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Should We Be Concerned with Long-Term Health Problems Associated with Pesticides in Namibian Groundwater?

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1. Introduction

In the modern world there are several sources of pesticides and other phenyl type organic compounds. Why do we use pesticides? Simply that the world's agricultural practices have commercialized to feed an overgrowing world population. Agriculture has also become a very lucrative business, where various players try to find niches to market their products. At the same time, societies have continued to become more aware about their natural environment and how to sustain it. As far back as 500 A.D., the city of Athens passed a law requiring all refuse to be disposed in a designated landfill outside the city walls (Zakrzewski, 1997); this was followed by many such laws in Europe. However direct linking of disease and health to environmental occupation was done by Dr. Percival Pott, in 1775 (quoted in Zakrzewski, 1997), who correctly linked the "chimney workers" with the unusual high rate of scrotal cancer, which he associated with exposure to soot in their work environment (Zakrzewski, 1997).

In a city like Windhoek, pesticides may arise from the control of grasses on road pavements (Mapani, 2005); or from small scale urban agricultural gardens behind homes. However the major source of pesticides is by far from the farming industry. It is estimated that in the United States alone, close to 98% of the sprayed insecticides and 95% of the herbicides finally reach an unintended sink (destination) (Miller, 2004). The effect of this is obvious when it comes to infiltration of water into the ground that has been used in the irrigation of crops. Pesticides are one type of compounds that undergo "biomagnification" in the food chain (US EPA, 2003). This aspect is especially dangerous as it ensures that the threat from the pesticide is not decreased with time, but rather increased. The United States Environmental Protection Agency (US EPA, 2003) has classified pesticides into four categories; namely; (i) organophosphates; (ii) N-methyl carbamates; (iii) triazines and (iv) chloroacetanilides. Some specific pesticide compounds have common mechanisms of toxicity, and require cumulative risk assessment over a relative long period, in order to define the potential risks. However the danger to aquatic life as described below in section 2 is well known, but the danger to human health is ill defined in comparison; with only a few

pesticides that have been well studied such as DDT (dichloro-diphenyl-trichloroethane), which was used widely across the world in the 1960's and 1970's.

In Karst areas such the Tsumeb-Grootfontein-Otavi (TGO) area of Namibia (Figure 1), that is underlain by limestone and dolomite aquifers and has in excess of 4000 square km where commercial agriculture is practiced, the danger from pesticide poisoning can not be over emphasised. The area receives on average about 760 mm of rain per annum. The area also serves as a major source of groundwater for the capital city Windhoek, which lies some 500 km to the south. Such relationships (groundwater source versus commercial agriculture) are generally present but the effect of pesticide use is not generally given the attention it deserves. No systematic studies have been conducted to especially ascertain attenuation rates of pesticides used on agricultural land.

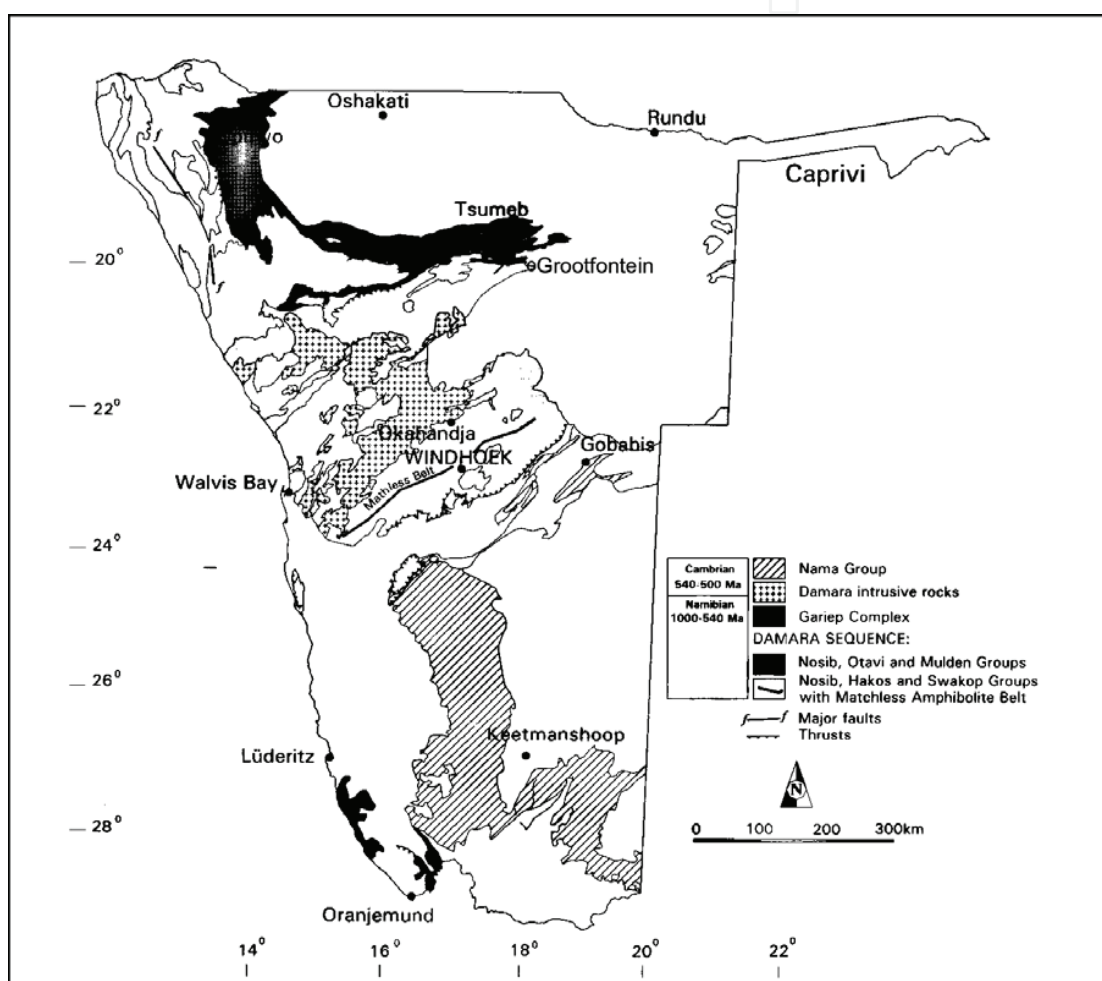


Fig. 1. Simplified Geological Map of Namibia, showing the crystalline carbonates of the Otavimountainland (Grootfontein-Tsumeb) area shown in black.(Geological Survey Namibia, 2000).

It must be borne in mind that treatment of drinking water only eliminates biological threats, and does not usually address pesticides. Generally water analyses do not target phenyl compounds routinely; such that it is not possible to always know whether a particular area is affected or not. Pesticides may be point sources, i.e., only emanating from one particular location, with one general pesticide; or they could be termed as multiple sources or mixtures

of point sources. When mixtures of point sources or multiple point sources occur in one particular area, then pesticides may present completely different mechanisms of toxicity. It has also now been known that pesticides can persist in rivers and in groundwater (Chilton, 2000) for long periods of time. This coupled with the fact that these xenobiotics are bio-cumulative in the ecosystems and in humans (USEPA, 2003), the concern is then raised as to how long their effects take or whether or not the effects will appear as diseases in humans after a critical period of time.

In this paper, the conditions are examined, that should raise concern on the possibility of severe effects appearing among the general population that uses groundwater obtained from areas that have been affected by pesticide exposure. These areas are mainly the Grootfontein-Tsumeb-Otavi (GTO) area in the northern part of the country, including the Tsumeb townlands; the Windhoek area and Okahandja towns, that are sustained from Kombat and Berg Aukas aquifers in the GTO area and the Stampriet area, in the south between Windhoek and Keetmanshoop where the Stampriet aquifer is both used as a water source for domestic use and for farming purposes (Figure 1); the Mariental area, which receives its water from the Hardap dam, whose catchment is a traditionally farming area, situated some 200 km north of Keetmanshoop (Figure 1).

2. Effect of pesticides on groundwater, aquatic life, humans and other biota

Pesticides degrade, and their products of degradation (degradates) can find their way into groundwater and surface water (Chilton et al., 2000; Foster et al., 1991). However as the some authors have pointed out, e.g., Barret (1996), Houtman et al (2004); the process of degradation takes very long that the effects of these xenobiotic compounds generally do affect aquatic life in surface waters. The danger to aquatic life is better defined compared to human health (USEPA, 2003). To human health pesticides have long term effects that need to be known and avoided where possible. As indicated above at least 98% of sprayed insecticides and 95% of herbicides reach an unintended destination, including surface and groundwater (Miller et al., 2004). This implies that pesticides are ending up in areas where they must not be present, and its here that the trouble begins. Once pesticides have entered the hydrological cycle, their elimination is difficult, and in most places impossible, especially so with groundwater. However when pesticides percolate together with surface water, towards the groundwater table, certain quantities may be trapped by clay minerals (Mapani & Schreiber, 2008). The effectiveness of this trapping process (attenuation) depends on the soil types developed in a particular area. In areas where montmorillonite clays are abundant, this process is much better, although it may not completely eliminate the danger. In arid areas such as Namibia, soils are not well developed and the trapping ability of soils is virtually non-existent.

2.1 Effects of pesticides on groundwater

In the area around Windhoek, Mapani (2005) reported the use of pesticides and herbicides in the removal of weeds in paved areas of the city. This kind of usage is continuous, and poses a major threat to groundwater, as it is continuous and the threat is present in all seasons. Windhoek is further disadvantaged by having a thin soil cover, less than 30 cm in most places before bedrock is reached (Figure 2). Thus contamination via percolation of rainwater into the aquifer is made much easier and faster. In an arid country like Namibia,

where some agricultural activities such as livestock watering, vegetable and horticultural farming are mainly supported by irrigation, there occurs a danger to recycle the pesticides via groundwater pollution, through groundwater abstraction and usage. As a result, percolating irrigation water on farms that have been treated by herbicides and insecticides allow these chemicals to reach down to the groundwater water table. The percolation times (displacement times) are varied, and slower in very arid areas, or where thick soil acts as a filter. In alluvial aquifers of ephemeral rivers as is the case for Namibia, these displacement times are rapid and get flushed at least once a year when these streams are in flood. In zones away from ephemeral rivers and streams, this process of displacement time can take months to years. For example, in Windhoek, the water table occurs at 70-76 m below surface; and the displacement time can take up to ten (10) years due to the nature of the fractured aquifer (Mapani & Schreiber, 2008). In other aquifers with semi-arid conditions, chemicals used today may take 50 years to reach the groundwater table. The displacement times for the pesticides and other contaminants in groundwater are different for different aquifers, and also depend on other factors such as soil composition, soil thickness and rainfall. In areas of high rainfall with thick loamy and clayey soils, the displacement times are longer; however if the soils are sandy, and high rainfall is characteristic to the area, the displacement time is accelerated. A general rule is that with increasing permeability, and absence of clay minerals, displacement times for pollutants are shorter; and become longer with increasing volume of clay minerals and deeper levels to the groundwater table.

Once the pesticides have found their way to the water table, cleaning them is difficult. The pesticides will then be ingested by both livestock and humans through drinking water. In Namibia, livestock farming forms the largest source of export oriented agricultural activity (Table 1). In arid areas, which is mainly in the freehold zones of the country, groundwater is the only source of water for livestock. This is especially the case in the southern part of the country, where cropping is not practiced.



Fig. 2. Windhoek soil profile measuring 20 cm from the Northern Industrial area. The bottom of the pen shows the bedrock-soil profile contact. Note the immaturity of the soil horizon.

Tenure	Cattle	Sheep	Goats	Pigs	Poultry	Ostriches
Freehold	824 207	1 727 210	479 930	9 035		51 464
Communal	1 368 152	359 224	1 230 260	5 671		929
TOTAL	2 192 359	2 086 434	1 710 190	14 706	403 937	52 393

Table 1. Livestock statistics in Namibia as of 1998 census (source: National planning commission)

Once pesticides have found their way to the groundwater, uptake of this water by livestock will ensure the beginning of bioaccumulation in the animal tissues. The accumulated pesticides will then accumulate in the food chain and remain there for a considerable time (Chilton et al., 2000). Pesticides and insecticides are some of the inorganic compounds with a property of bio-magnification. This property implies that if one particular pesticide or herbicide is used over a long time, it may eventually reach the maximum contaminant limit (MCL) in the organism. This danger is very great to areas where groundwater is used for domestic use; for livestock watering in areas where livestock is also slaughtered for food.

2.2 Effect of pesticides on surface water

Pesticide routes into humans are through water, vegetables, fruits, dust and aerosols. The pesticides that are sprayed as aerosols can drift long distances on windy days and end up in surface water sinks, whether they be dams or running river systems. The northern part of Namibia is characterized by subsistence farming (communal land tenure), where river water and shallow wells are the main source of water. For such populations, which depend on cultivation of vegetables, crops, and fruits for their livelihoods are as much exposed to the danger of pesticides as are the commercial farmers to the south. Application of pesticides and herbicides, especially for crops such as cotton, have become a norm to try and maximize crop yields for rural populations. Commercial agriculture that has recently commenced on the banks of the Okavango and Zambezi rivers is also a possible new source of pesticides. Along the Orange river in the south, commercial agriculture in fruit farming (grapes) has traditionally been practiced for a long time. Farm workers experience the greatest exposure to pesticides through direct contact with these chemicals. This is further proved by studies that show that nearly every human being has a small percentage of pesticides in their fat samples (DPR, 2008).

Pesticide contaminated surface water has been known to kill aquatic life, such as fish, frogs and zooplankton (Science Daily, 2006). Zooplankton is one of the major sources of food for fish in surface water bodies. These pesticides also kill insects on which some fish feeds. The herbicide ‘atrazine’ has been shown to turn some male frogs into hermaphrodites, thus decreasing their ability to reproduce (Science, Daily, 2006). Thus these pesticides become xenobiotic in aquatic life forms, and when MCL for each organism is reached, due to bio-accumulation and bio-magnification, they die off. This is probably the most dangerous aspect about pesticides; their bio-magnification and bio-accumulation properties.

Pesticides can also persist in river systems for a long time, up to time spans of years. This aspect of persistence ensures that aquatic biota can be continuously contaminated during that time span (Kolpin et al.,1996). This is a common feature of pesticides, their resilience in natural systems. Kolpin et al (1996) found significant amounts of pesticide residue and their metabolites in near surface aquifers of the mid-western United States. The British situation on pesticides in water has been well documented, showing that a definite threat exists; for

instance, Lawrence and Foster (1987) showed how agricultural pesticides end up in surface and groundwater aquifers. It is clear that nearly every country where some research has been done, reflects the potential of pesticides to affect the surface water. Li and Zhang (1999) studied the situation in China, and found diffuse pollution from agricultural pesticides in surface and ground waters. The situation can not be expected to be any different in Namibia.

Pesticides that remain in residual amounts in soils have other negative effects on ecosystems. Firstly they degrade nitrogen fixation in soils (Fox et al., 2007; Potera, 2007). This is caused especially by some organochlorine pesticides where they degrade natural nitrogen fixing bacteria (Fox et al., 2007; Potera, 2007). This leads to soil degradation and poor crop yields; then farmers react by adding more fertilisers to the soils. The pesticides that hinder this important natural process are dichloro-diphenyltrichloroethane (DDT); methylparathion and pentachlorophenol. These hinder legume rhizobium chemical signaling, and larger quantities of fertilisers are then required.

It has been shown by several authors that endocrine disrupting compounds (EDCs) that are xenobiotic can cause reproductive impairment in fish even when they have been in the aqueous ecosystem for some time (e.g., Jobling et al., 1996; Gray and Metcalfe, 1997; Gronnen et al., 1999 Metcalfe et al., 2000). The EDCs washed in surface water systems have a debilitating effect on wildlife.

All the fishes that partake of pesticides that end in surface waters will inevitably end up in humans through fish consumption. This will continue to happen until such time that intolerable levels are reached and humans get ill from pesticide effects. As they continually accumulate in surface waters, so do they as well in the food chain. These have long lived effects on fishing rural societies that couple with agriculture.

2.3 Pesticides and insecticides in air and in household pest control

Many households spray their homes for pest control, in one form or another. Concern exists over long term exposure of pesticides and insecticides in infants. Some authors have attributed the early onset of leukemia on pesticides (Lowengart et al., 1987). Fenske et al. (1990) have shown that pesticides in air have serious consequences when sprayed in rooms to eradicate pests. Concentrations that affect humans and children in particular can linger in the air for more than 24 hours post application period (Fenske, et al., 1990; Ritter et al., 2007; Woody, 1984). Woody (1984) has shown that children were intoxicated by pesticides with organophosphate active ingredients after houses were sprayed with dichlorvos in Arkansas in the USA. In Texas, USA, thirty seven (37) children were hospitalized after their homes were sprayed with organophosphate and carbamate containing pesticides (Zwiener & Ginsburg, 1988). This implies that these xenobiotics can accumulate in humans also from this route and bio-accumulate in our systems, and when a critical level is reached they become a health hazard. These results of how pesticides and insecticides affect humans are direct evidence that these xenobiotics can cause serious harm to human health.

3. Results and discussion

3.1 Results

Work done around the Windhoek area has shown that the main threats to the groundwater are pesticides, crude oil products such as diesel, petro and motor oil. The areas around Windhoek show very thin soil cover, with an average maximum depth of 30 cm. This soil is mainly made of kaolinites, smectites and illites (Table 2). This data is also summarized in figure 3. This clay distribution map, gives an idea of the most vulnerable zones to pesticide infiltration into the groundwater. Some 97% of the country have soils with a clay content of

Area & geology	Soil Type	Capacity to retard effluents and pollutants
Windhoek area	Mainly kaolinite, illite and smectites	Little capacity
SE of the country- area is dominated by Kalahari sands, a few granite and basaltic rocks	Covered by Kalahari sands, dominated by micas and illite, chlorite, mixed layer silicate and minor kaolinite	Very little capacity
North central part of the country – dominated by carbonates and schists	Some illite, smectites, palygorskite, kaolinite and minormontmorillonite	Medium to good capacity
Northern regions (wet areas)	Palygorskite and smectite	Medium capacity
Southern areas	Illites and chlorites, some smectites occur	Limited capacity

The map displays the Kunene region in Botswana, bounded by 15°S to 30°S and 25°E to 30°E. It shows the Atlantic Ocean to the west, with coastal features like the BOC and BCC. Major rivers include the Kunene, Okavango, and Zambezi. Key locations marked include Etosha Pan, Lake Ngami, and the Makgadikgadi Pans. Numbered circles (1-7) indicate clay mineral provinces, and dots represent clay sample sites. Mineral assemblages are noted at various sites: K+Sm, P+S, Sm+I+K+C, Sm+I+K+ML, I+Sm+P+K, I+Sm (P,C,ML), I+C, I+Sm+K, and Sm+P. A scale bar shows 0 to 200 km. An inset map shows the location of the study area within Southern Africa.

1 Clay mineral provinces

- Clay sample site

C - Chlorite
I - Illite
ML - Mixed-layer
Sm - Smectite
K - Kaolinite
P - Palygorskite
S - Sepiolite

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The northern part of the country, in the Oshana regions of Namibia, does receive infrequent floods in the summer. When this occurs, the generally sandy soils, do get an admixture of loamy sediments brought from the Angolan side of the border. However the shallow wells get flooded together with the fields where rain-fed agriculture is practiced. Fortunately only few farmers use pesticides on a regular basis, most subsistence farmers only use fertilisers. An example shown in figure 4, where a flood completely inundates the village, any pesticide/herbicide that were applied, get dispersed in the ecosystem, affecting large swaths of subsistence farmlands.

In Windhoek pesticides are applied for weed removal in paved areas such as airfields car parks, road pavements, and railway lines and sports facilities where grass is kempt for recreation purposes. These sources of pesticides pose serious problems, given the fact that the Windhoek aquifer is currently used as a major storage facility of fresh water.



Fig. 4. Flooding in the Oshakati area in 2009, some 800 km north of Windhoek. www.sulekha.com

3.2 Discussion

Plimmer et al. (1998) in a comparative study, showed that Africa, followed by Asia and South America experienced the largest crop losses due to insects and pathogens. This implies that the use of pesticides in these areas is a requirement to improve productivity. However the fate of pesticides in soils and water is least studied in these places compared to Europe and North America. Of the common pesticides and herbicides, Carbofuran, Alachlor, Ametryn, Atrazine and Isoproturon have been studied to see how they degrade in agricultural uses (e.g., Agrawal, 1999; Chilton et al., 1995; Harrison et al., 1998; Johnson et al., 1998; Johnson et al., 2000), although more work is still required similar to that of Houtman et al (2004) that traces endocrine disrupting compounds (EDCs) in sediments of river deltas. Most of the studies have been on laboratory batch experiments, a few on actual field samples of the groundwater and surface waters (Chilton et al., 1995; Johnson et al.,

1998 & 2000). Carbofuran breaks down to a 3-OH-7-phenol group when quantities of 12 kg per hectare are applied, with groundwater analyses picking up concentrations of 10–60 lg/l (Chilton et al., 2000). Alachlor is detected at the water table level, without much breakdown, together with Ametryn, when both are applied at a rate of 4 kg/hectare. Atrazine on the other hand may not be detected in wells, but will be detected in abstracted drinking water in the range 0.2–3 lg/l, implying that it has a less resident time at the water surface (Chilton et al., 2000). This behaviour of pesticides and common herbicides shows that these complex compounds pose a threat to all groundwater resources due to their long residence times, and their possibility to pass from one group of aquatic wildlife to another through the food chain. In the United Kingdom, Atrazine was banned for non-agricultural use (Chilton et al., 2000) because of its persistence in groundwater, and its effects on human health.

In the case of Namibia, alluvial aquifers in ephemeral river channels form a significant source of groundwater. These flow in general once or twice a year. This effect of once off flows and flooding, flush any substances such as pesticides down stream. This then leads to the lateral distribution of herbicides in the groundwater system once the rivers have stopped flowing, and water has percolated down into the aquifers. Some of the ephemeral rivers do not flow all the way into the ocean, the flow may stop mid stream due to insufficient water. This aspect is especially common, and the re-concentrating of pesticides in these ephemeral rivers occurs each year.

In Europe several studies have shown that pesticides and associated EDCs have effects on wildlife (Vos et al., 2000). In the Netherlands, quantities of EDCs analysed from sediments of the Rhone delta were generally low, but their effect on biota is significant (Houtman et al., 2004). In Japan, the work of Gray and Metcalfe (1997) and Gronnen et al. (1999) showed that there was an impairment of reproductive organs in fish as a result of xenobiotic compounds found in the fish. These xenobiotic compounds then can find their way into humans via oral ingestion. As fish forms one the largest source of protein for the human population, it is expected that bioaccumulation of these xenobiotic compounds will begin to show some health effects and in cases cause some poisoning (Weinbroum, 2005). Ollson et al (1998) discussed the effects of endocrine disruption substances in soils from around Sweden. In their discussion, Ollson et al (1998) conclude that these xenobiotic substances as pesticides impair the growth of animals and impair the reproductive systems. These effects lead to mutagens in species (Houtman et al., 2004). Brouwer et al. (1998) have shown that human health is also at risk from these organo-halogen compounds such as pesticides and herbicides. Feldman and Maibach (1974) carried out direct experiments on man, exposing the skin to the pesticides Carbaryl and Diquat. Subsequent urine tests showed that the human body easily absorbed Carbaryl and a little of Diquat. This study has direct implications on farm workers. The work of Chu et al.(1999) shows that there are circumstances when the rice can take up these xenobiotics, although the concentrations are low in the seeds but higher in the leaves. Fox et al. (2007) showed that pesticides directly reduced the efficiency of nitrogen fixing rhizobia and host plants.

4. Conclusions

Pesticides in groundwater are as a result of percolating irrigation water that has been treated with pesticides into the groundwater. In areas where soil cover is thick with clays such as montmorillonite that have the capacity to trap organometallic and organic molecules, the attenuation of pesticides can be appreciable. Soil is not an effective filter, and some

groundwater aquifers will be contaminated where prolonged use of pesticides is practiced. In the case where ephemeral rivers flow through irrigated land, they serve as a mechanism to re-distribute pesticides in the groundwater aquifers. Where flooding is frequent, the same mechanism of redistribution of pesticides occurs. The long-term effects of pesticides in groundwater are much more long lived, and are difficult to remove from the aquifers. Hence their effects will be cumulative on the communities using the aquifers. The effects of pesticides on human health has now been shown to have several health effects with long term effects that need to be minimized or avoided.

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Pesticides in the Modern World - Risks and Benefits

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This book is a compilation of 29 chapters focused on: pesticides and food production, environmental effects of pesticides, and pesticides mobility, transport and fate. The first book section addresses the benefits of the pest control for crop protection and food supply increasing, and the associated risks of food contamination. The second book section is dedicated to the effects of pesticides on the non-target organisms and the environment such as: effects involving pollinators, effects on nutrient cycling in ecosystems, effects on soil erosion, structure and fertility, effects on water quality, and pesticides resistance development. The third book section furnishes numerous data contributing to the better understanding of the pesticides mobility, transport and fate. The addressed in this book issues should attract the public concern to support rational decisions to pesticides use.

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