Quality of Groundwater, Proceedings of an International Symposium, Noordwijkerhout, The Netherlands, 23—27 March 1981, W. van Duijvenbooden, P. Glasbergen and H. van Lelyveld (Eds.),
Studies in Environmental Science, Volume 17

THE SPATIAL DISTRIBUTION OF POLLUTED GROUNDWATER FROM RURAL CENTRES IN A RECHARGE AREA IN THE NETHERLANDS - THE VELUWE

L. VASAK, G.J.W. KRAJENBRINK and C.A.J. APPELO
Instituut voor Aardwetenschappen, Vrije Universiteit Amsterdam

ABSTRACT

A topographically elevated area of ice-pushed ridges was selected for a study on groundwater chemical composition in relation to the potential pollution sources.

A groundwater sampling technique using small ceramic cups was adapted for this study. This technique allows detailed sampling in depth for each borehole, even in areas with deep groundwater levels.

Results of the chemical analyses show great variations in vertical distribution of the ion-concentrations in groundwater. These variations reflect the differences in land use and are also shown to be a function of the groundwater flow patterns.

INTRODUCTION

In May 1979 a hydrochemical study was started in the NW part of the Veluwe in the province of Gelderland. The purpose of this study was to evaluate the quality of groundwater as affected by factors such as precipitation composition, soil type, land use and in particular the disposal of manure and use of fertilisers.

The NW part of the Veluwe is a region where intensive cattle-farming has been practised during the past 20 years. An ever increasing production of manure on the one hand and a lack of space on the other have resulted in the disposal of excessive amounts of manure on small areas.

Under certain hydrogeological and biochemical conditions, some manure and fertiliser compounds may reach the saturated zone and hence pollute the groundwater. Good quality of groundwater is essential in the Veluwe, since it is an important recharge area for drinking water supplies.

STUDY AREA

The Veluwe is a topographically elevated area of ice-pushed ridges bordered in the west and east by two valleys, the Gelderse Valley and the IJssel Valley respectively (see fig. 1).

Reprinted from *The Science of the Total Environment*, 21 (1981) 105—112

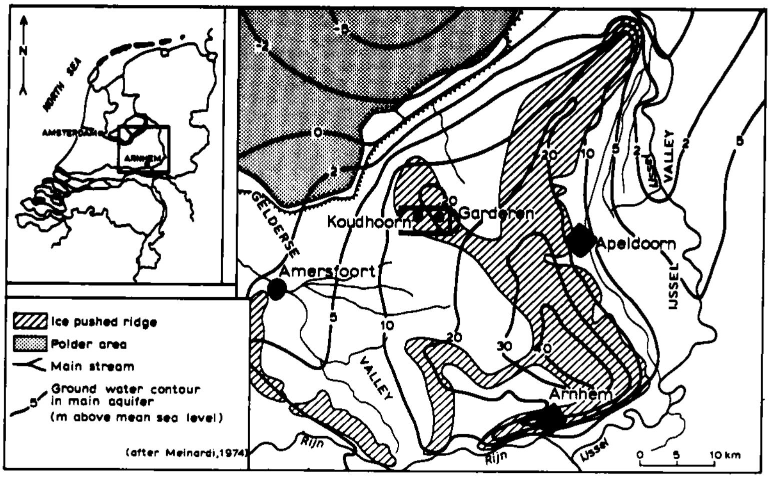

Fig. 1. Location of the study area.

Geological structure of the Veluwe is rather complex. The subsurface preglacial Pleistocene sediments consist of marine and fluvial sands and clays. During the Saalian (= Riss-Ice Age), the older Pleistocene sediments were pushed and new, glacial (boulder clay) and glaciofluvial (sand, gravel and clay) sediments were laid down. Aeolian sands formed during the last Ice Age in Weichselian times (= Würm) cover these ice-pushed ridges.

Two main soil types can be distinguished in the Veluwe : podzolic and non-calcareous sand-soils. In the areas surrounding old rural centres mineral rich soils were developed as a result of human activities (long term manuring).

The Veluwe is a recharge area with a mean annual precipitation of 840 mm and an estimated evapotranspiration of 470 mm (ref. 1). The infiltrating precipitation excess is distributed by groundwater flow to the lower lying areas surrounding the Veluwe (ref. 2). The most important aquifer consists of Pleistocene sands and gravels with varying k-values (mean value ± 60 m/day), laid down before and during the Riss-glaciation. This aquifer is up to 200 m thick and its base is formed by impervious Early Pleistocene marine clays. At locations where fluvial and glaciofluvial clays occur, two or more aquifers can be distinguished. In the higher parts of the Veluwe, depths to groundwater exceed 25 m. Groundwater levels can be locally effected by pumping stations.

A large part of the Veluwe region is covered by forest and heath which are source areas of good quality groundwater. The remaining cultivated areas consist mainly of grassland and arable land with corn, beet and potato fields. The pollution sources in these areas may cause contamination of deep groundwater, due to the high permeability of the sediments, the aerobic conditions, and absence of organic matter within the aquifer.

METHODS AND MATERIALS

Preliminary evaluation of the hydrogeological and chemical data obtained from existing wells in the NW Veluwe led to the selection of two small areas for more detailed study. The locations of these areas are shown in fig. 2.

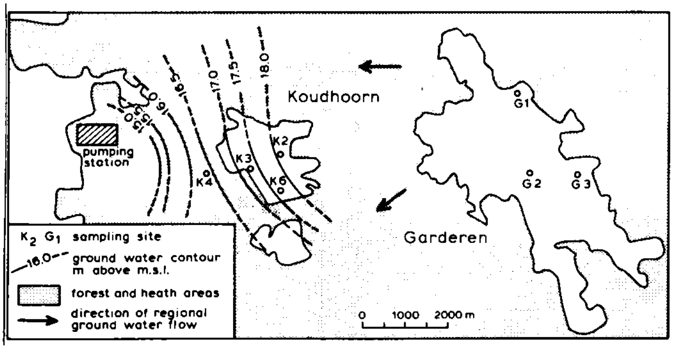

Fig. 2. Sampling sites and groundwater flow in the Koudhoorn and Garderen areas.

Both areas can be characterized as rural centres with intensive cattle farming. A brief description of the two areas is given in table 1.

TABLE 1
Characteristics of the studied areas

Location	Elevation (m+m.s.l.)	Mean depth to g.w.(m)	Farm land area (ha)	Grass/arable land ratio	Manure prod. (ton N/yr.)
Garderen	35 - 45	20	380	4 : 1	83.23
Koudhoorn	20 - 30	11	100	9 : 1	17.23

The groundwater flow pattern in both areas is complex due to non-homogeneity of the aquifer. To the west (downstream) of Koudhoorn the flow is also affected by a pumping station (see fig. 2).

In these two areas 11 borings were carried out to depth which varied from 13 to 75 m. Locations of the seven boring sites discussed in this paper are shown in fig. 2. One boring is situated in the forest and the remainder are located in or immediately adjacent to farm land.

Porous ceramic cups, commonly used in soil moisture studies (ref. 3), were adapted for the groundwater sampling programme. This technique allows detailed sampling in depth for each borehole even in a situation with deep groundwater levels (> 8 m). Construction details of the ceramic cup device are schematized in fig. 3.

The groundwater samples were analyzed at the Institute of Earth Sciences laboratory in Amsterdam. Nitrogen compound concentrations (NO_3^-, NO_2^- and NH_4^+) were determined on a Technicon Autoanalyzer. HCO_3^- and Cl^- concentrations were

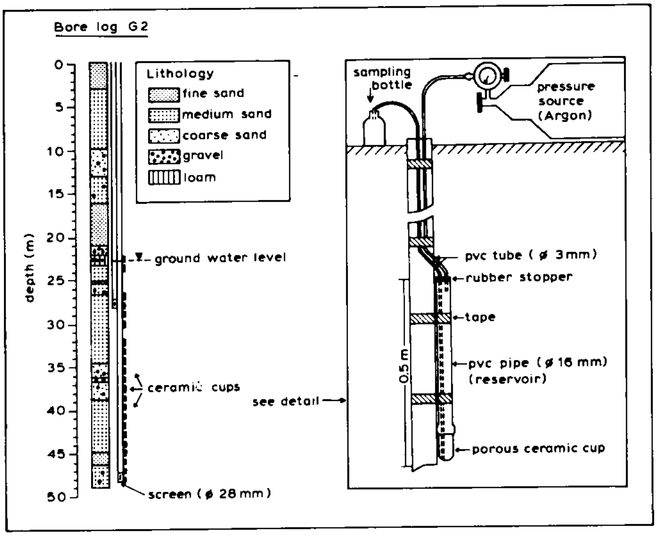

Fig. 3. Construction details of the ceramic cup device for sampling of deep groundwater.

obtained by titration, SO_4^{2-} by a turbidiometrical procedure, and PO_4^{3-} ions were determined colorimetrically. A flame spectrometer was used for the K^+ analyses. All other cations were determined by ICP-emission spectrometry. Results of the analyses are stored on magnetic tape for further processing (ref. 4).

Cumulative diagrams are used here for presentation of the analyses results. In these diagrams, the concentrations of major ions (in meq/l) are added and plotted against depth of sample (see fig. 4).

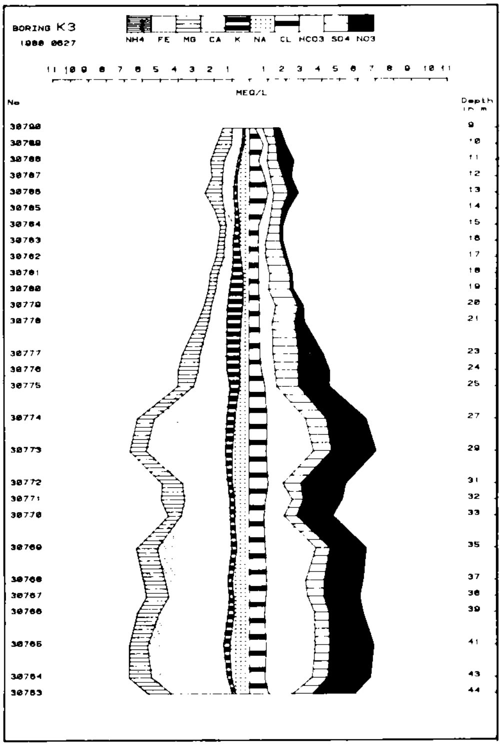

Fig. 4 Cumulative diagram showing ion-concentration variations with depth.

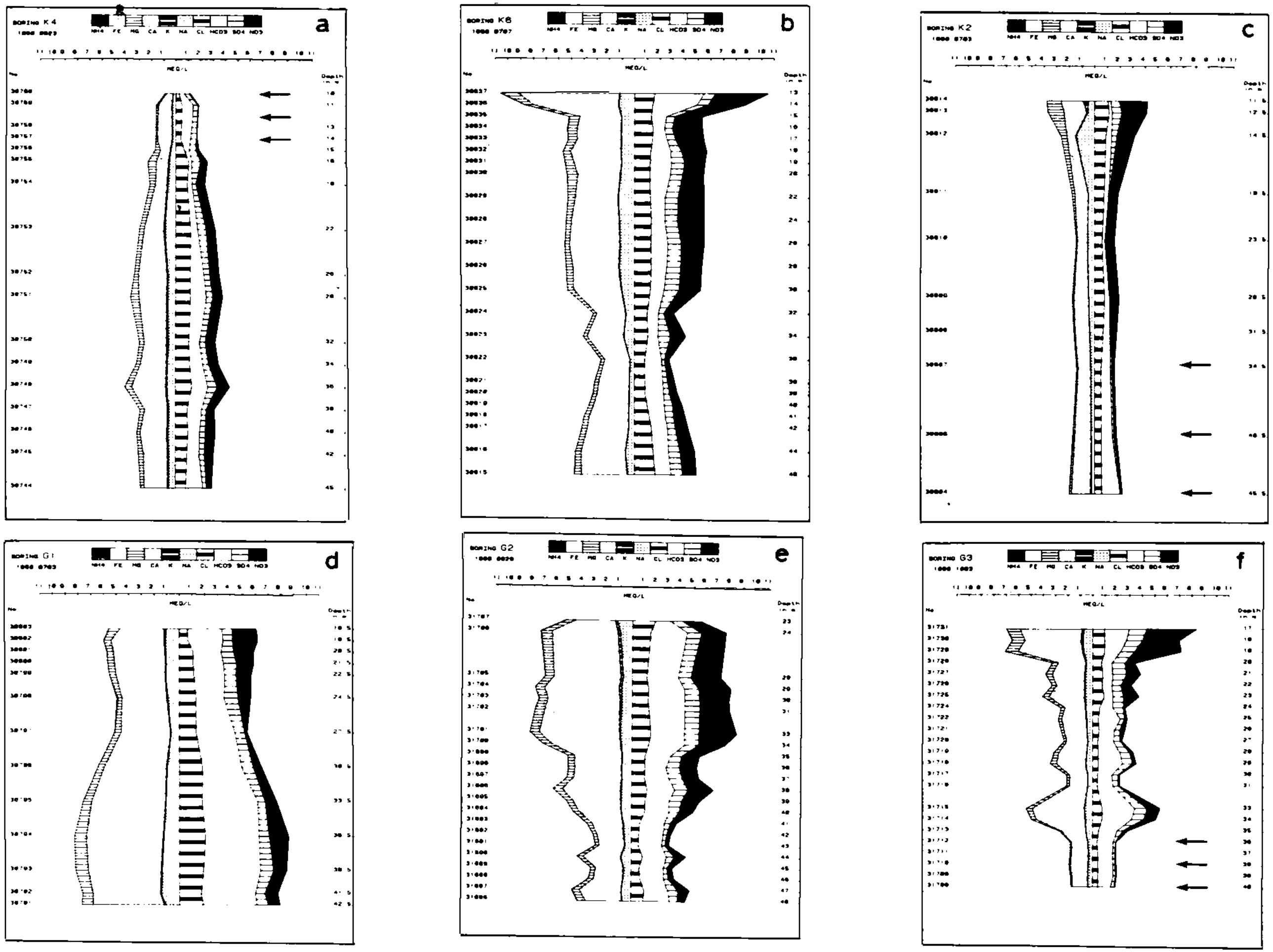

Fig. 5. Cumulative diagrams showing the ion-concentration variations with depth in Koudhoorn (a, b, c) and Garderen (d, e, f). Arrows indicate the reference water quality.

RESULTS AND DISCUSSION

Meinardi (ref. 1) found that chemical composition of reference (unpolluted) groundwater from the Veluwe region is similar to that for rain water, multiplied by an evapotranspiration factor. This evapotranspiration factor, which depends on the vegetation cover, was estimated to be 2.2 and its use results in estimated concentrations in the annual precipitation excess given below :

Cl^-	SO_4^{2-}	HCO_3^-	NO_3^-	Na^+	Mg^{2+}	Ca^{2+}	NH_4^+	(mg/l)
9	10*	6	1	7	2.5	3.5	1	

*may have changed in recent years

Similar concentrations, with the exception of Ca^{2+} and HCO_3^- ions, are commonly found in the deep groundwater beneath the whole Veluwe region (ref. 1) and in upper parts of the aquifer in the heath and forest areas (ref. 5). The concentrations of Ca^{2+} and HCO_3^- ions are greater (up to 50 and 150 mg/l respectively) due to solution of $CaCO_3$ from the aquifer sediments. Concentrations of the other ions are more or less uniform over the whole Veluwe, since the aquifer consists principally of sands containing up to 98 % unreactive quartz.

Due this unique situation a pollution index of groundwater is readily defined : any substantial increase of the above ion concentrations can be considered as pollution.

Variations in ion concentrations with depth at the seven sampling sites are shown in figs. 4 and 5. The water quality which is similar to that for the reference water is indicated by arrows. It can be seen that this reference water quality is either absent or is present in only a minor part of the studied profile. All chemical profiles show great variations of TDS concentrations with depth and the concentrations of individual ions can increase or decrease rapidly (within 1 m).

Table 2 shows the minimum and maximum concentrations of major ions (in mg/l) at the seven sampling sites in Koudhoorn and Garderen.

TABLE 2

Minimum and maximum concentrations (mg/l) of major ions at the sampling sites in Koudhoorn (K) and Garderen (G)

Sample Site	μmho's/cm		mg/l															
	EC		Mg^{++}		Ca^{++}		K^+		Na^+		Cl^-		HCO_3^-		$SO_4^=$		NO_3^-	
	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.
K2	155	550	1.1	15.7	17.9	40.1	0.6	16.3	6.2	14.6	19.4	44.0	17.6	83.1	2	32	1.0	163
K3	210	725	3.9	17.4	11.0	86.6	3.9	33.0	6.1	25.3	12.8	37.9	20.0	166	14	63	8.5	156
K4	160	480	1.1	7.7	17.6	57.7	0.8	6.5	4.7	21.2	9.7	36.1	18.8	82.2	15	40	0.5	57
K6	280	1050	3.2	12.4	40.5	156	0.8	9.9	8.2	29.2	26.6	55.7	38.4	248	8	47	26.2	248
G1	520	850	3.8	11.4	71.7	118	1.1	2.7	14.7	32.4	24.3	74.4	89.1	270	31	49	11.5	112
G2	320	870	3.8	11.0	41.3	131	1.2	8.7	11.4	28.7	20.0	65.2	106	183	14	58	16.1	188
G3	195	820	1.1	13.1	24.9	105	0.6	6.1	7.4	18.4	13.4	34.1	43.2	160	9	69	1.1	247

The concentrations of K^+, Na^+, Mg^{2+}, Cl^-, SO_4^{2-} and NO_3^- can be many times greater than those calculated for the reference water. The maximum NO_3^- concentration exceeds 50 mg/l at all sampling sites, this value being the upper limit recommended for drinking water purposes. The peak concentration of 248 mg/l was found at sampling site K6, immediately below the groundwater table. However, nitrate concentrations of more than 100 mg/l have also been recorded at depths which are considerably below the groundwater table. For example :

site K3 : 143 mg/l at 34 m below groundwater table (43 m below the surface)
K6 : 104 mg/l " 17 m " " " (30 m " " ")
G2 : 125 mg/l " 14 m " " " (38 m " " ")

There are three potential pollution-sources in the studied areas :

- manure production from the intensive cattle farming
- use of fertilisers
- domestic sewage (including the camping grounds).

Data on the use of fertilisers have not yet been obtained. The two other sources can be quantified approximately on the basis of inhabitant equivalent numbers (i.e.):

	Koudhoorn	Garderen
manure production :	7.858	51.143
domestic sewage :	952	2.350

These figures indicate that manure production can be considered as the main source of pollution in Koudhoorn and Garderen when compared with the output of domestic sewage.

The composition of infiltrating water in the manured farming areas is determined by the manure type (from cows, calves, pigs and poultry), the quantity of manure transported to the land, the period of manuring and by the crop cover and soil type.

The transport of polluted water in the saturated zone depends on hydrogeological characteristics of the studied area. Despite the fact that the hydrogeological situation is in a general sense known, the local flow patterns are poorly defined. Consequently, the detailed relationships between the horizontal variations in land use and the vertical variations in the composition of groundwater have not yet been determined in the present study phase. The complex situation may be briefly illustrated by consideration of the chamical profiles derived for the area of Koudhoorn.

The reference water which infiltrates in the forested area upstream of Koudhoorn is, with the exception of K2 (fig. 5c), not found at the sampling sites. This implies that the polluted groundwater originates from the rural area of Koudhoorn. The great depths at which polluted groundwater is found (figs. 4 and 5b,c) and the relatively small size of source area indicate a deep recharge system for this area.

The chemical profile at K4 (fig. 5a) on the other hand, in the forested area downstream of Koudhoorn, indicates a shallow infiltration system. The unpolluted reference water is here found to only 5 m below the groundwater table. The relatively high concentrations of Cl^-, SO_4^{2-}, NO_3^-, Na^+, K^+ and Ca^{2+} at greater depth suggest that the source area of this water is located in the upstream rural area.

It is concluded that the chemical composition of groundwater in the studied areas is very heterogeneous. The vertical variations in the groundwater composition reflect, on the regional scale, a transition between the reference water from forest and heath areas and polluted water from the rural centres. Concentration-increases in the polluted water with respect to the reference water depend on the local differences in composition of infiltrating water. The distribution of polluted water from the source areas to a given depth in the studied profile is governed by the local groundwater flow pattern, which in turn depends on the aquifer characteristics.

ACKNOWLEDGEMENTS

We thank Tini Bäer, Hetty de Liefde and Peter Overweg for their analytical work, and Paul Smit for writing the computer-program that plots the cumulative diagrams. The Ministerie van Volksgezondheid and Milieuhygiëne (Ministry of Health & Environmental Protection) financially supports this study.

REFERENCES

1 C.R. Meinardi, RID Med. 74-4, Nat. Inst. for Water Supply, Voorburg, 1974, pp. 1-48.
2 C.R. Meinardi, RID Med. 78-4, Nat. Inst. for Water Supply, Voorburg, 1978, pp. 1-50.
3 C. Ploegman, Landbouwk. Tijdschr./pt 86-7, (1974) 1-3.
4 C.A.J. Appelo and P.M.H. Smit, submitted to H_2O (1981).
5 L. Vasak, Basis rap. CWG, Vrije Universiteit Amsterdam, 1979, pp. 1-33.