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NON-POINT POLLUTION OF GANGA RIVER WITH PESTICIDES: A QUANTITATIVE APPROACH*

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ABSTRACT

Rivers are the main source of water in India, particularly for agricultural irrigation and drinking water supply. As most of the rivers pass through agricultural fields, they are subject to contamination with different pesticides used for crop protection. Residues of these chemicals have been detected in many Indian rivers. In the present study, the transport of insecticides from soil to river was measured on the basis of surface run-off, sedimentary transport, and movement of ground water from aquifer to river and vice-versa. It was found that agricultural applications of HCH, DDT, aldrin, endosulfan, and organophosphates contributed as much as 0.708, 0.682, 0.200, 0.374, and 0.926 g/ha, respectively, to the river water. In all, 2.890 g/ha was transported to the river. These values were in close agreement with overall contribution of agricultural fields to the river Ganga calculated on the basis of the amount of insecticides actually flowing in water at Farrukhabad and total catchment area from Haridwar to Farrukhabad.

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INTRODUCTION

Direct application of insecticides, agricultural runoff, disposal of outdated stocks, containers and packets, and discharge of waste waters are the major sources of pesticides in water bodies. However, leaching from agricultural fields is the single important non-point source of pollution in the aquatic environment [1]. Rivers flowing through the agricultural fields readily become contaminated with pesticide residues present in soil under the influence of rain water as well as irrigation water, by the processes of surface run-off, sedimentary transport, and movement of ground water from aquifer to river. The ground water flows to the river when the water table is higher than the level of water in the river. The extent of surface transport and run-off to the river depends on the intensity of rainfall, slope, texture and porosity of soil, erosivity of rain water, erodibility of soil, water table and solubility, and polarity of pesticides [1-3].

Growing population in India will necessitate the use of larger quantities of insecticides in coming years to protect and improve the quality and quantity of our agricultural produce. This places rivers under a constant threat of pollution by these toxic compounds. Most Indian rivers are already contaminated with insecticide residues [4-10]. However, there has been no quantitative approach to the study of non-point pollution of any of these rivers.

In this article, we have made a preliminary attempt to quantify the pollution load on a river from non-point sources taking all the factors governing the transport of pesticides from agricultural fields to the river into account. The whole calculation was based on analytical data obtained from experimental site and on the estimated input of pesticides in the region.

STUDY AREA

An area under intensive agricultural activity in the district of Farrukhabad (27° N and 79° E) on the southern bank of the river Ganga (Figure 1) was selected for this study. The river Ganga arises in the Himalayas and reaches the plain at Haridwar. Farrukhabad is 250 km from Haridwar. The climate of the area is characterized by a hot summer, cold winter, and intensive rainfall during monsoon. The average annual rainfall is 832 mm, of which the monsoon months account for more than 87 percent.

It is estimated that 42500 kg of pesticides are used in this region each year [11], of which about one half are insecticides. Organochlorines comprise more than 60 percent of the total insecticides used. Consumption of pesticides in this area has more than doubled in recent years (Figure 2). Major crops grown in the area are potato, maize, wheat, and vegetables. Soils from the agricultural fields were found to be either silt loam or sandy loam with as low as 0.5 percent organic matter.

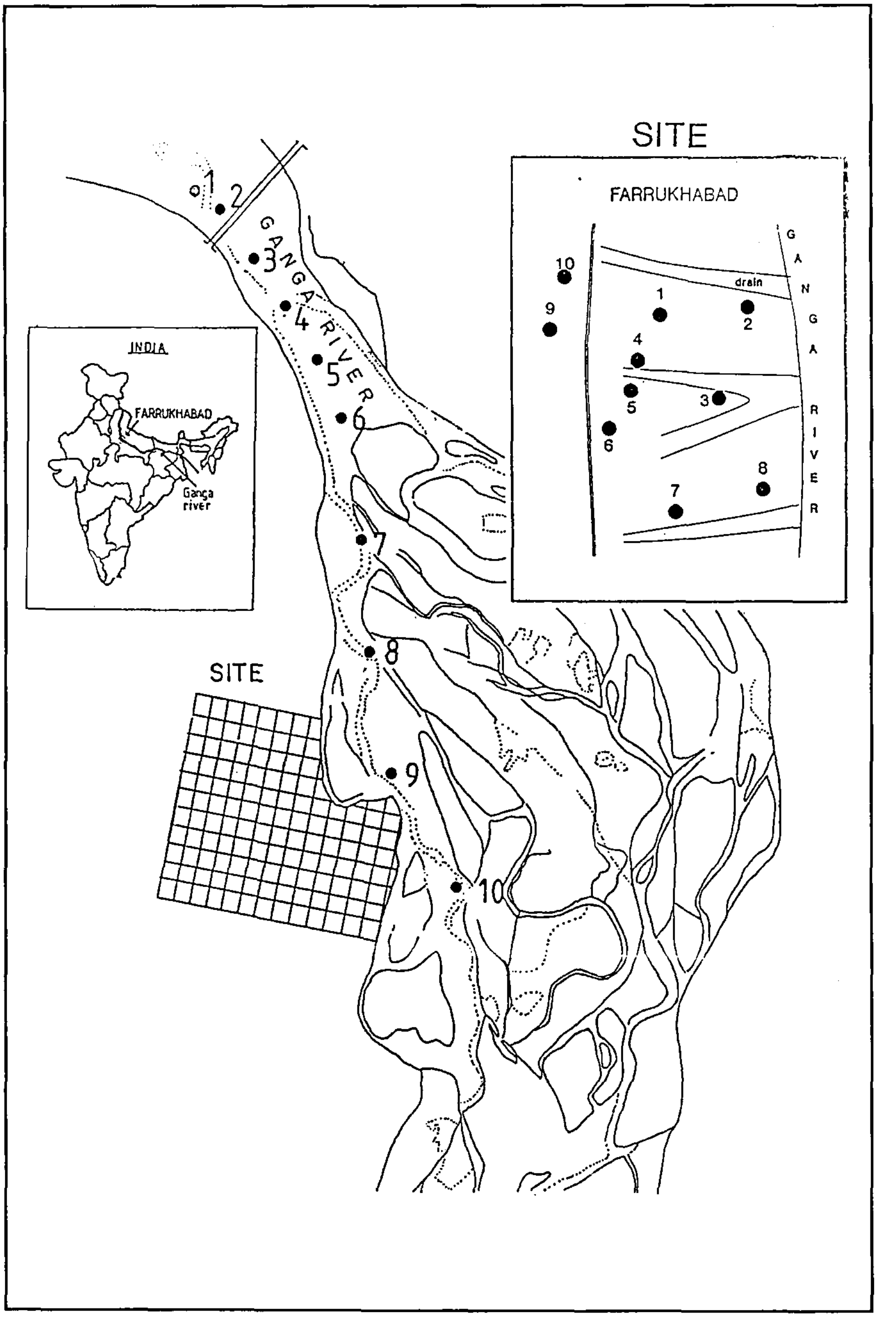

Figure 1. Sampling locations near Farrukhabad.

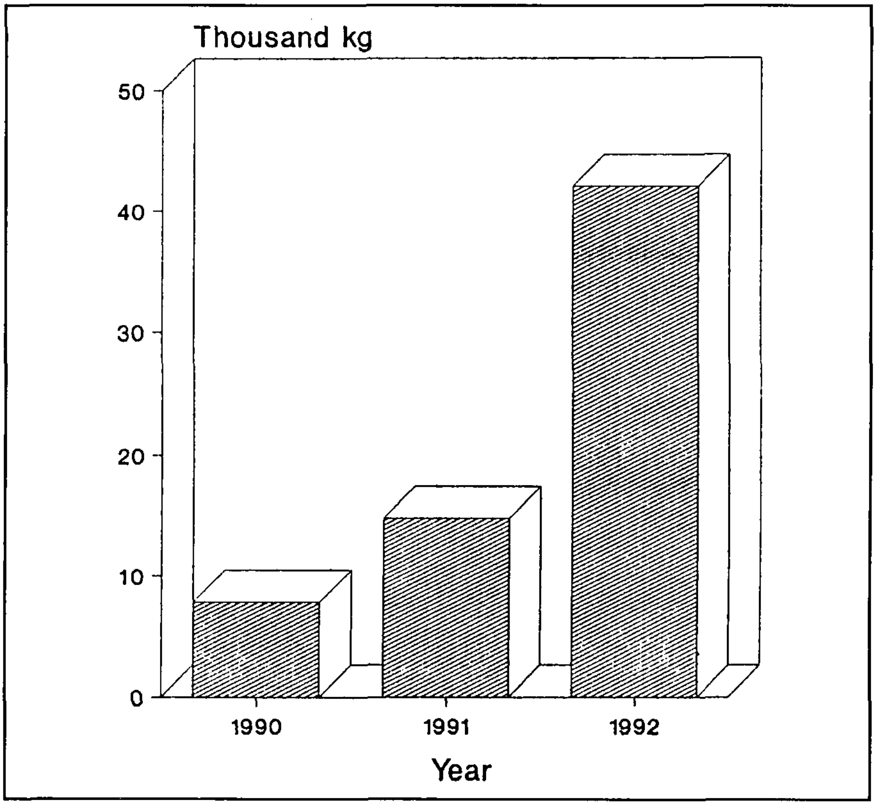

Figure 2. Pesticide consumption in Farrukhabad district.

Samples of river water were drawn from different locations, as shown in Figure 1. Ground water samples were drawn from agricultural fields selected from the southern side of river Ganga. Some water samples were taken from the drains carrying effluent from agricultural fields to the river. Extraction of samples was carried out by the method outlined by Agnihotri et al. [10]. The sample extracts were analyzed by Hewlett Packard model 5890-A gas chromatograph for organochlorine and organophosphorus insecticides.

Transport of Pesticides to River

In the present study, transportation of pesticide from agricultural fields to river as non-point source has been calculated on the basis of:

1. Surface run-off;
2. Sedimentary transport; and
3. Flow of ground water into river.

Surface Run-off

Surface run-off occurs when rainfall is so intense that all the water cannot percolate into the soil. The excess water flows out of the field and carries the residues of pesticides either in dissolved state or in undissolved form driven away by water current. Higher rainfall rates cause higher dissolved-chemical concentrations at the soil surface [12]. The extent of run-off from soil surface as a result of rainfall depends on factors such as surface condition, moisture content of soil profile, topography, and agricultural practices. Under normal conditions, with a gentle slope of less than 1 percent, the run-off for sandy or sandy loam soils under crop cover has been estimated to range from 14 percent to 25 percent [13].

In the present study, the run-off water was calculated assuming that about 20 percent of the rainfall water was lost by surface run-off. Since run-off usually takes place during monsoon months, the rainfall during other months is not considered in run-off calculations. The concentration of pesticide in run-off water was determined from water samples drawn from the drains leading to the river Ganga, assuming that the concentration of pesticides in run-off water was the same as that in drain water.

Pesticide loss with run-off water (g/ha)

= volume of run-off water (L/ha) $\times$ concentration of pesticide (g/ha);
= precipitation (cm) $\times 2 \times 10^4$
$\times$ pesticide concentration in drain water (ug/L) $\times 10^{-6}$;
= precipitation (cm) $\times$ pesticide concentration in drain water $\times 2 \times 10^{-2}$.

The amount of pesticide lost from agricultural fields by surface run-off and carried to the river has been calculated in Table 1.

Sedimentary Transport

During monsoon, fine soil particulates are transported from the surface of the soil to nearby water bodies under the influence of surface run-off. It is known that fine particles adsorb both polar and non-polar pesticides due to large surface area, essentially by physical processes. These particles carry with them the residues of pesticides which are adsorbed onto them [14].

The amount of soil removed from the field as influenced by rainfall can be worked out using the soil loss equation, which takes into consideration factors like rainfall, erosivity, soil erodibility, crop cover, and conservation-supporting practices. By applying the soil loss equation, iso-erosion rates at various parts of the country have been calculated [13]. Based on the iso-erosion contours, the soil loss at the experimental site was worked out to be 5 tons/ha/year. A similar rate of loss was also noted from the other sites of river Ganga starting from Haridwar to Farrukhabad.

Pesticide loss through sedimentary transport (g/ha):

Table 1. Pesticide Loss from Agricultural Fields through Surface Run-Off

Period	Rainfall (cm)	Average Concentration of Pesticide in Drain Water (ug/L)					Pesticide Loss Through Surface Run-Off Water (g/ha)				
		HCH	DDT	Aldrin	Endos	OPs	HCH	DDT	Aldrin	Endos	OPs
September to October	12.1	0.360	0.330	0.139	0.076	0.109	0.044	0.040	0.017	0.009	0.013
November to December	4.7	1.784	0.467	0.203	0.115	0.140	0.083	0.022	0.009	0.005	0.006
July to August	27.9	0.415	0.313	0.151	0.000	0.000	0.116	0.087	0.042	–	–
Total							0.240	0.149	0.068	0.014	0.019

= soil loss by surface run-off (kg/ha) × concentration of pesticide (g/kg);
= soil loss (t/ha/yr) × 10^3 × precipitation (cm) / monsoon rain (cm) × concentration of pesticide in soil × 10^{-3} × 100 / % (silt+clay);
= soil loss (t/ha/yr) × precipitation (cm) / monsoon rain (cm) × concentration of pesticide in soil (ug/g) × 100 / % (silt+clay).

The amount of pesticide lost from agricultural fields by sedimentary transport and carried to the river has been calculated in Table 2.

Ground Water Movement

The ground water and river water form a continuum. Therefore, whenever there is a difference in water level between river and ground water, the water flows from higher to lower level. During monsoon, there is rise in water levels both in the river and the aquifer. The level in the river rises rapidly during rainy season, and water flows from river to the aquifer. During the remaining period, the ground water level is higher than the river and, therefore, water flows from aquifer into the river. Along with these movements of water, pesticides dissolved in water also move.

The potential available ground water in the Farrukhabad region was estimated to be 1181 × 10^6 m^3 spread over a geographic area of 428883 hectares [11]. The volume of water corresponds to the highest water table attained during the rainy season.

The volume of water present in the aquifer at different times of the year was calculated by measuring the difference in the water table. A 10 cm of water column was taken to be equivalent to 1 m change in the water table.

The water balance in aquifer is affected by events responsible for increase/decrease in the volume of water. The events responsible for increase in volume of water in aquifer are:

1. Leaching of rain water;
2. Leaching of irrigation water;
3. Inflow of river water.

The events responsible for decrease in volume of water are:

4. Water withdrawn for irrigation;
5. Outflow of water from aquifer to river.

The leaching of water to aquifer occurs when the soil is saturated. It has been estimated that about 10 percent of water added by rainfall or irrigation leach down to ground water. Thus, it is possible to calculate the volume of water added to ground water due to leaching from the amount of rainfall during monsoon and the volume of water used for irrigation from September to February as follows:

Addition through leaching of rain water

= precipitation × geographic area × 0.1.

Table 2. Pesticide Loss from Agricultural Fields through Sedimentary Transport

		Average Concentration of Pesticide in Soil Water (ug/L)					Pesticide Loss Through Sedimentary Transport Run-Off Water (g/ha)				
Period	Rainfall (cm)	HCH	DDT	Aldrin	Endos	OPs	HCH	DDT	Aldrin	Endos	OPs
September to October	12.1	0.086	0.035	0.009	0.096	0.009	0.209	0.085	0.022	0.234	0.022
November to December	4.7	0.102	0.059	0.008	0.105	0.010	0.096	0.056	0.007	0.099	0.009
July to August	27.9	0.018	0.074	0.011	0.005	0.149	0.101	0.415	0.062	0.030	0.836
Total							0.406	0.556	0.091	0.363	0.867

Addition through leaching of irrigation water

= volume of water used for irrigation $\times$ 0.1.

The volume of water withdrawn for irrigation from the aquifer was calculated on the basis of the fact that about 6-7 irrigations each of 6 cm water columns were applied per annum in the area under study.

Volume of water withdrawn for irrigation:

= Number of irrigations during the period
$\times$ amount of irrigation water (6 cm) $\times$ area under irrigation.

The area under irrigation at Farrukhabad during Kharif (rainy) season is about 15200 ha and about 83314 ha during Rabi (winter).

The volume of water flowing in or out of aquifer was calculated by balance method as follows (Table 3):

Volume of water in aquifer at a given time

= volume of water present initially $\pm$ [difference in table
$\times$ 0.1 $\times$ area of the aquifer]
= volume of water present initially (L) $\pm$ [difference in water table (m)
$\times 0.1 \times 4288883 \times 10^4 \times 10^3$]
= volume of water present initially (L) $\pm$ [different in water table (m)
$\times 4.28883 \times 10^{11}$]

Volume of water flowing in or out of aquifer

= volume of water in aquifer at a given time
– [volume of water initially present in the aquifer
+ water added through leaching of rain water
+ water added through leaching of irrigation water
– water withdrawn for irrigation]

The amount of pesticide moving in or out of aquifer was calculated as follows:

Inflow of pesticide to the aquifer (g)

= volume of water flowing into the aquifer from river (L)
$\times$ average concentration of pesticide river water (g/L)

Outflow of pesticide from aquifer to the river (g)

= volume of water flowing out of aquifer from river (L)
$\times$ average concentration of pesticide in ground water (g/L)

The amount of pesticide moving out from aquifer into the river or vice versa is shown in Table 4.

Table 3. Volume of Water Flowing In or Out of Aquifer

Period	Volume of Water ($x 10^{11}$ L)		Water Added Through Leaching ($x 10^{10}$ L)		Water Withdrawn for Irrigation ($x 10^{10}$ L)	Water Flowing In or Out of ($x 10^{10}$ L)
	Beginning	End	Rain Water	Irrigation		
						Water Flowing Out
September to October	10.95	9.23	5.189	0.591	5.911	17.029
November to December	9.23	8.20	2.016	0.999	9.998	3.308
January to February	8.20	7.09	–	0.999	9.998	1.292
March to April	7.09	6.10	–	–	4.999	4.861
						Water Flowing In
May to June	6.10	8.38	4.718	–	–	18.010
July to August	8.38	10.95	9.543	–	–	16.187

Total transport of pesticides from agricultural fields to Ganga river water at Farrukhabad was calculated by summing the amount of pesticide lost through the above three pathways (Table 5).

Actual Amount of Pesticide Flowing in the River

The average contribution of agriculturally applied pesticides to Ganga river water was also calculated on the basis of water received from the catchment area. The actual amount of pesticide flowing in Ganga river at Farrukhabad can be assumed to be contributed mainly from agricultural fields located at both sides of river, from Haridwar to Farrukhabad. At Haridwar, there are very few agricultural fields on hills, where farmers use pesticides. The catchment area between Haridwar and Farrukhabad is 40,09,600 ha. Since we know the monthly discharge of water at Farrukhabad and the concentration of pesticide in water during the period, the total amount of pesticide flowing in river at Farrukhabad can be calculated. The contribution of agricultural fields to river water (ug/ha) could be obtained by dividing the total amount of pesticide flowing in Ganga river over the year at Farrukhabad by the catchment area.

Contribution of agricultural fields to river water (g/ha)

= amount of pesticide flowing in river water (g) / catchment area (ha)

Actual amounts of pesticides flowing in Ganga river water at Farrukhabad have been estimated as above in Table 5.

DISCUSSION

The amount of pesticide moving into the river depends on the concentration in soil and the amount of rainfall. The loss of pesticides from agricultural fields to the Ganga river through surface run-off in dissolved form and sedimentary transport occurred from July to December only. The loss of HCH, DDT, aldrin, endosulfan, and organophosphates was 0.240, 0.149, 0.068, 0.014, and 0.019 g/ha by surface run-off and 0.406, 0.556, 0.091, 0.363, and 0.867 g/ha by sedimentary transport, respectively. The loss of HCH, DDT, and aldrin by surface run-off was maximum during July-August, whereas maximum loss of endosulfan and organophosphates occurred during September-October. Similarly, losses of DDT and aldrin by sedimentary transport were greatest in July-August, whereas the maximum loss of HCH, endosulfan, and organophosphates occurred in September and October, when soil contained high amounts of these pesticides.

Interestingly, the loss of pesticides by sedimentary transport was much higher than that by surface run-off. The loss of HCH was two times and that of DDT was four times greater from sedimentary transport than from surface run-off. The loss of endosulfan and organophosphates, which are more soluble than other insecticides, was twenty-six and forty-six times higher, respectively, from sedimentary

Table 4. Pesticides Flowing In or Out of Aquifer Along with Water

Pesticide Flowing Out of Aquifer to River											
	Water Flowing Out of the Aquifer	Average Concentration of Pesticide in Ground Water (ug/L)					Pesticide Flowing from Aquifer to River Along with Water in Grams (g/ha)				
Period	($x\ 10^{10}$L)	HCH	DDT	Aldrin	Endos	OPs	HCH	DDT	Aldrin	Endos	OPs
September to October	17.029	0.275	0.441	0.150	0.044	0.169	46830 (0.109)	75098 (0.175)	25543 (0.059)	7493 (0.018)	28779 (0.067)
November to December	3.308	0.249	0.236	0.110	0.036	0.050	8237 (0.019)	7807 (0.018)	3639 (0.008)	1191 (0.003)	1654 (0.004)
January to February	1.292	0.227	0.201	0.077	0.036	0.016	2933 (0.007)	2597 (0.006)	995 (0.002)	465 (0.001)	207 (0.005)
March to April	4.861	0.142	0.162	0.061	0.024	–	6903 (0.016)	7875 (0.018)	2965 (0.007)	1167 (0.003)	– –
Total Amount of Pesticide Flowing Out of Aquifer							64923 (0.151)	93377 (0.218)	33142 (0.077)	10316 (0.024)	30640 (0.071)

Table 4. Cont'd.

Period	Water Flowing Out of the Aquifer ($\times 10^{10}$L)	Average Concentration of Pesticide in River Water (ug/L)					Pesticide Flowing from River into the Aquifer in Grams (g/ha)				
		HCH	DDT	Aldrin	Endos	OPs	HCH	DDT	Aldrin	Endos	OPs
May to June	18.010	0.076	0.292	0.033	0.031	0.027	13688 (0.032)	52589 (0.123)	5943 (0.014)	5583 (0.013)	4863 (0.011)
July to August	16.187	0.149	0.315	0.059	0.036	0.054	23983 (0.056)	50702 (0.118)	9497 (0.022)	5794 (0.014)	8692 (0.020)
Total Amount of Pesticide Flowing Into Aquifer Along with River Water							37671 (0.089)	103291 (0.241)	15440 (0.036)	11377 (0.027)	13555 (0.031)
Net Amount of Pesticide Flowing Out of Aquifer							27252 (0.062)	−9914 (−0.023)	17702 (0.041)	−1061 (−0.003)	17085 (0.039)

Table 5. Transport of Pesticides from Agricultural Fields to Ganga River Water at Farrukhabad

	Calculated Pesticide Movement				Actual Amount Flowing	
Pesticide	Surface Run-Off (g/ha)	Sedimentary Transport (g/ha)	Ground Water (g/ha)	Net Amount Moving to River (g/ha)	Total kg[a]	g/ha[b]
HCH	0.240	0.406	0.062	0.708	4229	1.070
DDT	0.149	0.556	–0.023	0.682	6940	1.731
Aldrin	0.068	0.091	0.041	0.200	1262	0.316
Endos	0.014	0.363	–0.003	0.374	778	0.194
OPs	0.019	0.867	0.040	0.926	1147	0.286
Total	0.490	2.283	0.117	2.890	13416	3.597

[a] Total flow of water x concentration of pesticide in water.
[b] Total amount/catchment area.

transport than from surface run-off. It seems that pesticides which are relatively more soluble in water have a tendency to be adsorbed on soil particles and these are readily lost by sedimentary transport.

The loss of pesticides from ground water to the river was calculated on the basis of movement of water from aquifer to river, and vice-versa. As noted, the flow of water from May to August was from river to aquifer and from September to April in the reverse direction. Since the river water contained pesticide residues, it also contributed to pesticide concentration in ground water during the period from May to August. The amount of pesticide added due to flow of water from river to aquifer was taken into consideration in computing the net amount of pesticide moving into river (Table 3). The net amounts of HCH, DDT, aldrin, endosulfan, and organophosphorus insecticides moving from ground water to river were 0.062, -0.023, 0.041, -0.003, and 0.039 g/ha, respectively. It may be noted that in the case of DDT and endosulfan, there was net movement of these two pesticides from river to the aquifer.

Although it was difficult to know the exact quantity of pesticide being added into the fields in the experimental area, a reasonable approximation was made on the basis of the increase in the level of pesticide in the soil. Normally, application of pesticide at 1 kg ai/ha to soil results in an increase of 0.5 ug/g of residues in the plow layer (0-15 cm), assuming that soil from one hectare of land in 0-15 cm layer weights approximately two million kilograms. In the present study, therefore, the amount of pesticide added was calculated on the basis of increase in the level of residues. For example, 0.1 ug/g increase in the level of residues will result in an apparent addition of 200 g pesticide per hectare of land. The actual amount added will be on the higher side, as some of the pesticide is lost by degradation and volatilization before sampling is made. Furthermore, some pesticides are applied as foliar sprays, so that only part of pesticide falls on the ground. Nonetheless, the present study is mostly concerned with the pesticide present in soil, as soil borne pesticide only can contaminate the river water.

Thus, it can be concluded that residues of HCH, DDT, aldrin, endosulfan, and organophosphates contributed as much as 0.708 g/ha HCH, 0.682 g/ha DDT, 0.200 g/ha aldrin, 0.374 g/ha endosulfan, and 0.926 g/ha organophosphorus insecticides to the river. In all, 2.890 g/ha was transported to the river (Table 4). These values closely agree with the overall contribution of agricultural fields to the river Ganga as estimated on the basis of amount of pesticide actually flowing with river water at Farrukhabad and the total catchment area from Haridwar to Farrukhabad (Table 5).

We suggest that the above model could be used in monitoring riverine pollution, where the total pesticide load on river water could be calculated on the basis of surface runoff, sedimentary transport, and ground water movement. In addition, some of the factors influencing the pesticide loss from agricultural fields to river can be controlled to minimize pollution.

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