - biotic indices (e.g. trophic types)
   - species richness / diversity
   - dominance
   - food chain length/complexity

1.15 Chemicals of Ecotoxicological Interest

Ecotoxicological studies are ideal models of disturbance, particularly regarding frequency, intensity or multitude of stress. Patterns of secondary succession after a major chemical damage can directly be related to the intermediate disturbance hypothesis[13]. Hazard and risk evaluation of polluted soil samples are generally performed by means of physical and chemical measurements, but chemical analysis alone may not be sufficient for biological assessment[14].

Chemical contamination can affect the genetics of natural populations in two ways: overall genetic variability is decreased by population bottlenecks or by appearance of new mutations[8]. Even a single chemical application might result in sturdy effects on abundance and diversity, observable long beyond the detectability of the compound[15]. Recurrent or harsh disturbances may reduce biodiversity dramatically, including whole functional groups[16].

- They are toxic and in many cases their metabolites are also harmful e.g. DDT & DDE (metabolite of DDT)
- They are very stable both chemically and environmentally
- Their stability has lead to their persistence and ubiquitous nature in the environment
- Almost all chemicals of ecotoxicological interest are available biologically and in

most cases undergo bioaccumulation and biomagnification (food chain)

1.16 Chemical Behavior and Bioavailability

Bioavailability: It is the fraction of a chemical that is in an available form to an organism e.g. fish: food, absorption from water

a) Bioconcentration (from external environment)

Where the chemical concentration in an organism exceeds the concentration in the surrounding media (i.e. aquatic environment) as a result of exposure through the respiratory surfaces (i.e. gills/dermal surfaces) - not food!

$$\text{Bioconcentration Factor} = \frac{\text{Conc. in organism}}{\text{Conc. in ambient medium (usually water}}$$

b) Bioaccumulation (from external environment/food)

Environmental persistence can alone does not make a chemical problematic in the environment. If the chemical cannot enter the body of organisms, then it would pose no threat to toxicity. Once absorbed, the chemical must accumulate in the body to sufficient levels to elicit toxicity. Bioaccumulation is defined as the process by which organisms accumulate chemicals both directly from the abiotic environment (i.e., water, air, soil) and from dietary sources (trophic transfer). Environmental chemicals are largely taken up by organisms by passive diffusion, where the chemical concentration in an organism achieves a level that exceeds that in the water/media as a result of chemical uptake through all routes of exposure. It should be noted that bioaccumulation is typically much greater from water than from food, and it is unlikely that an organism would accumulate a chemical to the same degree from both sources.

$$\text{Bioaccumulation factor} = \frac{\text{Conc. in organism}}{\text{Conc. in food (or ingested water)}}$$

Bio-accumulation of Cadmium is higher than most metals as it is assimilated rapidly and excreted slowly and it depends on the rate of excretion

Factors that influence bioaccumulation

- Environmental persistence
- Lipophilicity
- Biotransformation

c) Biomagnification (at higher tropic level)

Biomagnification can be defined as the chemical concentration in an organism achieves a level that exceeds in the organism's diet due to dietary absorption i.e. higher trophic levels accumulate more chemical (fig5).

$$\text{Biomagnification Factor} = \frac{\text{Conc. in predator}}{\text{Conc. in prey}}$$

1.17 Ecosystems: Terrestrial

The ecotoxicology mainly developed as terrestrial toxicology and aquatic toxicology, terrestrial ecotoxicology studies lag behind aquatic ones, as stated already 20 years ago by van Straalen and Denneman (1989)[17,18]. Soils are more and more becoming sinks for a wide variety of hazardous pollutants generated by human activities. Pollutants which are a cause of concern comprise polycyclic aromatic hydrocarbons (PAH) which are residues from coke production, combustion, petroleum refining, and other high-temperature industrial processes[19].

There are many reports that have shown short-term or long-term exposure to toxic metals results in the reduction of microbial diversity and activities in soil[20,21]. Diversity and activity of microbial communities are important indices of soil quality.

The basic and first purpose of ecological investigations is to explain and understand natural phenomena, ecological processes and therefore the resulting abundance, diversity and interactions of species[22]. Effects of chemicals on soil organisms may differ with further factors like temperature, drought, soil properties or vegetation[15,23,24], however the combination of biotic, abiotic and anthropogenic stress factors is still widely not explored. Since multiple stress may be the rule (e.g., metabolites, climate change), ecological research should focus on this. Mangrove ecosystems are one of the most threatened tropical environments though it has recently received ecological and socioeconomic importance.

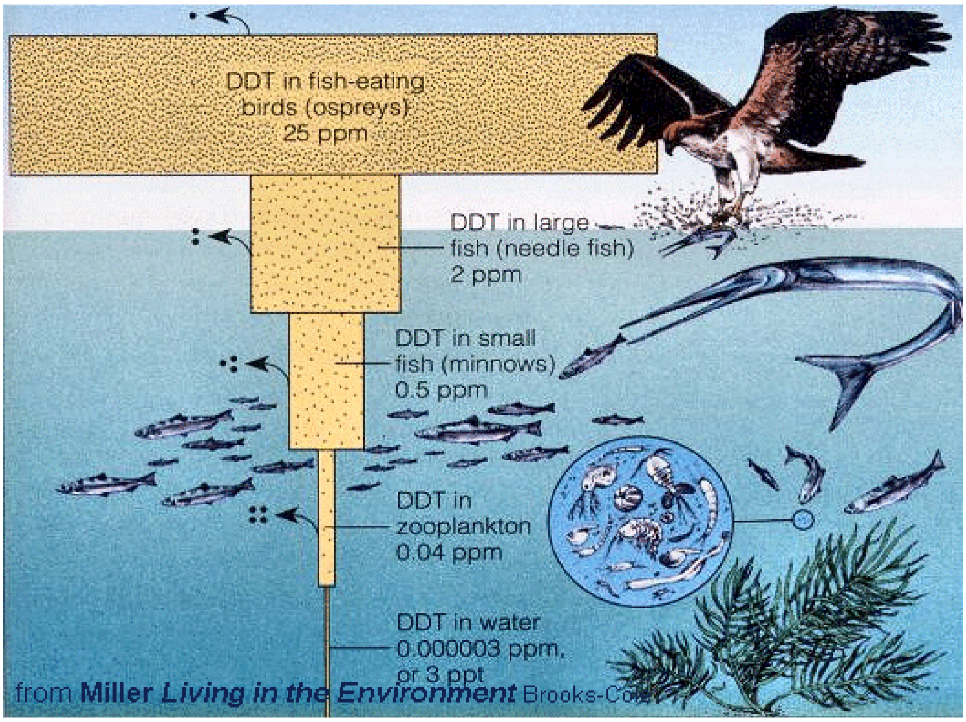


Fig 5: Stages in biomagnification (Miller living in the environment, Brooks-co)

Besides direct clearance certain factors like hydrological alterations, climatic changes or insect infestations, chemical pollution could be a significant contributor of mangrove degradation[25].

1.18 Soils are contaminated by

a) Metals and radioactive isotopes resulting from industrial, mining or other activity or deposition from agricultural practices such as application of

- metal-containing pesticides or
- metal-contaminated sewage sludge
- Wet or dry deposition from smelting activity, lead-containing car exhaust, atmospheric nuclear weapon testing or accidents such as Chernobyl.
- Contamination of soils by radioactive materials is largely due to nuclear weapon testing (Australian and Nevada deserts)

1.19 Mobility of metals in soils is dictated argely by

- clay content
- amount of organic matter
- pH

In general the higher the clay and/or organic matter content and pH, the more firmly bound are the metals and the longer is their residence time in soil. Change in behavior may result in decreased population growth, alterations of ecosystem processes and shifts in interspecies interactions. When ecosystem engineers or friend of farmer such as earthworms emigrate from or do not re-colonize at a polluted site, this will result in loss or reduction of a number of vital functions, i.e., in degradation of soil quality[26,27]. Acid rain helps in leaching nutrient (magnesium in European soil) from top to lower soil (inaccessible to root system)

1.20 Ecosystem: Aquatic

Ecology in aquatic toxicology focuses on the interactions between organisms, abundances of organisms and distributions, the functioning of biological populations, communities and processes that affect all these parameters[28]. The persistence and success of populations that require all ontogenetic stages to be completed successfully and, due to their sensitivity to environmental stressors, planktonic stages may be a population bottleneck in a changing ocean[29]. The aquatic environment receives daily considerable amounts of environmental pollutants that have the possibility to cause oxidative stress in aquatic organisms via free radical and ROS (reactive oxygen species) mechanisms. The uptake of these pollutants by aquatic organisms can occur from sediments, suspended particulate matter with toxic properties, and food sources. Exposure to these contaminants will depend on the particular dietary and ecological lifestyles of the aquatic organisms[30].

Ecotoxicology is being used to identify the marine invertebrate developmental stages that are vulnerable to climate change. Due to direct pH effects ocean acidification has negative impacts on development, hypercapnic suppression of metabolism and is a major threat to marine calcifiers because acidification decreases carbonate saturation with a negative impact on skeleton formation[31, 32, 33. 34, 35 36, 37, 38 and 39]. Marine ecotoxicology is nowadays addressing a new challenge to assess the impacts of an emerging suite of stressors, ocean warming, acidification and hypercapnia[40].

Aquatic organisms are more susceptible to exposure and toxicity as compared to terrestrial organisms including mammals and in this respect they may provide experimental data for evaluation of slight effects of oxidative stress, mutagenicity, and other adverse effects of pollutants[41].

- The ultimate "sink" for metal is the ocean but difficult to estimate effect on biota due to massive dilution
- Effect of metals on biota is much felt in estuaries especially those receiving water from contaminated sites
- In estuaries the flow rate diminishes, suspended sediments settled and dissolved metals precipitated
- Contaminated water affect organisms living in it, because of their high sensitivity to pollutants[11], marine invertebrate gametes and embryos have long served as a model system for marine ecotoxicology[42,43,44,45].
- Aquatic ecosystems are often impacted by chemical pollution, originating from municipal and industrial waste water effluents (point sources), airborne deposition as well as runoff from urban and agricultural areas (diffuse sources). Acutely toxic events—most notably fish kills—which were relatively common a few decades ago, are now rarely observed in most industrialized countries, however, even sub lethal toxicity can lead to severe impacts on entire populations.

Chief ecological paradigms have been developed which includes the controversial[46]. keystone species concept[47]; community flexibility/ecologically alternative states[48]; and the influence of biotic factors (carnivores and herbivores) on patterns of biomass[49]. The keystone species concept, if correct, may be particularly useful for aquatic ecotoxicology as will be discussed later. A keystone species is simply a species whose impact on its community or ecosystem is disproportionately large relative to its abundance[50], thus its loss from or addition to a system would change community composition, structure or function that is sufficient to stimulate concern[46]. Keystone species differ from species that are dominant in terms of biomass or abundance, which latter are critical for the maintenance of the structure and dynamics of communities. However, keystone species may not exist in all environments. For example, in wetland plant communities the relative importance of a species to community structure and function is strongly correlated with the species' overall abundance, and there is a great deal of functional redundancy within guilds of wetland plant species [1].

Toxic effects

- The biochemical (molecular in nature) or physiological (observed at organ and whole organism levels) changes which adversely affect individual organisms' birth, growth or mortality rates.
- Both biochemical and physiological changes could lead to behavioral (whole organism level) changes

Example: Stages

The pollutant binding to a receptor

↓

Followed by biochemical response at both cellular and organ levels

↓

Leading to physiological responses

↓

Finally, behavioral changes on the individual leading to effects on the population, community and the ecosystem.

1.21 Behavioral Effects

- Migration
- Intra specific attraction,
- aggregation,
- aggression,
- predation,
- vulnerability,
- mating

1.22 Binding:

- Reversible vs. Irreversible binding
- Irreversible binding (covalent) causes harmful effects.

1.22.1 Types of bonding:

Covalent > ionic > Hydrogen binding > Vander waals > hydrophilic

1.22.2 Biochemical Responses:

- Biochemical response could be **protective or non-protective** (may or may not cause harmful effect).
- Non-protective biochemical responses have Carcinogenic, Mutagenic, Teratogenic and Neurotoxic potentials.

1.22.3 Protective Biochemical Responses:

- Monoxygenase (OCs and PAHs)
- Induction and binding to metalothionein (Cu, Cd, Zn and Hg)
- Binding to blood plasma, bones and hair (Metals and xenobiotics)
- Dissolving in fat (organics- e.g. OCs)
- Mineralization (e.g. MeHg to Hg 2+)
- Demineralization (As to MeAs)
- Heavy metals for example can be stored and detoxified by organisms either by binding to specific proteins e.g. metallothioneins (-SH proteins)
- In some cases it is mineralized to inorganic form, which is less toxic: e.g. Hg bound to Se is a mineralized Hg (detoxified Hg: MeHg to Hg). On the other hand, the inorganic form, which is more toxic can be methylated to a less toxic form e.g. As.

1.23.1 Biotic Mode of Action (Receptors)- Chemicals That Interfere With Biochemical Receptor Sites

- Signaling
- proteins in membranes
- Replication
- Protein synthesis

1.23.2 Chemicals That Damage Biochemical or Molecular Targets

- DNA damage
- Strange breakage
- Chromosome abnormalities
- Cancer
- Non-genotoxic effects such as immunosuppressant

Phase 1: Reaction.

- Organic pollutants could also be metabolized and detoxified by Cytochrome P450 enzymes (Microsomal Monoxygenase; MMO).

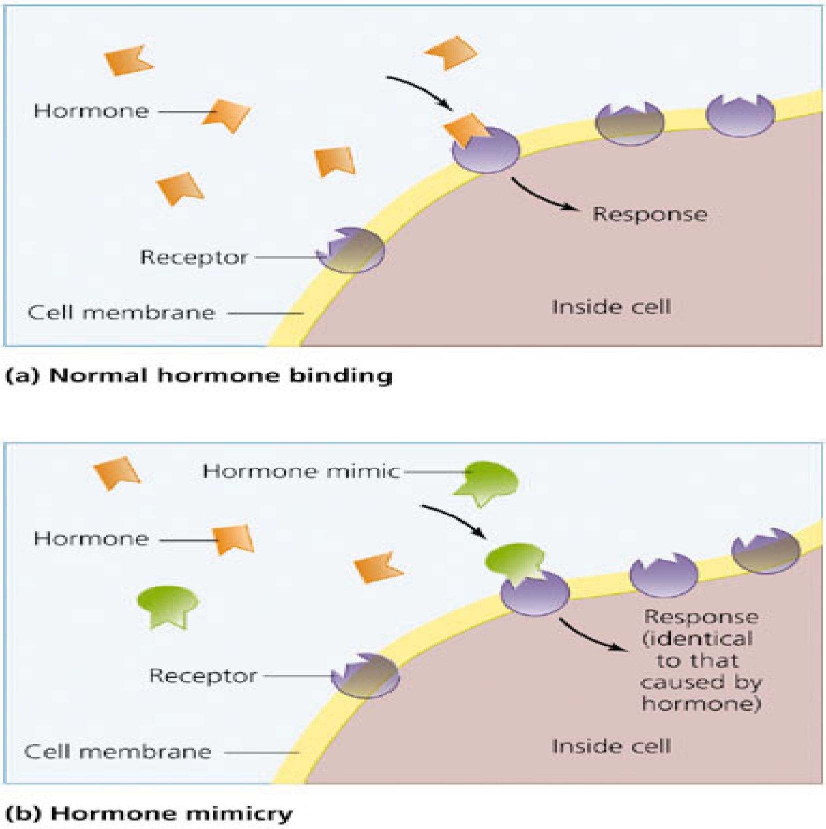


Fig 6: Endocrine Disruption

Phase 2: Reactions

- The metabolites undergo conjugation with endogenous molecules e.g. GSH.
- For some chemicals the metabolites/conjugated form are more toxic than the parent compound and can lead to cancer formation.

1.22.3 Non protective responses

- Binding to DNA (DNA adduct)
- DNA Structural damage (strands break) induced by genotoxic compounds
- Binding to SH-Protein (Protein adduct); enzymes and proteins
- Neurotoxicity: prolongation of K and Na flow and inhibition of AChE activity in the brain
- Mitochondrial Poison (lost of proton gradient)
- Inhibition of vitamin K cycle (competition with vit K binding site)
- Inhibition of Thyroxin (competition with thyroxin binding site)
- Inhibition of ATPase (enzymes for transport of ions e.g. K, Na, Ca)
- Environmental Estrogens (eg DDT) and androgens (tributhyl Tin)
- Endocrine disrupters (binding to endocrine receptors), fig.6.
- Photosystems of Plants (interruption of electron flow)
- Plant growth regulation.

1.22.4 Physiological Change

Non-protective biochemical responses lead to Physiological changes which could be observed at organ and organism levels

1.22.4.1 Organ level:
- accumulation of Cd in kidney, which could cause cell death (cytotoxicity), resulting in dysfunction of the kidney
- PAHs and Lung cancer

The bioavailability of PAH compounds is noticeably affected by soil properties and the ageing of soils[51,52,53]. Although PAHs are responsible for the contamination of a wide range of industrial soils, ecotoxicological data on PAH-contaminated soils is rare[54].

1.22.4.2 Organism Level:
- Decrease in production (growth and reproduction)
- Changes in gene frequency
- decrease in resources acquisition and uptake

1.22.5 Behavioral Changes
- Either or both physiological and biochemical effects could lead to behavioral effects at organism level-e.g. caring for young ones and avoidance of predator.

Biochemical, Physiological and Behavioral effects on the individual organism culminate effects observed at the Population, Community and Ecosystem levels.

1.22.6 Population Changes
- Changes in population may come about as a result of direct changes in numbers of individual organism and gene frequency (resistance)
- By indirect means (decrease in population of predators due to toxic chemicals could lead to increase in numbers of its prey).

1.22.7 Changes in Community Structure
- change in phytoplankton assemblage due to eutrophication
- acid rain affecting microorganisms in the soil, aquatic life.

1.22.8 Changes in Ecosystem Level (earth as an ecosystem)
- Carbon dioxide increase and ozone depletion
- Decrease in the suitability of the abiotic component as a habitat for the biotic components of the ecosystem, which have been naturally established and adapted to that ecosystem
- Detrimental impact on part of the biotic component (vulnerable species) as related to the intensity and type of pollution
- Alteration to the community structure and in most cases, there is a declined in the number of species present
- Matter and Energy flow within the ecosystem changes
- Removal of larger organisms with longer life spans
- The appearance of opportunistic species with short life spans exhibiting large population fluctuations in time and space

1.22.9 Ecological Risk Assessment has three primary phases
Three aspects of ecotoxicological risk assessment are introduced[13]:
- Exposure and bioavailability, which is directly connected to environmental heterogeneity;
- Tests on ecosystem functioning, suffering from major drawbacks; and
- Modelling.

Modelling has been widely used for assessing fate and distribution of chemicals (e.g., 55), but only few attempts exist for predicting their hazardous potential for soil organisms.
Risk is defined as the probability of some adverse consequence occurring to an exposed human or to an exposed ecological entity. Risk assessment is technical support for decision making under uncertainty or the process by which one estimate the probability of some harmful effects of a present or planned release to either human or ecological entities. Though the future is unpredictable but one can estimate the likelihood of alternative outcomes of an action. Risk

assessment is used when a decision must be made that has uncertain outcomes were resulting from varying conditions or uncertainty concerning the nature of the situation. Risk assessment estimates the absolute or relative probabilities of prescribed negative outcomes of alternative choices.

In order to estimate risk associated with metal toxicity to human health from the intake of metal contaminated vegetables was characterized using hazard quotient (HQ). HQ is a ratio of determined dose of a pollutant to the dose level (a reference dose or R_fD). If the ratio is less than 1, there will not be any obvious risk[56]. Though the HQ-based risk assessment technique does not provide a quantitative estimate on the probability of an exposed population experiencing a reverse health effect, it indeed provides an indication of the risk level due to pollutant exposure. This risk estimation method has recently been used by researchers[57,58] and proved to be valid and useful. An estimate of the potential hazard to human health (HQ) through consumption of vegetables grown on metal-contaminated soil was calculated using the equation below:

$$HQ = \frac{[W_{plant}] \times [M_{plant}]}{R_fD \times B}$$

Where,
W_{plant} is the dry weight of contaminated plant material consumed (mg d^{-1}),
M_{plant} is the concentration of metal in the vegetable(s) (mg kg^{-1})
R_fD reference dose for the metal (mg d^{-1})
B is human body mass (kg).

A risk assessment is different from hazard assessment; a hazard assessment compares the expected environmental condition (EEC) to some estimated threshold effect (ETT) with the intent of deciding. A risk assessment is like a hazard assessment except that it has as its goal the generation of a quantitative estimate (probability) of some adverse effect occurring[59].

1.23 Aspects of Ecological Risk Assessment:

- Problem formulation
- Analysis
- Risk characterization

1.24 Categories of Risk Assessment

- Retroactive risk assessment- it deals with an existing condition for example a contaminated seepage basin and
- Predictive risk assessment- it deals with a planned or proposed condition, such as planned discharge of a waste. In some cases it also deals with future consequences of an existing situation or might be framed as comparative risk assessment.

1.25 Data Required to Conduct an Ecological Risk Assessment Include the Following:

Ecological risk assessment (EIA) is fretful with assessing risks to non human populations, organisms or ecosystems. It includes problem formulation, an analysis of exposure and of the relationship of exposure to response and characterization of risks. It is associated to the risk management process at the commencement when the problem to be assessed and the goals of the assessment are defined and at the end when results are communicated.

- Toxicity to wildlife, aquatic organisms, plants, an non target insects
- Environmental fate
- Environmental transport
- Estimated environmental concentrations
- Where and how the pesticide will be used
- What animals and plants will be exposed
- Climatologic, meterologic, and soil information

1.26 Ecotoxicological Evaluation

Any unfavorable effect of a chemical upon an ecosystem can be called as a disturbance (Van Straalen, 2003) fig7. In order to determine the predicted no effect concentration (PNEC) which is required for characterization of risk can be calculated by dividing effective concentration (EC50) by assessment factor whereas predicted effect characterization or PEC by using following calculation:

Environmental Exposure- PEC calculation(predicted environmental concentration)
PEC (g/l) = (A. (100-R))/(365.P.V.D.100)
A(kg): amount of drug used per year per specific area
R%: Removal rate (adsorption, biodegradation, volatilization)
P: Number of inhabitants human or animals
V (m^3): Volume of waste water per capita per day
D: Factor of dilution of waste water by waste water flow

a) Laboratory evaluation- international water and soil model and PNEC (predict no effect concentration.)

PNEC = EC/AF

EC: Effect concentration determined as EC_{50} or LC_{50} in several test organisms
AF: Assessment factor

b) Field evaluation- Conformation and monitorisation studies with use of bioindicators and biomarkers.

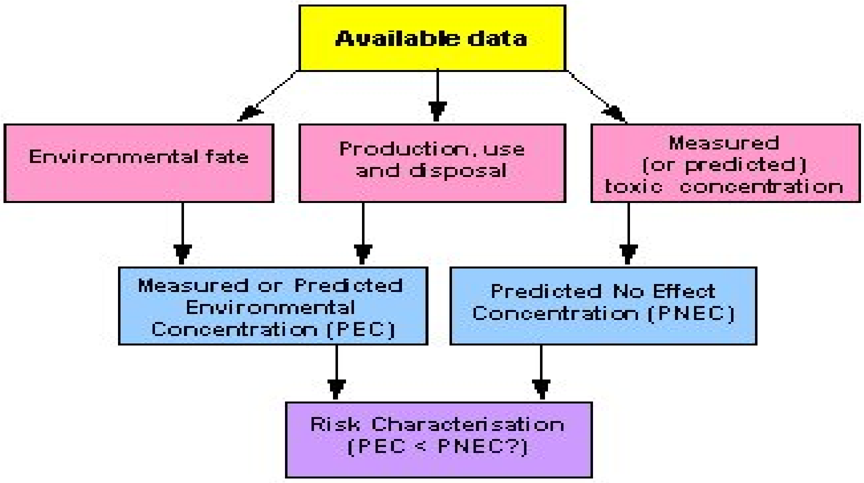


Fig 7: Ecological Risk Assessment

In essence the risk assessment compares the expected environmental exposure to a chemical with the amount needed for a harmful effect: the predicted environmental concentration (PEC) is compared with a predicted no effect concentration (PNEC).

2. Case Study

The distribution of heavy metals in aquatic organisms of different trophic levels in Taihu system exhibited a clear pattern in all lake areas, i.e., metal concentrations in phytoplankton> zooplankton> zoobenthos> fish, and the essential elements such as zinc and copper have a much higher concentration in organisms than non-essential elements such as chromium, lead, and cadmium.

This distribution is controlled by the nature of organisms and the interaction between environmental concentrations of metal elements and resident organisms.
Spatially, plankton and zoobenthos in north and west lake areas have a higher concentration than in east and south lake areas for many metals. This is mostly related to river inputs of metals from wastewater. Bio-concentration factor (BCF) is used to evaluate the ability of the aquatic organism to accumulate chemicals from the water environment.

Bio-concentration factor (BCF) was used to evaluate bioaccumulation of metal elements in organisms and it can also be used for field investigation data (USEPA,1991). It is calculated by

$$BCF = C_{org}/ C_w$$

Where C_{org} is the concentration of the metal element (wet weight) in the muscle of organisms;
C_w is the concentration of the metal element in water environment.

The BCF value is an average of the entire lake for each species. If BCF>1, it indicates that the organism has a potential to accumulate the chemical but is generally not considered to be significant unless the BCF exceeds 100 or more[60]. The calculation of BCF of metals for different organisms indicated that the primary producer bio-concentrated more metals than higher trophic organisms, and lead and zinc were the most bio concentrated element in all organisms. Although fish products from the lake are generally safe based on the potential health risk assessment, the consumption of Bellamya sp. should be very cautious especially for the local fishermen who consume this much more than the rest of the population. In summary, this work provides a comprehensive status of heavy metals in aquatic organisms of different trophic levels from Taihu lake, and provides a comparison with international results, which would be useful for local governments to refer and develop their own water quality criteria. Aquatic organisms of different trophic levels were taken from Taihu lake. Heavy metals (Cu, Zn, Cr, Ni,Cd, Pb) were measured in phytoplankton, zooplankton, in two species of zoobenthos, and in eight fish species, as well as in the water column and bottom sediments. Results showed that the concentration of Cu and Zn for all organisms was much higher than for other metals, and Cd was the lowest in all species. Generally, heavy metal concentrations in phytoplankton were higher than in zooplankton. In zoobenthos, the concentration in Bellamya sp. (human edible snail) was higher than that in Corbiculidae (bivalve). Metal concentrations had no significant difference between fish species but tended to be higher in predator fish such as Coilia ectenes and Erythroculter ilishaeformis than in herbivorous fish. The level of measured metals in Taihu fish was moderate-low compared with that of fresh water fishes from international results. Spatially, metal concentrations in organisms were higher in the north and west Taihu lake but lower in south and east lake and this appears to be related to river inputs that are heavily influenced by anthropogenic activities. The bio-concentration factor (BCF) for all aquatic organisms in the food chain indicated that it was generally highest in planktons, followed by zoobenthos, and lowest in fish. Fish from Taihu lake is an important commercial aquatic product in the Yangtze Delta regions. In addition, Bellamya sp. (edible snail), a benthic organism, is a favorite daily food for local people. Therefore, it is necessary to assess the potential health risks caused by the consumption of local aquatic products. Health risk assessment and comparison with national and international standards showed that consumption of aquatic products from the lake was generally safe but fishermen were a higher risk group especially through dietary intake of Bellamya sp.

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