[RADIOCARBON, VOL 31, NO. 3, 1989, P 919–925]

GROUNDWATER ANALYSIS OF ENVIRONMENTAL CARBON AND OTHER ISOTOPES FROM THE JAKARTA BASIN AQUIFER, INDONESIA

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ABSTRACT. Groundwater of the Jakarta Basin aquifer is heavily exploited for drinking water. As a result, the piezometric head has dropped dramatically. Extensive hydrogeologic and numeric model studies have been made to find a reliable basis for managing available groundwater resources. Environmental carbon (^{14}C, ^{13}C) and other isotope analyses (^{18}O, ^{2}H, ^{3}H) were made. Two sampling strategies were employed, which show that using well-defined and representative sampling sites, no matter how few, is the only way to obtain reliable geoscientific information. Large quantities of data from randomly distributed samples of uncertain origin is not recommended.

INTRODUCTION

The rapidly increasing demand for drinking and industrial water, especially in the commercial and industrial centers of the Third World, make it necessary to conduct comprehensive hydrogeologic studies on groundwater resources and management. Groundwater plays a dominant role in the drinking water supply because it is considered to be well protected from direct pollution. However, over-exploitation of the usually limited resources associated with drawdown of the groundwater table increases the danger of vertical entry of polluted water from a shallow aquifer into the underlying confined one.

Groundwater surveys involve the delineation of the aquifer system and an inventory of existing wells and construction details. Drilling records are frequently missing or incomplete due to inadequate administrative regulations. Often even the depths of wells and pumping rates cannot be verified. Under such conditions, any forecast of the response of an aquifer system to future increases in groundwater abstraction involves many uncertainties. One way to determine the origin of the pumped water is to analyze its chemical and environmental isotope content. Two procedures are used. Samples are collected from randomly distributed wells without construction documentation and the isotope data are treated statistically. The second method is to analyze a limited number of selected wells from which the construction details are available. We had the opportunity to compare the results obtained from both procedures in an Indonesian-German Technical Cooperation Program from 1983 to 1985 (Söfner, Hobler & Schmidt, 1986).

THE HYDROLOGY AND HYDROGEOLOGY OF JAKARTA

The population of Jakarta was 7,500,000 in 1985 and is expected to increase to >12,000,000 by the year 2005. The present water demand is ca 450,000,000m^3/yr; 200,000,000m^3/yr are pumped from innumerable shallow wells and 50,000,000m^3/yr from deep wells, 50 times more than before 1945. The pressure head of the deep groundwater system in the northern and central districts of Jakarta was 5–15m asl in 1900, and the wells were generally flowing. From 1900–1970, water levels dropped at a rate of 0.1–0.2m/yr. Later, the rate locally increased to>1m/yr. In areas with intensive industrial development, the pressure head was between 10–30m bsl in 1985 and even land subsidence became locally evident.

The aquifer system of Jakarta was delineated from archives data of the Geological Survey of Indonesia, recent results of geologic and geoelectric field studies, surveys of groundwater head and quality, and data from >20 recently constructed monitoring wells. The area finally selected for a detailed numeric model study extends to the Java Sea in the north, the Cisadane and Cikeas Rivers in the west and east, respectively, and the Depok area in the south. The base of the aquifer system consists of consolidated Miocene sediments, which crop out at the southern boundary. The basin fill consists of marine Pliocene and Quaternary fan and delta sediments 0–>300m thick. Djaeni *et al* (1986) believe that thin sandy aquifer layers only 1–5m thick are intercalated in the predominantly silty, clayey sedimentary sequence and form a rather uniform aquifer system, which for the region as a whole can be treated hydraulically as a rather homogeneous and isotropic medium. An older idea (Sukardi, 1982) divides the basin fill into three confined aquifers regionally well separated by continuous aquicludes.

According to Djaeni *et al* (1986), the horizontal hydraulic conductivity is 0.1–40m/d and the vertical hydraulic conductivity is 100–5000-fold smaller, hampering the replenishment of the deeper aquifer system from which groundwater is pumped. Only the shallow unconfined aquifer is fully replenished during the rainy season. Deep groundwater generally moves from the recharge area in the south (precipitation >2900mm/yr) to the discharge area of the coastal plain (precipitation ca 1700mm/yr). However, the horizontal inflow across the hinge line, estimated to be 15,000,000m^3/yr, does not counterbalance the pumping rate of ca 50,000,000m^3/yr (Soefner, Hobler & Hobler, 1986).

ENVIRONMENTAL ISOTOPE STUDY OF RANDOMLY DISTRIBUTED WELLS

Wandowo, Manurung & Zainal (1985) analyzed the environmental isotopes of samples collected from 130 randomly distributed wells in the Jakarta city district. Information on construction details was generally uncertain (Wandowo, pers commun). Results of ^{14}C measurements and corresponding δ^{13}C values for 75 samples, ^{3}H dates for 111 samples, as well as δ^2H and δ^{18}O values for 91 samples, showed that several ^{14}C and ^{3}H values are clearly below the detection limits.

The conventional ^{14}C ages plotted *vs* the performed sampling depth are shown in Figure 1. Wandowo, Manurung and Zainal (1985) observed a trend of increasing ^{14}C water ages with depth. From these dates we calculated mean values for ^{14}C ages, δ^{18}O, and δ^2H for the samples from the wells grouped in three depth ranges (0–60m, 60–150m, and 150–250m). Only a weak depth trend of the mean ^{14}C ages is visible and was interpreted as confirmation of the presence of a confined three-aquifer system. The decreasing

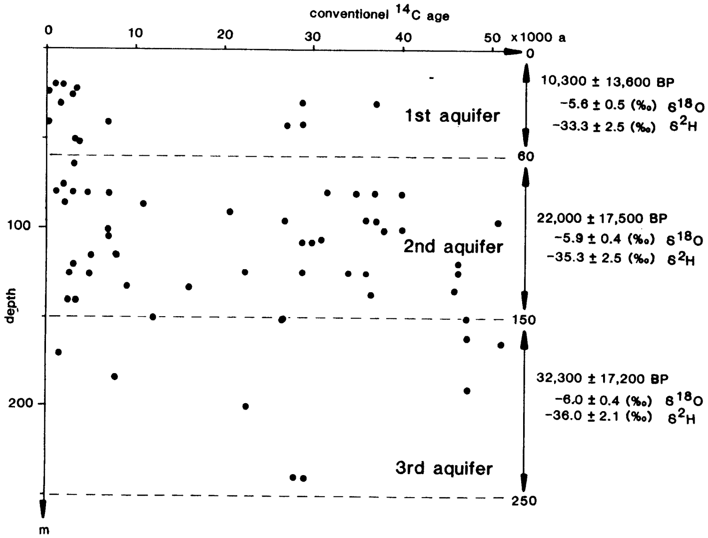

Fig 1. Conventional ^{14}C ages of randomly distributed groundwater samples from the Jakarta City district *vs* assumed sampling depth and calculated mean values for conventional ^{14}C ages, $\delta^{18}O$, and $\delta^{2}H$ for different ranges of assumed well depth (after Wandowo, Manurung & Zainal, 1985)

$\delta^{18}O$ and $\delta^{2}H$ values with increasing depth may reflect the altitude effect as the deep groundwater is recharged in areas with altitudes above 200m in the south while the shallow groundwater is replenished locally at near sea level. All groundwater ages are rather high and increase from south to north.

ENVIRONMENTAL ISOTOPE STUDY OF WELL-DEFINED REPRESENTATIVE WELLS

In 1985, we did environmental isotope and hydrochemical analyses on 21 samples from selected wells in the Jakarta city district for which construction details were available. The isotope results and a selection of the hydrochemical data are compiled in Table 1. The complete data are in Geyh, Hobler and Söfner (1986). The conventional ^{14}C ages and $\delta^{13}C$ values are represented in Figure 2.

Measurable tritium was found only in a sample from the recharge area in the south. The general trend of increasing and quite large ^{14}C water ages from south to north was confirmed. Hence, the bulk of groundwater in the aquifer system was recharged a long time ago. In disagreement with the statement derived from the statistical evaluation of the ^{14}C ages (Wandowo, Manurung & Zainal, 1985), there is no definite relationship between ^{14}C age and sampling depth. The ^{14}C ages of the deepest groundwater may be even lower than those of the shallower groundwater.

A rough estimate of 1m/yr may be made for the tracer velocity from the ^{14}C data. A value of 1.6m/yr was obtained from the Darcy law using a mean gradient of the groundwater table of 1/1500 and a mean conductivity of 1.5 $\times 10^{-5}$ m/s. Total porosity was assumed to be 20%. Considering the uncertainties in estimating regionally valid hydraulic parameters, as well as in ^{14}C groundwater dates, agreement is excellent.

Table 1

Results of the environmental isotope and hydrochemical analyses of groundwater samples from the Jakarta area

Hv no.	Site	Well no.	Depth m	$\delta^{18}O$ ‰	$\delta^{13}C$ ‰	Conv ^{14}C age yr BP	^{14}C value pMC	pH	HCO_3^- mg/l	Cl^- mg/l	SO_4^{--} mg/l	EC µmho/cm
I. Fresh groundwater from the south and central Jakarta region												
13822	Cilodong 1	1870	22–76	–6.13	–13.9	540± 190	93.4±2.2	7.9	81	68	0	105
13820	Pasar Mingu 1	1836	193–250	–5.60	–15.3	14,300± 400	16.9±0.8	7.5	262	8	0	350
13821	Pondok Gede	1766	117–140	–6.23	–14.2	18,100± 480	10.5±0.6	7.4	309	10	10	415
13816	Parkir Jaya	1800	177–193	–6.18	–16.2	24,500± 900	4.8±0.6	7.6	349	20	0	530
12817	Wisma Harapan	8567	141–168	–6.25	–13.5	31,200±1900	2.0±0.6	6.9	349	10	12	500
II. Fresh groundwater from the northern Jakarta region												
13812	Sunter 2	1857	173–177	–6.22	–18.1	28,000±1240	3.0±0.5	7.5	564	39	20	800
13803	Pedongkelan 2	1845	142–146	–5.76	–18.4	28,500±1420	2.7±0.6	7.3	564	30	0	835
13814	Cakung	1824	75–81	–4.89	–15.4	29,500±1740	2.6±0.5	7.2	850	58	12	1100
13806	Tongol 1	1710	129–152	–6.41	–16.3	32,000±2510	1.8±0.6	7.4	700	40	10	700
13813	Sunter 3	1854	115–132	–5.48	–15.3	33,300±2440	1.6±0.5	7.5	658	15	0	885
13808	Tongol 3	1865	184–197	–6.17	–17.4	34,000±2800	1.5±0.6	8.6	558	93	0	1020
III. Anthropogenically disturbed groundwater												
13818	Kuningan	2102	35–38	–6.05	–18.7	970± 120	88.5±1.3	7.5	201	11	0	280
13819	Manggarai	8818	100–125	–6.01	–19.8	1560± 130	82.4±1.2	6.9	221	6	12	300
IV. Saltwater intrusion												
13804	Pedongkelan 4	1851	42–45	–5.59	–14.1	5400± 160	17.8±0.5	6.3	342	3800	0	16,500
13810	Tongol 5	1878	45–50	–3.19	–11.3	9900± 240	29.0±0.9	6.3	201	9560	840	32,000
13807	Tongol 2*	1863	214–227	–3.26	–12.5	8950± 220	32.7±0.9	6.5	282	10500	634	33,000
13809	Tongol 4	1867	76–86	–4.89	–15.6	31,000±2100	2.1±0.6	6.8	67	2660	75	8200
13802	Pedongkelan 1	1844	231–234	–5.34	–12.4	32,700±2600	1.7±0.6	7.1	1261	240	0	2300

Tongol 2* – damaged well

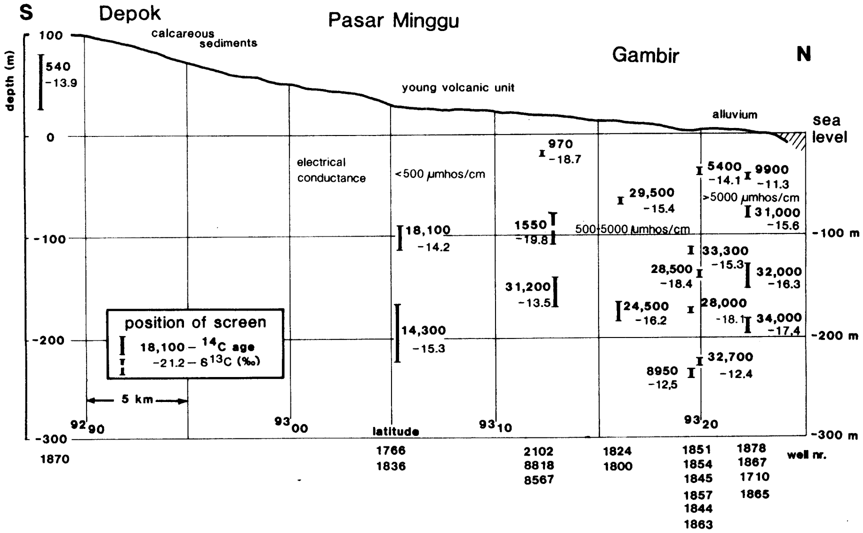

Fig 2. Conventional ^{14}C ages and δ^{13}C values of representative groundwater samples from the Jakarta City District *vs* sampling depth (after Wandowo, Manurung & Zainal, 1985)

There are three new results: 1) rather low ^{14}C water ages were found in southern and central Jakarta; 2) according to the δ^{18}O values and the chloride content, ocean water is the origin of the high mineral content of the upper part of the aquifer system of northern Jakarta; 3) most of the δ^{13}C/HCO_3^- values cluster in three groups.

The δ^{13}C values were plotted *vs* the bicarbonate concentration (Fig 3). Freshwater samples from southern and central areas of the study, which have

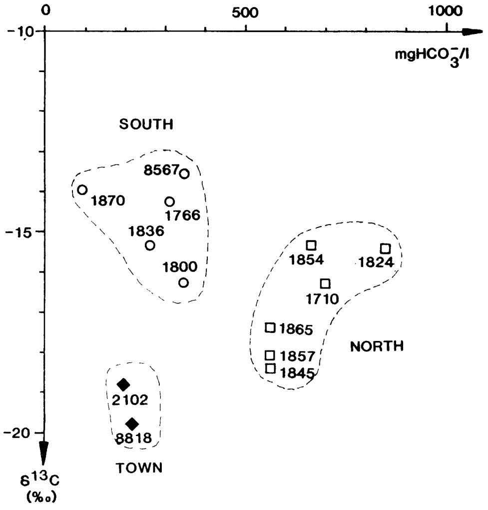

Fig 3. δ^{13}C values for the DIC of groundwater samples from the Jakarta district *vs* bicarbonate concentration

conventional ^{14}C ages of up to 30,000 yr, form one group. The bicarbonate content increases rapidly from 80mg/l in the recharge area to a rather constant value of ca 300mg/l for the groundwater older than 10,000 yr. Hence, any correction for the corresponding ^{14}C ages concerning the initial ^{14}C content would only shift all the ^{14}C water ages in one direction but would not change the relative ages.

The second group of $\delta^{13}C/HCO_3^-$ values is for water samples with bicarbonate concentrations of 550–800mg/l and ^{14}C ages exceeding 28,000 yr. The corresponding samples are from the northern part of the study area. The bicarbonate concentration tends to decrease with increasing depth. Again, age correction would not change the picture. Due to the different bicarbonate contents of the two groups of groundwater there may be an age bias between the first and second one of 5000 yr.

These observations might be explained by changes in the paleohydrogeological situation during the last 30,000 yr. At the beginning of this period, the sea level was a maximum of ca 100m lower than today and the surface may have consisted of both calcareous and volcanic sediments. In recharge areas formed by calcareous sediments, groundwater with rather high bicarbonate values was recharged compared to groundwater from volcanic areas. After that, the sea level rose and volcanic sediments covered most of the calcareous sediments. Hence, the old groundwater with high δ^{13}C and bicarbonate values might be a relic of former times.

The groundwater ages agree better with the results of the numeric model (Djaeni *et al*, 1986) than with that of the old hydrogeological concept. A final decision whether a confined three-aquifer system exists is not possible with so little data. This is mainly due to the fact that we are most probably dealing with long-term processes in which groundwater seeped through aquitards for thousands of years. This may also have changed the ^{14}C values of the groundwater by mixing groundwater of different ages (Geyh *et al*, 1984).

The third cluster of $\delta^{13}C/HCO_3^-$ values (Fig 3) represents samples from a part of the natural groundwater system that may be disturbed due to overexploitation. Groundwater with low ^{14}C ages from the shallow aquifer appears to have already entered the deeper part of the system. If this is true, repeated ^{14}C analysis may help to monitor mining of fossil groundwater.

A fourth group of groundwater samples showed elevated chloride contents. This is explained by encroachment of seawater into the aquifer, mainly due to the drop in hydraulic pressure head. However, the high age of well no. 1867 indicates that mixing of seawater and freshwater occurred, at least locally, in the past. The plot of chloride *vs* δ^{18}O values shows a mixing line between seawater and freshwater (Fig 4).

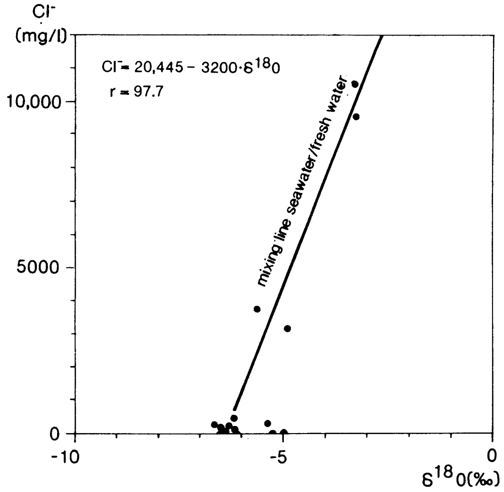

Fig 4. $\delta^{18}O$ and chloride mixing line for water samples from the Jakarta region

CONCLUSION

A comparison of the results from a study conducted on samples from randomly distributed wells for which construction details were not available and one on samples from a selection of representative wells in the Jakarta city district for which the construction details were known proved that only the data from the latter study yield hydrogeologically reliable information. For such studies, however, a detailed hydrogeological survey made prior to the sampling to select wells with well-know construction details (filter depth, coordinates, etc) is indispensable. The hydrological isotope study is then even less expensive and less time consuming than the analysis of randomly collected samples.

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