Chapter 6
Insecticides: Impact on the Environment and Human Health

M. Shafiq Ansari, Maher Ahmed Moraiet and Salman Ahmad

Abstract Insecticides have saved millions of human and animal lives since the date of their synthesis and use. They have played an important role that brought revolution in the field of agriculture and human health on control of insect pests of crops and vector-borne diseases. More than 80,000 chemical substances are now commercially available in agriculture and industry. About 4.6 million t of pesticides are applied into the environment and insecticides accounted for the largest portion of total use in the world to increase the productivity of food and fibre as well as to prevent the incidence of vector-borne diseases.

Insects are the most successful group of animals existing in every segment of environment. They are polyphagous and migratory in nature, with high fecundity and short life span and diapausing (over-wintering) under adverse conditions. Food and fibre crops are damaged by more than 10,000 species of insects, with an estimated annual loss of 13.6 % globally. In human health, more than 3,100 species of mosquitoes, vector of malaria, kill more than 1–3 million people annually. Approximately 40 % of the world's population lives in areas at risk of malaria and every year about 500 million people become severely ill with malaria. Dengue, the most prevalent mosquito-borne viral disease, is estimated to cause 100 million infections each year, 250,000–500,000 of which are the cause of severe illness.

Despite their importance, insecticides also have negative impact, like toxic residues in food, water, air and soil, resurgence and resistance of insect pests, and effect on non-target organisms. More than 645 species of insects and mites have developed resistance to insecticides with 542 species of arthropods resistant to at least one compound. About 7,470 cases of resistance have been reported in insects to a particular insecticide; 16 species of arthropods accounted for 3,237 (43 %).

The effects of insecticides on human health are more risky because of their exposure either directly or indirectly; yearly, more than 26 million people suffer from pesticide poisoning with nearly 220,000 deaths. Hundreds of millions of people are

M. S. Ansari (✉) · M. A. Moraiet · S. Ahmad
Department of Plant Protection, Faculty of Agricultural Sciences,
Aligarh Muslim University, Aligarh 202002, India
e-mail: mohdsansari@yahoo.com

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exposed to pesticides every year, primarily through agriculture: Globally, 36 % of workers are employed in agriculture; this figure is rising to almost 50 % in Southeast Asia and the Pacific and to 66 % in sub-Saharan Africa. However, with all their hazards, the production of insecticides is continuously increasing in the international trade. Global pesticide use reached record sales of US$ 40 billion in 2008.

We are continuously facing the challenges to decrease the incidence of insect pests and vectors to maintain a safe environment for future generations. Therefore, concerted global efforts shall be made to achieve this goal by safer alternatives.

Keywords Insecticides · Resistance · Pollution · Organophosphates · Pesticide residue · Resurgence

6.1 Development of Insecticides

Insect pests in agriculture and public health cause undesirable effects: negative impact on human activities and damage, spoilage, and losses of crop plants, infrastructure and the materials of everyday life. The losses may range from 10 to 40 % for all kind of food and fibre crops. Several insects are spreading human diseases such as malaria, river blindness, sleeping sickness and a range of serious fevers and illnesses. Mosquito, ‘Public Enemy Number One’, remains a major public health problem as vector of malaria, West Nile virus and yellow fever, filariasis, dengue fever and Japanese encephalitis. About 40 % of the world’s population lives in areas at risk of malaria and 1–3 million deaths occurred annually, of which 90 % of cases are reported from sub-Saharan Africa (Snow et al. 2005). In Africa, malaria accounts for an estimated 25 % of all childhood mortality below age five, excluding neonatal mortality. Dengue, a mosquito-borne viral disease, is estimated to cause 50–100 million infections annually, 250,000–500,000 of which are the cause of severe sickness. The other serious vector-borne diseases are as follows: schistosomiasis, 200 million; lymphatic filariasis, more than 90 million; onchocerciasis, nearly 18 million; leishmaniasis, 12 million; dracunculiasis, 1 million; and African trypanosomiasis, 25,000 new cases are reported per year (WHO 2012).

Food and fibre crops are damaged by about 10,000 insect species with an estimated annual loss of 13.6 % globally, but the most damage to crops, whether in the field or stored, is caused by about 700 insect species. Thus, great efforts are required to figure out the problems caused by insects.

About 870 million people are still hungry and 8 million people died due to hunger and poverty from 2010 to 2012 (FAO 2012). The elemental sulphur was used as an insecticide by Sumerians in 4500 BC to protect their crops from insects. Body lice were controlled with mercury and arsenical compounds by the Chinese in 3200 BC. Nicotine sulphate extracted from tobacco leaves was used as an insecticide in the seventeenth century. Pyrethrum, derived from chrysanthemum and rotenone, from the roots of *Derris spp*. was used in the nineteenth century.

Synthetic organic insecticides were developed during World War II. Dichlorodiphenyltrichloroethane (DDT) and other chlorinated hydrocarbon insecticides were marketed between 1942 and 1950. However, DDT was first synthesized by Zeidler, a German chemist in 1874, but it was not used as an insecticide until 1939 when Dr. Paul Muller, who discovered the insecticidal property of DDT, was awarded the Nobel Prize in 1948. Rachel Carson, American biologist and editor, published *Silent Spring* in 1962, which says that the pesticides including DDT were toxic to human beings and wildlife and were contaminating the environment. As a result, the production and sale of DDT were banned in Sweden in 1970 and the USA in 1972 (Lear 2009), and, subsequently, banned from agricultural use worldwide under the Stockholm Convention, but its limited use in disease vector control continues to this day and remains controversial in many parts of this world. But it opened up a long line of new organic chemical insecticides that may be expected to change the agricultural systems.

In the late 1900s, the pyrethrum extracts containing pyrethrins were used as an insecticide. As a result of their thermal and photolability, analogues of pyrethroids were synthesized and were more potent and photo stable than natural pyrethrins (Housset and Dickmann 2009). By the 1980s, the neonicotinoid group of insecticides, chemically belonging to nicotine, had been introduced such as the neonicotinoid imidacloprid, which was used extensively in the world (Yamamoto 1999). Ryondine is an insecticidal component which was isolated from the roots and the stemwood of *Ryania speciosa* by Rogers et al. (1948) and its analogue was developed as rynaxypyr, causing paralysis and death of insect (Lahm et al. 2007).

The insecticide research and development process is a long journey that requires a multidisciplinary approach. Today, about 1,000 insecticides have been tested for their insecticidal properties and are available in the market.

6.2 Applications

Synthetic insecticides have played an important role in the management of insect pests in order to reduce the losses caused by them to meet the demands of increasing population. Generally, insecticides are often the only way to manage vectors. Organochlorines (OCs) had been used to control malaria, dengue fever and insect vectors in the 1950s. In 1955, World Health Organisation (WHO) released a programme to eliminate malaria worldwide, relying largely on DDT. It was primarily successful in the Caribbean, Taiwan, part of Northern Africa, the Balkans, etc. and played a minor role in North America and Europe. About seven million human lives have been saved by the control of insect-borne diseases, such as malaria, sleeping sickness, bubonic plague and typhus, with DDT and organophosphate (OP) compounds from 1945.

Today, about 1,000 pesticides are available in the market. For the global market of crop protection products, market analysts forecast revenues of more than US$ 52 billion in 2019 (Anonymous 2012b). Application of pesticides is increasing tremendously in recent years and about 5.2 billion pounds (of which 22 % used in USA) of pesticides were used with herbicides constituting 40 %, followed by insecticides (17 %) and fungicides (10 %) in 2006 and 2007 (Grube et al. 2011) where 70 % of pesticides were used in the developed countries. Globally, almost 85 % of the pesticides (estimated 2.9 million t) are used in the agriculture sector each year. Currently, there are more than 1,055 active ingredients recorded as pesticides to produce more than 20,000 agro-pesticides that are being marketed in the USA. However, 76 % of the pesticides are used as insecticide in India (Mathur 1999). The USA was the highest consumer of insecticides from 1990 to 2007, followed by China, Russia, Japan, Italy, Brazil, Turkey, India, Bangladesh and Vietnam.

6.3 Negative Impact of Insecticides on Agricultural Ecosystem and Environment

The environmental pollution caused by pesticides in Asia, Africa, Latin America, Middle East and Eastern Europe is now a serious concern (Zhang et al. 2011). The most important pollutants among the toxicants in India are OC and OP pesticides (Shafiani and Malik 2003). Even in earlier years, the residuals of DDT, lindane and dieldrin in fish, eggs and vegetables have been much beyond the safe range in India (Wu 1986). In India, the DDT content in humans was the highest ever in the world (Zhang et al. 2011).

Agricultural growth has taken place at various sectors in the twentieth century to fulfil the demand of food for the ever-increasing population. This target was achieved with increased application of agrochemicals, insecticides, fungicides, herbicides, etc., and chemical fertilizers that have resulted in loss of natural and semi-natural habitats and decreased habitat heterogeneity at agriculture ecosystem levels and the environment (Atreya et al. 2012). In fact, only 1 % of used insecticides reached their target pests and more than 99 % of them are disseminated in the environment (Zhang et al. 2011; Pimentel and Burgess 2012). Generally, 4.6 million t of pesticides are released into the environment annually (Zhang et al. 2011) and more than 500 insecticides are applied excessively, of which are OCs, while some of them containing mercury, arsenic and lead, which are highly poisonous and major contaminants of the environment (Zhang et al. 2011). Indiscriminate use of insecticides has created a fourfold problem through different trophic levels: health-related problems, environmental pollution, yield loss due to adverse effect on non-target resulting in insecticide-induced pest resurgence and financial burden to the poor farmers (Venkatesh et al. 2012). Insecticides are generally the most acutely toxic class of compounds, and they are lipophilic and degrade slowly in the environment.

6.3.1 Air

Generally, insecticides can contribute to air contamination. They are sprayed in the air as particles that could be drifted away by wind to other areas off target, potentially polluting the air (Fig. 6.1). They can volatilize or evaporate from contaminated non-

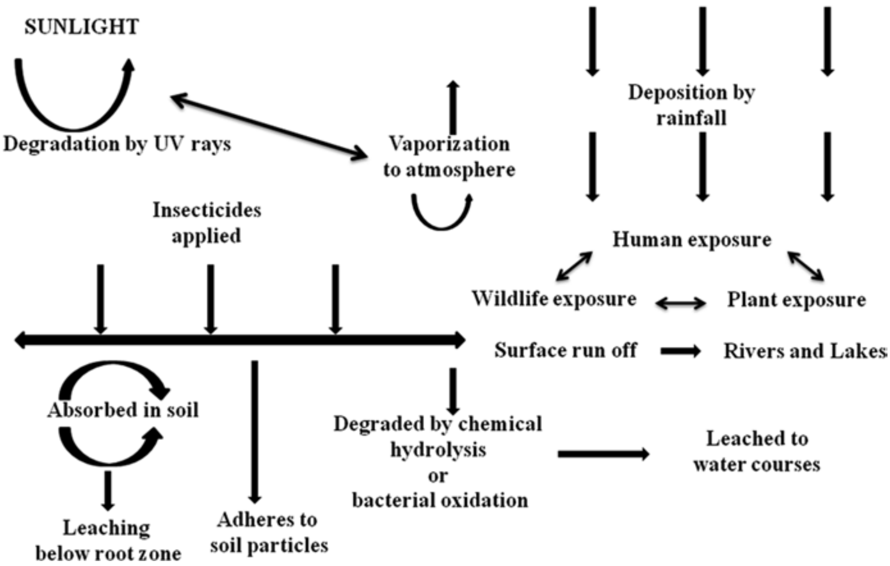

Fig. 6.1 Movement of insecticides into the environment

target. OCs were found at an altitude of 4,250 m on the snow of Nanjiabawa peak in Tibet (Shan 1997). DDT, lindane and aldrin residues were detected on the equator in India and to the high altitude of cold regions even in the Greenland ice sheet due to circulation of atmospheric and ocean currents and enrichment of biological pesticides (Zhang et al. 2011). Insecticides tend to volatilize at the time of application into atmosphere: affected by wind velocity, terrain/fetch, temperature, chemical properties, solubility, soil texture and type, molecular properties, concentration and vapour pressure (Kellogg et al. 2002). However, ground spraying of insecticide will produce less drift as compared to aerial spraying. Fumigants are also applied to field soil that can produce substances called volatile organic compounds, which react with other chemicals and form a contaminant called tropospheric ozone. Nearly 6 % of total insecticide application accounts for tropospheric ozone levels and is one of the reasons for global warming and the depletion of ozone layer.

6.3.2 Water

Insecticides are relevant stressor for various aquatic and terrestrial lives. They have been shown to cause potential negative effect on all groups of organisms in aquatic ecosystems: microorganisms (DeLorenzo et al. 2001), invertebrates (Castillo et al. 2006), plants (Frankart et al. 2003) and fish (Grande et al. 1994). The main route of movement of pesticides into water is through drift outside of areas off target when they are sprayed; they may percolate or leach through the soil, may be carried to the water as runoff or may be spilled, accidentally or through neglect (Fig. 6.1).

Insecticides may enter surface water and groundwater directly via spray drift or indirectly via surface run-off or drain flow from treated crops and soil. In UK, pesticide concentrations override those allowable for drinking water in some samples of river water and groundwater (Bingham 2007). The waterways are also polluted by insecticides: cypermethrin and chlorpyrifos mainly through spray drift rather more than drainage and surface run-off (Maltby and Hills 2008). Although pesticides had negative effects on aquatic organisms, such as reduced feeding rates, the changes were not seen in the population as a whole. Pesticide pollution is found in every stream and more than 90 % of water and fish in the USA (Gilliom et al. 2007). Pesticide residues have also been found in rain and groundwater (Kellogg et al. 2002), as well as in urban streams than in agricultural streams. Anjum and Malik (2013) reported the presence of lindane, α-endosulfan, β-endosulfan, chlorpyriphos, monocrotophos, dimethoate and malathion from the pesticide industrial wastewater samples from the Chinhat industrial area, Lucknow, India. Ansari and Malik (2009) showed the presence of certain OC (dichlorodiphenyldichloroethylene, DDE; DDT; Dieldrin; Aldrin and Endosulfan) and OP (Dimethoate, Malathion, Methlyparathion and Chlorpyrifos) pesticides in both the sampling sites of industrially polluted Ghaziabad, India, from January 2005 to June 2007. Rehana et al. (1996) indicated the presence of several pesticides such as DDT, α-BHC, aldrin, endrin and dieldrin at concentrations of 1.36, 1.38, 0.95, 0.61 and 0.41 ppb, respectively in the river Ganga at district Narora, India. The OP pesticides, such as dimethoate and methyl parathion, also appear to be present at concentrations of 0.20 and 0.41 ppb, respectively, obtained in water samples collected from the river Ganga at district Narora, India.

Insecticide concentrations in urban streams are generally exceed guidelines for protection of aquatic life. In India, 58 % of drinking water samples (ground water) obtained from several hand pumps and wells around Bhopal were found to be polluted with higher concentrations of OC insecticides that were more than the Environmental Protection Agency (EPA) standards (Kole and Bagchi 1995). Residues of DDT, hexachlorocyclohexane (HCH), dieldrin, endrin, etc. were detected in most of the water bodies in China also (Zhang et al. 2011). Several factors that affect pesticide's ability to pollute water consist of its water solubility, the distance from an application site to a body of water, weather, soil type, presence of a growing crop and the method used to apply the chemical.

6.3.3 Soil

Chemicals from agricultural field repeatedly penetrate the soil, subsoil and aquifer. This may happen either by normal management practices followed by the workers or by accident, and the resulting chemical residues in the soil create risks to the environment and ecosystem (Ali 2011). Pesticides are a common hazard around the world, as these chemicals are leaching into soils, groundwater and surface water and creating health concerns in many communities (Anjum et al. 2012). In India, alarming levels of pesticides have been reported in air, water, soil as well as in foods and biological materials (Nawab et al. 2003) and some common OC pesticides; DDT, dichlorodiphenyldichloroethane (DDD), DDE, HCH and Aldrin were found in the soil samples of Aligarh district, India. They have estimated c-HCH as 47.35 ppb whereas the concentrations of a-HCH, b-HCH, p,p′-DDE and o′,p′-DDT were 38.81, 1.79, 7.10 and 13.30 ppb, respectively, in the same soil. Soil contamination or soil pollution is caused by the presence of man-made chemicals or other alterations in the natural soil environment. It is typically caused by agricultural chemicals, industrial activity or improper disposal of waste. Most of the insecticides applied on the crops eventually end as accumulation in the soil. There are many ways in which an insecticide reaches the soil and aquatic ecosystem such as by direct application, spray drift, aerial spraying, atmospheric fallout, soil erosion and run-off from agricultural areas, discharge of industrial and domestic sewage, leaching, careless disposal of empty containers in the soil and equipment washing (Kaushik et al. 2010). The insecticides are more risky in soil as a result of their residues which may be comprised of many substances including any specified derivatives such as degradation products, metabolites and congeners that are considered to be of toxicological significance, such as OC insecticides, DDT, HCH, aldrin and dieldrin (Kalaikandhan et al. 2012), and their residues are still present. Insecticides not only contaminate the soils and water but also persist in the food and then enter the body system, blood and organs via food chain (Sheikh et al. 2011).

Pesticide leaching also occurs when pesticides are mixed with water and move through the soil, eventually contaminating groundwater as well as soil (Fig. 6.1). The amount of leaching is linked with a particular soil (like clay soil, sandy soil, alluvial soil) and characteristics of a pesticide and the degree of rainfall and irrigation. For example, both solarization and biosolarization enhanced the degradation rates of endosulfan, bifenthrin and tolclofos-methyl (Fenoll et al. 2011). The insecticidal application reduces the biodiversity of the soil. The microorganisms of soil are more spoiled by soil disturbance by application of chemicals than any other parameters. The communities of beneficial microorganisms in soil have declined due to overuse of pesticides, which has a negative impact on the available nitrogen, phosphorous and potassium (NPK) from soil (Sardar and Kole 2005). Insecticides may affect the population of invertebrates, which consist of the blooming of individual species of floodwater zooplankton and reducing populations of aquatic oligochaetes in soil. Many of the chemicals used in pesticides are continual soil pollutants, whose impact may continue for decades and adversely affect soil conservation.

The contaminated soil affects human health through direct contact with soil or via inhalation of soil pollutants which have been vaporized, while significantly greater hazards are posed by the penetration of soil contaminants into groundwater aquifers used for human consumption directly. The average consumption of insecticides in India is much lower than that of many other developed economies, but the problem of insecticide residues is very high (Abhilash and Singh 2009). Risks range from minimum to maximum, and there may be short- or long-term effects on human health and the most obvious is the possibility of xenobiotics that may enter the ground water through leaching from the surface soil and constitute a direct threat to human health (Philp 2013).

6.3.4 Non-Target Organisms

6.3.4.1 Aquatic Organisms

Insecticides are more toxic to aquatic life than herbicides and fungicides. Pesticide-polluted water is causing harmful effect on aquatic biota, such as fish and other kinds of organisms. Zooplankton, the major source of food for many young fish, could be killed by pesticides when they accumulate in bodies of water to dangerous levels (Anonymous 1999). Negative effects of chemical pollution on salamanders were likely a result of pesticide-induced reductions of food resources, as zooplankton abundance decreased by as much as 97 %, following carbaryl application (Metts et al. 2005). Some fish feed on the insects which may be killed by pesticides causing a fish migration to look for food and, thereby, exposing them to greater risks such as predators. A single application of malathion, carbaryl, chlorpyrifos, diazinon and endosulfan at 2–16 ppb as well as a mixture of insecticides with herbicides affect aquatic communities composed of zooplankton, phytoplankton, periphyton and larval amphibians such as gray tree frogs, *Hyla versicolor* and leopard frogs, *Rana pipiens* (Relyea 2009).

In North America and Europe, fish-eating water birds and marine mammals have been affected by OCs (Barron et al. 1995). Application of pesticides may be one of the reasons for reduction of amphibian population which has been happening all over the world, in the past decades. Aquatic mammals such as dolphins have the ability to accumulate increased concentrations of persistent organic pollutants as a result of their high trophic level in the food chain and relatively low activities of drug-metabolising enzymes (Tanabe et al. 1998) and are thereby vulnerable to toxic effects from contaminant exposures. Dolphins are more vulnerable to sources of pollution because of their close proximity to activities of humans in riverine and estuarine ecosystems. Decline of marine mammal populations is suspected to be a result of organochlorinated chemicals as well as degradation of their habitat (Borrell et al. 2001). DDT and polychlorinated biphenyls (PCBs) have negative effects on reproductive and immunological functions in captive or wild aquatic mammals (Colborn and Smolen 1996). Black sea dolphins accumulated different concentrations of OCs: PCBt, endrin, o,p DDT, β HCH and γ HCH and α HCH (Popa et al. 2008). Concentrations of OCs including lindane, heptachlor, aldrin, heptachlor-epoxide, endosulfan I, dieldrin and endrin were detected in the bodies of dolphins in the French Mediterranean (Wafo et al. 2012).

Globally, populations of amphibians are declining in agricultural ecosystems, which are characterized by pesticides (Brühl et al. 2013). Amphibians are more threatened than birds or mammals. Low concentrations of insecticides have indirect consequences on non-target members of the community across the multiple trophic levels, and the indirect insecticide-mediated effects are generalized across two geographically distinct amphibian assemblages (Hua and Relyea 2012). Tadpoles were killed and growth abnormalities were observed, when fields were sprayed with endosulfan. Tadpole mass was reduced to 20–35 % by the application of chlopyriphos for 4 days (Widder and Bidwell 2008).

Reduced cholinesterase (ChE) was monitored in 50 % of the population of *Hyla regilla* exposed to 190 ppb w/w of OP residue. In addition, up to 86 % of some populations had measurable endosulfan concentrations and 40 % had detectable 4,4′ dichlorodiphenyldichloroethylene, 4,4′-DDT and 2,4′-DDT residues (Sparling et al. 2001). Mortality of juvenile European common frogs, *Rana temporaria*, was 100 % after 1 h, and 40 % after 7 days at recommended level of registered insecticides under an agricultural overspray scenario (Brühl et al. 2013). Toxicity of chlorpyrifos, malathion and diazinon and their oxons can be harmful to the foothill yellow-legged frog, *R. boylii*, populations, and the corresponding oxons were 10–100 times more toxic than their parental forms (Sparling and Fellers 2007). Growth of African giant snails may be impaired by repeated application of endosulfan in cocoa plantations (Wandan et al. 2010).

6.3.4.2 Birds

Birds are killed regularly and frequently in insecticide-treated fields (Mineau 2005). It may be due to increasing application of systemic insecticides, notably neonicotinoids and fipronil in the past two decades (Mason et al. 2012), and also outbreaks of infectious diseases in bats and birds were negatively linked with toxic insecticides (Mineau et al. 2005). Pesticides kill about 72 million birds annually in the USA. In UK, more than 30 species have declined because of the agricultural practices (Donald et al. 2001). Populations of birds declined from 600 million to 300 million between 1980 and 2009 in farmlands of Britain and 116 species of birds are threatened in Europe (Anonymous 2012a). In India, the wild birds (resident and migratory birds) are exposed to great amounts of OC pesticides and their residues have been detected in whole-body homogenates (Tanabe et al. 1998).

Birds may be killed directly by some pesticides when they eat granular pesticides mistaking them to be grains of food. DDT and its metabolite, DDE, induced egg shell thinning especially in the European and North American bird populations (Vos et al. 2000). Sparrow hawks declined as a result of reduced eggshell thickness from application of OC insecticides in seed treatments during the 1950s and the 1960s (Bright et al. 2008).

Evidence of indirect effects of pesticides was thought to have resulted from reduction of plant and invertebrate species (insect food resources) on which the birds feed (Bright et al. 2008; Mineau and Whiteside 2013). Mortality of chick of grey partridge occurred because of the application of insecticides in soil (Bright et al. 2008). Indirect negative impact of insecticides was also observed on yellowhammer (Hart et al. 2006), corn bunting (Brickle et al. 2000) and songbirds (Mineau 2005; Mineau and Palmer 2013). Mortality rate of 3.0–16 songbirds/ha (17–91 million birds in total fields) occurred annually when cornfields were treated with granular carbofuran in Midwest USA. (Mineau 2005). A single corn kernel treated with a neonicotinoid can kill a songbird, and even a tiny grain of wheat or canola applied with neonicotinoid, imidacloprid can be toxic to a bird (Mineau and Palmer 2013).

Mortality in a colony of bats could be up to 95 % and about one million bats have died since 2006 in the USA. (Anonymous 2009). Decline of bat populations have also been linked to OC pesticide exposure in different parts of the world (Thies and Mc Bee 1994). High concentrations of *p,p′*–DDE have been detected in tissue of bats in Mexico and USA (Thies and Mc Bee 1994).

Biodiversity is greatly affected because of the delivery of ecosystem services (Hooper et al. 2005). Servicing by insecticides is commonly found to contaminate air, water, soil and non-target organisms as well as agriculture ecosystem. Non-target organisms include beneficial animals, birds, fish and other wildlife, beneficial insects, parasites, predators and pollinators and microorganisms and non-target plants.

6.3.4.3 Biological Control Agents

In an agricultural ecosystem, the services are considered most at risk from intensification of agricultural practices like biological pest control, crop pollination (Biesmeijer et al. 2006) and protection of soil fertility (Brussaard et al. 1997). Insecticides are directly or indirectly affecting the life history parameters or population dynamics of natural enemies. Indirect effects on natural enemies may have occurred via several mechanisms including killing of prey, consumption of contaminated floral parts and plant fluids and parts of prey either lethal or sub-lethal concentrations of the active ingredient, feeding upon the contaminated honeydew excreted by phloem-feeding insect prey and may also be associated with alterations in prey quality or induced changes in host plants which may reduce the attractiveness of plants to parasitoids (Elzen et al. 1989), thus impacting the foraging behaviour and searching efficiency of natural enemies (Elzen et al. 1989). Several studies have been conducted to determine the effect of insecticides on beneficial insect. In hot spots, a significant decline in population of birds, earthworms, natural predators, such as Coccinellids, *Chrysoperia carnea*, *Trichogramma* spp., *Apanteles* spp., spiders, black burni, Cheloanus, etc. (Palikhe 2007), has been seen. Insecticides have exhibited various degrees of toxicity to *Trichogramma* spp. (Zhao et al. 2012), predator of brown planthopper, *Nilaparvata lugens* (Preetha et al. 2010), *Cotesia plutellae*, endoparasitoid of *P. xylostella* (Haseeb et al. 2004), natural enemies of citrus scale pests, *Aphytis melinus* DeBach, *Coccophagus lycimnia* Walker, Leptomastix dactylopii Howard (Suma et al. 2009), *Aphytis melinus* Debach, *Eretmocerus eremicus* Rose and Zolnerowich, and *Encarsia formosa* (Gahan) and Mymaridae, *Gonatocerus ashmeadi* Girault that attack California red scale, *Aonidiella aurantii* (Maskell); sweetpotato whitefly, *Bemisia tabaci* (Gennadius) (both *E. eremicus* and *E. formosa*); and glassy-winged sharpshooter, *Homalodisca vitripennis* (Germar), respectively (Prabhaker et al. 2007), *Habrobracon hebetor* (Say), an ectoparasitoid of larval stage of lepidopterous pests (Rafiee-Dastjerdi et al. 2012), predatory lady bird beetle, Coccinellid spp. (Mollah et al. 2012) and the chrysopid, *Chrysoperla externa*—an important predator (Zotti et al. 2013). The insecticides, OPs, carbamates, pyrethroids, insect growth regulators (IGRs), neonicotine, phenylpyrazole and antibiotics showed negative effect against the adult parasitoid, *Anagrus nilaparvatae,* an egg parasitoid of the rice planthopper (Wang et al. 2008). OPs (chlorpyrifos, fenitrothion, phoxim, profenofos and triazophos) and carbamates (carbaryl, carbsulfan, isoprocarb, metolcarb and promecarb) exhibited the highest intrinsic toxicity to *Trichogramma japonicum*, an egg parasitoid of rice (Zhao et al. 2012).

6.3.4.4 Honeybees

The unintentional and the intentional exposure to insecticides can kill honeybees or any insect pollinators. Pesticide residuals have been detected in hive products, specifically beeswax (Johnson et al. 2010). Colony losses were especially severe from 1981 to 2005 with a drop from 4.2 to 2.4 million. Pesticide applications in the fields have eliminated nearly one fifth of honeybee's colonies and 15 % is harmed in the USA. More than 150 different agrochemicals have been detected in colony samples; most of them were insecticides and more concentrated in pollen than adult bees and occasionally honey, than in wax in the USA. (Mullin et al. 2010). Newer classes of insecticides have been detected in honey or pollen at ppb levels like phenylpyrazoles (fipronil) or neonicotinoides (imidacloprid) which significantly affected honeybee health (Desneux et al. 2007). In Europe, high losses of honeybee colonies were detected by the beekeepers when imidacloprid was applied on the crops (Rortais et al. 2005). Pesticides are the major problem for colony collapse disorder (CCD) and decline in the population of honeybees (Johnson et al. 2010). A total of 121 pesticides and metabolites with an average of 6.2 detections per sample were found in 887 heavy product samples (wax, pollen, bee and associated hive) from migratory and stationary beekeepers. Overall, pesticides in total wax and bee residues were pyrethroids and OPs, followed by fungicides, systemics, carbamates and herbicides, whereas in pollen samples, fungicides were found, followed by OPs, systemics, pyrethroids, carbamates and herbicides. Insecticides at lethal and/or sublethal doses affected adversely on immature and mature stages to reproductive stage of the queen bee (Desneux et al. 2007).

6.3.4.5 Other Animals

Contamination of animal food or water is the main pathway of poisoning of animals (Ledoux 2011). Persistent organic pollutants such as OC pesticides can be accumulated in livestock and domestic animals from contaminated food and water resources and/or from using pesticides on livestock area, treatment of cowshed, pigsties, sheepfold, etc. (Stefanelli et al. 2009) or on livestock pests (insects, ticks, mites, etc.). Poisoning in domestic animals and livestock was caused by carbamate insecticides with 50.3 %, rodenticides–anticoagulants 18.9 %, OP insecticides 5.1 %, rodenticides–non-anticoagulant 3.4 % and others 22.3 %, including molluscicides, herbicides, etc. Out of 225 animals, 123 animals were found positive for pesticide intoxication (Wang et al. 2007). OP insecticides and rodenticides were the most common causes of poisoning of livestock and accounted for one in 25 of all fatal poisonings between 1977 and 1980 (Quick 1982). The majority (60.1 %) of the intoxications in animals in the USA were caused by rodenticides and insecticides (38.6 and 21.6 %, respectively) and pesticides (66.6 %) (Brown and Patton 2012). Negative effect and detection of chlorpyrifos (Dursban) in animals, when fed to cows, were detected unchanged in the faeces, but changed in urine or milk (Anonymous 1984). Immunoglobulins and lymphocytes were decreased, while medulla and cortex were also depleted in chickens treated with imidacloprid (Kammon and Brar 2012). Terrestrial animals such as birds and small mammals may consume earthworms which are contaminated with pesticides (Yasmin and D'Souza 2010).

DDT residues were found in about 82 % of the 2,205 samples of bovine milk collected from 12 different states of India. About 37 % of the samples contained DDT residues above the tolerance limit of 0.05 mg/kg (whole milk basis). The highest level of DDT residues found was 2.2 mg/kg. The proportion of the samples with residues above the tolerance limit was lowest in Punjab (51 %), followed by Himachal Pradesh (56 %), Andhra Pradesh (57 %), Gujarat (70 %) and highest in Maharashtra (74 %). In the remaining states, this proportion was less than 10 %. Data on 186 samples of 20 commercial brands of infant formula showed the presence of residues of DDT and HCH isomers in about 70–94 % of the samples with their maximum level of 4.3 and 5.7 mg/kg (fat basis), respectively (Anonymous 1993).

The most commonly poisoned animals were dogs, particularly younger animals, as well as from exposure to insecticides and rodenticides in five European countries—Belgium, France, Greece, Italy and Spain in the last 10 years (Guitart et al. 2010). Most of the poisoning incidents were found in companion animals especially in dogs and cats because of insecticides while agrochemicals, heavy metals and toxic plants were the problems in farm animals in Belgium (Vandenbroucke 2010).

Physical endurance and working capacity of rats is reduced when exposed to chlorophos, diazinone and lindane (Georgiev et al. 1980). There are many health-related issues associated with HCH (Mehboob et al. 2013). Alpha, beta and gamma isomers of HCH act as depressants of nervous system and may cause cancer in mice (Nagata et al. 1996). Bensultap and fipronil insecticides can pass the blood–brain barrier in rats (Szegedi et al. 2005). Chlorpyrifos causes a significant ChE inhibition but does not exert overt toxicity and adversely affects the expression levels of critical genes involved in brain development during the early postnatal period in the rat (Betancourt et al. 2006). Pirimiphos-methyl (62.5 and 125 mg/kg) is detrimental to the reproductive potentials of male rats (Ngoula et al. 2007).

6.3.5 Insecticide Resistance

A significant progress has been made in controlling insect pests by means of insecticides. While insecticides have greatly improved the agricultural production and safety to human health worldwide, their utility, however, has been limited by the development of resistance in many major pests, including some that became pests only as a result of insecticide use. Continuous use of the insecticides may lead to the development of resistant populations of insect pests, and control failures were also observed in the field conditions (Avilla et al. 2010). The number of insect pests to be known as resistant to different insecticides is increasing with the time. In 1986, 260 insect species had been reported to develop resistance to various molecules of insecticides, but by 2009, 600 arthropod pests developed resistance to at least one insecticide or acaricide (Whalon et al. 2008). For example, the cotton bollworm, *Helicoverpa armigera*, has developed resistance to almost all the groups of insecticides all over the globe (Avilla et al. 2010; Yang et al. 2013). Fourteen populations of *H. armigera* from Northern China showed very strong resistance to fenvalerate (from 43- to 830-fold) when compared with the susceptible Specific Carbohydrate Diet (SCD) strain (Yang et al. 2013). High levels of pyrethroid resistance were recorded in intensive cotton- and pulse-growing regions of Central and Southern India where excessive application of insecticide is common (Armes et al. 1996). OP and pyrethroid resistance is reported in various African, Asian and Australian populations of *H. armigera*, with some reports indicating resistance factors exceeding a 100-fold for the OPs and a 1,000-fold for the pyrethroids. Srinivas et al. (2004) reported that *H. armigera* had developed high resistance to insecticides in the Gulbarga region of Karnataka, India. Highest seasonal average percentage survival of resistant strain was recorded by fenvalerate (65.0 %), followed by cypermethrin (62.4 %). Acetylcholinesterase (AChE) of resistant larvae was less sensitive to monocrotophos and methyl paraoxon. *H. armigera* has developed resistance to all the major insecticide classes and it has become increasingly difficult to control their population in India. Resistance to OP and carbamate insecticides has been reported in *H. armigera* and *Spodoptera litura* (Fabricius) in India (Kranthi et al. 2001). High resistance in *S. litura* against a wide variety of insecticides including OP (profenofos), carbamate, pyrethriods (deltamethrin) and some selected new chemistry insecticides (spinosad and indoxacarb) have been reported from South Asia (Ahmad et al. 2008; Saleem et al. 2008).

The insecticide resistance is primarily the result of the selection pressure exerted on sprayed populations, which increases the frequency of resistant individuals in the nature.

6.3.5.1 Knockdown Resistance (kdr)

The resistance developed in insects and other arthropods to DDT and pyrethroid insecticides results from reduced sensitivity of the nervous system caused by point mutations in the insect population's genetic make-up (Zhu et al. 2010). DDT and pyrethroids act fast on the central nervous system of the insects, leading to convulsions, paralysis and eventually death, an effect known as knockdown (Martins and Valle 2012). *kdr* occurs due to a point mutation in the voltage-gated sodium channel in the central nervous system, the target of pyrethroids and DDT action (Martins and Valle 2012).

6.3.5.2 Cross-Resistance

Cross-resistance enables the resistant species to survive exposure to related chemicals. For example, DDT-resistant houseflies are also resistant to methoxychlor. Cross-resistance was also found in *Leptinotarsa decemlineata* (Say) against neonicotinoid group of insecticides. Cross-resistance usually occurs from a common detoxification system or target site insensitivity (Metcalf 1994) or P450-monooxygenase detoxification mechanism in insects (Liu et al. 2010). The nicotinic acetylcholine receptors (nAChRs) in the insect central nervous system are the primary target for neonicotinoid insecticides, including imidacloprid.

6.3.5.3 Multiple Resistance

Multiple resistance is a far more serious type of resistance and extends to a variety of classes of insecticides with different modes of actions and dissimilar detoxification pathways. For example, knockdown resistance mechanism of houseflies showed reduced sensitivity of nerve axon to DDT as well as to completely unrelated pyrethroids. Multiple resistance is now present in at least 44 families of 10 insect orders. Multiple resistance to DDT and methoxychlor, lindane and cyclodienes, OPs and carbamates and pyrethroids is reported in *Musca domestica*; *Blattella germanica*; *Culex pipiens, Boophilus micropls; Tribolium castenium*; *Sitophilus granarius*; *Myzus persicae*; *Cacopsylla pyricola*; *Heliothis virescens*; *Plutella xylostella*; and *Spodoptera exigua* (Metcalf 1994).

6.3.5.4 Factors Responsible for Resistance

A number of factors are responsible for a susceptible pest population to evolve resistance against the toxicant. Firstly, most of the insects are capable of producing large number of offspring. The probability of random mutations is increased and it ensures the rapid build-up in numbers of resistant mutants once such mutations have occurred. Secondly, insects have been exposed to natural toxins for a long time before the onset of human civilization. For example, many plants produce phytotoxins to protect them from herbivores. As a result, co-evolution of herbivores and their host plants required development of the physiological capability to detoxify or tolerate the toxicants (Bishop and Grafius 1996). Insecticide resistance is characterized by quick evolution under strong selection of gene(s) that confers tolerance to insecticides. AChE has become insensitive, which has been associated as one of the mechanisms of resistance to organophosphorous and carbamate insecticides in *Bemisia tabaci* (Genn.) (Dittrich et al. 1990) and *H. virescens* (Brown and Bryson 1992). Similar insensitive AChE variants have now been detected in heterogeneous populations of many important insects such as *M. Domestica*, *Aphis gossypie* and several mosquito species. Overproduction of non-specific carboxylesterases as an evolutionary response to organophosphorus and carbamate selection pressure has been reported in mosquitoes, cattle ticks, aphids and cockroaches (Hemingway et al. 2004). A cytochrome P450 gene, *Cyp9m10*, is more than 200-fold over-expressed in a pyrethroid-resistant strain of *Culex quinquefasciatus* (Itokawa et al. 2011).

6.3.6 Insect Resurgence

Resurgence of insect pest occurs when the residual activity of the insecticide terminates and the pest population is able to rise more rapidly and natural enemies are absent or in low abundance. Insecticide-induced resurgence of insect pests has been reported a long time ago when chemicals were used as the principal tool for pest control. This can cause an increase in fecundity (physiological hormoligosis) or oviposition behaviour (behavioural hormoligosis) of the pest leading to a significant increase in its abundance. In 1947, the use of DDT sprays for citrus pest control was followed by dramatic resurgence of cotton cushiony scale, *Icerya purchasi* Maskell, which was under its best biological control by the introduction of predatory beetle, *Rodolia cardinalis* (Mulsant) (Metcalf 1994). Insecticide-stimulated pest reproduction is an important ecological mechanism of pest resurgence termed as insecticide hormoligosis. Insecticide hormoligosis was also known to occur in some insects and mites previously, which sometimes may result in resurgence of pests (Luckey 1968). Locust plagues may be caused by a mild stress which induces growth and reproduction inflicted by certain hormoligants (Luckey 1968). Fecundity of *P. xylostella* increased when larvae were exposed to fenvalerate at LC_{25} (Fujiwara et al. 2002). Spinosad has caused an enhanced fecundity of *Orious insidiosus* (Elzen 2001). Methyl parathion, quinalphos and deltamethrin enhance fecundity of *Sogatella furcifera* (Suri and Singh 2011), which leads to the resurgence of this pest in rice. Pest resurgence is mostly associated with indirect, secondary/minor pests for several reasons. Many factors are responsible for resurgence of the insect pests like reduced biological control, reduced competition, direct stimulation of pest to acute dose of insecticides and improved growth of crop. Studies of resurgent populations infrequently examine other mechanisms, although numerous alternative mechanisms, such as physiological enhancement of pest fecundity, reduction in herbivory, herbivore competition, changes in pest behaviour, altered host-plant nutrition or increased attractiveness, may also cause or enhance the probability of resurgence. Outbreaks of arthropod pests induced by pest control agents are end points triggered by complex interactions of environmental factors modulated vis-a-vis the external challenge are the major cause of resurgence (Cohen 2006) and might be correlated with the eradication of responsible competitors at a given ecological niche, as a sublethal level for one species might be toxic to another (Cohen 2006). The pyrethroid cypermethrin applied at low rates increased the fecundity and survival of immature stages of mite (Costa et al. 1988), suggesting that homeostatic modulations are involved.

6.4 Negative Impact on Human Health

Synthetic insecticides, introduced in the 1940s, a heterogeneous category of biologically active compounds, have become crucial, widely used weapons for pests control and infectious diseases (Bolognesi and Merlo 2011). In recent years, there has been an increasing concern that pesticides constitute a risk to the general population through residues in the food supply and through food chain (Margni et al. 2002) and cause potential effects on human health, wildlife and sensitive ecosystems (Ansari et al. 2013). Overzealous use of synthetic insecticides led to numerous problems unforeseen at the time of their introduction, like acute and chronic poisoning of handlers, farm workers and even consumers as the pesticides may enter food chain

(Fig. 6.2); destruction of water life, birds and other wildlife; interruption of natural biological control agents and pollinators; extensive contamination of groundwater, potentially threatening to human health by causing direct hazards to the users; and the development of resistance to pesticides in pest populations (Ansari et al. 2013), as well as occupational exposure to pesticides and adverse human health outcomes such as various cancers like leukaemia, lymphoma, liver, lung, brain, breast, prostate, kidney, pancreas, skin cancers, Parkinson's and other chronic diseases, and also potential adverse effects on mental health and reproduction (Bolognesi and Merlo 2011). In India, the first report of poisoning due to insecticide was reported from Kerala in 1958, where more than 100 people died after consuming wheat flour infected with parathion (Karunakaran 1958). The average daily intake of HCH and DDT by Indians was reported to be 115 and 48 mg per person, respectively, which was higher than those observed in most of the developed countries (Kannan et al. 1992). Pawar et al. (2006) have studied 200 patients with moderate organophosphorus poisoning (excluding severely ill patients) in Maharashtra, India. For human health, intake of food contaminated with insecticides results in the highest toxic exposure, about 10^3–10^5 times higher than that induced by drinking water or inhalation (Margni et al. 2002). Presence of DDT was found in milk to exceed the maximum residue limit fixed at 0.05 mg kg^{-1} in Punjab, India (Battu et al. 2005). The mean levels of total DDT and HCH in human blood were recorded as high as 743 µg L^{-1} and 627 µg L^{-1} for district Nagaon, while 417 µg L^{-1} and 348 µg L^{-1} for district Dibrugarh of North East India (Mishra et al. 2011). p,p′-DDT was the major component with the mean value of 6.125 mg/L, followed by p,p′-DDE, c-HCH, a-HCH and b-HCH, while in 2002, b-HCH and p,p′-DDE were comparable with mean values of 0.053 and 0.052 mg/L, respectively, followed by p,p′-DDT, a-HCH and p,p′-DDD in human blood during 1992 (Kaushik et al. 2012). The samples from human breast milk contained detectable residues of p,p′-DDT (urban mean 0.11 ± 0.18 mg kg^{-1}, rural mean 0.07 ± 0.03 mg kg^{-1}) and p,p′-DDE (urban mean 0.05 ± 0.04 mg kg^{-1}, rural mean 0.76 ± 1.46 mg kg^{-1}) (Burke et al. 2003). OC pesticides were detected in all pooled human milk samples typically with highest concentrations of p,p′-dichlorodiphenyldichloroethylene (p,p′-DDE) (median concentration 311 ± 174; 279 ng g^{-1} lipid), followed by β-hexachlorocyclohexane (β-HCH) (80 ± 173; 21 ng g^{-1} lipid). Other OCs consistently detected included dieldrin (16 ± 6; 17 ng g^{-1} lipid), hexachlorobenzene (HCB) (18 ± 16; 14 ng g^{-1} lipid), transnonachlor (11 ± 5; 9 ng g^{-1} lipid) and p,p′-dichlorodiphenyltrichloroethane (p,p′-DDT) (9 ± 6; 7 ng g^{-1} lipid) (Mueller et al. 2008). Rao et al. (2005) have recorded > 1,000 pesticide poisoning cases occurring each year with hundreds of deaths in India. They have also reported 1,035 cases of poisoning; 653 patients were reported to have ingested organophosphorus pesticides, 213 had ingested OCs (one patient ingested OP and OC) and 170 had ingested other pesticides in 2002 in India. Insecticide residues are nearly everywhere, in soil, air, water and human adipose tissues and they are highly persistent non-degradable compounds, such as DDT, dieldin, endrin, benzene hexachloride (BHC) and heptachlor epoxide. The development of diseases in susceptible children may be more due to increased exposure through food and breast milk along with under developed detoxification pathways and long latency periods (Cohen 2006). It is estimated that 99 % of all deaths from

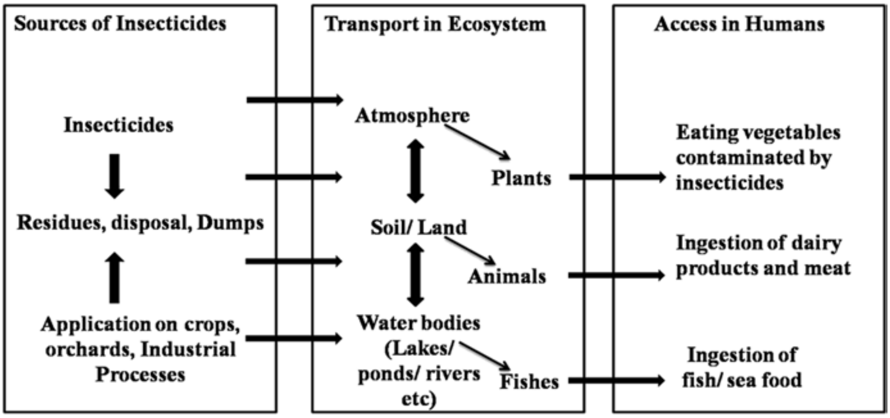

Fig. 6.2 Entry of insecticides into the human body

pesticide poisoning occur in developing countries (De Silva et al. 2006). The insecticides used in developing countries often consist of OCs (lindane and dieldrin), OPs (monocrotophos, parathion, methamidophos) and carbamates (carbofuran, thiodicarb, maneb; Wilson and Tisdell 2001).

The aerial spray of highly toxic insecticides has caused the poisoning of the people in that area contaminated by spray drift, and workers working in the orchards and vineyards have suffered a substantial number of incidents of parathion poisoning from the toxic residues from foliage and fruits (Metcalf 1994). Epidemics of poisoning by insecticides, especially through the accidental contamination of flour with parathion and endrin, have poisoned hundreds of people in India, Malaya, Arabia, Egypt, Columbia and Mexico. The Supreme Court of India, on 13 May 2011, ordered a country-wide ban on manufacture, sale and use of endosulfan citing its toxic effects on humans and environment. Endosulfan is readily absorbed by humans via the stomach, lungs and through the skin and causes acute and chronic toxicity. It has been demonstrated that much lower doses of toxicants may result in adverse health effects manifesting in functional and organic disorders in later stages of life if the exposure takes place during the early developmental phase.

6.5 Risk Assessments

The method used for evaluating the potential for health and ecological effects of an insecticide is known as risk assessment. Before allowing an insecticidal product to be sold in market, it is ensured that the insecticide will not pose any unreasonable risks to plants, wildlife, humans and the environment. Although pesticides are developed through very strict regulation processes to function with reasonable certainty and minimal impact on human health and the environment, serious concerns are raised about health risks resulting from occupational exposure and from residues in food and drinking water (Damalas and Eleftherohorinos 2011). The adverse effects of the insecticides on the water include soil and air contamination from percolating, surface run-off and drifting, as well as the detrimental effects on wild and water life, plants, and other non-target organisms, including humans depend on the toxicity of the insecticide, the measures taken during their applications, the dosage applied, the adsorption on soil colloids, the weather conditions prevailing after application and persistence of insecticide in the environment. Human population exposure to insecticides occurs mainly through eating food and drinking water polluted with insecticides, whereas significant exposure to the toxicant can also happen when residing near a workplace that makes use of pesticides or even when employees bring home-contaminated articles (Damalas and Eleftherohorinos 2011).

Apart from the difficulties in assessing risks of insecticide use on human health, the authorization for pesticide requires data of potentially negative effects of the active substances on human health. These data are usually obtained from several analyses focused on acute toxicity, sub-chronic or sub-acute toxicity, chronic toxicity, carcinogenicity, genotoxicity, teratogenicity, generation study and also irritancy trials using rat as a model mammal or in some cases dogs and rabbits. The risk assessment required acute toxicity test which considers the short-term effect of the single dose of insecticide; sub-lethal toxicity tests which assess the effects of intermediate repeated exposure of the insecticides or the long-term effect of an insecticide (Damalas and Eleftherohorinos 2011). The acute toxicity tests are involved in the calculation of lethal dose (LD_{50}), which is the insecticide dose that is required to kill half of the tested animals when entering the body by a particular route. In addition to this, the acute inhalation lethal concentration (LC_{50}), which is the insecticide concentration that is required to kill half of the exposed tested animal to an insecticide, can be calculated. Acute toxicity of an insecticide is referred to as the chemical's ability to cause injury to a person or animal from a single exposure, generally of short duration, whereas chronic toxicity of an insecticide is determined by subjecting test animals to long-term exposure to the active ingredient. The measurements of toxicity based on individuals, such as the LC_{50}, and effects on reproduction are used extensively in determining ecological risk (Stark et al. 2007). But only determination of LC_{50} and LD_{50} is not the only criteria for risk assessment of any insecticide (Stark et al. 2007; Ahmad et al. 2013). The use of demography incorporated with toxicants was proposed by Stark and Wennergren (1995) who put side by side the fitness parameters for unexposed populations with those exposed to various concentrations of an insecticide. It is the better way to understand the overall effect a toxicant might have on an exposed individual because it gives a complete portrait of life history of an insect (Stark et al. 2007; Ahmad et al. 2012; Ahmad and Ansari 2013; Ahmad et al. 2013).

6.6 Conclusion

Insecticides have been playing a significant role in the field of agriculture and human health but their debits have resulted in serious health implications to man, non-target organisms and the environment. They generally cause accidental environmental effects and are also toxic to the non-target organisms. Indiscriminate use of the insecticides has led to the development of insecticide resistance in the populations of insects and control failures are also constantly observed because of the pest resurgence. Environmental effects of insecticides are widely documented and their undesired residues are contaminating the air, soil, water bodies as well as causing deleterious effects on human health including neuromuscular dysfunctions and weakness. Recently, the residues of the insecticides are also detected in the human body at much higher levels. They get into aquatic ecosystems and affect many non-target organisms including fishes and birds due to biomagnifications through the food chain and food web. Therefore, sale and use of OC and cyclodiene insecticides should be banned so that their concentrations in the environment can be reduced below the tolerance level. Efforts should be made to increase the awareness among the farmers regarding the negative effects of insecticides on human beings and the environment. Biopesticides may be used as an alternative method to manage the insect pests, which are safer to the environment and non-target organisms.

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