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《Original》

Environmental Isotope-Aided Studies on River Water and Ground Water Interaction in the Region of Seoul

Part I: Isotope Hydrology of the Shallow Alluvial Aquifer Han R. Valley

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同位元素를 利用한 서울 地域의 江水와 地下水와의 相互聯關性에 關한 硏究

제1보：同位元素를 利用한 漢江流域 冲積帶水層 地下水의 水文學的 硏究

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Abstract

A preliminary study of the isotope hydrology of the Han River Valley is presented. This investigation is part of a project whose overall aim is to relate the levels of heavy metal ions to the dynamics of the groundwater movement in order to establish (i) whether there is any evidence for the deterioration in groundwater quality associated with the release of industrial effluents and (ii) if so, to determine the migration pathways. Evidence is adduced that the recharge mechanism is principally determined by the degree of urbanisation. In the metropolitan area of Seoul, river recharge dominates probably due to the combined effects of reduced infiltration and increased pumpage. In the inter-urban region, the major source of recharge is local precipitation. During the spring sampling period when the river levels were low, evidence was obtained for appreciable groundwater infiltration in the vicinity of the upstream transect. No significant correlations were observed between the levels of heavy metals in the groundwater, and the recharge mechanism, the distance from the river or the electrical conductivity of the samples.

要 約

漢江流域 江水와 地下水와의 相互關係를 環境同位元素 重水素, 三重水素 및 酸素-18을 利用하여 基礎硏究를 遂行하였다. 本 報告는 ① 産業廢水의 放出이 地下水質의 惡化에 어떤 影響을 미치는지의 如否와 ② 影響이 있다면 어떤 經路를 통하여 浸透되어 移動되는가의 硏究目的의 一環으로서 地下水 移動特性과 重金屬 ion 과의 關係를 알아보았다. 地表水로부터 地下水로의 물 注入機作은 主로 都市化의 程度에 依해서 결정되는 것으로 나타났다. 즉, 서울 都心地域에서는 降水가 地下로의 流入되는 경우가 적고, 또한 이 地域에는 人口密度가 높아서 地下水를 펌프하여 使用하기 때문에 地下水位가 낮게되므로 江水가 地下水로 流入되는 것으로 생각된다. 그 외의 上流나 下流의 森林地나 農耕地에서는 地下水의 給源은 주로 降水가 源泉이 된다. 그리고 降水量이 적은 봄에는 江水位가 낮아지기 때문에 漢江上流地域에서는 地下水가 江으로 流出되는 것으로 생각된다. 地下水中에 重金屬水準, 流出動態, 江으로부터의 距離 및 江水와 地下水 사이의 電氣傳導度 사이에는 特別한 相互關係를 나타내지 않았다.

1. Introduction

The Han River is an important source of domestic, industrial and irrigation water for the 8.7million people who occupy Seoul and the surrounding areas. The river has a total length of 470 km and drains an area of 26000 km^2 or 27 per cent of South Korea. Much of the catchment is in mountainous terrain; about 50 per cent of the area has a slope exceeding 400 m/km, and only 10 per cent a gradient of less than 140 m/km. The slope of the river decreases from 4m /km near the headwaters to 0.2m/km near the mouth. The tidal influence extends 65 km inland.[1,2,3)]

The total quantity of groundwater stored within the Han River catchment is 406.8×10^9 m^3. The distribution amongst various rock types is summarised in Table 1. In 1977 groundwater contributed about 12 per cent to the total water demand or $4.6\times10^9 m^3 y^{-1}$. A 20 per cent increase is expected by 1991[3)]. Since much of the groundwater is used for drinking, care must be taken to ensure that the quality is maintained in the face of rapidly expanding industry and the concomitant redistribution of population towards the larger cities.

Table 1. Ground Water in Storage in Rocks of the Han River Basin

Geological Classification	Area (km^2)	Strata Thicness (m)	Porosity (per cent)	Total Groundwater $m^3\times10^9$
Granite	9,207	200	1	18.4
Gniess & metamorphic rock	17,443	200	1	24.8
Limstone & sedmentary rock	4,567	600	10	274.0
Alluvium*	6,822	8	25	13.6
Saprolite*	19,000	10	40	76.0
			Total	406.8

*:The alluvium and saprolite form, which most of the groundwater is draw, overlie the ingenous, metamorphic rocks and sedimentary formations.

The aim of the program reported here is to assess the possible threat to the groundwater of the Han River Valley from urban and industrial effects. The investigation has been restricted to the shallow alluvial aquifer underlying the region shown in Figure 1. Three transects approximately

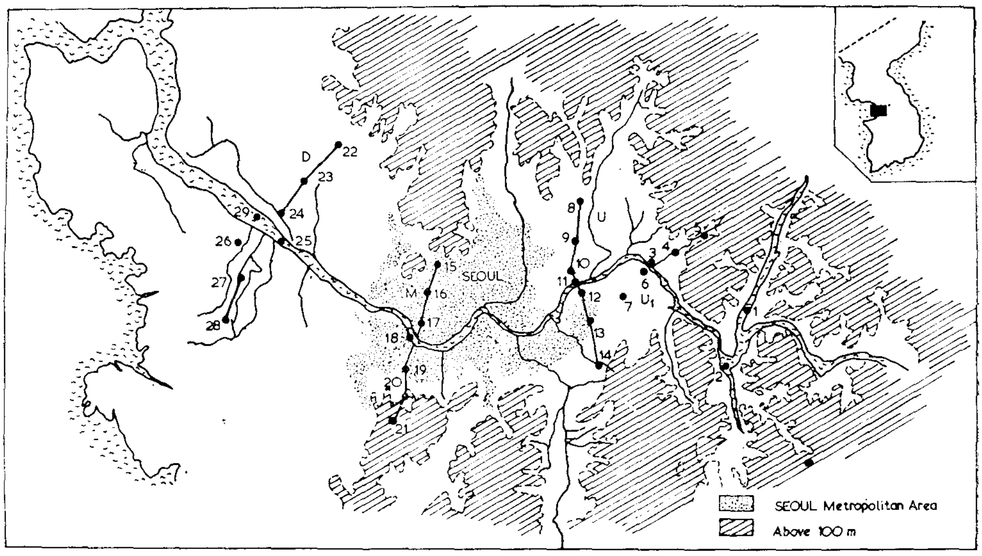

Fig. 1. Location of Sampling Points, Han River Valley. Elevation above 100m are distinguished by line shading. The approximate boundaries of the Seoul metropolitan area are also shown.

normal to the river were established. One was sited in the heavily urbanised region of Seoul (transect M) and the others upstream (U) and downstream (D) of the city. Environmental isotopes were used

(i) to determine the relative importance of the river and of precipitation to the recharge at various locations within the valley; and

(ii) to study the interaction of river and groundwater, and the dynamics of the important transport processes.

At a later stage of this project, any evidence for groundwater pollution will be examined with a view to determining migration pathways. Water samples will be collected every three months for tritium, stable isotope and chemical assay. After the extent of any seasonal variability is established, a much larger number of wells, over a wider geographical area, will be sampled at a representative period. In addition, isotope techniques will be used to study the extent to which the shallow groundwater recharges the underlying fractured crystalline rock aquifers which are an increasingly important source of industrial water.

2. Isotopic Composition of the Recharge Water

2.1 Rainfall

2.1.1 Tritium

Since none of the IAEA environmental isotope monitoring stations are within the Han River catchment the input function had to be assessed from data collected at the closest station Pohang which was operating between 1961 and 1976.[4)] The variation with time of the weighted annual means are shown in Figure 2. The ground water levels depicted in Figure 3 are discussed in Section 3.2. The data are expressed

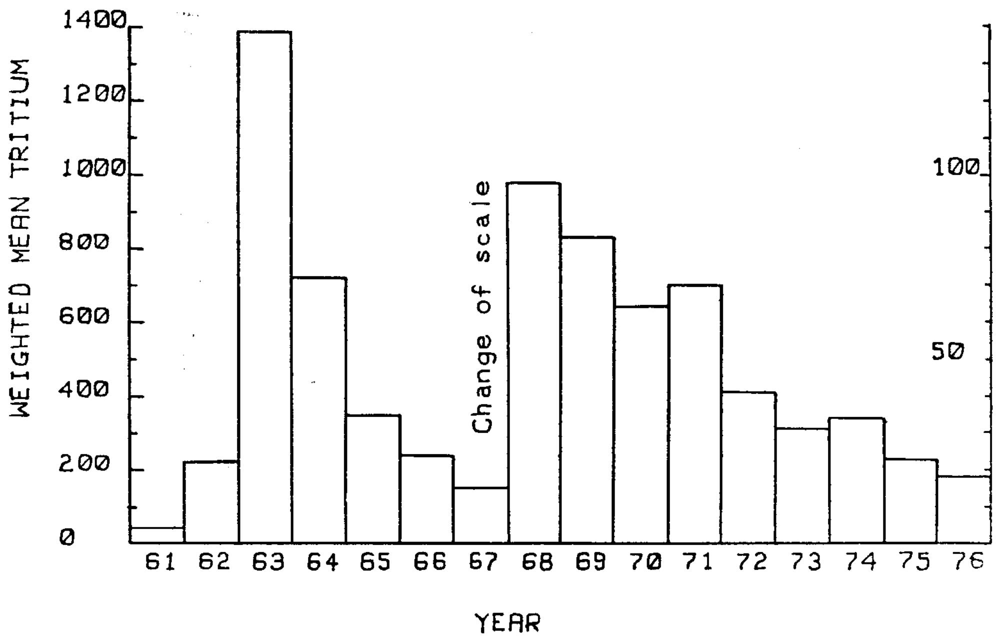

Fig. 2. The Variation with Time of the Annual Weighted Means of Tritium Levels

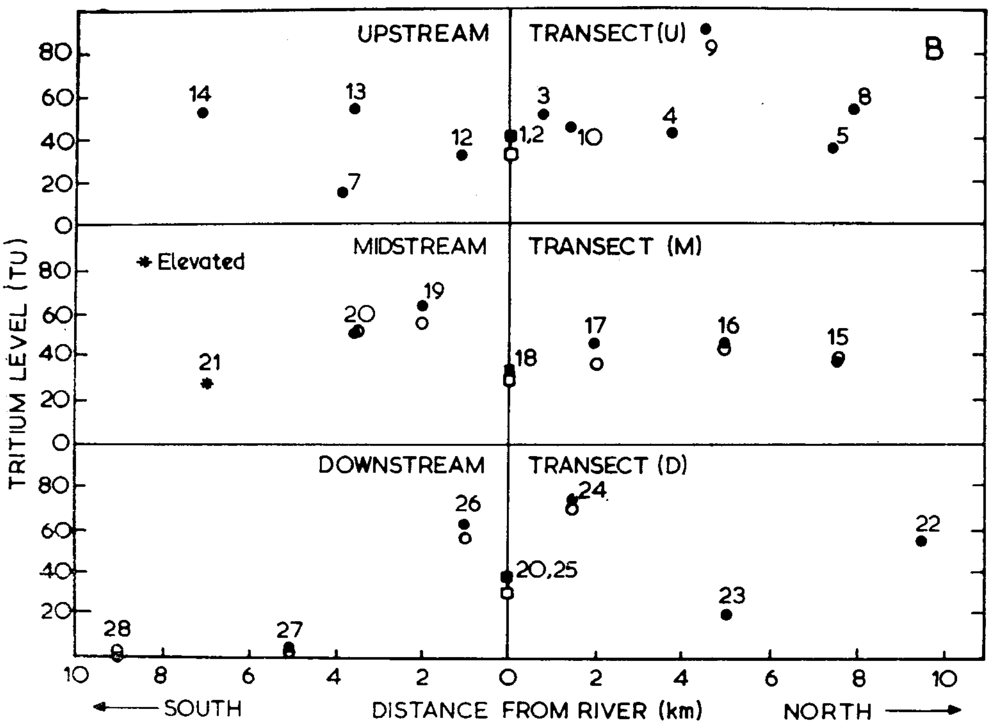

Fig. 3. The Tritium Levels of Groundwater (●, ○) and River Water (■, □) of the Han River Valley. Samples were collected during late March, early April (●) and in June (○, Table III). The sampling points (Figure 1) are shown. The elevation of all sampling locations (except 21) was less than 100m.

Table 2. Environmental Isotope and Associated Data

Sample No.	Description [1]	Date (1980)	Dist. from River(km)	Depth (m)	Temp. (°C)	Conductivity (μm-ho cm^{-1})	Tritium [2] (TU)	δD [3] (per mille)	$\delta^{18}O$ [4] (per mille)
K1	river(u)	28/3			18	69	40.8	−61.3	−8.71
K101		3/6				91	35.0	−60.4	−8.86
K2	river(u)	28/3			20	111.1	40.4	−59.1	−8.86
K102		3/6				156.2	32.0	−58.6	−8.99
K3	gw(u, n)	28/3	0.8	3.5	11	1000	56.3	−48.3	−7.11
K103		3/6				625	40.3	−52.5	
K4	gw(u, n)	28/3	3.8	3.6	13	286	44.5	−51.9	−7.62
K104		3/6				250	37.4	−48.5	−7.54
K5	gw(u, n)	28/3	7.5	16	11	59	37.8	−56.0	−8.97
K105		3/6				222	33.0	−54.9	
K6	river(u)	28/3			19	455	43.5	−50.9	
K106		3/6				143	35.8	−60.1	−9.3
K7	gw(u, s)	28/3	3.8	5		222	17.3	−55.9	−8.45
K107		3/6							
K8	gw(u, n)	11/4	8.0	18.2	14	200	56.7	−54.4	
K108		3/6				182	55.6	−55.6	−8.48
K9	gw(μ, n)	11/4	4.5	7.0	12	90	86.2	−51.9	
K109		3/6				111	88.9	−54.2	−7.88
K10	gw(μ, n)	11/4	1.5	9.1	10	179	43.4	−54.0	
K110		3/6				100	46.6	−56.0	−8.72
K11	river(μ)	11/4			19	133	30.2	−54.9	
K111		3/6				125	35.9	−60.0	−8.83
K12	gw(μ, s)	11/4	1.0	5.5	12	435	31.2	−56.9	
K112		4/6				500	46.4	−57.6	−8.7
K13	gw(μ, s)	11/4	3.5		12	213	53.5	−55.9	
K113		4/6				166	67.4	−57.2	−8.85
K14	gw(μ, s)	11/4	7.0	18.2	13	250	53.4	−52.2	
K114		4/6				200	59.1	−55.8	−8.58
K15	gw(m, n)	11/4	7.5	7.5	12	667	38.5	−57.7	−8.91
K115		4/6				500	40.2	−58.5	−8.63
K16	gw(m, n)	11/4	5.0	5.8	14	833	42.5	−57.1	−8.8
K116		4/6				833	42.1	−58.9	−8.82
K17	gw(m, n)	11/4	2.0	6.2	14	556	45.7	−58.6	−9.09
K117		4/6				500	36.1	−59.2	−9.01
K18	river(m)	11/4				167	32.7	−59.1	−8.95
K118		4/6				200	32.2	−57.1	−8.87
K19	gw(m, s)	11/4	2.0	6.0	15	625	62.2	−58.9	−9.07
K119		4/6				625	58.5	−58.5	−8.95
K20	gw(m, s)	11/4	3.5	12.0	15	500	51.1	−59.4	−9.01
K120		4/6				625	55.3	−57.2	−8.7
K21	gw(m, s)	11/4	7.0	4.5	12	400	28.3	−47.7	−7.9
K121		4/6				1000	27.8	−50.6	−7.81
K22	gw(d, n)	2/4	9.5	5.0	12	133	57.1	−51.5	
K122		4/6				125	59.7	−52.5	−8.18
K23	gw(d, n)	2/4	5.0	21.2	12	125	20.9	−54.7	−8.76

K123		4/6				118	23.4	−58.0	−9.07
K24	gw(d, n)	2/4	1.5	5.0	12	476	75.4	−50.8	−7.96
K124		4/6				400	72.4	−52.2	−8.14
K25	river(d)	2/4			21	370	39.2	−59.1	−8.85
K125		4/6				250	31.0	−58.4	−9.01
K26	gw(d, s)	2/4	1.0	15.0	11	93	63.7	−53.9	−8.48
K126		4/6				178	58.0	−54.7	−8.71
K27	gw(d, s)	2/4	5.0	12.0	12	263	2.4	−53.0	−8.34
K127		4/6				233	0.8	−54.2	−7.88
K28	gw (d, s)	2/4	9.0	24.2	12	333	2.2	−52.8	−8.72
K128		4/6				270	0.5	−55.7	
K29	river(d)	2/4			21	125	39.4	−57.2	−8.53
K129		4/6				250	35.9	−58.9	−8.95

(1) gw-groundwater. u, m, d-upstream, mid stream, downstream transect respectively.
(2) Standard error-less than ±0.9 TU.
(3) Standard error-less than ±0.7 per mille
(4) Standard error-less than ±0.1 per mille.

as tritium units(TU). By definition, 1 TU is one tritium atom for every 10^{18} hydrogen atoms.[5,6]

2.1.2 Stable isotope ratios

The frequency distribution for the available D/H ratios from Pohang precipitation (1966-67; 1973-75)[4] is illustrated in Figure 4. The distributions for those months in which the precipitation exceeded the 90 percentile value and those for which it was less than the 10 percentile value are distinguished by hatching. In general, the heavier the precipitation, the more depleted

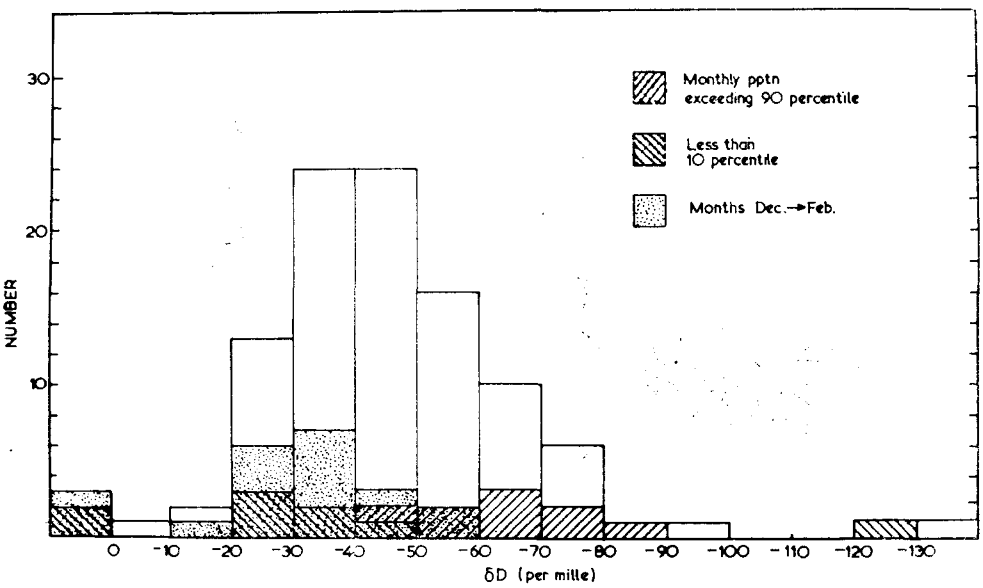

Figure. 4. The Frequency Distribution of D/H Ratios in Pohang Precipitation. Hatching indicates where monthly precipitation is greater than the 90 percentile value and less than the 10 percentile level. The months December to February during when there is substantial snow are shown by light shading.

it tends to be. To emphasise this point, the histogram for the months December through February during which much of the precipitation falls as snow is distinguished by light shading. There is a clear tendency towards enrichment in these samples. This is contrary to what would be expected if the stable isotope ratios were determined principally by seasonal temperature but consistent with the observed inverse correlation between D/H ratios and the amount of monthly precipitation. The stable isotope ratios are expressed conventionally as δ values. For instance

$$\delta D = \{(D/H)_{sample} \,|\, (D/H)_{V(SMOW)}{}^{-1}\} \times 1000 \qquad (1)$$

where V(SMOW) is the standard mean ocean water supplied by the IAEA, Vienna.[4,7,8] The $^{18}O/^{16}O$ ratios are defined similarly.[10]

2.2 Han River

The variations of the tritium and D/H ratios with distance from the sampling point 29 (Figure 1) are shown in Figure 5.

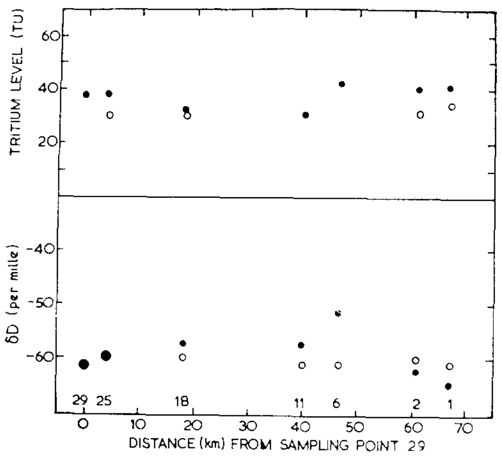

Fig. 5. The Variation in River Water Samples of the Tritium Levels and D/H Ratios with Distance from the Sampling Point 29 (Fig 1). ● April Sampling; ○ June Sampling.

The sample numbers (Figure 1 and Table 2) are shown on the abscissa. Several points are worth noting.

(a) The deuterium levels are appreciably more depleted than either the average Pohang precipitation (weighted mean −51.0 per mille) or the groundwater of the lower Han River Valley ($\delta D = -53.6$ mille) where direct ranfiall recharge dominates. The effect is almost certainly due to altitude. The headwaters are about 1700m above sea level; about 14 per cent of the catchment is above 800m and 28 per cent above 200m. An analagous observation was made in a study of the recharge to the deltaic plain of the Chimbo River (Ecuador) which drains water from the high elevations of the Andes.[9]

(b) The D/H ratios in samples collected from locations (1) and (2) in March/April were −61.3 and −59.1 per mille respectively. The sample collected at position 6 had a δD value of −50.9 per mille. Since the sample was collected from the bank during a period of low flow, and since the D/H ratio is close to the groundwater taken from a nearby well (No. 3, $\delta D = -48.3$ per mille), it is tempting to suggest that there is significant groundwater input at this point.

There is no statistical evidence for any variation in the D/H ratios of the river water during the June sampling period. The average value was -59.4 ± 0.8 per mille, where the standard deviation is of the population. The individual results are shown in Figure 5. Any groundwater input at point 6 would be diminished or eliminated by the higher level of the river during late Spring.

The available tritium and conductivity data are consistent with groundwater input

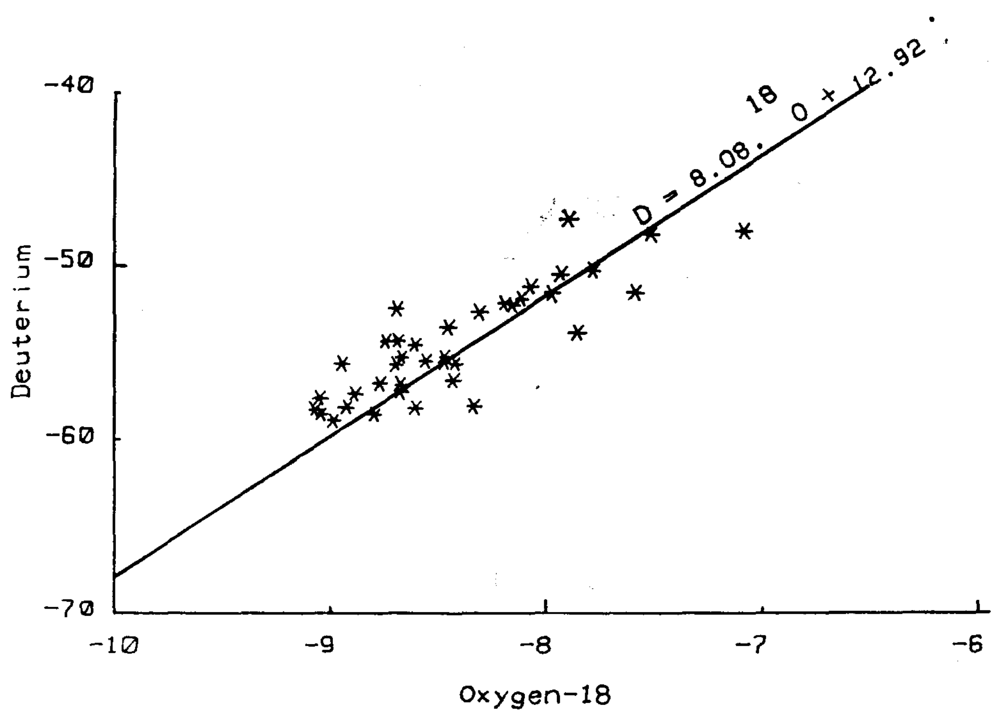

Fig. 6. The Variation of the δD Values of Groundwater Samples with $\delta^{18}O$. The local meteoric water line based on precipitation for Pohang (δD=8.08$\delta^{18}O$+12.92) is shown.

near sampling point 6 during the April sampling period. The observed tritium levels at the upstream locations 1 and 2 were 40.6 and 40.8 TU respectively. The increase to 43.5 TU may reflect the higher tritium level in the groundwater, e.g. 56.3 TU at position 3. The generally lower levels further downstream are due to surface water inflow. Although post-1976 data for Pohang are not available, evidence from the Tokyo rainfall would suggest that modern tritium levels would be less then 25 TU.

The electrical conductivity data are consistent with the above hypothesis. Between locations (1) (and (2)) and (6), the conductivity of the April samples increased from 70 (and 111) to 455 μ mho cm^{-1}. The groundwater at point 3 was found to have a high conductivity of 1000μ mho cm^{-1}(Table 3). In June, when a higher discharge would have been expected, the conductivities exhibited simply a regular increase with distance downstream.

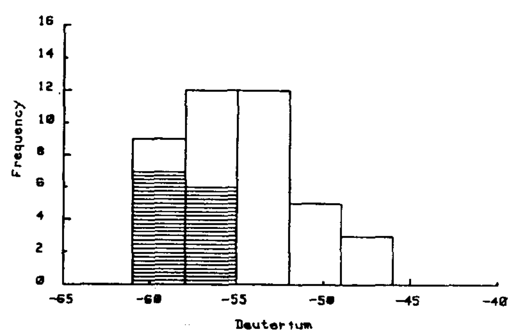

Fig. 7. Frequency Distribution of D/H Ratios in Groundwater Samples. Those wells located in the metropolitan area are distinghished by shading

Table 3. Han R. Valley: Chemical Data

Sample No.	Description	pH	Zn (mg L^{-1})	Pb (mg L^{-1})	Mn (mg L^{-1})
K1	river (u)	6.2*(7.4)**	0.01(0.01)	0.04(T)	(T) (T)
K2	river (u)	6.4 (8.2)	0.01(0.01)	0.04(T)	0.01(0.15)
K3	gw (u, n)	7.0 (5.9)	0.43(0.13)	0.04(T)	0.1 (0.11)
K4	gw (u, n)	6.9 (6.3)	0.02(0.01)	0.02(T)	T (1.25)
K5	gw (u, n)	6.8 (5.8)	0.03(0.01)	0.01(0.01)	T (T)
K6	river (u)	6.5 (7.2)	0.02(0.01)	0.02(T)	0.17(0.02)
K7	gw (u, s)	6.7 (−)	0.06(−)	T (−)	T (−)
K8	gw (u, n)	6.4 (5.9)	0.43(0.39)	T (T)	T (0.01)
K9	gw (u, n)	7.4 (6.1)	0.01(0.01)	T (T)	T (T)
K10	gw (u, n)	6.6 (6.0)	0.01(0.03)	T (T)	0.32(0.30)
K11	river (u)	6.9 (7.2)	0.03(0.02)	T (T)	0.01(0.01)
K12	gw (u, s)	6.8 (7.1)	0.42(0.45)	T (T)	0.01(0.13)
K13	gw (u, s)	6.6 (5.9)	0.40(0.15)	T (0.01)	0.03(0.002)
K14	gw (u, s)	6.9 (6.4)	0.38(0.28)	T (T)	T (T)
K15	gw (m, n)	6.4 (6.1)	T (0.03)	T (T)	0.01(0.07)
K16	gw (m, n)	6.7 (5.8)	0.02(0.01)	T (T)	T (0.01)
K17	gw (m, n)	6.5 (6.2)	0.38(0.03)	0.02(T)	0.04(0.11)
K18	river (m)	6.1 (6.9)	0.03(0.03)	0.02(T)	0.05(0.07)
K19	gw (m, s)	6.1 (5.8)	0.08(0.02)	0.02(T)	T (T)
K20	gw (m, s)	6.6 (6.1)	0.01(0.01)	0.02(0.01)	1.08(1.19)
K21	gw (m, s)	6.3 (5.0)	0.02(0.31)	0.02(0.01)	0.06(1.33)
K22	gw (d, n)	6.2 (5.8)	0.05(0.05)	T (T)	T (T)
K23	gw (d, n)	6.6 (6.2)	0.14(0.30)	T (0.01)	0.02(0.04)
K24	gw (d, n)	6.5 (5.7)	0.11(0.06)	0.01(0.01)	T (0.01)
K25	river (d)	5.9 (6.4)	0.09(0.04)	0.02(T)	0.16(0.09)
K26	gw (d, s)	6.4 (6.1)	0.4 (0.08)	T (T)	0.01(T)
K27	gw (d, s)	6.8 (6.2)	0.40(0.31)	T (0.01)	1.38(0.79)
K28	gw (d, s)	7.4 (6.7)	0.05(0.13)	T (0.01)	0.02(0.02)
K29	river (d)	6.4 (7.1)	0.04(0.03)	0.02(T)	0.41(0.12)

u; pstream m; midstream d; downstream n; north s; south. gw; groundwater
*; march sample. **; june sample. T; trace

3. Isotopic Composition of the Groundwater

3.1 Stable Isotope Ratios

The stable isotopes ratios of groundwater samples, listed in Table 2, are plotted on Fig. 6. The data are clustered about the local meteoric water line established on the basis of precipitation collected in Pohang from 1961 to 1976. The frequency distribution of the δD values in given in Fig. 7. wells sampled in the urban area are distinguished by hatching. Interestingly these data are grouped about a mean which is more depleted than the average of all groundwater collected, but is close to the river value at the time of sampling. It would appear that the combined effect of increased pumping and reduced infiltration in the metropolitan area has been to lower the potentiometric surface and to enhance the river recharge.

On the other hand, virtually all the wells

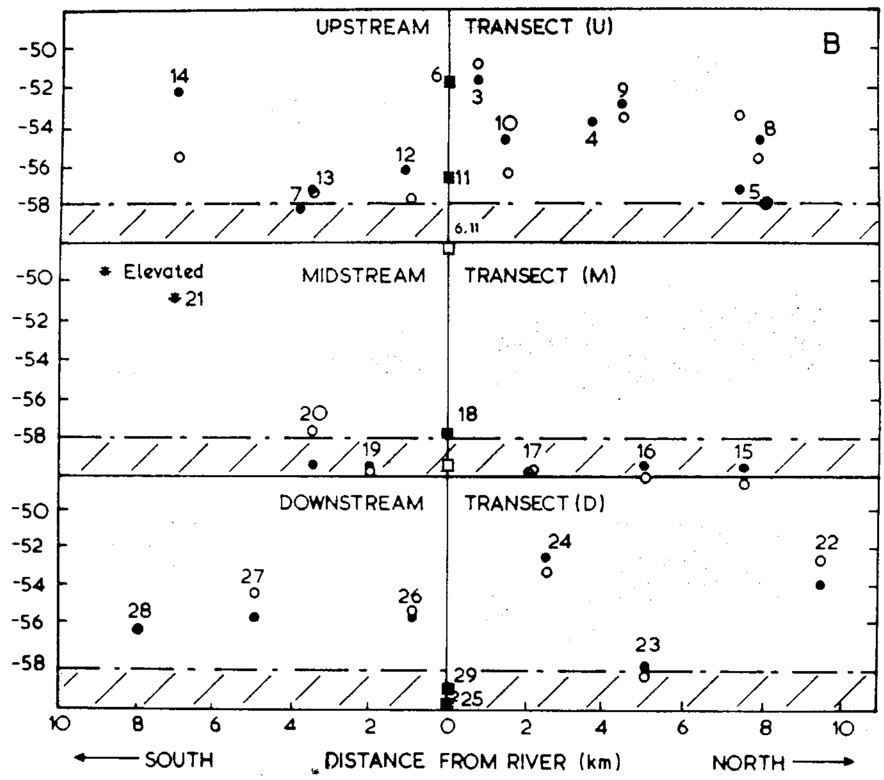

Fig. 8. The D/H Ratios of the River Water (■, □) and Groundwater (●, ○) of the Han River Valley. Samples were collected during April (●) and in June (○). The sample points are numbered (Fig.1). The range of river δD values is shown by shading.

sampled downstream (transect *D*, Figure 1) were more enriched than river water and within the range of values expected for precipitation. Recharge in the lower catchment appears to be dominated by rainfall. The contrast is most clearly seen by comparing the urbanized midstream, M, and downstream, *D*, transects (Figure 8).

The upstream transect U shows mixed behaviour. That portion of the transect to the north of the river is in the green belt and exhibits D/H values more depleted than those from the southern section which includes wells in the outlying urban area. It is tentatively proposed that, while recharge to the north is dominated by precipitation, the groundwater to the south is a mixture of precipitation and river infiltration.

The next stage of the study will be to sample a large number of wells over a wide geographical area and use established procedures to compute the relative contribution of precipitation and river recharge at various points. Appreciable differences in the D/H levels between April and June were observed only in locations 5 and 14. More work will be needed to establish whether genuine seasonal variations occur.

3.2 Tritium

The tritium concentrations of groundwater samples are shown in Fig. 3. As discussed above those wells in transect M are dominated by recharge from the river. The tritium data support this conclusion. From Fig. 3 it will be noted that the groundwater samples in transect M have tritium concentrations similar to that of the river.

The tritium levels in those parts of the aquifer recharged directly by precipitation are much more variable. Insufficient data are yet available to delineate trends. The two very low values (Nos. 27 and 28) are clearly significant. Although these sampling points lie close to the coast, there is no evidence for sea water intrusion. The δD values (-55.8 and -54.5 per mille) are typical of precipitation and do not exhibit the enrichment that would result from appreciable mixing with oceanic water ($\delta D = 0$). Moreover, the electrical conductivities of the samples are typical of the area. Obviously there must be another explanation for the low tritium values observed. It is tentatively suggested that the water is pre-nuclear and is derived by upwelling from a deeper aquifer.

4. Water Quality

The aim of the project was to relate the heavy metal content of the groundwater with the results of the environmental isotope survey in an endeavour to establish

(i) whether there is any evidence for the deterioration in groundwater quality associated with the release of industrial effluents; and (ii) if so, to determine the migration pathways.

Special attention was paid to those areas in which it was shown that river recharge predominated. The results are listed in Table III. The work is in a very preliminary stage; as yet no correlation has been established between the levels of Zn, Pb or Mn and recharge mechanism, distance from the river or electrical conductivity of water. It is interesting that the temperature of the groundwater sampled in the metropolitan area is significantly higher (13.6°C (mean), transect M) than either the upstream or downstream averages (12°C).

5. Conclusions

The environmental isotope survey that is being conducted has enabled a number of conclusions to be drawn on the groundwater hydrology of the Han River Valley.

(1) In the area studied, the mechanism of recharge is determined principally by the degree of urbanisation. As a result of reduced infiltration and increased pumpage in the metropolitan area, the river is the dominant source of groundwater.

(2) The recharge to the Valley downstream of Seoul is by infiltrated precipitation. There was no evidence of exchange between the groundwater and the river in the vicinity of transect D. Two samples collected near the coast exhibited very low tritium. The effect was not due to sea water intrusion but to the tapping of an older pre-nuclear source which possibly welled up from a deeper aquifer.

(3) The recharge along the upstream transect U is more complicated. The portion to the north of the river lies in the green belt and is dominated by precipitation recharge; that to the south, intersects the outer urban region and appears to exhibit both river and precipitation recharge. At one point during the April sampling period there appeared to be a significant contribution from groundwater infiltration. The

effect was not observed during the June collection.

(4) Since there was little seasonal variation, the work will be extended to include a much wider geographical coverage of sampling points with the aim of mapping the relative proportion of precipitation and river recharge over the valley. In addition, isotope techniques will be used to study the extent to which shallow groundwater recharges the underlying fractured crystalline rock aquifers.

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