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Groundwater contamination by organic chemicals in industrializing countries: the unseen threat

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Abstract Industrialization brings with it a high production of wastes. Many of these are disposed of in the environment and can have a serious impact on groundwater. In developed, industrialized countries, hierarchical approaches to investigating contamination problems are generally well established. In many instances, individual organic chemicals have been identified as being critical in pollution plumes. On the other hand, in many industrializing countries, individual organic contaminants are rarely determined during groundwater pollution investigations. The reasons for this include low level of awareness, lack of analytical facilities and cost constraints. Three case studies are presented from the Western Cape, South Africa, where although organic contaminants were suspected, the investigation concentrated on inorganic contaminants. It is concluded that there is need for increased awareness of the potential impact of organic contaminants on groundwater and ultimately guidelines need to be developed for principal organic contaminants that should be analysed for at contaminated sites.

INTRODUCTION

Human settlement and industrial development have an inevitable impact on groundwater resources. With industrialization, a wide range of inorganic and organic chemicals are manufactured, used and disposed of. Many of these chemicals, if not well managed, can pollute groundwater. Friesel (1987) estimated that there were some 100 000 chemical substances of potential concern for the environment, the vast majority of which are organic chemicals. In Germany and the United States, for example, approximately 1200 organic contaminants have been identified in groundwater pollution plumes at waste disposal sites (Kerndoff *et al.*, 1992).

The threat posed by organic contaminants to groundwater is recognized in many developed countries. Legislation is quite strict in these countries and the financial consequences of polluting groundwater can be severe. As a result, there are established procedures for investigating pollution problems (Fig. 1). The procedure usually involves (Schleyer *et al.*, 1992):

(a) recognition of a possible effect on groundwater;
(b) characterization of an established effect on groundwater; and
(c) evaluation of the groundwater contamination.

In many developing countries, investigations which are as detailed as shown in Fig. 1 are rarely conducted. The reasons for this include lack of analytical facilities, cost constraints and low level of awareness. In South Africa, for example, there are very few laboratories offering organic analysis for individual compounds. The cost of

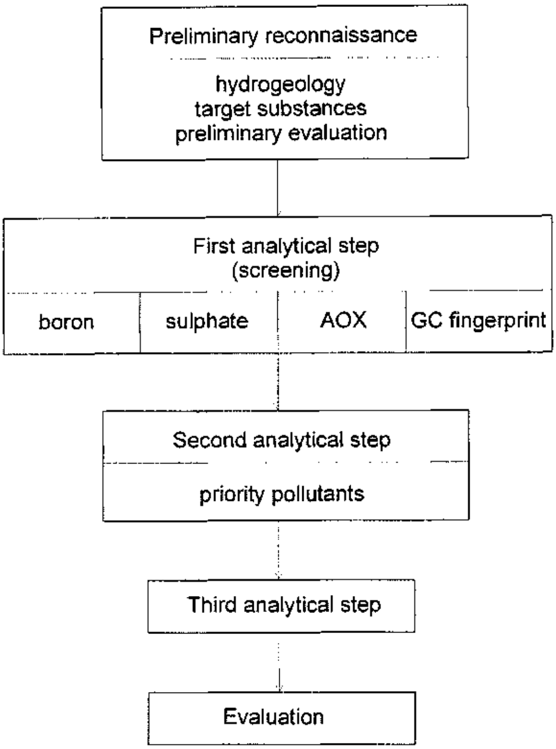

Fig. 1 Hierarchical procedure for investigating and evaluating the acute risk potential due to contaminant leachate from waste sites into groundwater (after Schleyer *et al.*, 1992).

analysing for the latter is quite high. It would cost about 85 US dollars to analyse for BTEX (benzene, toluene, ethylbenzene and xylene) in a sample, while for the same amount, a full cation-anion analysis can be conducted. The result is that bulk parameters such as Dissolved Organic Carbon (DOC) and Chemical Oxygen Demand (COD), which require less sophisticated analytical techniques and are therefore cheap to carry out are opted for when organic pollution is suspected. These bulk parameters are useful for determining the total mass of organic material present and for establishing overall compound patterns. They do not, however, indicate specific organic contaminants present. This may mask the presence of toxic and problematic compounds.

In the sections that follow, three case studies from the Western Cape, South Africa are presented. These are:

(1) groundwater contamination as a result of leakage of hazardous industrial chemicals at an industrial site;
(2) disposal of liquid wastes by flooding on an industrial site; and
(3) groundwater contamination by leachate from solid waste disposal.

These case studies are presented here to illustrate the fact that although pollution from organic compounds was suspected in all the cases, only bulk organic parameters were analysed for.

CASE STUDIES

Case study 1

In January 1996, the Environmental Unit of a plant involved in metal plating and dyeing activities discovered that one of the settling tanks which was used for treating effluent on site was leaking. This tank was buried below surface and there was concern that groundwater may have been effected. A number of organic chemicals are used in the industrial process, especially in the dyeing activities. These include Tebolan HP (polycarbonic acid derivative, combined with anionic compounds) and Ruco Carrier DCB (an aromatic chlorinated hydrocarbon).

An investigation programme was initiated to determine whether groundwater pollution had occurred. The plant is located on top of an unconfined aquifer, which consists predominantly of sands with intercalations of peat units. Twelve well points were installed and water samples collected for chemical analysis. A full cation-anion analysis was conducted on all the samples. In addition, analysis was conducted for CN, Ni, Cu, Zn, DOC and EC.

Figures 2 and 3 show the plots of EC and DOC measured in water samples from the well points. It is clear that chemical deterioration of groundwater had occurred at the site. The highest concentrations were recorded near the leakage point, declining in the direction of water flow. There is evidence of contamination from organic compounds as indicated by the DOC. However, individual organic contaminants were not determined.

Case study 2

Effluent from the metal plating process at this plant is treated by precipitating most of the dissolved metal content by coagulation with a flocculent. The flocculent is filtered out, pressed and then transported to a waste site. The remaining filtered effluent

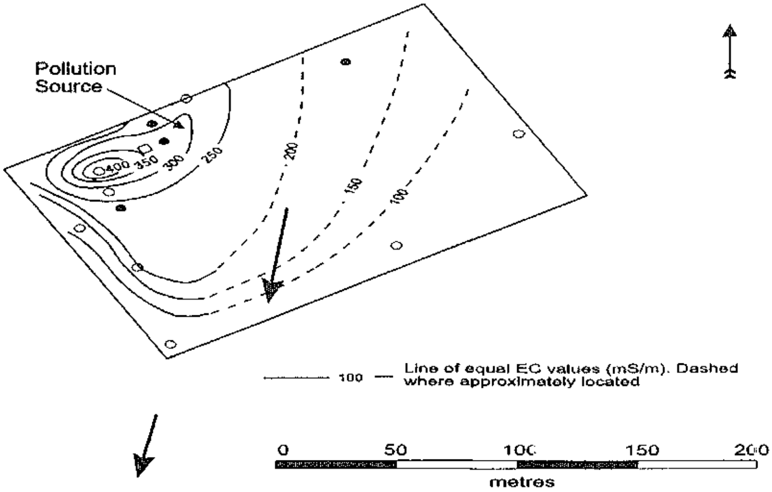

Fig. 2 Map showing electrical conductivity values, July 1996.

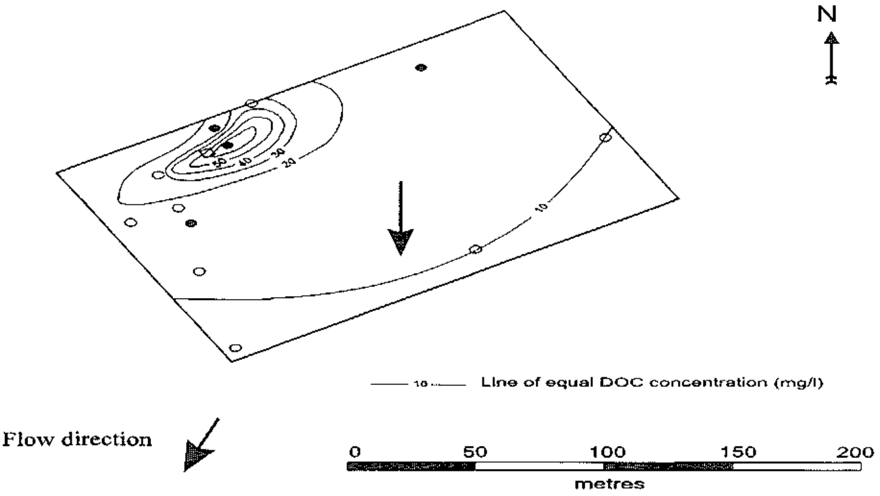

Fig. 3 Map showing dissolved organic concentrations, July 1996.

containing varying amounts of dissolved copper, zinc, chromium, nickel and cadmium (Table 1), is disposed of by flood spreading on a low lying area of the site where evaporation and soak-away occurs.

The plant is located on top of the Cape Flats aquifer, which is considered to be an important potential water supply source for the local urban communities and can supply ten percent of Cape Town's water supply needs. The aquifer consists essentially of Quaternary-age deposits, mainly silica sand underlain by impervious pre-Cambrian Malmesbury Shales or Cape Granite. A number of calcretized horizons are present within the sand units. *In situ* permeability tests in the area yielded saturated hydraulic conductivity values ranging from 20 m to 40 m day^{-1}.

There are seven monitoring boreholes about 50 m down-gradient of the flood spreading site. Typical concentrations of various constituents as measured in these boreholes is shown in Table 1. Metals are not detected. It is noted that heavy metals are not likely to be very mobile in this area because of the high pH buffering capacity of the sands. However, the DOC measured is relatively high indicating possible pollution from organic compounds. The individual organic contaminants were, however, not determined.

In infiltration experiments conducted in the vicinity of the flood spreading site, it was demonstrated that organic compounds could migrate rapidly in the area (Sililo,

Table 1 Comparison of chemical characteristics of effluent and groundwater in monitoring boreholes.

Parameter	Average effluent concentration	Borehole 1	Borehole 2
pH	5.6	7.00	7.40
EC (mS m^{-1})	285.0	620.00	330.00
Cd (mg l^{-1})	0.2	<0.01	<0.01
Cu (mg l^{-1})	4.2	<0.03	<0.03
Cr (mg l^{-1})	16.2	<0.05	<0.05
COD (mg l^{-1})	54.4	not determined	not determined
DOC (mg l^{-1})	not determined	38.00	27.00

1997). Aliphatic hydrocarbons penetrated through an 8 m thick unsaturated zone and reached the water table in less than two days. Thus while metals may not be very mobile in this area, some organic compounds may travel rapidly to contaminate groundwater reserves.

Case study 3

A domestic waste disposal site was brought into operation in 1975. The site was used for the disposal of domestic refuse, building rubble and non toxic industrial wastes such as textiles, paper and cardboard. The site was officially closed in 1988 and in the following year a groundwater monitoring programme was initiated. The objectives of the programme were (Parsons, 1993):

(a) to monitor the possible groundwater pollution effects of the disposal site on the immediate environment;
(b) to protect the aquifer from contamination such that valuable water resources are not lost;
(c) to comply with legislative requirements.

The waste site is located on unconsolidated windblown sands. These sands form an extensive aquifer, which is the sole water supply source for the local urban community. The aquifer is unconfined with the depth to the water table varying between 2.4 m and 3.6 m. *In situ* permeability tests in the area yielded saturated hydraulic conductivity value of about 15 m day^{-1}.

A set of eight well points were installed around the waste site (seven down-gradient and one up-gradient). Water samples were collected from the well points every three months for chemical analysis. The results showed that the waste site was polluting groundwater at the site. By 1993, the pollution plume had travelled more than 200 m from the waste site at an estimated rate of 40 m year^{-1}.

Figure 4 shows the DOC concentrations for three wellpoints. It is clear that organic contamination of the water has occurred. The individual organic contaminants were not determined and therefore remain unknown.

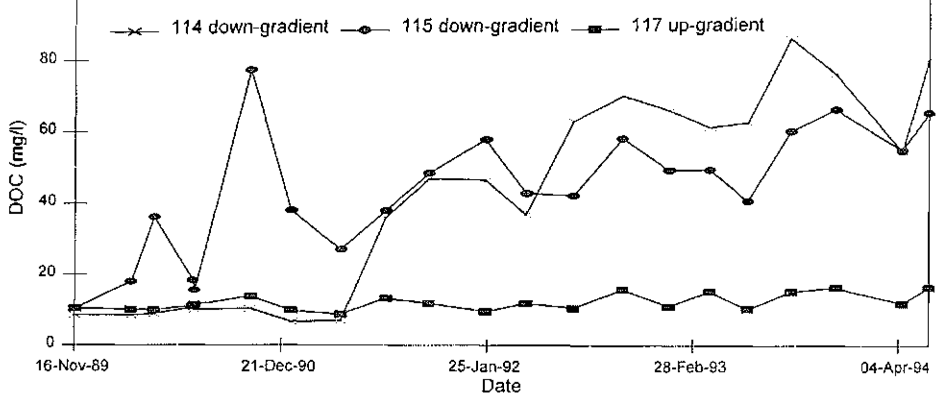

Fig. 4 A plot of dissolved organic concentrations *vs* time.

DISCUSSION AND CONCLUSIONS

Three case studies have been presented above. In all the cases, although there was evidence of pollution from organic compounds, only general parameters, DOC and sometimes COD were analysed for. The main disadvantage of this approach is that individual contaminants and their properties are not known. Without this information, it is difficult to predict the fate and transport of the contaminants in the subsurface. It follows that under such circumstances, it would be difficult to design a remedial strategy, which is usually the ultimate aim of pollution investigations. It is also noted that some organic contaminants may cause harmful effects at very low concentrations. For example, the US Environmental Protection Agency (EPA) drinking water standard for benzene is $5\ \mu g\ l^{-1}$. Thus, measuring only bulk parameters, which are usually expressed in $mg\ l^{-1}$, may mask presence of harmful constituents.

The fact that individual organic contaminants are rarely determined during pollution investigations in many industrializing countries means that the extent of the problem is not known in these countries. This is likely to remain so for sometime to come. Scientists will have to prove to the main role players, including governments, the potential dangers of contamination from organic compounds. With limited resources in these countries, it is not an easy task to convince governments to spend substantial amount of money on problems that do not manifest in an immediate and concrete way. As pointed out by Osibanjo (1992): "The plight of the scientist receives no sympathy from government which sees no particular reason why special budget funds should be allocated to research that may not yet have a proven social value". Despite this, the scientist should continue to communicate and raise the awareness of the general public, practitioners and policy makers. Ultimately guidelines need to be developed for principal or "priority" organic contaminants that should be analysed for at contaminated sites. Such a list need not to be as extensive as that of the US Environmental Protection Agency (EPA) list of 129 priority pollutants. It should, however, take into account potential contaminants from various industrial activities within a given area.

Legislation also needs to be strict and enforceable. The financial penalties for polluting groundwater should be high to discourage bad waste management practises.

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