Ecological Effects of Pesticides

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1. Introduction

1.1 Definition of ecology

At a community level, ecology can be defined as complex interactions that exist among interdependent organisms that cohabitate the same geographical area and with their environment (Johnson and Strinchcombe, 2007). At individual level, it entails the relationships that exist between that particular individual with numerous physical and biological factors. The physical environment along with organisms (biota) inhabiting a particular space make up an ecosystem. Some typical examples of ecosystems include a farm pond, a mountain meadow and rain forest. In a natural environment, an ecosystem follows a certain sequence of processes and events through the days, seasons and years. The processes include not only the birth, growth, reproduction and death of biota in that particular ecosystem, but also the interactions between species and physical characteristics of the geological environment. From these processes and interactions, the ecosystem gains a recognizable structure and function, and matter and energy are exchanged and cycled through the ecosystem. Over time, better adapted species come to dominate; entirely new species may change, perhaps in a new or altered ecosystem.

1.2 The organisation in ecosystems

The basic level of ecological organisation is with the individual such as a single plant, insect or bird. The definition of ecology is based on the interactions of organisms with their environment. In the case of an individual, it would entail the relationships between that individual and numerous physical (rain, sun, wind, temperature, nutrients, etc.) and biological (other plants, insects, diseases, animals, etc.) factors. The next level of organization is the population. Populations are no more than a collection of individuals of the same species within an area or region. We can see populations of humans, birch trees, or sunfish in a pond. Population ecology is concerned with the interaction of the individuals with each other and with their environment.

The next, more complex, level of organization is the community. Communities are made up of different populations of interacting plants, animals, and microorganisms also within some defined geographic area. Different populations within a community interact more among themselves than with populations of the same species in other communities, therefore, there are often genetic differences between members of two different communities. The populations in a community have evolved together, so that members of that community provide resources (nutrition, shelter) for each other.

The next level of organization is the ecosystem. An ecosystem consists of different communities of organisms associated within a physically defined space. For example, a forest ecosystem consists of animal and plant communities in the soil, forest floor, and forest canopy, along the stream bank and bottom, and in the stream. A stream bottom community, for example, will have various fungi and bacteria living on dead leaves and animal wastes, protozoans and microscopic invertebrates feeding on these microbes, and larger invertebrates (worms, crayfish) and vertebrates (turtles, catfish). Each community functions somewhat separately, but are also linked to others by the forest, rainfall, and other interactions. For example, the stream community is heavily dependent upon leaves produced in the surrounding trees falling into the stream, feeding the microbes and other invertebrates.

Terrestrial ecosystems can be grouped into units of similar nature, termed biomes (such as a "deciduous forest," "grassland," "coniferous forest," etc.), or into a geographic unit, termed landscapes, containing several different types of ecosystems. Aquatic ecosystems are commonly categorized on the basis of whether the water is moving (streams, river basins) or still (ponds, lakes, large lakes) and whether the water is fresh, salty (oceans), or brackish (estuaries). Landscapes and biomes (and large lakes, river basins, and oceans) are subject to global threats of pollution (acid deposition, stratospheric ozone depletion, air pollution, the greenhouse effect) and human activities (soil erosion, deforestation, pesticides use).

1.3 Why pesticides are unique among environmental contaminants

Pesticides released into the environment may have several adverse ecological effects ranging from long-term effects to short-lived changes in the normal functioning of an ecosystem. Despite the good results of using pesticides in agriculture and public health, their use is usually accompanied with deleterious environmental and public health effects. Pesticides hold a unique position among environmental contaminants due to their high biological toxicity (acute and chronic). Pesticides by definition are toxic chemical agents. A pesticide is usually capable of harming all forms of life other than the targeted pest species. On account of this behavior then, they can best be described as biocides (capable of killing all forms of life). Although some pesticides are described to be selective in their mode of action, their range of selectivity is only limited to the test animals.

1.4 The vast potentials of pesticides distribution and fate in the environment

The term chemodynamics of pesticides refers to the study of the movement and transformation of pesticides as well as their fate in various compartments of the environment. The environment can be divided into four major compartments, namely; air, water, soil and biota (Fig.2. 1).

The widespread use and disposal of pesticides by farmers, institutions and the general public provide many possible sources of pesticides in the environment. Pesticides once released into the environment may have many different fates. Pesticides that are sprayed can move through the air and may eventually end up in other parts of the environment, such as in soil or water. Pesticides that are applied directly to the soil may be washed off the soil into nearby bodies of surface water or may percolate through the soil to lower soil layers and groundwater (Harrison, 1990). This incomplete list of possibilities suggests that the movement of pesticides in the environment is very complex with transfers occurring continually among different environmental compartments. In some cases, these exchanges occur not only between areas that are close together (such as a local pond receiving some of the herbicides applied on adjacent land) but also may involve transportation of pesticides over long distances. The worldwide distribution of DDT and the presence of pesticides in bodies of water such as the Great Lakes far from their primary use areas are good examples of the vast potential of such movement.

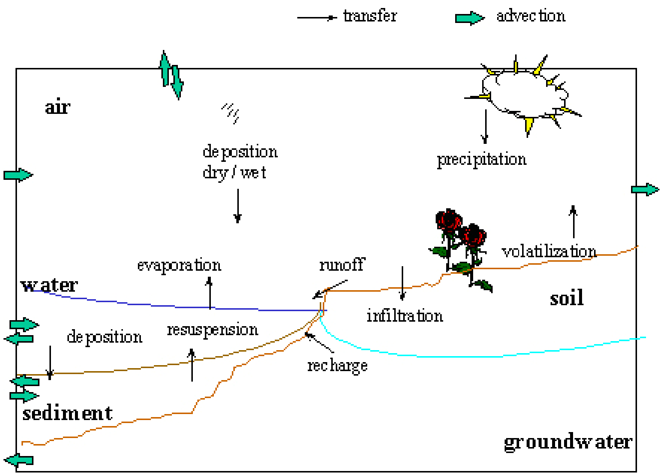

Fig. 2.1 Distribution of pesticides in different environmental compartments

In this chapter, a closer and detailed look on the major ecological effects of pesticides are described based on contemporary accumulated knowledge on the behavior of pesticides and the damage they cause to the ecosystem and the environment at large as a result of excessive use and/ or injudicious use of pesticides. The effects may range from minor deviation on the normal functioning of the ecosystem to the loss of species diversity in the ecosystem. Since organisms in the ecosystem live in a complex interdependent association with each other, the loss one key species may result in the collapse of the particular ecosystem. These effects are an important reason for the current strict regulations on the judicial use of pesticides.

2. Ecological effects of pesticides

The primary objective of using pesticides in the fields and the environment in general is to achieve a control of crop pests and disease vectors. This has been a deliberate human effort in a search for increasing agricultural yields and improving public health (Helweg, 2003). Pesticides applied to the environment have shown to have long term residual effects while others have shown to have acute fatal effects when not properly handled. Organochlorine pesticides for example have shown to be persistent in the environment, the result of which find their way to contaminate ground water, surface water, food products, air, soil and may affect human being through direct contact. Pesticides exposure to humans have been well documented to be the route cause of some diseases such as cancer, respiratory diseases, skin diseases, endocrine disruption, and reproduction disorders. It is this aspect of pesticide in the environment that has raised concern among environmental scientists to study their behaviour in the environment and then come out with a sound alternative so as to rescue the human population from their adverse effects.
Fifty years (half a century) after Rachel Carson’s eloquent warning to the world about the devastating effect pesticides have on birds and beneficial insects, pesticides continue to be

a pervasive and insidious threat to the world's ecosystems. A massive chemical assult on our environment is launched each year. This poisonous barrage aggravates other pressures on our ecosystems such as expanding suburbarn development and dammed rivers, threatening the survival of many birds, fish, insects, and small aquatic organisms that form the basis of the food web. More generally, pesticides reduce species diversity in the animal kingdom and contribute to population decline in animals and plants by destroying habitats, reducing food supplies and impairing reproduction (Kegley, *et al*, 1999).

2.1 Loss of species diversity among the food chains and food webs

Organisms in ecosystems exist in complex interdependent associations such that losses of one keystone species as a result of pesticides (or other causes) can have far reaching and unpredictable effects. A keystone species is a species that is disproportionately connected to more species in the food-web. The many connections that a keystone species holds means that it maintains the organization and structure of entire communities. The loss of a keystone species results in a range of dramatic cascading effects that alters trophic dynamics, other food-web connections and can cause the extinction of other species in the community. Sea otters (*Enhydra lutris*) for example, are known to be keystone species in marine ecosystems that limits the density of sea urchins (Mills, *et al*, 1993).

A pesticide may eliminate a species essential to the functioning of the entire community, or it may promote the dominance of undesired species or it may simply decrease the number and variety of species present in the community. This may disrupt the dynamics of the food webs in the community by breaking the existing dietary linkages between species. The literature on pest control lists many examples of new pest species that have developed when their natural enemies are killed by pesticides. This has created a further dependence on pesticides. Finally, the effects of pesticides on the biodiversity of plants and animals in agricultural landscapes, whether caused directly or indirectly by pesticides, constitute a major adverse environmental impact of pesticides.

2.2 Effects involving pollinators

Some natural pollinators, such as honeybees and butterflies, are very sensitive to pesticides. Pesticides can kill bees and are strongly implicated in pollinator decline, the loss of species that pollinate plants, including through the mechanism of Colony Collapse Disorder (Hackenberg, 2007), in which worker bees from a beehive or Western honey bee colony abruptly disappear. Application of pesticides to crops that are in bloom can kill honeybees, which act as pollinators. The USDA and USFWS estimate that US farmers lose at least $200 million a year from reduced crop pollination because pesticides applied to fields eliminate about a fifth of honeybee colonies in the US and harm an additional 15% (Miller, 2004).

Since these are important pollinators of both crops and native plants, reduced number of natural pollinators can therefore result into reduced seed and fruit production. This is both an ecological effect as well as economical effect. Bees are extremely important in the pollination of crops and wild plants, and although pesticides are screened for toxicity to bees, and the use of pesticides toxic to bees is permitted only under stringent conditions, many bees are killed by pesticides, resulting in the considerably reduced yield of crops dependent on bee pollination.

Fig. 2.2 A butterfly and bee as representative natural pollinating agents for plants

2.3 Effects on nutrient cycling in ecosystem

A large proportional of pesticides used in the environment ultimately reaches the soil where soil building processes and the cycling of nutrients back into living plants is accomplished. Pesticides can affect the soil organisms involved in these processes directly or indirectly hence interfering with the natural nutrient cycling in the ecosystem.

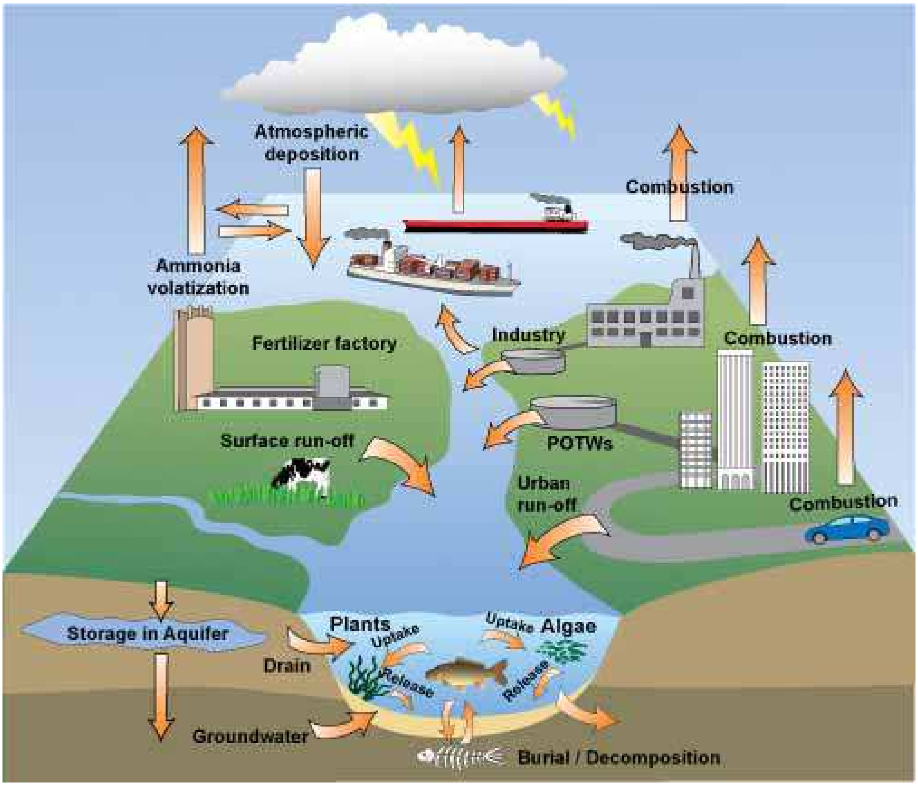

Fig. 2.3 Nutrient cycling in ecosystem

Nitrogen fixation, which is required for the growth of higher plants, is hindered by pesticides in soil. The insecticides DDT, methyl parathion, and especially pentachlorophenol have been shown to interfere with legume-rhizobium chemical signaling. Reduction of this symbiotic chemical signaling results in reduced nitrogen fixation and thus reduced crop yields (Rockets, 2007). Root nodule formation in these plants saves the world economy $10 billion in synthetic nitrogen fertilizer every year (Fox, 2007). When the natural nutrient cycling (figure 2.3) in the ecosystem is interfered in any way by pesticides or other sources of pollution, it will lead to decline in soil fertility and soil productivity.

2.4 Effects on soil erosion, structure and fertility

Many of the chemicals used in pesticides are persistent soil contaminants, whose impact may endure for decades and adversely affect soil conservation. The use of pesticides decreases the general biodiversity in the soil. Not using the chemicals results in higher soil quality (Johnson, 1986), with the additional effect that more organic matter in the soil allows for higher water retention. This helps increase yields for farms in drought years, when organic farms have had yields 20-40% higher than their conventional counterparts. A smaller content of organic matter in the soil increases the amount of pesticide that will leave the area of application, because organic matter binds to and helps break down pesticides (Lotter, *et al*, 2003).

Herbicides for example can reduce vegetative cover of the ground, thus promoting soil erosion via runoff and wind. Soil erosion deforms the soil structure and therefore creates an imbalance in soil fertility. A bare land with poor soil structure and poor soil fertility cannot support the growth of plants on it. Ecologically this land cannot support other forms of life in it hence may lead to the collapse of the particular ecosystem.

2.5 Effects on water quality

Pesticides applied in the environment can find their way into water bodies either from the air or by runoff or by percolation to groundwater. There are four major routes through which pesticides can reach the water bodies: it may drift outside of the intended area when it is sprayed, it may percolate, or leach, through the soil, it may be carried to the water as runoff, or it may be spilled, for example accidentally or through negligence. They may also be carried to water by eroding soil. Factors that affect a pesticide's ability to contaminate water include its water solubility, the distance from an application site to a water body, weather, soil type, presence of a growing crop, and the method used to apply the chemical. Once pesticides enter water bodies they have a potential to cause harmful effects on human health, aquatic organisms and can cause disruptions of the aquatic ecosystems. This may result into a loss in fish production in streams and large water bodies especially where fishing is one among the major economic activities of a particular community.

In the United States for example, pesticides were found to pollute every stream and over 90% of wells sampled in a study by the US Geological Survey (Gillion, *et al*, 2007). Pesticide residues have also been found in rain and groundwater. Studies by the UK government showed that pesticide concentrations exceeded those allowable for drinking water in some samples of river water and groundwater (Bingham, 2007).

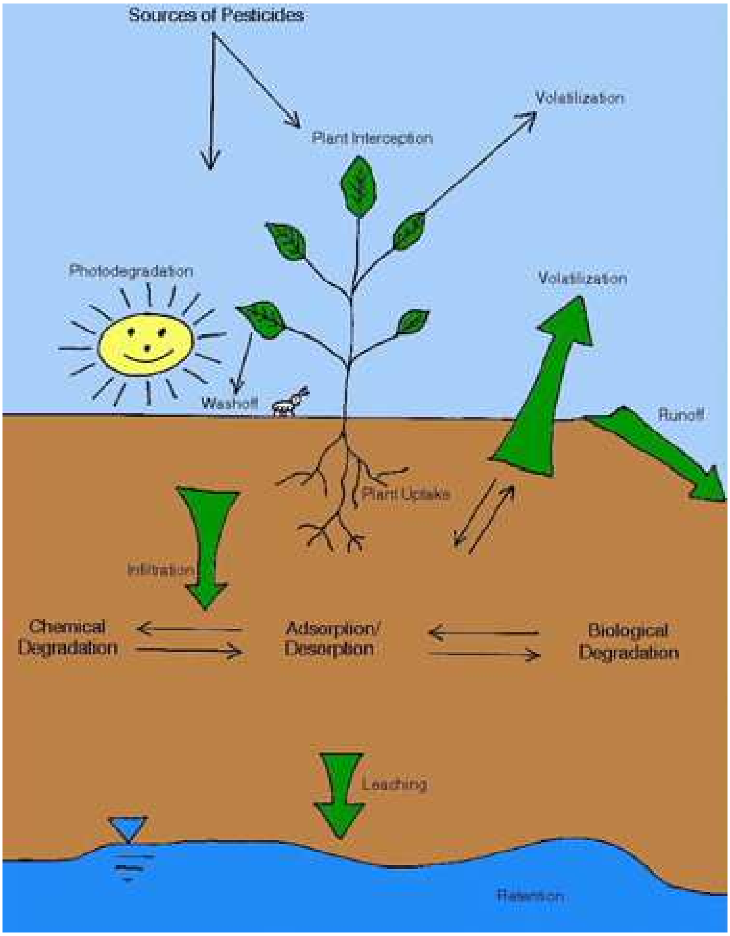

Fig. 2.4 Pesticieds pathways in contaminating water bodies (Heather, *et al*, 1997)

2.6 Effects on birds

Pesticides have had some of their most striking effects on birds, particularly those in the higher trophic levels of food chains, such as bald eagles, hawks, and owls. These birds are often rare, endangered, and susceptible to pesticide residues such as those occurring from the bioconcentration of organochlorine insecticides through terrestrial food chains. Pesticides may kill grain- and plant-feeding birds, and the elimination of many rare species of ducks and geese has been reported. Populations of insect-eating birds such as partridges, grouse, and pheasants have decreased due to the loss of their insect food in agricultural fields through the use of insecticides. The loss of even a few individuals from rare, endangered or threatened species pushes the entire species close to extinction. Some pertinent examples associated with birds' kills as a result of pesticides include the insecticides diazinon and carbofuran which are well document as causing bird kills in many parts of the world (Kegley *et al*, 1999). Organochlorine insecticides such as DDT are also well

documented to have continued impairing avian reproduction even after years of banned use. Most bird kills go undocumented, with reported kills representing only a small fraction of actual bird mortality due to pesticides.
Birds exposed to sublethal doses of pesticides are also afflicted with chronic symptoms that affect their behaviour, reproduction, and nervous system. Weight loss, increased susceptibility to predation, decreased disease resistance, lack of interest in mating and defending territory, and abandoning of nestlings have been observed as side effects of pesticides exposure.

Fig. 2.5 A bird that died as a result of pesticides use (U.S. EPA)

2.7 Effects on fish and other aquatic organisms

A major environmental impact has been the widespread mortality of fish and marine invertebrates due to the contamination of aquatic systems by pesticides. This has resulted from the agricultural contamination of waterways through fallout, drainage, or runoff erosion, and from the discharge of industrial effluents containing pesticides into waterways. Historically, most of the fish in Europe's Rhine River were killed by the discharge of pesticides, and at one time fish populations in the Great Lakes in USA became very low due to pesticide contamination. Additionally, many of the organisms that provide food for fish are extremely susceptible to pesticides, so the indirect effects of pesticides on the fish food supply may have an even greater effect on fish populations. Some pesticides, such as pyrethroid insecticides, are extremely toxic to most aquatic organisms. It is evident that pesticides cause major losses in global fish production. Furthermore, recent laboratory studies of endosulfan and fenitrothion in the tilapia species from Lake Victoria in Tanzania indicated a high capacity of the species to absorb the two pesticides from water with rapid distribution in the organs each with a bioaccumulation factor of 33 and 346 L/kg fresh weight respectively (Henry, 2003).
Multiple pesticides contamination are very common in water and sediments, frequently at concentrations exceeding the lethal limits for many species of zooplankton, small species of animals eaten by fish. Because of the significant high water solubility of the insecticides diazinon and chlorpyrifos and the herbicides simazine, diron, and EPTC are found most commonly in water bodies and have been associated with fish kills and decline in zooplankton population in aquatic environment.

Fig. 2.6. Spraying an aquatic herbicide

2.8 Effects on frogs and other aquatic amphibians

Atrazine being one of the world`s most used pesticide has recently reported by laboratory studies to have a effect on changing male frogs (African clawed frog; *Xenopus laevis*). Adult frogs exposed to atrazine turn female one in ten (10%). These male frogs are missing

Fig. 2.7 Kihansi spray toads from Kihansi Gorge in Tanzania

testesterone and all things controlled by testesterone including sperm production. So their fertility is as low as 10 percent when treated in isolation, but when treated with normal males, they stand a zero chance of reproducing. Although 10 percent of these mutant females can successful mate with male frogs, their offspring are all male because they are genetically male frogs. The ultmate effect of this is that the sex ratios of frogs is badly skewed and this is very dangerous for the survival of that species (Hayes *et al*, 2010).Kihansi spray toads is one among the world`s rarest amphibian species that was close to extinction from their natural environment in Tanzania. The species was first discovered in 1996 during an environment impact study for a large new hydroelectic dam in Udzungwa mountains in Southern Tanzania. The toads lived exclusively in a five acre zone under spray of a waterfall from Udzungwa mountains, hence the name Kihansi spray toads. Among other reasons that contributed to the decline is the use of pesticides in the environment. To rescue this rare species of toads, a colony of them was taken to Bronx zoo and Toledo zoo in USA where they were reared and bread in laboratories for 10 years.

2.9 Pesticides disrupt the natural balance between pest and predator insects

Broad spectrum pesticides such as organochlorine, organophosphorus and carbamate insecticides destroy both pest and beneficial organisms indiscriminately, thus upsetting the natural balance between pests and predator insects. Beneficial organisms serve many valuable functions in an agricultural ecosystem including pollination, soil aeration, nutrient cycling, and natural pest control through pest-predator relationship. Application of insecticides indiscriminately kills both pests and beneficial organisms. Pest populations often recover rapidly because of their lager numbers and ability to develop resistance, but beneficial organisms do not, resulting in a resurgence of the target pest as well as secondary pests that reproduce rapidly without natural predator to check down their numbers. This prompts an escalation in the use of more pesticides by the farmers in an attempt to control them and boost their harvest.

Fig. 2.8 Aerial spraying of pesticides onto the crops using an aircraft

2.10 Pesticides cause pest rebound and secondary pest outbreaks

Non-target organisms, organisms that the pesticides are not intended to be killed, can be severely affected by the use of pesticides. In some cases, where a pest insect has some controls from a beneficial predator or parasite, an insecticide application can kill both pest and beneficial populations. A study comparing biological pest control and use of pyrethroid insecticide for diamondback moths, a major cabbage family insect pest, showed that, the insecticide application created a rebounded pest population due to loss of insect predators, whereas the biological control did not show the same effect (Muckenfuss, *et al* 1990). Likewise, pesticides sprayed in an effort to control adult mosquitoes, may temporarily depress mosquito populations, however they may result in a larger population in the long run by damaging the natural controlling factors. This phenomenon, wherein the population of a pest species rebounds to equal or greater numbers than it had before pesticide use, is called pest resurgence and can be linked to elimination of predators and other natural enemies of the pest (Daly, *et at*, 1998)

The loss of predator species can also lead to a related phenomenon called secondary pest outbreaks, an increase in problems from species which were not originally very damaging pests due to loss of their predators or parasites (Daly, *et at*, 1998). An estimated one-third of the 300 most damaging insects in the US were originally secondary pests and only became a major problem after the use of pesticides (Miller, 2004). In both pest resurgence and secondary pest outbreaks, the natural enemies have been found to be more susceptible to the pesticides than the pests themselves, in some cases causing the pest population to be higher than it was before the use of pesticide.

2.11 Effects on human beings

Pesticides can enter the human body through inhalation of aerosols, dust and vapor that contain pesticides; through oral exposure by consuming contaminated food and water; and through dermal exposure by direct contact of pesticides with skin (Sacramento, 2008). Pesticides are sprayed onto food, especially fruits and vegetables, they secrete into soils and groundwater which can end up in drinking water, and pesticide spray can drift and pollute the air.

The effects of pesticides on human health are more harmful based on the toxicity of the chemical and the length and magnitude of exposure (Lorenz, 2009). Farm workers and their families experience the greatest exposure to agricultural pesticides through direct contact with the chemicals. But every human contains a percentage of pesticides found in fat samples in their body. Children are most susceptible and sensitive to pesticides due to their small size and underdevelopment. The chemicals can bioaccumulate in the body over time. Exposure to pesticides can range from mild skin irritation to birth defects, tumors, genetic changes, blood and nerve disorders, endocrine disruption, and even coma or death (Miller, 2004).

2.12 Pesticides may cause pest resistance

Pests may evolve to become resistant to pesticides as a result of continued use of pesticides in a particular environment. Many pests will initially be very susceptible to pesticides, but some with slight variations in their genetic makeup they become resistant and therefore survive to reproduce. Through natural selection, the pests may eventually become very resistant to the pesticide. Pest resistance to a pesticide is commonly managed through pesticide rotation, which involves alternating among pesticide classes with different modes of action to delay the onset of or mitigate existing pest resistance. Tank mixing pesticides is the combination of two or more pesticides with different modes of action in order to improve individual pesticide application results and delay the onset of or mitigate existing pest resistance.

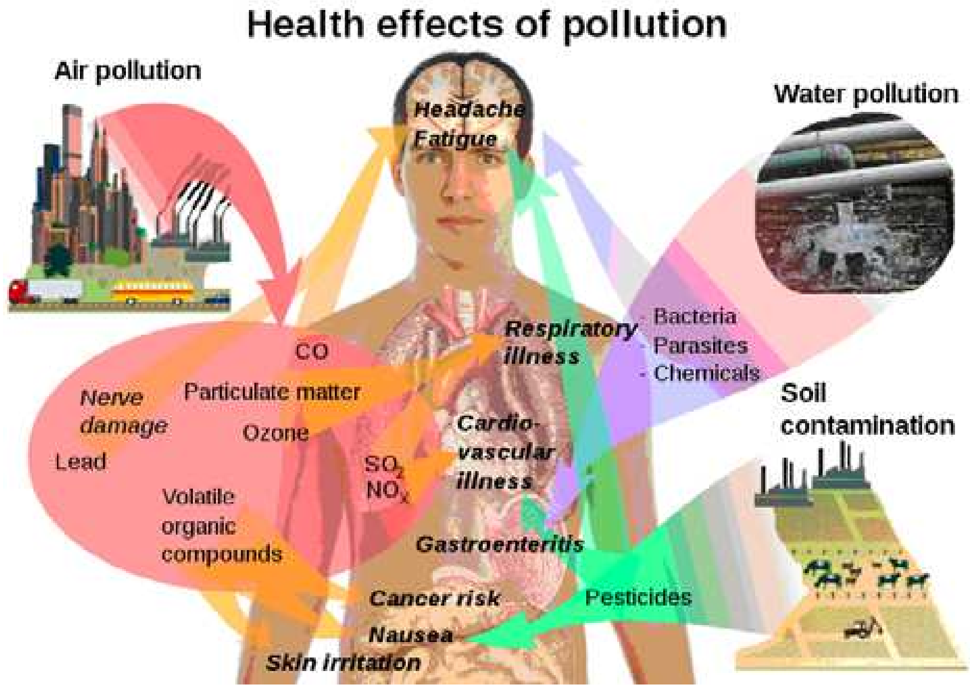

Fig. 2.9 Impacts of pesticides on human health

3. Summary and recommendations

3.1 Summary

In summary, the adverse ecological effects from pesticides occur at all levels of biological organization. The effects can be global or local, temporary or permanent, or short-lived (acute) or long-term (chronic). The most serious effects involve loss in production, changes in growth, development and/ or behavior, altered diversity or community structure, changes in system processes (such as nutrient cycling), and losses of valuable species. These ecological losses in turn may be economically or socially important. Hence, ecological effects are of serious concern in regulating pesticides use and a variety of tests have been devised to help evaluate the potential for adverse ecological effects of pesticides. Developing an understanding of how these tests and other information can be used to prevent environmental problems caused by pesticides is the basis for ecological risk assessment research.

3.2 Recommendations

Pesticides destroy the delicate balance between species that characterize the functioning ecosystem. With pesticides now being found routinely in drinking water, on food and in the air, we are all taking part in an experiment in pesticide exposure on a global scale, but without the benefit of an exposed control group for comparison. For that matter we are likely not be able to quantify the exact risk of these exposures. Because we cannot know for certain the consequences of the expanding pesticides use, the rational and most protective course of action is to take a precaution approach phasing out the use of the most dangerous pesticides, reducing our reliance on toxic chemicals for pest control and promoting ecologically based pest management.

The adverse effects of pesticides on humans and wildlife have resulted in research into ways of reducing pesticide use. The most important of these is the concept of integrated pest management (IPM), first introduced in 1959. This combines minimal use of the least harmful pesticides, integrated with biological and cultural methods of minimizing pest losses. It is linked with using pesticides only when threshold levels of pest attacks have been identified. There is also a move toward sustainable agriculture which aims to minimize use of pesticides and fertilizers based on a systems approach.

There has been a growing concern recently on the promotion of organic farming which emphasize on techniques such as crop rotation, green manure, compost and biological methods of pest control to maintain soil productivity. Organic farming strictly excludes the use of manufactured fertilizers, pesticides, plant growth regulators, livestock antibiotics, food additives, and genetically modified organisms. Organic foods resulting from organic farming are deemed free from pesticides and hence providing an alternative source of quality and safe food in the future. By promoting the use of organic foods means will push the farmers to opt for organic farming. Market forces are a powerful incentive to encourage famers to go organic.

Pesticides manufacturers should conduct long-term studies on ecosystem-wide impacts to demonstrate that a pesticide has no adverse effects before allowing it to be registered for use in the environment. The fact that present regulations view a pesticide as innocent until proved guilty is detrimental to the environment health. It is critical to know more about the long-term ecological effects of a pesticide before it is released to the environment. Using a combination of prior gained field experience with the existing pesticides and applying fundamental chemodynamic principles to newly developed compounds, we can now predict with some degree of accuracy the fate of new chemicals before they are even used in the environment.

4. References

Johnson, M. T.; Strinchcombe, J. R. (2007). "An emerging synthesis between community ecology and evolutionary biology". *Trends in Ecology and Evolution* 22 (5): 250–7

Harrison, S. A. (1990). The Fate of Pesticides in the Environment, Agrochemical Fact Sheet # 8, Penn, USA

Helweg, C. *et al* (2003). Fate of pesticides in surface waters, Laboratory and Field Experiments; Ministry of Environment, Danish Environmental Protection Agency,. Pesticides Research No. 68.

Kegley, S. *et al* (1999). Disrupting the Balance, Ecological Impacts of Pesticides in California, California, USA

Hackenberg D (2007). "Letter from David Hackenberg to American growers. Plattform Imkerinnen Austria.

Mills, L. S. Et al (1993) The Keystone-Species Concept in Ecology and Conservation, BioScience 43, (4), 219-224

Miller, G. T. (2004), Sustaining the Earth, 6th edition. Thompson Learning, Inc. Pacific Grove, California, USA

Rockets, R. (2007). Down On the Farm, Yields, Nutrients And Soil Quality

Fox, J. E, et al (2007). "Pesticides reduce symbiotic efficiency of nitrogen-fixing rhizobia and host plants". *Proceedings of the National Academy of Sciences, USA*

Johnston, A. E. (1986). "Soil organic-matter, effects on soils and crops". *Soil Use Management* 2, 97–105

Lotter DW, Seidel R, and Liebhardt W (2003). "The performance of organic and conventional cropping systems in an extreme climate year". *American Journal of Alternative Agriculture* 18: 146–154

Gilliom, R.J. *et al* (2007). The Quality of our nation's waters: Pesticides in the nation's streams and ground water, 1992–2001. US Geological Survey

Bingham, S (2007), Pesticides in rivers and groundwater. Environment Agency, UK.

Heather, B. *et al* (1997). Movement of Pesticides and Best Management Practices, Ground Water Pollution Primer, Virginia, USA

Henry, L. (2003) Levels of some Pesticides in Environmental Samples from Southern Lake Victoria and its Catchments and their Chemodynamics in Tilapia Species, Water and Sediments Under Experimental Conditions, Tanzania

Hayes *et al*, (2010) The cause of global amphibians decline: a developmental endocrinologist perspective, Journal of experimental biology, 213 (6) 921

Muckenfuss A. E. *et al*, (1990). Natural mortality of diamondback moth in coastal South Carolina Clemson University, Coastal Research and Education Center

Daly, H. *et al* (1998). Introduction to insect biology and diversity, 2nd edition, Oxford University Press, New York, USA

Sacramento, C. A. (2008). Department of Pesticide Regulation "What are the Potential Health Effects of Pesticides?" Community Guide to Recognizing and Reporting Pesticide Problems, 27-29

Lorenz, E. S. (2009) "Potential Health Effects of Pesticides." Ag Communications and Marketing. 1-8

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