

Engineers and scientists warn that storms in space like hurricanes and earthquakes could have a devastating impact on society. A new generation of satellites is expected to monitor space meteorology in the same way as its terrestrial counterpart. The scientific future of solar physics offers exciting prospects for the simple reason that the Sun presents more and more mysteries representing opportunities to learn new physics. And as Yeats says elsewhere, 'I will... pluck till time and times are done... the golden apples of the Sun', the objective of enthralled SOHO scientists is to unlock the secrets of our dynamic Sun.

1. Rosner, R., Golub, L. and Vaina, G. S., *Annu. Rev. Astron. Astrophys.*, 1985, **23**, 413–452.
2. Priest, E. R., Foley, C. R., Heyvaerts, J., Arber, T. D., Culhane, J. L. and Acton, L. W., *Nature*, 1998, **393**, 545–547.
3. *Coronal Holes and High Speed Wind Streams* (ed. Zirker, J. B.), Colorado Associated University Press, Boulder, 1977.
4. van de Hulst, H. C., *Bull. Astron. Soc. Netherlands*, 1950, **11**, 150–160.
5. Koutchmy, S., *Solar Phys.*, 1977, **51**, 399–407.
6. Hassler, D. M., Wilhelm, K., Lemaire, P. and Schuhle, U., *Solar Phys.*, 1997, **175**, 375–391.

7. Wilhelm, K., Lemaire, P., Curdt, W., Schuhle, U., Marsch, E., Poland, A. I., Jordan, S. D., Thomas, R. J., Hassler, D. M., Huber, M. C. E., Vial, J.-C., Kuhne, M., Siegmund, O. H. W., Gabriel, A., Timothy, J. G., Grewing, M., Feldman, U., Hollandt, J. and Brekke, P., *Solar Phys.*, 1997, **170**, 75–104.
8. Dwivedi, B. N., *Astronomy Now*, 1998, **12**, 19.
9. Kohl, J. L., Noci, G., Antonucci, E., Tondello, G., Huber, M. C. E., Gardner, L. D., Nicolosi, P., Strachan, L., Fineschi, S., Raymond, J. C., Romoli, M., Spadaro, D., Panasyuk, A., Siegmund, O. H. W., Benna, C., Ciaravella, A., Cranmer, S. R., Giordano, S., Karovska, M., Martin, R., Michels, J., Modigliani, A., Naletto, G., Pernechele, C., Poletto, G. and Smith, P. L., *Solar Phys.*, 1997, **175**, 613–644.
10. Wilhelm, K., Marsch, E., Dwivedi, B. N., Hassler, D. M., Lemaire, P., Gabriel, A. H. and Huber, M. C. E., *Astrophys. J.*, 1998, **500**, 1023–1038.
11. Dwivedi, B. N., Mohan, A. and Wilhelm, K., paper presented at 32nd COSPAR Scientific Assembly, Nagoya, 12–19 July, 1998.
12. Innes, D. E., Inhester, B., Axford, W. I. and Wilhelm, K., *Nature*, 1997, **386**, 811–813.
13. Dwivedi, B. N., Curdt, W. and Wilhelm, K., *Astrophys. J.*, 1998, submitted.
14. Gosling, J. T., *J. Geophys. Res.*, 1993, **98**, 937–949.
15. Dwivedi, B. N., *Curr. Sci.*, 1996, **70**, 135–142.

Received 13 July 1998; accepted 1 September 1998

Groundwater contamination and health hazards by some of the most commonly used pesticides

Imran Ali* and C. K. Jain

The groundwater contamination and health hazards by some of the most commonly used pesticides have been discussed. The persistence of pesticides in food chain has been evaluated and various factors responsible for the leachability of pesticides in groundwater have been discussed. Maximum and most possible preventions from the pesticide health hazards have been suggested.

WATER is a very important constituent of our ecosystem and so we have to preserve and improve its quality. Among various organic and inorganic water pollutants, pesticides are very dangerous and harmful because of their tissue degradation and carcinogenic nature¹. Pesticides are bioaccumulative and relatively stable, as well as toxic/carcinogenic, and, therefore, require close monitoring. The EEC Directive² concerning the quality of water for human consumption, established the maximum concentration of each pesticide at 0.1 µg/l and the total pesticides concentration at 0.5 µg/l (ref. 3). A list of most commonly used pesticides with acceptable daily

intake⁴ is given in Table 1. The WHO has classified the pesticides into five groups on the basis of their (LD₅₀ values) hazardous nature. The EPA⁵ elaborated the list of properties of pesticide which indicate their groundwater contamination potential (Table 2).

Sources of pesticide pollution

The major sources of pesticide pollution are industries, agriculture, forestry and domestic activities. However, pesticide pollution through air has also been reported. The dust particles in the air adsorbed the pesticides (due to pesticides spray in agriculture, forestry and domestic use) and then contaminate water bodies, sediments and soil through rain water⁶. The possible route of water pollution due to pesticides is shown in Figure 1.

The authors are at the National Institute of Hydrology, Roorkee 247 667, India.

*For correspondence. (email:ia@cc.nih.ernet.in)

Table 1. Some most commonly used pesticides with their acceptable daily intake concentrations

Pesticide	Maximum acceptable values ($\mu\text{g/l}$)
Alachlor	20.00
Aldrin/Dieldrin	0.03
Atrazine	2.00
Carbofuran	5.00
Chlordane	0.20
DDT	2.00
HCB	1.00
Heptachlor	0.03
Lindane	2.00
Methoxychlor	20.00
Simazine	2.00

Table 2. Properties of pesticides which indicate their high ground-water contamination potential

Parameter	Value
Water solubility	$> 30 \text{ mg l}^{-1}$
K_d	< 5 , usually < 1
K_a	< 300
Henry's law constant	$< 10^{-2} \text{ atm. m}^{-3} \text{ mol}$
Speciation	Negatively charged, fully or partially at ambient pH
Hydrolysis half time	$> 25 \text{ weeks}$
Photolysis half life	$> 1 \text{ week}$
Field dissipation half life	$> 3 \text{ weeks}$

Table 3. Concentrations of some of the pesticides in groundwater

Pesticide	Concentration ($\mu\text{g/l}$)
Acetachlor	0.05
Atrazine	0.10 and 1.11
Alachlor ESA	0.05
Alachlor	0.05
Diethyl atrazine	0.05
Cyanazine	0.05
Cyanazine amide	0.05
Metachlor	0.05
Prometrin	0.05
Simazine	0.05
Terbutylin	0.05
Heptachlor	0.05

Pesticides in groundwater

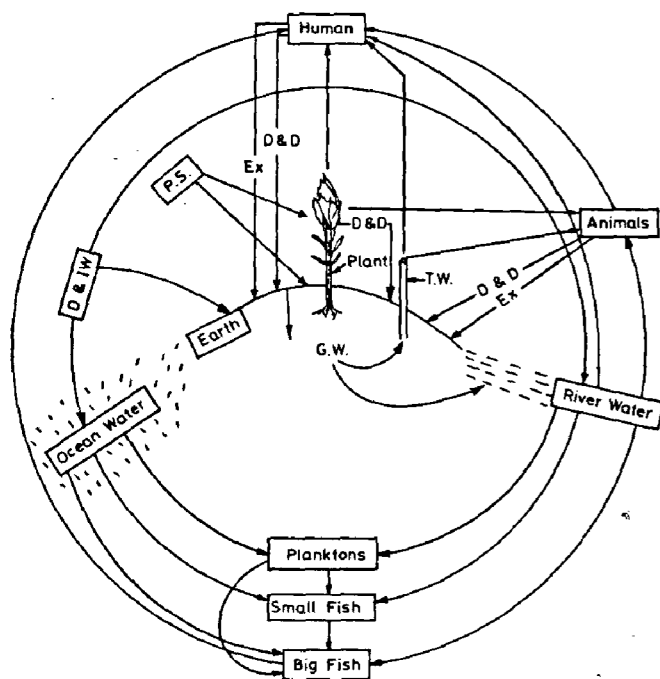
The study of pesticides in groundwater started in 1979 in USA with multiple detection of various pesticides. The same issue has been addressed in other countries. It has been reported that increasing amount of the pesticide residue may be present in the soil and these can ultimately be leached to aquifer levels and contaminate the groundwater or they may be carried away by runoff waters and soil erosion⁷⁻⁹. The leachability of the pesticides is measured in terms of the groundwater ubiquity score (GUS). The GUS index¹⁰ can be written as

$$\text{GUS} = \log(DT_{50}) \cdot [4 - \log(K_a)],$$

where DT_{50} and K_a are persistence and mobility respectively. Bottoni and Funari¹¹ have evaluated the impact of 48 herbicides on groundwater quality. The tendencies of groundwater contamination are (i) non-leacher ($\text{GUS} < 1.8$), (ii) transition ($1.8 < \text{GUS} < 2.8$) and (iii) leacher ($\text{GUS} > 2.8$).

Global scenario

Groundwater pollution due to pesticides is a worldwide problem. Atrazine was found in groundwater and surface water in maize-producing areas of the Transvaal (South Africa) in 1991-92 (ref. 11). Leaching of atrazine in Germany¹³ and Denmark¹⁴ was also reported. Contamination of well water by atrazine, alachlor and carbofuran has been found in Switzerland¹⁵. Atrazine, simazine and cyanazine were determined in wellwater in USA¹⁶. Pesticides have also been found in wells in The Netherlands, Italy, Israel, Japan, Canada and Australia. Herbicides and nematicides are supposed to be the major groundwater pollutant pesticides as they are applied directly to the soil. There are many reports published on groundwater contamination due to pesticides¹⁷⁻¹⁹ all over the world. The level of some of the pesticides in groundwater is given in Table 3. It is clear from this table that the values of the pesticides are higher than the permissible health values as given by US EPA 1995.

**Figure 1.** Pesticides in food chain. D & D, Death & decay; D & IW, Domestic and industrial wastes; Ex, Excretion; GW, Groundwater; PS, Pesticides spray; TW, Tube well.

The Indian scenario

More than 50% domestic water supply is obtained from groundwater in India and, therefore, it is very important to check the purity of groundwater before it is supplied to the public. DDT, BHC, carbamate, Endosulfan, etc.²⁰ are the very common pesticides used in India both in agricultural and public health sectors. Very little monitoring of water pesticides has been done in India. However, some reports have been published on the presence of organochlorine pesticides in some urban water resources near Calcutta²¹. Groundwater contamination by some arsenic pesticides²² has been reported in some of the districts of West Bengal. Groundwater contamination has also been reported in some areas near water storage ponds in Gujarat. In these areas, the rain water containing pesticides from agricultural fields, is stored in ponds and during the course of time water (with pesticides) from these ponds enter into the aquifer leading to groundwater contamination by pesticides.

Factors affecting the leachability of pesticides

The leachability of the pesticides in groundwater is controlled by the nature of the soil and the pesticides themselves⁵. The pattern of pesticide use, their degradation products, soil texture and the total organic matter in the soil are important factors for this process. Fine texture soils, in general, inhibit pesticide leaching because of either low vertical permeability or high surface area which enhance adsorption of pesticides. The high organic matter content in the soil dissolves the pesticides and checks their transportation into the soil. pH and the temperature of the soil are also important factors for the leachability of pesticides^{7,19,23,24}. However, the mass flow of water through the soil profile is also an important factor for the leaching of pesticides in groundwater.

Food chain

The pesticides from domestic, industrial and agricultural effluents enter the food chain through ground/surface water. The pesticides from the contaminated water are taken up by plants and animals and enter the food chain. The detailed rout of pesticides through food chain is given in Figure 1.

The persistence of organochlorine pesticides in water has a special significance as they are picked up by unicellular organisms like plankton, fish, etc. and in the process pesticide residues enter the food chain. The pesticides applied to the plants and crops enter the grain, fruits, etc. and are finally consumed by humans and other organisms. Residues of HCB pesticide have been found in foods, feeds, fruits and animals tissue. The different concentrations of a typical and very

Table 4. Food chain concentration of a persistent pesticide, DDT

Source	Concentration (mg/l)
Water	0.00005
Plankton	0.04
Silverside minnow	0.23
Sheephead minnow	0.94
Pickrel (predatory fish)	1.33
Needlefish (predatory fish)	2.07
Heron (feeds on small animals)	3.57
Tern (feeds on small animals)	3.91
Herring gull (scavengers)	6.00
Fish hawk (osprey) egg	13.80
Merganser (fish eating duke)	22.80
Cormorant (feeds on large fish)	26.40

Source: Ref. 25.

common pesticide, i.e. DDT²⁵ in different components of the food chain is given in Table 4. It is clear from Table 4 that all the organisms belong to the aquatic environment and, therefore, take the pesticide contaminated water and in this way pesticides get deposited in their bodies. The different concentrations of DDT pesticides in these organisms is due to the different pesticide deposition capacities of their body tissues. Finally, the pesticides enter the human body through these organisms.

Health hazards

Pesticides are by nature toxic to one or more life forms and it was realized at an early stage by many users that there was a certain risk attached to their use. Pesticides are tissue degradative, relatively stable, as well as toxic or carcinogenic in nature¹. Generally, pesticides damage the liver and the nervous system. Tumour formation has also been reported in the liver. Besides, certain pesticides are found to disturb the enzymatic activities of the body which leads to different types of diseases³. The various diseases/adverse effects produced due to some commonly used pesticides are listed in Table 5.

Prevention and control of pesticides hazards

The groundwater pollution by pesticides is a very serious and dangerous problem throughout the world. The pesticides enter the food chain and are taken up by humans which leads to various diseases. Therefore, the use of the pesticides should be banned. Other methods of pest control such as mechanical, electronics, etc. should be developed. The municipal and industrial (pesticides-producing industries) wastes should be treated properly before its disposal into the river or land. The storage of rain water in lakes and ponds should be avoided as much as possible so that the contamination of groundwater may be controlled. Drinking water (ground or surface

Table 5. Most commonly used pesticides and their health hazards

Pesticide	Diseases/adverse effects
Aldrin	Attacks the nervous system, convulsion, repeated dosage damages the liver, carcinogenic
BHC	Liver tumour
Captan	Abnormality in the eyes and brain, carcinogenic
Chlordane	Carcinogenic
DDT	Liver damage, carcinogenic
Dieldrin	Liver damage, carcinogenic, destroys enzymatic activities
Endosulfan	Carcinogenic
HCB	Highly toxic, bone marrow damage, mutagenic, teratogenic, carcinogenic
Heptachlor	Liver damage, carcinogenic
Malathion	Low toxic but sometimes carcinogenic
Methoxychlor	Low toxic but sometimes carcinogenic
Mirex	Carcinogenic

These were the effects of the pesticides served in mouse, rat, rabbit, monkey and chimpanzee.

water) should be analysed for pesticides before its use. In case any pesticide is present, water should be treated to remove the pesticides.

Conclusion

Groundwater pollution due to pesticides is a very serious and dangerous problem all over the world. Therefore, the use of pesticides should be banned. Other methods of pest control such as mechanical, electronics, etc. should be developed. The municipal and industrial (pesticides-producing industries) wastes should be treated properly before its disposal onto land or in the river. The drinking water (if pesticides contaminated) should be treated properly prior to its use.

1. IARC Monographs, Suppl. 7, IARC, Lyon, 1987, 54, 40.
2. EEC, *Drinking Water Directive*, Official Journal N 229/11, Directive 80/778/EEC, 1988.
3. Vettorazzi, G., *International Regulatory Aspects for Pesticide Chemicals*, CRC Press, Boca Raton, 1979, vol. 1, p. 141.
4. Guidelines for Drinking Water Quality, Geneva, WHO, II edn., 1996, vol. 2, p. 944.
5. Cova, D., Molinari, G. P. and Rossini, L., *Toxicol. Environ. Safety*, 1990, 20, 234.
6. Jain, C. K. and Ali, I., *Int. J. Environ. Anal. Chem.*, 1998, 68, 83.
7. Raju, G. S., Jacques, A. and Khan, S. U., *Chemosphere*, 1993, 26, 1442.
8. Miliadis, G. E., *Bull. Environ. Contam. Toxicol.*, 1994, 52, 25.
9. Sherma, J., *Anal. Chem.*, 1995, 67, 1R.
10. Gustafson, D. I., *Environ. Toxicol. Chem.*, 1989, 8, 339.
11. Bottoni, P. and Funari, E., *Sci. Total Environ.*, 1992, 123, 581.
12. Pick, F. E., van Dyke, L. P. and Botha, E., *Chemosphere*, 1992, 25, 335.
13. Grandet, M., Quentin, K. E. and Weil, L., *Z. Wasser Abwasse. Forsch.*, 1989, 22, 231.
14. Felding, G., *Pestic. Sci.*, 1992, 35, 39.
15. Buser, H. R., *Environ. Sci. Technol.*, 1990, 24, 1049.
16. Poinke, H. B. and Glotfelty, D. E., *Water Res.*, 1989, 23, 1031.
17. Kolpin, D. W., Kalkhoff, S. J., Goolsby, D. A., Sneek-Fahrer, D. A. and Thurman, E. M., *Ground Water*, 1997, 35, 679.
18. Gomez de Barreda, D. Jr., Gamon Vila, M., Lorenzo Rueda, E., Saez Olmo, A., Gomez de Barreda, D., Garcia de la Cuadra, J. Ten, A. and Peric, C., *J. Chromatogr.*, 1998, 795, 125.
19. Carrillo, A., *Geofis. Int.*, 1998, 37, 35.
20. Haldar, P., Raha, P. and Bhattacharya, P., *Indian J. Environ. Health*, 1989, 31, 156.
21. Thakker, N. and Pande, S. P., *J. I.W.W.A.*, 1986, XVIII, 313.
22. Chaterji, A., Ph D Thesis, Calcutta University, 1994, p. 10.
23. Hutson, D. H. and Roberts, T. R., *Progress in Pesticide Biochemistry and Toxicology: Environmental Fate of Pesticides* John Wiley and Sons, New York, 1990, vol. 7, p. 15.
24. Beltran, J., Hernandez, F., Lopez, F. J. and Morell, I., *Int. J. Environ. Anal. Chem.*, 1993, 58, 287.
25. Wade, C. G., *Contemporary Chemistry, Science, Energy and Environmental Change*, Macmillan Publishing Co. Inc., New York, 1976, p. 382.

Received 4 May 1998; revised accepted 24 September 1998