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Review

Pesticide use and application: An Indian scenario

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ABSTRACT

Agricultural development continues to remain the most important objective of Indian planning and policy. In the process of development of agriculture, pesticides have become an important tool as a plant protection agent for boosting food production. Further, pesticides play a significant role by keeping many dreadful diseases. However, exposure to pesticides both occupationally and environmentally causes a range of human health problems. It has been observed that the pesticides exposures are increasingly linked to immune suppression, hormone disruption, diminished intelligence, reproductive abnormalities and cancer. Currently, India is the largest producer of pesticides in Asia and ranks twelfth in the world for the use of pesticides. A vast majority of the population in India is engaged in agriculture and is therefore exposed to the pesticides used in agriculture. Although Indian average consumption of pesticide is far lower than many other developed economies, the problem of pesticide residue is very high in India. Pesticide residue in several crops has also affected the export of agricultural commodities in the last few years. In this context, pesticide safety, regulation of pesticide use, proper application technologies, and integrated pest management are some of the key strategies for minimizing human exposure to pesticides. There is a dearth of studies related to these issues in India. Therefore, the thrust of this paper was to review the technology of application of pesticides in India and recommend future strategies for the rational use of pesticides and minimizing the problems related to health and environment.

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Abbreviations: BHC, Benzenehexachloride; BIS, Bureau of Indian Standards; CIL, Central Insecticide Laboratory DDT, Dichlorodiphenyltrichloroethane; DPPQS, Directorate of Plant Protection Quarantine & Storage; ILO, International Labor Organization; FAO, Food and Agricultural Organization; FFSs, Farmers Field Schools; GDP, Gross Domestic Production; GM, crops Genetically Modified crops; HCHs, Hexachlorocycloheaxnes; ICM, Integrated Crop Management; IPM, Integrated Pest Management; KVK, Krishi Vigyan Kendra; MoH&F, Ministry of Health and Family Welfare; MRL, Maximum Residue Limit; NAMP, National Anti Malaria Program; NIC, National Information Centre; NPPTI, National Plant Protection Training Institute; PCP, Pentachlorophenol; PCBs, Polychlorinated Biphenyls; RUP, Rational use of Pesticides; SAUs, State Agricultural Universities; SDoA, State Department of Agriculture; ULV, Ultra Low Volume; UT, Union Territory; WTO, World Trade Organization.

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1. Introduction

Chemical pesticides have contributed greatly to the increase of yields in agriculture by controlling pests and diseases and also towards checking the insect-borne diseases (malaria, dengue, encephalitis, filariasis, etc.) in the human health sector [1,2]. The need to increase world food production for the rapidly growing population is well recognized [3,4]. One of the strategies to increase crop productivity is effective pest management because more than 45% of annual food production is lost to pest infestation. In tropical countries, crop loss is even more severe because the prevailing high temperature and humidity are highly conductive to rapid multiplication of pests [5,6]. Thus, the application of a wide variety of pesticides on crop plants is necessary in the tropics to combat pests and vector borne diseases. However, the sporadic use has been leading to significant consequences not only to public health but also to food quality resulting in an impact load on the environment and hence the development of pest resistance [7]. Through over use and misuse there is considerable waste, adding to the cost and contributing to the adverse environmental and health consequences. Inappropriate application of pesticides affects the whole ecosystem by entering the residues in food chain and polluting the soil, air, ground and surface water [7–9].

Humans are exposed to pesticides (found in environmental media such as soil, water, air and food) by different routes of exposure such as inhalation, ingestion and dermal contact [2]. Exposure to pesticides results in acute and chronic health problems. Pesticides being used in agricultural tracts are released into the environment and come into human contact directly or indirectly [1]. Increasing incidence of cancer, chronic kidney diseases, suppression of the immune system, sterility among males and females, endocrine disorders, neurological and behavioral disorders, especially among children, have been attributed to chronic pesticide poisoning [7]. Human health hazards vary with the extent of exposure. Moderate human health hazards from the misapplication of pesticides include mild headaches, flu, skin rashes, blurred vision and other neurological disorders while rare, but severe human health hazards include paralysis, blindness and even death [8]. Pesticide pollution to the local environment also affects the lives of birds, wildlife, domestic animals, fish and livestock [10]. The use of un-prescribed pesticides in inappropriate doses is not only disturbing the soil conditions but is also destroying the healthy pool of bio-control agents that normally co-exist with the vegetation. These biocontrol agents are the friends of agriculture and hence need to be nurtured, cared and developed by reducing the reliance on chemical's use in agriculture [11].

Orgnochlorine insecticides, such as DDT, hexachlorocyclohexane (HCH), aldrin and dieldrin, are among the most commonly used pesticides in the developing countries of Asia because of their low cost and versatility against various pests [3,12,13]. Nevertheless, because of their potential for bioaccumulation and biological effects, these compounds were banned in developed nations two and half decades ago [14–16]. Their resistance to degradation has resulted in contamination universally found in many environmental compartments. Such residues may be comprised of many substances, which include any specified derivatives such as degradation products, metabolites and congeners that are considered to be of toxicological significance. According to the Food and Agriculture Organization (FAO) inventory [17], more than 500,000 tons of unused and obsolete pesticides are threatening the environment and public health in many countries. Public concern over pesticide residue has been increasing during the last decade. Recovering from the euphoria of green revolution, India is also now battling from residual effects of extensively used chemical fertilizers and pesticides such as HCH, DDT, endosulfan, phorate, etc. [2,4,11].

India is predominantly an agrarian society. GDP for agriculture and allied sector during 2005–2006 was estimated at Rs. 61 Trillion at current price (USD 130 Billion), which was 19% share in GDP of total economy [11]. After independence, agriculture in India has undergone significant transformation [18]. The agricultural production increased tremendously due to introduction of high-yielding varieties, use of agro-chemicals and improved irrigation facilities [4]. However, there are several constraints for further increase in agricultural production. One of the limiting factors is the increased incidence of pests and diseases. On the other hand, increased use of chlorinated non-degradable pesticides leave residue in various living systems for prolonged periods of their span and are presumably responsible for a variety of toxic symptoms [19]. Therefore, the thrust of this discussion was to review the technology of application of pesticides in India and recommend future strategies for the rational use of pesticides and minimizing the problems related to health and environment due to inappropriate application of pesticides [12].

2. Pesticide usage in India

The use of synthetic pesticides started in 1948–49 with the use of DDT for malaria control and BHC for locust control [12,19–23]. The Indian pesticides production industry started with the setting up of a BHC technical plant at Rishra near Kolkata in 1952. Shortly after, Hindustan insecticides Ltd. set up two units to manufacture DDT. In 1969, Union Carbide set up a small plant (Union Carbide India Ltd (UCIL)) in Bhopal, the capital city of Madhya Pradesh, to formulate pesticides. The Bhopal facility was part of India's green revolution aimed to increase the productivity of crops. The industry produced various pesticides, mainly sevin brand carbaryl insecticide and temikcbrand aldicarb pesticide. All the pesticides produced at UCIL were sold in the Indian market. The Union Carbide continued pesticide production till 1984 Bhopal disaster. Today, the Indian pesticides industry comprises of more than 125 basic producers of large and medium scale and more than 500 pesticide formulations. The pesticide formulation produced in the country are mainly of the conventional type currently, dusting powder has a major share (85%) in the market followed by water-soluble dispersible powder (12%) and emulsification concentrates (2%.) The use of granules, which are advantageous in terms of lower drift, ease of application and safety to operate is still in infancy. Most of the units are in small scale industry (SSI) sector [19].

Table 1
Annual pesticide consumption in different countries.

S no.	Country	Ton a.i.	Ton product	US$ '000 value
1	Bangladesh	3635	22100	75000
2	Cambodia	42	198	226
3	China	258000	1000000	5670000
4	DPR Korea	3000	12000	60000
5	India	41020	164080	820400
6	Rep. of Korea	26610	100000	842638
7	Lao PDR	10	40	200
8	Malaysia	51065	204260	85020
9	Myanmar	758	3030	15095
10	Nepal	145	580	2100
11	Pakistan	32500	129589	172300
12	Philippines	7934	31735	158675
13	Sri Lanka	1696	6329	49000
14	Thailand	49108	132509	253537
15	Vietnam	24473	50000	159000

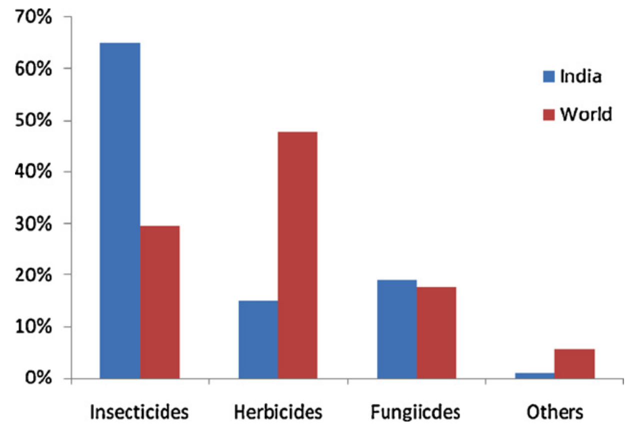

Fig. 1. Comparison of pesticide use in India and worldwide.

India is one of the few remaining countries still engaged in the large scale manufacture, use and export of some of the toxic chlorinated pesticides, such as *p,p′*-dichlorodiphenyltrichloroethane (DDT), hexachlorocyclohexane (HCH) and pentachlorophenol (PCP). Even in the 1990s more than 70% of the gross tonnage of pesticides used in agricultural applications in India consisted of formulations which are banned or severely restricted in the east and west [20–24]. According to a Green Peace Report, India is now producing 90,000 metric tons of pesticides as the largest industry in the whole of Asia and twelfth largest in the entire world (http://www.greenpeaceindia.org.nopesti.htm). The cumulative consumption of the pesticide, hexachlorocyclohexane (HCHs), in India until 1985 was 575,000 tons and since then about 45,000 tons of HCHs has been used annually [25]. The usage of DDT and HCH continued till recently [12,26]. Apart from the US, India is the only country which has applied more than 100,000 tons of DDTs since its formulation, mainly in its agricultural and malarial control programs until it was banned for agricultural use in 1989 [10,27]. Even though usage of technical HCH was finally banned completely in 1977 [28–31], the Government of India is encouraging its replacement with Lindane (γ-HCH), an isomer which has all the hazardous properties of HCH. Even though DDT has been banned for agricultural use, India has sought exemption under Stockholm Convention for use of 10,000 tons of DDT for restricted use in the public health sector [13]. The national malaria program (NAMP) used 3750 tons of DDT in the year 2001, in rural and peri-urban areas for residual spraying [12].

The pattern of pesticide use differs significantly between the countries (Table 1). The worldwide consumption of pesticide is about two million tons per year, of which 24% is consumed in the USA alone, 45% in Europe and 25% in the rest of the world. The usage of pesticides in India is only 0.5 kg ha^{-1}, while in Korea and Japan, it is 6.6 and 12.0 kg ha^{-1}, respectively. Among the various pesticides used in India, 40% of all the pesticides used belong to organochlroine class of chemical pesticides [3,12,32]. The other major category is organophosphate pesticides. Monocrotophos, phorate, phosphamidon, methyl parathion and dimethoate are some of highly hazardous pesticides that are continually and indiscriminately used in India. The three commonly used pesticides, lindane (γ-HCH), DDT and malathion account for 70% of the total pesticides consumption. Regarding the usage of technical pesticides, insecticides account for 80% of total pesticide used in the country, followed by herbicides and fungicides (Fig. 1). Globally herbicides are the leading category followed by insecticides and fungicides. In India, the share of herbicides is insignificant [33] .The higher consumption of insecticides is partially due to warm humid and tropical climate which provides favorable breeding environment for insects coupled with shorter life cycle and higher hatching rate. Organophosphorous compounds have overtaken organochlorine compounds as the most used insecticides in the recent decade [26]. Phorate is amongst several systemic compounds, which is generally applied near to roots of seedling plants to give protection against aphides and viral disease. Carbamate and pyrethroid insecticides are frequently employed to control insects. These pesticides are particularly useful for dealing with aphides and other pest, which have developed resistance to organophosphorus compounds. Permethrin is a pyrethroid insecticide with a high level of activity against lepidopterous pests. It is also effective against a wide range of Hemiptera, Diptera and Coleoptera. The compound is a both stomach and a contact insecticide, and shows adulticidal, ovicidal and, particularly, larviicdal activity [34,35]. Pesticides commonly used in India are presented in Table 2.

The changes brought about during modernization of agriculture have directly or indirectly led to increased incidences of pests and diseases [36]. For instance, areas under crops such as coarse cereals, small millets and barley are decreasing whereas monoculture and continuous cultivation of paddy, cotton and other commercial crops are increasing [19]. However, there has been an increase in number of species as well as absolute number of pests attacking

Table 2
Pesticides commonly used in India.

Pesticide: common name	Chemical family
I a Extremely hazardous[a]	
1. Phorate	Organophosphate
I b Highly hazardous[a]	
2 Monocrotophos	Organophosphate
3 Profenofos & Cypermethrin	Combination pesticide
4 Carbofuran	Carbamate
II Moderately hazardous[a]	
5 Dimethoate	Organophosphate
6 Quinalphos	Organophosphate
7 Endosulphan	Organochlorine
8 Carbaryl	Carbamate
9 Chlorpyrifos	Organophosphate
10 Cyhalothrin	Pyrethroid
11 Fenthion	Organophosphate
12 DDT	Organochlorine
13 Lindane	Organochlorine
III Slightly hazardous[a]	
14 Malathion	
IV Unlikely to present acute hazard in normal use[a]	
15 Carbendazim	Carbamate
16 Atrazine	Triazine

[a] WHO classification [54].

Table 3
Usage of pesticides in India [12].

Sector	Use
Agriculture	For control of pests, weeds, rodents, etc.
Public health	For control of malaria, filariasis, dengue fever, Japanese encephalitis, cholera, and louse-borne typhus
Other than agriculture and public health	
Industrial	Control of vegetation in forests and factory sites, fumigation of buildings and ships
Domestic	Household and garden spray, control of ecto-parasites, animals and birds
Personal	Application of clothing and skin care (Pediculicdes, Scabicides, etc.)
Material building	Incorporation of paints, glues, plastic protection, sheeting, foundation of buildings, etc.

the economically important crops. Pesticide use is high in regions with good irrigation facilities and in certain areas where commercial crops are grown. Cotton is one crop which is grown only on 5% of he cultivated areas, but consumes 45% of total pesticides used in the country (Table 3). The use of pesticides is high in few parts of the country such as Andhra Pradesh, Karnataka, Maharashtra, Gujarat and Punjab [11]. Andhra Pradesh and Punjab consume major quantity of pesticides. Pesticides account for 40–50%, 25% and 38% of cost of cultivation for cotton, paddy and cole crops, respectively. The cropped area wise pesticide shares of major Indian crops are depicted in Table 4.

3. Factors related to pesticide safety in India

Pesticides must be used with care, but in many developing countries in the third world and even in some developed countries many factors make safety impossible [8,18,19,33,37–42]. The major agriculture practices and related factors relevant to pesticide usage and safety measures in India are enumerated below:

- Lack of training in pesticide use
- Ignorance about potential dangers to health and environment
- Poor literacy, which makes it impossible to read or follow complex label instructions
- Inappropriate mixing (insecticides combinations i.e. mixing of two insecticides without technical advice)and application methods
- Repeated application of pesticides and application of same pesticides at all stage of life cycle
- Over application of pesticides
- Wrong application practices, such as use of same concentration mixture for different sprayers and measurement of dosage by own convenient scale
- Poor or faulty application equipment
- Long hours of spraying
- Smoking or chewing betel while spraying
- Poor regulation and easy availability of hazardous pesticides, including sales by untrained dealers
- Lack of personal protective equipment (boots, gloves and glasses), which are costly and not adapted to a tropical climate
- Lack of suitable washing facilities for workers
- Demand for containers, leading to reuse of poorly cleansed pesticide bottles, barrels or cans
- Poor household storage and disposal
- Lack of health centers, medical facilities, antidotes and poison treatment centers, as well as confusion of symptoms of pesticide poisoning with common illness

Table 4
Cropped area wise pesticide share of major Indian crops.

Crops	Pesticide share (%)	Cropped area (%)
Cotton	45	5
Rice	20	24
Chilies/vegetables/fruits	13–24	3
Plantation	7–8	2
Cereals/Millets/Oil seeds	6–7	58
Sugarcane	2–3	2
Others	1–2	6

The above safety factors clearly indicate that risks from pesticides in India are considerable higher than in industrialized countries.

4. Methods of pesticide application and application equipments

Some common types of application methods used in India are:

- Seed treatment
- Soil treatment
- Foliar treatment

Pesticides application equipment used in the country are mostly portable equipments which are manually operated. Tractor mounted techniques have been used only for big farms and air crafts have been used selectively on high value crops. In India, most commonly used equipment is hand carried lever operated knapsack sprayer which is not very well designed [16,19]. A study has revealed that two third of the users have experienced various problems with this equipment during spraying. The most common problems identified were replacement of the piston and clogging of the nozzles. Though this equipment is affordable to most of the farmers, it lacks maintenance and safety considerations. The other equipment used are hand compression sprayers, tree sprayers mist blowers cum duster, tree sprayers, thermal foggers, and ultra low volume (ULV) applications (spinning disc sprayers). Studies show that spinning disc sprayers are second in use after the hand compression sprayers. Insecticides are the most common pesticides for a spinning disc sprayer followed by herbicides [19–23].

5. Factors affecting proper application of pesticides

While modern pesticides have reached country, the technology used for their application has not been upgraded, resulting in a waste of pesticides and unnecessary environmental contamination. Reports indicate that changing the design of nozzles of lever operated knapsack sprayers could save 70% of pesticides compared to the farmer's previous practice [18,19]. The major factors affecting the proper application of pesticides are discussed below.

5.1. Operator knowledge

Farmers and sprayers equipment operators still have wrong notion that high volumes, high pressure and high doses being perceived as the most appropriate ways for pesticide application.

5.2. Equipment design

As the application equipment market in India insists on lower costs and does not demand quality, manufactures are not encouraged to offer equipment with any extras to improve safety, durability, comfort or efficiency, not considered essential for smooth functioning of the equipment. Further, as the market insists on lower costs, inferior materials are often used. Examples include tanks with rough surfaces, hoses or washers not being pesticide proof and crimped hose clips [23]. This sort of equipment competes on the market, as it sold at very low price difficult to be matched by quality equipment.

5.3. Service conditions of equipment

Usually the major part of the spraying equipment in use is in extremely poor condition, due to lack of maintenance. A high percentage of farmers never change sealing washers in their equipment. As a result, most of the spray equipment leaks [23]. Nozzles are normally not replaced and are even enlarged on purpose to achieve higher flow rates. The distribution patterns under these conditions are uneven; leaving sections with no pesticide coverage and others receiving overdoses [18,19].

5.4. Weather conditions

Accurate timing of pesticide applications is a critical component in obtaining the best results possible from pest control products [43]. Timing decision may simultaneously incorporate multiple variables. Weather conditions play a major factor in affecting timing decisions; these conditions also play a significant role in the occurrence of spray drift. Spray drift is a major concern because it diverts the pesticide from the intended target, reduces efficacy, and deposits pesticide where it is not needed or wanted. The factors influence spray drift contamination are: operating pressure; nozzle, type, orientation, orifice size, wind speed, wind direction, temperature, relative humidity and atmospheric stability. When a pesticide drifts, it may cause both environmental and economic damage through injury to susceptible vegetation, harm to wildlife, deposition of illegal residues on crops, and contamination of water supplies. Many pest control product labels contain either guidance or specific instructions regarding suitable environmental conditions and application timing. While following the label instructions to the letter may not guarantee applicator's freedom from inadvertent economic or environmental damage, these directions are based on both generic drift studies and specific product tests. Hence, applicators should monitor and make accurate records of weather conditions at application time both to reduce liability and make better decisions regarding timing of the application [43].

6. Regulations in pesticide application

6.1. Indian scenario

In the regulation of pesticide application, government bodies have an important and major role because both producers and users are not likely to limit themselves in the sales and use of pesticides [44–47] (Table 5). Quality control of pesticides is ensured through a rigorous registration procedure requiring testing in four different climatic conditions and making available toxicological data in Indian conditions. The import, manufacture, sale, transport, use, etc. of pesticides is being regulated under a comprehensive statute 'The insecticides act, 1968' and the rules framed there under, to ensure availability of quality, safe and efficacious pesticides to the farming community, comprehensive regulations to ensure that no part of the pesticide industry operate outside its watchful eye. Not only every pesticide product is manufactured, imported or used in India required to be registered with the Central Insecticides Board, any body selling, stocking or distributing pesticides products, also requires a license. The act also allows the Board to ban or restrict the use of any pesticide product. Accordingly, the Government has banned the use of more than 30 pesticides, restricted the use of 7 pesticides including DDT, and refused registration for 18 pesticides. India also has a BIS standard (Bureau of Indian standard) for pesticide application equipment. However, implementation of legislations and standards at field level needs to be strengthened to prevent misuse and inappropriate use of pesticides with equipment that does not meet the minimum of quality standards.

Table 5
Major pesticide control legislations in India [44–47].

S no.	Legislation	Regulatory body
1	Insecticide Act, 1968 and the Insecticides Rules, 1971	Ministry of Agriculture Department of Agriculture & Cooperation
2	Environment Protection Act, 1986	Ministry of Environment & Forest
3	Prevention of Food Adulteration Act, 1954	Ministry of Health & Family Welfare

Under the Insecticide Act, compulsory registration of pesticides is provided. The use of chemical pesticides can be initiated only after the proper registration by the Registration Committee, after close scrutiny of the data about bio-efficacy and safety of human beings, wildlife, birds, domestic animals, beneficial parasites and predators. The Insecticide Rules takes care of the safety culture in pesticide handling and use. It covers periodical clothing, respiratory devices, antidotes and first aid medicines, training of workers and disposal of used packages, surplus materials and washing of insecticides. The Registration Committee reviews the pesticide from time to time and the recommendations are considered by the Ministry of Agriculture. The committee as the policy has decided not to register WHO class IA and IB pesticide unless there is sufficient justification. The Directorate of Plant Protection, Quarantine & Storage (DPPQS) has good schemes for training at the state level. Besides, training is imparted to the doctors of health centers of states by the medical experts of the Directorate of Plant Protection, Quarantine & Storage. The National Plant Protection Training Institute (NPPTI) at Hyderabad imparts training to the State Plant Protection functionaries. Farmers Field Schools (FFS) are regularly organized under the IPM programme in addition to season-long training for Masters Trainers under which State Extension Functionaries are trained for full cropping periods of various crops. State Agricultural Universities (SAUs), Krishi Vigyan Kendras (KVKs), and State Department of Agriculture (SDA) also organize training to farmers on safe use of pesticides.

For the enforcement of the quality of pesticides, four important functionaries are notified under the provisions of the Insecticide Act/Rules viz., Licensing Officers, Appellate Authority, Insecticide Inspectors and Insecticide Analysts. A network of 46 pesticides testing laboratories, situated in 18 States and 1 Union Territory across the length and breadth of the country, with an annual analysis capacity of over 55,666 samples of pesticides is available in the country for continuously monitoring the quality of pesticides. One of the notified functionaries of the Government, Insecticide Inspectors can enter and search, at all reasonable times and with such assistance as he considers necessary in which he has the reason to believe that an offence under the Insecticides Act, 1968 and the Rules made there under has been or is being or is about to be committed, or for the purpose of satisfying himself that the provisions of this Act or the Rules made there under or the conditions of any certificate of registration or license issued there under are being

Table 6
International instruments concerning pesticide use and application [48–58].

S no.	Convention	Adopted	Entry into force	Number of parties	Remarks
Legally binding					
1	Rotterdam Convention on the Prior informed Consent Procedure for Certain Hazardous Pesticides and Industrial Chemicals in International Trade	1988	2004	117	Substances covered: specific types of pesticides (24 pesticides and 4 severely hazardous pesticide formulations) and 11 industrial chemicals
2	Stockholm Convention on Persistent Organic Pollutants	2001	2004	149	Substances covered: persistent organic pesticides (9 of which are pesticides)
3	Basel Convention on the Transboundary Movement of Hazardous Wastes and Their Disposal	1989	1992	170	Substances covered: hazardous wastes including pesticides, including pesticides at the end stages of their life cycle
4	Montreal protocol on Substances that Deplete Ozone Layer	1987	1989	191	Substances covered: methyl bromide, a specific type of pesticides, which is also an ozone-depleting substances
5	ILO Convention on Safety and Health in Agriculture, No. 184	2001	2003	8	Substances covered: not specified, addresses all aspects of health and safety for chemicals used in agriculture
6	ILO Convention concerning Safety in the use of chemicals at Work, No. 170	1990	1993	15	Substances covered: (hazardous) chemicals used in all kinds of economic activities
Voluntary					
1	FAO International Code of Conduct on the Distribution and Use of Pesticide	Adopted, 1985 Revised; 2002			Substances covered: pesticides (broadly defined)
Selected FAO Guidelines to the Code of Conduct					
1	Glossary of terms and definitions for the guidelines in support of the code of conduct (continuously updated)				
2	Guidelines on monitoring and observance of code of conduct (2006)				
3	Legislation on the control of pesticides (1989)				
4	Manual on submission and evaluation of pesticide residues data for the estimation of maximum residue limits in food and feed (2002)				
5	Initial introduction and subsequent development of a simple national pesticide Registration and Control Schemes (1991)				
6	Addenda to the registration and control of pesticides (1988)				
7	The registration and control of pesticides (1985)				
8	Guidelines on efficacy data for the registration of pesticides for plant protection (1985)				
9	Guidelines on good labeling practices for pesticides (1995)				
10	Guidelines for the packaging and storage of pesticides (1985)				
11	Guidelines on procedures for the registration, certification and testing of new pesticide application equipment (2001)				
12	Guidelines on compliance and enforcement of pesticide regulatory program (2006)				
13	Pesticide storage and stock control manual (1996)				
14	Provisional guidelines on tender procedures on the procurement of pesticides (1994)				
15	Guidelines for retail distribution of pesticides with particular reference to storage and handling at the point of supply to users in developing countries (1988)				
16	Guidelines on good practices for aerial application of pesticides (2001)				
17	Guidelines on good practices for good application of pesticides (2001)				
18	Guidelines on personal protection when working with pesticides in tropical climate (1990)				
19	Guidelines on organizational and operational training schemes and certification procedures for operators of pesticide application equipment (2001)				
20	Guidelines on the management and disposal of used containers (2007)				
21	Guidelines for the management of small quantities of unwanted and obsolete pesticides (1999)				
22	Guidelines on disposal of bulk quantities of obsolete pesticides in developing countries (1996)				
23	Provisional guidelines on prevention of accumulation of obsolete stocks (1995)				
24	Guidelines on post registration surveillance and other activities in the field of pesticides (1988)				

complied with. Insecticide Inspectors also draw samples of pesticides, Insecticide analysts, carry out their analysis. Besides, the Central Government has also established two regional pesticides testing laboratories to supplement the resources of the States/UTs, who do not either, have a pesticide testing laboratory or adequate analysis capacity or adequate analysis facility for monitoring the quality of pesticides. Any disputes in the results of analysis are settled by a referral laboratory of the Central Government, called the Central Insecticides Laboratory (CIL). In order to strengthen the existing laboratories and to set up new pesticides testing laboratories, the Central Government also extends financial assistance to the States/UTs as grants-in-aid. Besides, State Governments also establish additional Pesticides Testing Laboratories with their own resources.

India has four poison information centers including the National Information Centre (NIC) at All India Institute of Medical Science in New Delhi. The Poison Information Centre is a specialized unit providing information on prevention, treatment of poisoning and hazard management. The information on poisoning due to pesticide is regularly collected and discussed in the national conferences. While registration of pesticide under the Insecticide Act 1968 for use in the county, it is ensured that no residue of pesticide is left at the time of harvest of the crop. The maximum residual limits (MRL) are fixed by Ministry of Health & Family Welfare (MOH&F) under the Prevention of Food Adulteration Act (PFAA) 1954 on the basis of the residue and the toxicological information provided by the Ministry of Agriculture and thus the monitoring of the pesticide residues fall under the preview of the MOH&F. However, Directorate of Agriculture & Co-operation has been allocated the pesticide monitoring recently. A central Scheme "monitoring of pesticide residues" have been formulated/approved with an objective to ascertain the prevalence of pesticide residues at farm-gate and market yards so that remedial measures could be undertaken through IPM campaign to eliminate the risk of pesticide residues from agricultural commodities with special emphasis on export products.

6.2. International scenario

Pesticides have traditionally being the object of international legislation in several fields (Table 6). Laws and regulations on

Fig. 2. Pesticide application without personal protection. A farmer is going to apply weedicide (without protective mask, clothes and gloves) against *Salvinia molesta* in Vemband lake, Kerala, South India (Photo credit: Sylas V.P., Doctoral Fellow, School of Environmental Sciences, Mahatma Gandhi University, Kerala).

human health, environmental protection, agricultural practices, international trade and border control all address the proper use, manufacture, export, import and application technologies for pesticides [13,14,36]. The international code of conduct and use of pesticides (Code of Conduct), adopted in 1985 by the 23rd session of the main governing body of the Food and Agriculture Organization of the United Nations (FAO), was formulated to provide universal standards of conduct for all parties, but especially national governments and pesticide industry. Since then, the code of conduct has been amended once, in 1989, to include the prior informed consent procedure, and revised in 2002. Since 1985, several other international instruments, either dealing explicitly with pesticides or indirectly relating to their management, have come into force. The most relevant include the Rotterdam convention on the prior informed consent procedure, for certain hazardous chemicals and pesticides in international trade (Rotterdam convention), the Stockholm convention on persistent organic pollutants (Stockholm convention), the Basel convention on the transboundary movement of hazardous wastes and their disposal (Basel convention), the Montreal protocol on substances that deplete the ozone layer (Montreal protocol), the International Labor Organization convention No. 184 on safety and health in agriculture (ILO convention 184) and numerous standards on pesticide residues in food issues by the Codex Alimentarius Commission. Furthermore, a new globally harmonized system of classification and labeling of chemicals (GHS) has been designed to improve the protection of human health and the environment during the handling, transport and use of chemicals. However, it is very important to note that legislation alone is unlikely to balance effective pesticide management with an environmentally sustainable approach to pest control. Governments should consider adopting other policies and strategies to improve pesticide management, such as providing farmers with support and training in integrated pest management (IPM), allocating subsidies for the purchase of minimum-risk products and fostering scientific research, public education campaigns and training for both inspectors and professional users. A solid legislative and regulatory framework, however, underpins all of these [36,47–58].

7. Problems related to improper pesticide application

Although India has national standards for spray equipment, which are followed by the major manufactures, there are still many manufactures serving local needs that do not comply with quality standards [3,19,23]. Pilot study in select hot spots in various parts of the country has indicated that substantial amount of applied pesticides are wasted due to poor spraying machinery and inappropriate application. In the hot spots studied, much of the spraying equipment was in extremely poor condition. Nozzles were normally not replaced and were even enlarged on purpose to achieve higher flow rates and most of the farmers were not trained in safety aspects. Also high levels of pesticide residues in food crops, compared to the world average, are reported from various parts of the country [16]. This is an indication that pesticides were used in a wrong way.

Most of the farmers use locally made spraying equipment which does not have adequate safeguard and is least durable. This sprayer develops cracks and leaks quite frequently. The use of protective clothing, masks or gloves is also very rare. (Fig. 2). Further, farmers are ignorant about proper use and efficient application. They are unable to distinguish one pest from other and use wrong or improperly maintained nozzles. Further, the study has revealed that farmers are mixing the pesticides that should not be mixed and are using ultra low volume formulations for knapsack sprayers. The equipment of the farmers is not properly maintained and proper cleansing and correct handling has not been done. Farmers are also not aware of the specific doses of the pesticides to use them in cost effective manner. The selection of the equipment is also not appropriate in many cases. For instance, the equipment such as knapsack sprayers that needs considerable amount of water per hectare has also been used even in water scarce areas [23,32].

Malpractice in pesticide application attributes greatly to the environmental and health hazard. Experiences with farmers on health implications of pesticides in Punjab revealed that incidences of occurrence of cancer, kidney failure, still birth, infertility, etc. have been substantially increased [59–63]. There have been a number of outbreaks of accidental poisoning that deserves special mention [34,64]. In India, the first report of poisoning due to

Table 7
Average daily intake of organochlorine pesticides in various states of India.

Location	Pesticides[a]	Reference
Gujarat (1980s)	HCH (23); DDT (141)	[128]
Punjab (1980–1981) (vegetarian)	HCH (125), γ-HCH (23), DDT (239)	[60]
Punjab (1980–1981) (non-vegetarian)	HCH (134), γ-HCH (22), DDT (225)	[60]
Uttar Pradesh (1981–1983)	HCH (1290), γ-HCH (190), DDT (200)	[114]
Gujarat (1990s)	HCH (77), DDT (20)	[124]
Punjab (1999–2000) (vegetarian diet)	γ-HCH (599.5)	[62]
Punjab (2001) (vegetarian diet)	γ-HCH (163.5), DDT (2.2)	[62]
Punjab (2002) (vegetarian diet)	γ-HCH (27.2), DDT (8.17)	[62]
Punjab (2001) (non-vegetarian diet)	γ-HCH (163.5), DDT (13.6)	[62]
Punjab (2002) (non-vegetarian diet)	γ-HCH (81.7), DDT (27.2)	[62]

[a] Results in parenthesis are the ADI (average daily intake; μg person^{-1}) value.

pesticides was from Kerala in 1958, where over 100 people died after consuming wheat flour contaminated with parathion [65]. The chemical used was ethyl parathion known as Folidol E 605, was introduced by Bayer. In the same year poisoning in Kerala caused deaths of 102 people. This was mainly due to careless handling and storage of wheat. Subsequently, several cases of human and animal poisonings, besides deaths of birds and fishes, have been reported. In general, it has been observed that organophosphorus pesticides are responsible for death in more than 70% cases [12,65]. The 1984 Bhopal tragedy was the world worst industrial disaster. On the night of December 2 and 3, 1984, a Union Carbide plant in Bhopal, began leaking 27 tons of the deadly gas methyl isocyanate (MIC). None of the six safety systems designed to contain such a leak were operational, allowing the gas to spread throughout the city of Bhopal. Half a million people were exposed to the gas and 20,000 have died to date as a result of their exposure. More than 120,000 people still suffer from ailments caused by the accident and the subsequent pollution at the plant site.

Several reports are available for the occurrence of pesticides in various environmental compartments. Recently, four hexachlorocyclohexane isomers in eight plant species growing in an industrial premise have been reported having high concentrations in *Withania somnifera* (L) Dunal and *Solanum torvum* [66,67]. Tanabe et al. [68] and Takeoka et al. [69] evaluated the transport of HCHs from land to sea in a paddy field and adjoining estuarine systems in southern India and found out that major portion of the HCHs used is removed to the air and contribute both to the regional and global pollution. A series of studies from other workers showed the existence of various pesticides in samples of air [70–73], water [70,74–85], soil and sediments [69–70,86–98] wildlife including dolphins, sharks and mussels [99–107], fish [106,108,109] birds [88,110–112] and food stuffs [113–129] from India. Average daily intake of organochlorine pesticides in various states of India is summarized in Table 7. Many of the above studies in the past two decades have shown that India has the highest concentrations of HCHs in its environmental and biological samples than in several other countries. Li et al. [31] has stated that India is one of the greatest consumers of HCHs and the most contaminated nation in the world. As a result of intensive application, relatively high levels of HCHs and DDTs were observed in the Indian environment and biota. Especially the finding of persistent organochlorine residues like DDTs, HCHs and PCBs in human breast milk [130–136] is of particular concern because infants and children may be susceptible to the toxic implications of any toxicant than the adults.

Apart from these, numbers of recent studies are coming with the health implications of pesticide workers and susceptible general populations in India [137–144]. More than twenty years of aerial spraying of endosulfan for cashew nut production, in the government owned Plantation Corporation of Kerala, South India, has been linked to massive health problems from horrendous birth defects to cancers and deaths in the communities around the Kasargod District, Kerala. People residing in the villages within the plantation have been afflicted with different kinds of illnesses [138,145–149]. People also noticed the death of fishes, honeybees, frogs, birds, chicken and even cows. The illnesses observed from the villages of Kasargod district are to be expected from the known intrinsic toxicologic properties of endosulfan. There is no evidence that other environmental toxicants that might possibly explain the observed health problems are presenting in the affected areas. There has been no other pesticide, not even household pesticides that have been used except endosulfan. There are no industrial activities at or near the areas affected. The preponderance of neurologic and mental illnesses among the reported health problems is compatible with the fact that endosulfan is a known neurotoxicant, blocks the inhibitory receptors of the central nervous system, disrupts the ionic channels, and destroy the integrity of the nerve cells [149]. Apart from its capacity to directly damage the nervous system [146], endosulfan is also an endocrine disruptor [148]. Even low levels of exposure during pregnancy could result in various forms of endocrine disrupting effects in the offspring, including mental retardation, reproductive organ anomalies, developmental disorders, behavioral disorders later in life and many others [147].

It could be inferred from above that the problems directly relating to pesticides application technique and equipment such as unavailability of standard equipment and appropriate pesticides, poor maintenance of equipment, misdirected and wrong targeted application of pesticides and malpractices in pesticide application have a spiraling effect and result in some associated problems having severe socio-ecological implications such as intoxication, poisoning and environmental hazard.

8. Recommendations

Pesticides are widely used chemical substances throughout the world in agriculture and public health. Because of their high biological activity, and in some cases of their persistence in the environment, the use of pesticides may cause undesired effects on human health and to environment. On the other hand, pesticides play a significant role in rural health program comprises of the control of biting, noxious, irritating, annoying or contaminating insects and other pests, which infest human and animals. Pesticide residue in food and feed crops, meat and poultry, fish and aquaculture as well as milk products generally arise from their indiscriminate use in agriculture and public health. Fortunately, there are encouraging trends towards phasing out the toxic and persistent group of pesticides. Some new molecules are being developed which are biodegradable and having low mammalian toxicity, low residual life and better compatibility with non-target organisms. Some of the other alternatives include:

(i) Regulating pesticide use
(ii) Use of biotechnology (Developing GM crops based on transgenic technology) to combat bacterial, fungal and viral diseases [150],
(iii) Encourage eco-friendly cultivation practices include polyculture (growing multiple types of plants) and crop rotation.
(iv) Use of trap crops that attracts pests away from the real crop (sex pheromones)

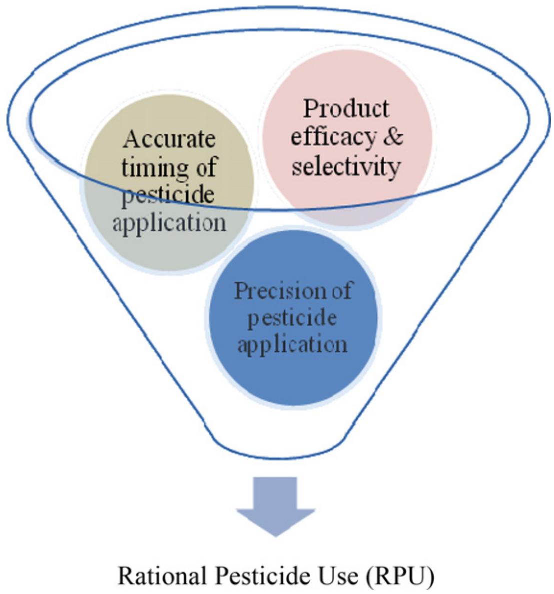

Fig. 3. Critical factors affecting the safety of pesticide application. Benefits of RPU are operator safety, reduced pesticide cost or equivalent cost with reduced environmental impact and pesticide resistance management.

(v) Use of self-micro-encapsulated pesticides and bacteria as well as encapsulated pesticide granules and powders, aimed at providing specific releases rate.
(vi) Use of bio-pesticides i.e. use of enemies of insect pests such as parasitoids, predators and insect pathogens, use of pesticides obtained from natural plant products such as neem extracts, tobacco extracts, garlic extracts, etc.

8.1. *Rational use of pesticides (RUP)*

The concept of rational use of pesticide (RUP) was coined in the title of a book by Brent & Atkin [151]. Rational pesticide use (Fig. 3) can be defined as a focused sub-set of integrated crop management and integrated pest management, which attempts to mitigate the adverse effects of pesticide use by improvements in the selectivity of the products themselves and the precision of their application in both space and time. The benefits of RPU are maximized with a combination of all three, and the potential benefits include: reduction of costs (for both pesticides and labour), improved safety and reduced environmental impact (through more efficient use of sprays and the use of specific agents, including biopesticides).

8.2. *Integrated pest management (IPM)*

Concern about the adverse effects of chemical pesticides due to their indiscriminate use is growing. The integrated pest management (IPM) approach, being promoted since 1985, is an eco-friendly strategy of pest containment by exploiting the role of natural agents/forces in harmony with other pest management tactics and with the sole aim to effect minimum disturbance to environment. Cultural control, use of natural enemies and plant resistant are basically compatible and supportive tactics in the IPM strategy. Strengthening of IPM infrastructure, especially for surveillance and forecasting the outbreak of pests and diseases and production/multiplication of bio-control agents for filed use, should be given adequate attention. Besides, reliable methods of forecasting should be developed and efforts should be make bio-control agents available on demand to farmers to help them adopt IPM in the true spirit by encouraging the private sector, Government organizations, central and state agricultural institute in providing such support services. The Governments efforts should be to provide new, safer and efficacious quality pesticide products to the farmers and encourage the use of bio-pesticides and bio-control agents. The IPM future thrust areas are listed below:

- Constitution of more intensive field based trainings and demonstrations for Human Resource Development on IPM.
- Establishment and strengthening of more biocontrol laboratories in the States for augmenting the biocontrol potential.
- Conservation of the naturally occurring biocontrol agents by discouraging the use of broad spectrum and hazardous chemical pesticides.
- Sustained publicity through electronic; and print media for creating greater awareness among the public/farmers.
- Encouragement to NGOs and women organizations for their greater participation in the promotion of IPM.
- Perspective National Plan for IPM is being prepared.
- Computer networking of all Biocontrol Units present in the country with Directorate of Plant Protection, Quarantine & Storage/DAC, Krishi Bhavan, New Delhi is required.
- Expert team report on use of remote sensing technology in Plant Protection has been received. Initially, the expert team has recommended taking up the studies in Rajasthan/Haryana/Punjab/Andhra Pradesh and Tamil Nadu.
- Working group has been constituted to recommend the pest monitoring strategy in future.

8.3. *Continuous monitoring of pesticide residues in agricultural commodities*

In view of the WTO and sanitary and phytosanitary agreements, international trade is likely to increase and pesticides residue certificate on agricultural commodities would become unavoidable. Therefore, emphasis should be given to establish additional facilities (all over the country) for pesticide residue testing in agricultural commodities being imported or exported and also for the regular monitoring in all agricultural commodities marketed within the country. Besides, the facilities for pesticide quality testing would be developed and strengthened to enforce the quality control for manufacture and marketing of pesticides.

8.4. *Organic farming*

One alternative to synthetic pesticide use is organic farming. Organic agriculture and food processing practices are being widely used in developed countries and overall seeks the development of a food production system that is socially, ecologically and economically sustainable. The key principles and practices of organic food production aims to encourage and enhance biological cycles within farming systems to maintain and increase long time fertility of soil, to minimize all forms of pollution caused by fertilizers and pesticides and to produce food of high quality in sufficient quantity. However, this process is costly, labor intensive, and in some cases ineffective.

8.5. *Farmers awareness*

The dangers of acute pesticide poisoning are well known to Indian farmers, but the need is to highlight the chronic exposure which can cause many neurological diseases. The current need is to address the awareness for long term moderate exposure. Further, Indian farmers are lagging behind in the use of new application technologies for pesticides spraying. The crux of the problem is that though, the technology is available in the country and is being used by few progressive farmers, majority of them are not in a position to implement these new technologies either due to lack of awareness or means. The farmers need to be educated by the crop protection industry sine they are the main end-users of the products. This realization leads to development of indigenous technology as required by the farmers [152–155]. Farmers in their quests to controlling pests and increasing yields ignore the problems of health and environment hazard.

8.6. Additional recommendations

Recommendations relating to minimizing the problems related to health and environment due to inappropriate application of pesticide are:

- A multidisciplinary integrated approach involving toxicology, epidemiology, physiology and behavioral sciences to appreciate the hazards and plan the preventive strategies need to be developed.
- Using economic incentives for pesticide usage reductions by evaluating the actual cost of pesticide pollution [155].
- There is need to monitor adverse reproductive outcomes of pesticides exposure and prevalence of pesticides related cancer to plan preventive action.
- There is need to promote and implement the holistic concept of Integrated Crop Management (ICM) to minimize adverse effects of pesticides.
- The government should strictly implement various legislation, standards and code of conducts for regulation of manufacturing, distribution, handling and application of pesticides.
- The setting up of pesticides limits for food stuff, water, air and soil may be done on priority and strict adherence ensured.
- Special training programmes for farmers, operators, consumers, medicos, pesticide dealers, pesticide equipment manufactures, etc. need to be frequently conducted.
- Effort should be made in improving pesticides application technology and ensuring that the equipments are of light standard and are properly maintained.
- Special awareness campaigns should be conducted to increase the awareness level about various environmental hazards of pesticides.
- Safety equipment and protective clothing should be designed according to Indian condition and made available at lower cost.
- Transformation from chemical based farming practices to eco-friendly alternatives may be encouraged.

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