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Groundwater isotope study in the Omaruru River delta aquifer, central Namib desert, Namibia

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Abstract In the German-Namibian groundwater exploration project the groundwater potential of the Omaruru River Delta (OMDEL) has to be assessed. The OMDEL aquifer extends 35 km inland up to the Namib Plain at 230 m a.s.l. with less than 50 mm year^{-1} precipitation. The Omaruru River catchment covers 15 700 km^2 and rises to 1450 m a.s.l. with a peak altitude of 2100 m a.s.l. The mountainous catchment area receives 200-450 mm year^{-1} rain from the east. The main channel is recharged by groundwater throughflow and ephemeral river discharge. The safe yield is estimated to be 4.5×10^6 m^3 year^{-1} but $6.5\text{-}8.5 \times 10^6$ m^3 year^{-1} groundwater is currently being abstracted. In 1993 the OMDEL dam came into operation to enhance groundwater recharge in order to counterbalance the current rate of over-exploitation. Environmental isotope analyses have begun to study groundwater recharge and mixing between fresh and brackish groundwater, and to improve water budgeting by applying $\delta^{18}O$ values of groundwater samples collected along the whole course of the Omaruru River channel.

INTRODUCTION

The German-Namibian groundwater exploration project has to assess the potential of the groundwater resources in the Omaruru River Delta (OMDEL). Environmental isotope analyses ($\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$, ^{3}H, ^{14}C) were applied to study the groundwater recharge. We hope to confirm or to improve the hydrogeologically evaluated groundwater budget and to obtain an estimate of the inflow of brackish groundwater into the fresh groundwater resources of the OMDEL aquifer downstream of the dam.

HYDROGEOLOGICAL SETTING

A comprehensive description of the hydrogeological setting of the OMDEL project area is given by Nawrowski (1990). The OMDEL aquifer is situated approximately 80 km north of Swakopmund and extends 35 km inland to an altitude of 230 m a.s.l. across the generally flat Namib plain. The climate of the OMDEL region is hyper-arid with less than 50 mm precipitation per annum. The total Omaruru River catchment covers an area of 15 700 km^2 and reaches an altitude of 1450 m a.s.l. with a peak area at 2100 m a.s.l. The mountainous region of the catchment above 1000 m a.s.l. receives a mean annual rainfall of between 200 and 450 mm (Table 1, Fig. 1). The runoff recharge of the OMDEL groundwater resources was estimated to be 4.5×10^6 m^3 $year^{-1}$ while the average runoff was estimated to be 2.5×10^6 m^3 $year^{-1}$ at the coast. The total groundwater reserve in the OMDEL aquifer was calculated to be 160×10^6 m^3 of which 50% is considered to be abstractable. The geohydraulically derived mean residence time (MRT), which is given by the quotient of the total volume of the groundwater reservoir divided by the coastal runoff rate plus abstraction rate, is $(160 \times 10^6\ m^3)/(6 \times 10^6\ m^3\ year^{-1}) = 27$ years for the total volume and 13 years for the abstractable proportion. The validity of Nawrowski's data may be questioned as they are based on only three flood events monitored in 1973-1974, 1975-1976 and 1984-1985. As sporadically occurring flash flood recharge excludes the application of the exponential model to isotope data an independent estimate of the mean residence time is not possible.

The OMDEL aquifer (Fig. 2) is the main groundwater resource for the water supply to Henties Bay, Swakopmund, Arandis and Rössing mine. It consists of coarse sand and gravel of a thickness of 10 to 40 m. A clay layer of a few metres to over 25 m thick forms a low permeable base layer. The 34 production wells tap the 70 to 110 m thick sandy-gravelly alluvium of the main channel of the Omaruru River bearing fresh to slightly brackish groundwater recharged by throughflow and ephemeral river discharge. They have operated since the beginning of the 1960s. Most observation wells penetrate the far thinner alluvium of the northern elevated channel where brackish groundwater predominates.

In spite of the limited runoff recharge of only 4.5×10^6 m^3 $year^{-1}$, 6.5-8.5×10^6 m^3 $year^{-1}$ groundwater is currently pumped. In 1993 the OMDEL infiltration enhancement dam came into operation. The dam is intended to enhance groundwater recharge by settling out the fine suspended sediment from river water and by infiltrating the clear water into the aquifer downstream through artificial ponds. A dam enhancement of the recharge rate of 3.5×10^6 m^3 $year^{-1}$ is expected, sufficient to counterbalance the current rate of over-exploitation.

Table 1 Division of the Omaruru River catchment area into sub-areas plus geometric and hydraulic data (after Nawrowski, 1990). The $\delta^{18}O$ values are calculated from the line shown in Fig. 4.

Sub-area	Altitude m a.s.l.	Size km^2	Average rainfall mm $year^{-1}$	$\delta^{18}O$ altitude effect −4‰/100 m
A	1450	1400	450	−6.60
B	1330	2832	350	−6.20
C	1100	2080	250	−5.20
D	750	5550	150	−3.80
E	400	1380	75	−2.40
F	300	1445	25	−2.00
Weighted $d^{18}O$ value (area & total rainfall)				−5.30

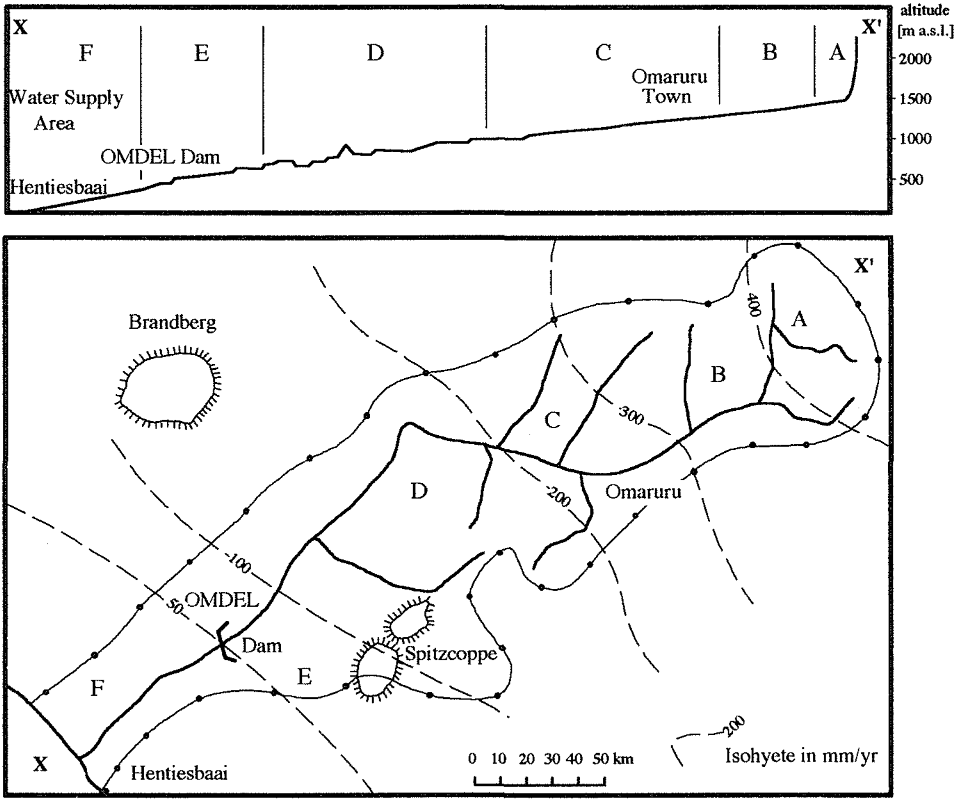

Fig. 1 Division of the Omaruru River catchment are into sub-areas (Nawrowski, 1990).

ENVIRONMENTAL ISOTOPE HYDROLOGICAL RESULTS

During the 1970s Dr John Vogel from the Council for Scientific and Industrial Research (CSIR), Pretoria, carried out a comprehensive environmental isotope study in the OMDEL aquifer. The accessible files contain, however, only ^{14}C dates and no δ^{18}O results. Not knowing this data bank, 27 production and 6 observation wells were sampled by the BGR staff for complete isotope analysis (δ^{18}O, δ^{2}H, δ^{13}C, ^{3}H and ^{14}C) in February-March 1993. Altogether 60 wells were sampled from which 83 complete isotope analyses were carried out between 1973 and 1993.

The ^{14}C data of 35 out of 40 wells in the main channel exceed 75 pMC. The histogram of the ^{14}C values (Fig. 3) shows three clusters similarly positioned for tritium-free and tritium-containing groundwater samples. The tritium-related clusters may be interpreted as reflections of different runoff events after the atom bomb tests were started. This interpretation, however, neglects mixing, which is probable. Many wells yielded high tritium values when sampled in the 1970s but not in 1993, though the ^{14}C values were similar. Two samples from one well gave 90 and 103 pMC in 1976. The analyses from 1993 confirmed the latter value. Such temporarily changing ^{14}C values show that the occasional flash flood recharge and the pumping action results in a confusing temporal and spatial ^{14}C distribution. The spatial ^{14}C distribution considering cross

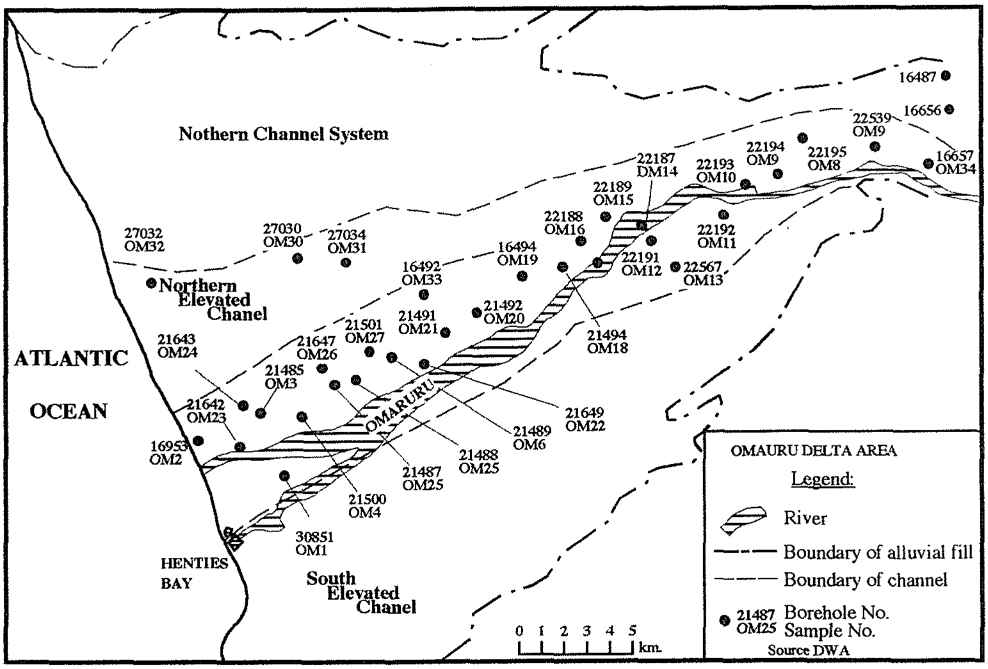

Fig. 2 OMDEL aquifer with the main channel, northern elevated channel and southern channel and also wells sampled.

sections by Vogel also did not yield new insights.

The clustering of the ^{14}C data of the tritium-free water samples may indicate flash flood recharge in catchment areas with deviating surface geology (Geyh, 1972) which is dominated by volcanic rocks and calcretes in the Omaruru catchment area. Both C_3 and C_4 vegetation grows there, and $\delta^{13}C$ values of TDIC of $-8.4 \pm 2.3‰$ suggest a

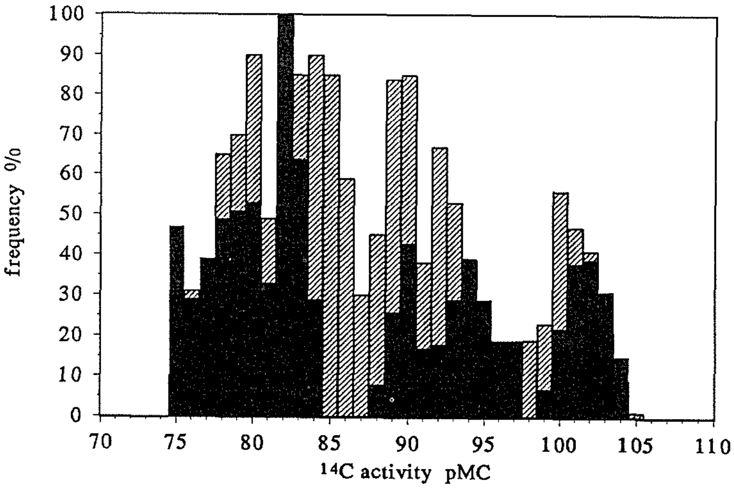

Fig. 3 Histogram of the ^{14}C values of TDIC in tritium-free (solid) and tritium bearing (hatched) groundwater samples from the OMDEL aquifer.

range of the initial ^{14}C value of > 85 pMC. This corresponds to a reservoir correction of > -1300 years used for the transformation of the conventional ^{14}C ages into actual water ages. Most of the ^{14}C values exceeding 85 pMC are due to the increased ^{14}C level in the atmospheric CO_2 since nuclear weapon tests were carried out after 1951.

The majority of the conventional ^{14}C ages of TDIC from samples in the northern and southern channel agree with that of the main channel while locally higher values of up to 8000 years were found. The oldest groundwater is pumped in the northeastern part of the OMDEL aquifer with ^{14}C ages of up to 17 000 years BP. Due to the scattered distribution of ^{14}C values of the brackish groundwater in both the northern and southern elevated channels the admixture of this groundwater to the main channel could be studied more precisely by the hydrochemical than the isotopic properties of groundwater samples.

In summary, there is no temporal or spatial trend of the ^{14}C values in the main channel where groundwater is being abstracted and the groundwater is recharged by throughflow and ephemeral river runoff. The quite distinct ^{14}C and $\delta^{13}C$ values exclude an intensive mixing of the groundwater from different flash flood events or recharge conditions.

Temporal changes of the ^{14}C values observed in wells along the border between the main channel and the northern elevated channel may be interpreted as reflections of the well-proved over-exploitation of the OMDEL aquifer during the last decade.

Based on the hydrological concept, groundwater recharge of the Omaruru River aquifer changes in a fashion similar to a braided river system moving from one subchannel to another. Therefore, it was expected that the $\delta^{18}O$ values would also show a wide scatter outside the confidence interval of a single measurement of 0.1‰. Surprisingly, this is not the case. The $\delta^{18}O$ values of the groundwater of the northern elevated channel at −6.87‰ deviate significantly from that of the young groundwater abstracted in the production wells of the main channel (−7.38 ± 0.1‰).

In order to localize the source areas of the groundwater in the OMDEL aquifer, well samples were collected along the Omaruru River catchment area from wells situated between 415 and 1620 m a.s.l. (Table 2). They were analysed for $\delta^{18}O$ and $\delta^{2}H$. Several of these samples show signs of evaporation as the $\delta^{18}O/\delta^{2}H$ data deviate from the meteoric water line (MWL; Fig. 4). Most of these samples were taken near to farm dams. Corrected $\delta^{18}O$ values were calculated as intercepts between the MWL and an evaporation line with an assumed slope of 4.0.

The mean of all $\delta^{18}O$ values collected along the Omaruru River catchment area and fitting the MWL is −7.55 ± 1.23‰, which is in the range of the $\delta^{18}O$ value of the groundwater in the main channel of −7.38‰ but the values show a wide scatter. The mean of 7.52 ± 0.51‰ calculated without the extreme $\delta^{18}O$ values of the samples from the border of the delineated catchment areas (Nawrowski, 1990) still has too large a confidence interval. In spite of this, one may conclude that the peak areas along the border of the catchment sub-areas with very negative $\delta^{18}O$ values do not contribute to the OMDEL groundwater recharge while the other parts of the sub-areas do. Additional samples from the sub-areas E and F are needed, however, to determine whether or not this groundwater must be isotopically excluded from the flash flood recharge.

The attempt to find a $\delta^{18}O$/altitude relationship did not succeed (Fig. 5). A line with a slope of an extreme altitude effect of −0.4‰/100 m does not meet the majority of the geomorphologically determined altitude ranges of the catchment area, bearing in mind

Table 2 Stable isotope data from the Omaruru River catchment area. The $\delta^{18}O$ values in brackets are calculated intersection points between the MWL and an evaporation line with a slope of 4. The division into sub-areas follows Table 1 in Nawrowski (1990).

Sample	Altitude (m a.s.l.)		Sub-area	$\delta^{18}O$	$\delta^{2}H$	$^{2}H_{excess}$	Remarks
	Min	Max		‰	‰	‰	
OM 49	280	950	F	−5.60 (−6.75)	−39.4	+5.40	
OM 36	415	2110	E	−7.04			
OM 37	595	2110	D	−7.10 (−9.27)	−55.5	+1.30	
OM 38	702	2110	D	−7.26			
OM 39	1090	1200	D	−2.71			farm pond
OM 41	1020	2110	D	−6.65 (−7.42)	−46.3	+6.90	
OM 52	900	2110	D	−7.62			piped water
OM 55	1045	1630	D	−4.94	−28.7	+10.82	TD: 57 m
OM 56	1040	1630	D	−4.96	−29.7	+9.98	TD: 63 m
OM 54	1260	1800	C	−6.26 (−7.59)	−45.4	+4.68	farm
OM 40	945	1065	C	−8.32			
OM 57	1120	1380	C	−9.47	−65.2	+10.56	TD: 70 m
OM 53	1195	1250	C	−5.43 (−7.49)	−41.7	+1.74	piped water
OM 51	805	930	(C)	−9.69	−9.69	+9.02	
OM 42	1320	1620	B	−7.61 (−7.96)	−52.3	+8.58	hot spring
OM 43	1310	1450	B	−7.83	−50.7	+11.94	
OM 44	1220	2110	B	−7.89	−51.5	+11.62	
OM 45	1400	1640	A	−7.29	−45.7	+12.62	
OM 46	1535	1720	A	−5.53 (−6.52)	−38.2	+6.04	farm dam
OM 47	1530	1610	A	−7.33	−45.8	+12.84	
OM 48	1620	2110	A	−8.38	−55.7	+11.34	karst?
Mean of all $\delta^{18}O$ values				(−7.55 ± 1.23)			
Mean ($-7.0 < \delta^{18}O > -8.5$)				(−7.52 ± 0.51)			

that groundwater recharged at high altitude mostly discharges at lower elevation. The weighted mean of the corresponding $\delta^{18}O$ values is higher than the measured one. According to Gat (personal communication) an altitude effect in arid regions seldom exists. In our study area it is not to be expected as the storms approach from the east and move from high to low altitude.

For the final interpretation of the isotope data one has to consider the additional points of view:

- a possible increase of the sealing of the river bed against seepage downstream resulting in a preferential seepage of flash floods from higher altitudes; and
- preferential rainfall events in sub-areas of the main channel during the last two decades.

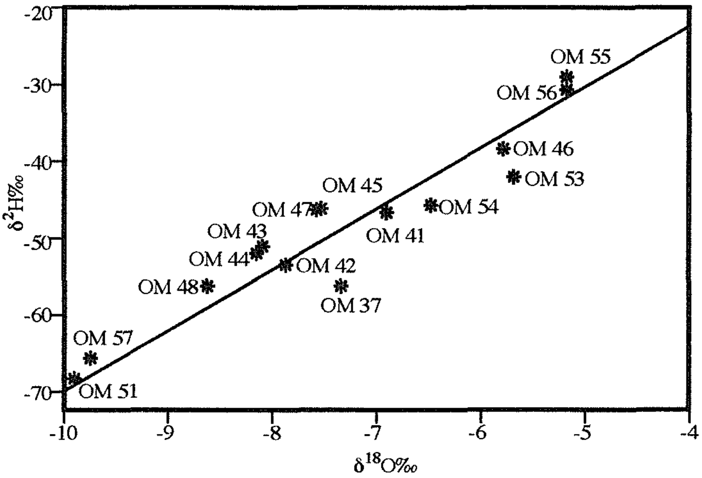

Fig. 4 $\delta^{18}O/\delta^{2}H$ plot of the groundwater samples from the OMDEL aquifer. There are a few samples which show properties of evaporation.

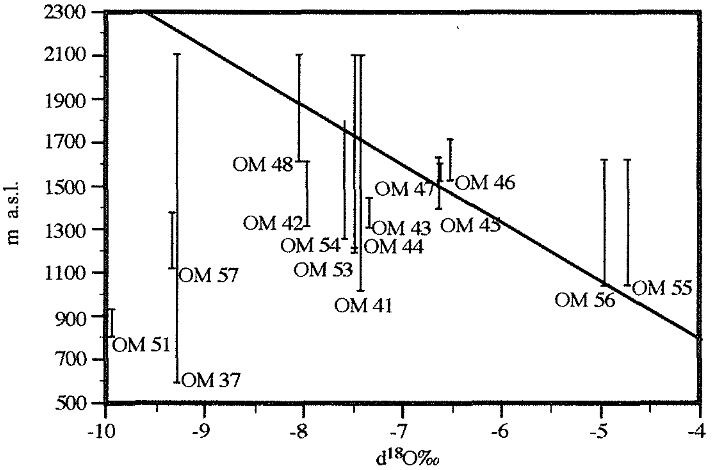

Fig. 5 Plot of $\delta^{18}O$ values *versus* geomorphologically estimated ranges of groundwater recharge. There is no relationship. The solid line belongs with an extreme slope of -0.4‰/100 m, is placed in such a way that as much as possible of the ranges are met. The dashed vertical line at -7.38‰ marks the mean of the measured $d^{18}O$ values of the groundwater samples collected from the OMDEL aquifer. As the maximum altitude of the catchment area is 1450 m a.s.l., the weighted $\delta^{18}O$ value (Table 1) deviates from the mean of the measured $\delta^{18}O$ values.

In summary, the preliminary isotope hydrological results show that the assumed catchment areas may have to be reduced. Mixing of groundwater between the main channel and the northern elevated channel should be studied hydrochemically rather than isotopically. The water budget of the OMDEL aquifer may be improved if additional samples from wells of the lower sub-areas and especially of precipitation are collected for hydrological isotope analysis in the next rainy season.

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