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Contribution of agricultural and non-agricultural use of pesticides to the environmental impact on aquatic life in regional surface water systems

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Abstract By means of a modelling tool an analysis was made of the local variation in the use of pesticides in the province of Utrecht in The Netherlands, and the potential environmental impact of pesticide emissions on the aquatic ecosystems. The aim of this study was to identify and quantify the major sources of pesticide use and environmental impact, taking the regional variation of pesticide use into account. The analysis was targeted at different levels: detailed (individual active substances, individual agricultural crops, civil land-use types, hydrological catchment basins) and globally covering agricultural use, non-agricultural use (some civil sectors) and recreational shipping. The results can be used for the (re)design of environmental monitoring programmes of pesticides in surface waters and for the development of region based policies towards sustainable pesticide use. The analysis tool that was developed is considered to be applicable for other regions as well.

Keywords Agriculture; antifouling; environmental impact; monitoring; pesticides; surface waters

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Introduction

Emissions of pesticides are a potential threat to the quality of surface water in Utrecht, a province in the centre of The Netherlands. Environmental monitoring data revealed that the environmental quality criteria for surface water were exceeded for a number of pesticides and their degradation products at some locations. However it was not clear whether all potential problem substances and problem locations are traced by monitoring data alone. There was a need to improve insight into the location and quantities of pesticide use, not only in agriculture but also outside agriculture (civil sectors e.g. weed control), including the recreational shipping. This kind of information was demanded for the development of policy with regard to the use of pesticides by agriculture and civil sectors in the province of Utrecht. It might be necessary to adjust the monitoring programme for pesticides, taking into account the variation in pesticide use between and within catchment basins. Besides quantities of pesticides, emission and effects of pesticides on aquatic life should also be included in the analysis.

Methods

Data were collected for pesticides concerning used quantities, emission factors and risk for the aquatic environment. Three sectors were considered:

- Agriculture (crop protection);
- Civil sectors (private, public and industrial areas);
- Recreational shipping (antifouling).

The use of pesticides in agriculture in the province of Utrecht is derived from available information for the pesticide use per agricultural crop in The Netherlands in 2000 (CBS, 2000). The latter is based on interviews of a large number of agricultural companies by Statistics Netherlands (CBS, the official national statistical office of The Netherlands). In the study presented here it is assumed that there are no differences in the actual pesticide use per individual crop between and within provinces. Information on non-agricultural pesticide use in civil sectors is investigated and documented less extensively than it is for pesticide use in agricultural crops (Ekkes *et al*., 2001; Loorij *et al*., 1999). Specific information was published for a restricted number of applications in civil sectors like amenity parks and gardens (Kerkhof and Heemsbergen, 2000) and (semi)hard surfaces (Kortenhoff, 2001a,b). In order to collect information on applications in civil sectors, interviews and expert judgement were applied.

The province of Utrecht consists of 13 separate hydrological surface water systems (catchment basins) with specific differences in the occurrence of agricultural land use and other land-use types of civil sectors. The pesticide use within the areas of the catchment basins is estimated by combining the specific pesticide use of agricultural crops and use in several civil sectors[1] with detailed information for actual land-use from agricultural census per municipality and available GIS maps about agricultural land use (LGN3-map) and civil land use categories (Statistics Netherlands, land cover statistics).

The environmental impact (risk) of pesticides in surface water is estimated with a risk assessment method, developed by Reus (1992). This method essentially is directed to the assessment of the risk of dispersion to surface water by the major environmental pathway of droplet drift. A database with toxicological data for aquatic life was used in connection (CLM, 2000). Specific information for emission and aquatic ecotoxicology of pesticides used as antifoulants in recreational vessels was collected from other sources (Smit and Karman, 1998; Wezel and Vlaardingen, 2001; Comber *et al*., 2000).

The method enables a simple calculation of dimensionless environmental impact numbers (called MBP) for every substance in the geographical areas to be considered. These environmental impact numbers (MBP) give an indication of the possibility that the concentration of that substance in the surface water might exceed the Maximum Permissible Concentration (MPC = legal water quality standard) in a specific area.

In the way the method is developed a powerful scanning tool is obtained which enables us to examine at once a big number of active substances in many agricultural crops and many civil sectors geographically spread over many areas.

The year 2000 was chosen as reference year. However the available land-use maps have 1996 as reference year. The results from the calculations were compared with the monitoring programmes of the three water board districts in the province of Utrecht.

The study is restricted to use of pesticides in the province of Utrecht and the resulting emission to surface water and the environmental impact. Only droplet drift is considered as an emission route.

The following dispersion routes are not included:
- Atmospheric deposition;
- Run-off from pesticide treated parcels;
- Leaching into (shallow) soil and supply via the drainage system;

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[1] Study delineation
The pesticides involved in the present study comprise active substances for combat of harmful viruses, bacteria, fungi, mites, nematodes, moss, plants, slugs and moles as far as applied outdoors.

The following applications were not included:
- Wood conservation products;
- Conservation products for food, feed and material;
- Disinfection and treatment against ectoparasites in fish farms;
- Disinfection and cleaning of/in buildings;
- Combat of ectoparasites of pet animals and animal husbandry;
- Combat of rodents.

- Leaching into groundwater followed by supply to surface water;
- Supply via surface water (mainly rivers) from outside the province;
- Atmospheric deposition resulting from use outside the province

Results and discussion

Pesticide use

Agricultural crop areas, agricultural sectors, active ingredients. Total agricultural area in the Utrecht province was about 68,300 hectares in the year 2000. Civil areas where pesticides could be applied amounted to 48,400 hectares. The total use of pesticides in the province of Utrecht in 2000 was estimated at approximately 69,000 kg. Agricultural applications and non-agricultural applications of pesticides comprise 76% and 24%, respectively, of this quantity.

The number of active substances among the pesticides that were applied in the year 2000 amounted to ±300 substances in agriculture, 27 substances in non-agriculture and 6 substances in the antifoulants applied in recreational shipping.

Cultivation and application. A large difference in the estimated quantity of pesticides between the nine considered main agricultural crop categories appeared to exist within the province of Utrecht. Orchards (apple and pear) comprise 62% of the total quantity used, whereas the acreage is only 2.7% of the total agricultural acreage of the province of Utrecht (Table 1). By contrast agricultural grassland has a share in the acreage of 87% with a share in the used quantity of 12% of pesticides. Non-agricultural application of pesticide use was estimated for 15 types of civil land-use. Total pesticide quantities were the highest for residential areas, followed by amenity parks and gardens, railways, paved surfaces inside municipalities and industrial areas (Table 2).

Recent changes. The pesticide use was estimated for two years: 1998 and 2000. A decrease of 39 per cent in agricultural pesticide use was estimated between these two years. The intervening period is too small and the influence of confounding factors like weather conditions is too high to allow conclusions on trends on pesticide use in the province of Utrecht. However, it can be expected that more than one factor has contributed to the 39% decrease in applied pesticide quantity in agriculture in 2000 as compared with 1998. Reduction in agricultural acreage (3%) plays a minor role. Replacement of active ingredients, lower application rates and more favourable weather conditions might give a better explanation. However this was not investigated explicitly. There were many substances with large differences in quantity for 2000 and 1998 for both agricultural and civil sectors. Many changes

Table 1 Share of agriculture categories in the province of Utrecht, in the total agriculture area, annual used quantity of pesticides and aquatic environmental impact of pesticides

Agriculture land use category	Area (%)	Quantity of applied pesticides (%)	Aquatic environmental impact of applied pesticides (%)
Grass	87.2	12	0
Maize	8.1	8	12
Orchards	2.7	62	77
Commercial land crops	1.4	9	7
Tree nurseries	0.4	2	2
Vegetables (greenhouses)	0.1	4	0
Flowers (greenhouses)	0.1	3	2
Vegetables, full field	0.0	0	0
Flower bulbs	0.0	0	0

Area for 2000, quantity of pesticides for 2000

Table 2 Share of civil land-use categories in the province of Utrecht, quantity and aquatic environmental impact of pesticides used in civil sectors

Civil land use category	Area (%)	Quantity of applied pesticides (%)	Aquatic environmental impact of applied pesticides (%)
Woodland and nature reserves	36.8	0.0	0.0
Amenity gardens	19.5	14.5	1.8
Residential areas (private)	11.9	57.3	67.5
Industrial area	5.5	4.9	0.0
Paved surfaces inside municipal areas	5.1	0.0	0.0
Paved surfaces outside municipal areas	5.1	6.1	0.0
Residential areas (public)	4.8	4.8	0.0
Sports fields	3.5	1.8	18.6
Defence areas	1.7	0.0	0.0
Farmyards (not for cultivation)	1.7	1.8	6.0
Railways including railways-yards	1.6	8.2	0.3
Recreational areas	1.3	0.0	0.0
Waters including banks	0.9	0.0	0.0
Allotment gardens	0.6	0.4	5.8
Gardening product sale centres	0.1	0.2	0.0

Area for 1996, quantity of pesticides for 2000

in legal application allowances of pesticide products on the market by official pesticide registration procedures were clearly visibly reflected in the figures about pesticide use. However a relatively small amount of illegal use also was still shown to be present in pesticide use figures. Illegal use was not excluded from the calculations.

Environmental impact

The emission behaviour of pesticides in agricultural sectors is rather well known from experimental studies.

However it should be kept in mind that very little scientific knowledge exists about the emission behaviour of the majority of pesticide use in the civil sectors. The emission of antifoulants in the recreational shipping is estimated for six active compounds (Table 3). The emission is expressed in an amount per berthing place per year. The frequency of application on a boat is contained in these values. The value for copper is more reliable than for the other five compounds. Emission figures of other compounds are no more than first order estimations with high uncertainties.

The results of the calculation of the environmental impact of the pesticides on aquatic life are shown in Tables 1 and 2 as well as in Figures 1, 2 and 3.

Contribution applications and substances. Substances with an estimated environmental impact number exceeding the 10 points level, corresponding with 10% of the maximum permissible concentration (MPC) in surface water are considered as potential problem substances. The substances which give rise to potential problems were identified for single

Table 3 Emission of some selected active substances from antifoulants applied in recreation shipping

Antifouling substance	Emission (gram/berthing place.year)	Reference/Status
Copper	50	DHV (2000)
Dichlofluanide	10	This study: 1st order estimation
Diuron	2.5	This study: 1st order estimation
Irgarol 1054	0.5	This study: 1st order estimation
Zineb	0.5	This study: 1st order estimation
Zinc oxide	10	This study: 1st order estimation

agricultural crops and single civil land-use categories. The following numbers of potential problem substances were found for the agricultural sector: 24 for commercial land crops, 14 for orchards and vegetables (full field grown), 13 for tree nurseries and 2 for maize. For civil sectors the number of potential problem compounds was: 3 for sports-fields and allotment gardens, 2 for private residential areas and 1 for railway areas. The most important compounds in both sectors are listed in Figures 1 and 2. The quantities of pesticide use and the totals of the environmental impact (total score) of these potential problem compounds vary between compounds and also between the land-use categories. Pesticide control in orchards gives the highest share in the environmental impact of all pesticides together in surface water in the province of Utrecht as a whole. The contribution of maize and commercial land crops is much lower but in turn importantly higher than that of other agricultural crop categories (see Table 1). Concerning the civil sectors the private residential areas have the highest share, followed by sports-fields, farm yards, allotment gardens, amenity gardens and railway areas (see Table 2).

Contribution of sectors in environmental impact rating. The contribution by the agricultural sector is estimated to be somewhat higher (19%) than that of the non-agricultural sector (16%). However, there are pronounced differences among the 13 catchment basins concerning the sector with the highest impact (see Figures 1, 2, 3). These differences can be attributed to the land-use characteristics in these areas. Surprisingly in the province of Utrecht as a whole, the recreation shipping might have the highest contribution (65%) to the environmental impact of pesticides on surface water. This conclusion however still is very uncertain because of lack of well established emission data for antifoulants.

Summary:

- Recreational shipping might dominate in catchment areas Amstelland-West, Eem and Vecht;
- Agriculture is most important in catchment areas Amsterdam-Rijnkanaal/Lek, Kromme Rijn/Amsterdam-Rijnkanaal and Lopikerwaard;
- Civil sectors are most important in catchment areas Heiligenbergerbeek, Stad Utrecht and Utrechtse Heuvelrug;
- Agriculture and civil sectors have a comparable influence in catchment areas Amstelland-West, Kromme Rijngebied, Leidsche Rijn, Valleikanaal, Vecht and Woerden.

Uncertainty of the assessment as a whole

The uncertainty in the present estimations is the highest for the recreational shipping due to a lack of information on use and leaching (emission). In addition, estimations of the environmental impact of a number of non-agricultural applications on surface water has to be interpreted with caution due to deficient information for use, emission percentages and removal in wastewater treatment plants. The estimations for the agricultural sector are considered as relatively reliable.

Recommendations for environmental monitoring

Relatively many (15) of the 32 substances on the monitoring list of the three water boards in the province of Utrecht were identified in the present study as potential problem substances in one or more catchment basins. This can be considered as a good confirmation of the very simple method that was applied for the hundreds of substances that are used. In case the evaluation is restricted to pesticide use within the province of Utrecht it can be recommended to maintain 20 of the 32 substances for monitoring. Furthermore six substances may be removed, whereas 11 substances may be added. The monitoring programmes should

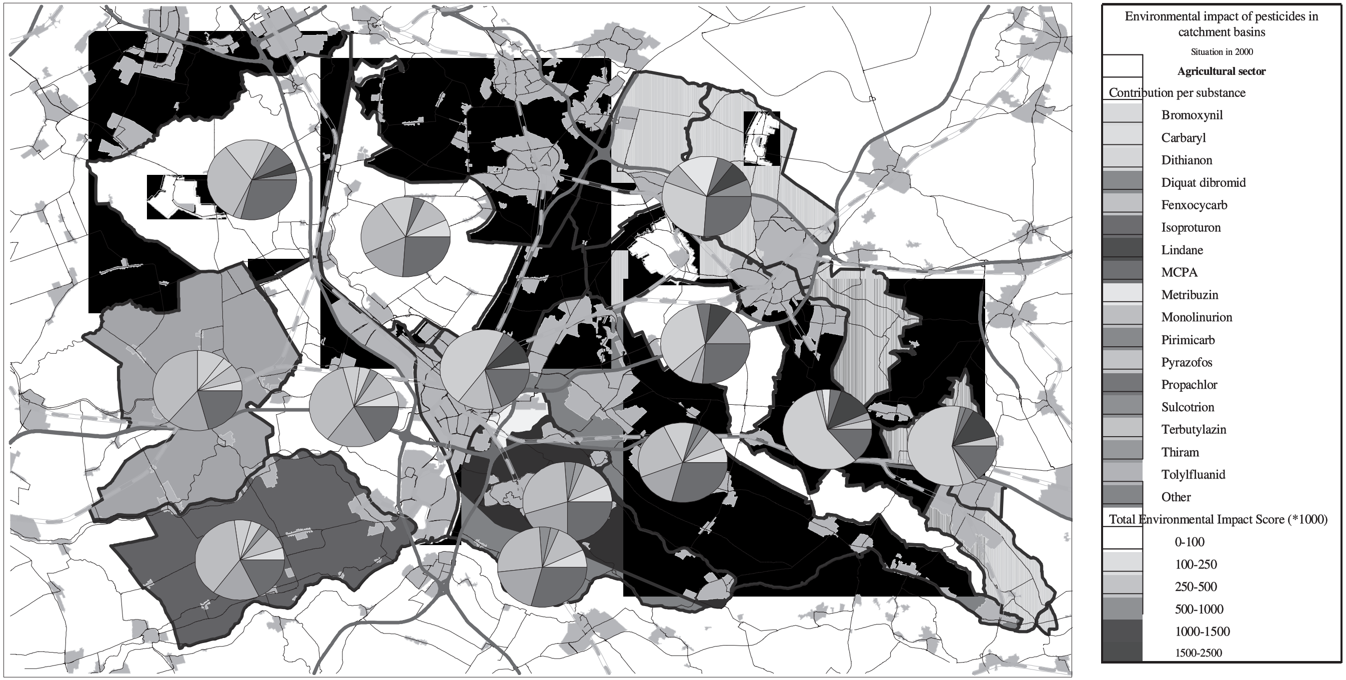

Figure 1 Environmental impact rating of pesticides in catchment basins in the province of Utrecht in 2000 resulting from application of pesticides in agriculture

Figure 2 Environmental impact rating of pesticides in catchment basins in the province of Utrecht in 2000 resulting from application of pesticides in civil sectors

Figure 3 Environmental impact rating of pesticides in catchment basins in the province of Utrecht in 2000 resulting from application of pesticides in agricultural and civil sectors including recreational shipping

be adjusted to the regional differences between and within catchment basins by using available information on land-use categories and linked pesticides.

Environmental policy recommendations

Some results of the study can be used for development of the policy on pesticide use and risk reduction. The most important recommendations are listed below:

Use

- Changes in crop acreage, ban and admittance of active substances, influence of weather conditions, disease occurrence should be followed in the studies on trends in pesticide use.
- Quantities (kg) of used pesticides generally do not provide reliable indications on the contamination stress of surface water systems due to the influence of differences among application types and pesticides in the extent of emission and effects on aquatic life.
- The use and environmental impact of pesticides in civil sectors should not be neglected and should gain more attention in scientific research and development of environmental policy.
- The use of pesticides as antifoulants in recreational shipping is considered as very unreliable. However calculations show in any case that relatively high environmental impact on surface water systems can be assumed when recreation shipping is present. A nationwide extensive investigation into the actual use, emission and present contamination is highly advisable.

Surface water

- Results of the present study can be used for composition and adjustment of the list of substances for monitoring in surface water.
- Monitoring programmes are advised specifically on the basis of hydrological catchment basins. The tools and data from the present study, as a theoretical approach, can be used for this purpose.
- A ban may be justified on certain insecticides (chlorpyrifos, deltamethrin, permethrin) in non-agricultural applications due to the relatively high environmental impact while economic benefit is virtually absent.
- Effluents of public wastewater treatment plants could be a significant secondary emission source of pesticides. Emission measurements of a broad spectrum of substances is advised.

Target groups

- Important groups of users of pesticides could be approached directly with a policy programme in order to reduce the environmental impact of pesticides. The most likely candidates are one group from the agricultural sector (orchards), five groups from the non-agricultural sector (private house areas, sport-fields, agrarian non-crop areas, allotment gardens, amenity gardens, railway areas) and the recreational shipping sector.

Conclusions

Pesticides pose a very complex problem in environmental science which is caused by the large number of active substances with very different toxicological properties that are applied in many agricultural crops and also are applied in many civil sectors which geographically are spread over many different types of areas.

The scanning tool that was developed in this study enables a well balanced environmental impact rating for surface water protection with a good and proven ratio between results desired and expenditure of human resources and data handling.

The tool that is developed can be used for the development of environmental monitoring programs of pesticides and for the development of regional environmental policies towards surface water quality concerning pesticides in catchment basins.

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