Isotopes based assessment of groundwater renewal and related anthropogenic effects in water scarce areas: Sand dunes study in Qasim area, Saudi Arabia

A. Al- Sagaby, A. Moallim

Earth Sciences Program,
Institute of Natural Resources and Environment,
King Abdul Aziz City for Science and Technology,
Riyadh, Saudi Arabia

Abstract. The investigation of recharge in the sand dune, Qasim, Saudi Arabia, with the help of chloride concentration and isotope content has revealed inconsistent pattern and less homogeneity. Monotonic chloride concentration and isotope content was the result of seasonal recharge occurrence in the study area. In addition, applying chloride mass-balance method, recharge rate calculation in the sand dune site, Qasim, Saudi Arabia, was made. The results (1.80 and 1.84mmy^{-1} – dune site) estimated during this project using this method was a long way below the recharge rates (30mmy^{-1}, 13.4mmy^{-1} in the dune site and 5mmy^{-1} in the swale site) obtained with the application of tritium method in the previous years (1994 and 1996). 1.80 and 1.84mmy^{-1} was for CRP-Saud-9405 project and was calculated 1997 and 1998 respectively. The reason for the lower recharge rate with the application of chloride mass-balance method could be the source of chloride input and high evaporation, which causes accumulation of chloride salts in the area.

Introduction

The project forms part of the International CRP projects of IAEA. Its number is SAU-9405 and entitled "**Isotopes Based Assessment of Groundwater Renewal and Related Anthropogenic Effects in Water Scarce Areas: Sand Dune Study in Qassim Area, Saudi Arabia**". The project was formally commenced in April 1997 where drilling and coring some boreholes were conducted in Qassim region, Saudi Arabia.

The objectives of the project was to assess and ascertain the movement and renewal of groundwater in sand dunes of Qassim region and estimate the annual volume of recharge to the sand dune aquifers in the region, using stable isotope content and chloride concentration in the soil samples.

In the previous report (Oct. 1997), water content, water potential, deuterium and chloride results were presented. The rate of recharge and water movement was also presented. The rate of recharge result calculated in 1997 in the dune site using chloride mass-balance method was about 1.80mmy^{-1}[1]. The value was much far below the previous results of recharge rate (30mmy^{-1}, 13.4mmy^{-1} in the dune site and 5mmy^{-1} in the swale site) presented in the previous studies for the area in 1994 and 1996 [2,3]. The latter results were obtained by using tritium method. Comments and comparison of the two methods (tritium peak and chloride mass-balance) in terms of application for recharge calculation was made in the previous report. The influence of the nature for both methods was discussed. The purpose is to present a comprehensive and conclusive result of the project in this paper.

1. Materials and methods

1.1. Site location

The field sampling was carried out at the KACST field station located at Qassim (320-km northwest of Riyadh). A portable Global Positioning System (GPS) unit was used to "map" the position of all sites in relation to each other and to the boundaries of the KACST

field station (Fig. 1). The intention of the trip was to sample at the dune where previous work has been carried out. Upon arrival it was found that access to the dune site was not possible due to roadwork, and another site ~1-km southeast of the previous dune sites was selected. The hole at this site was designated CRP-1.

Climate

The precipitation is very scarce in this part of the Kingdom of Saudi Arabia and attains 110mm annually and some times less than that value. Temperature variation throughout the year is the characteristic of the study area. The average precipitation (133mm) in the study area for last 6 years is higher than the annual average precipitation in Kingdom of Saudi Arabia. Table 1 shows the results of rainfall for the last 6 years. The precipitation of some months is missing from the table, indicating no precipitation occurred during that month or not recorded.

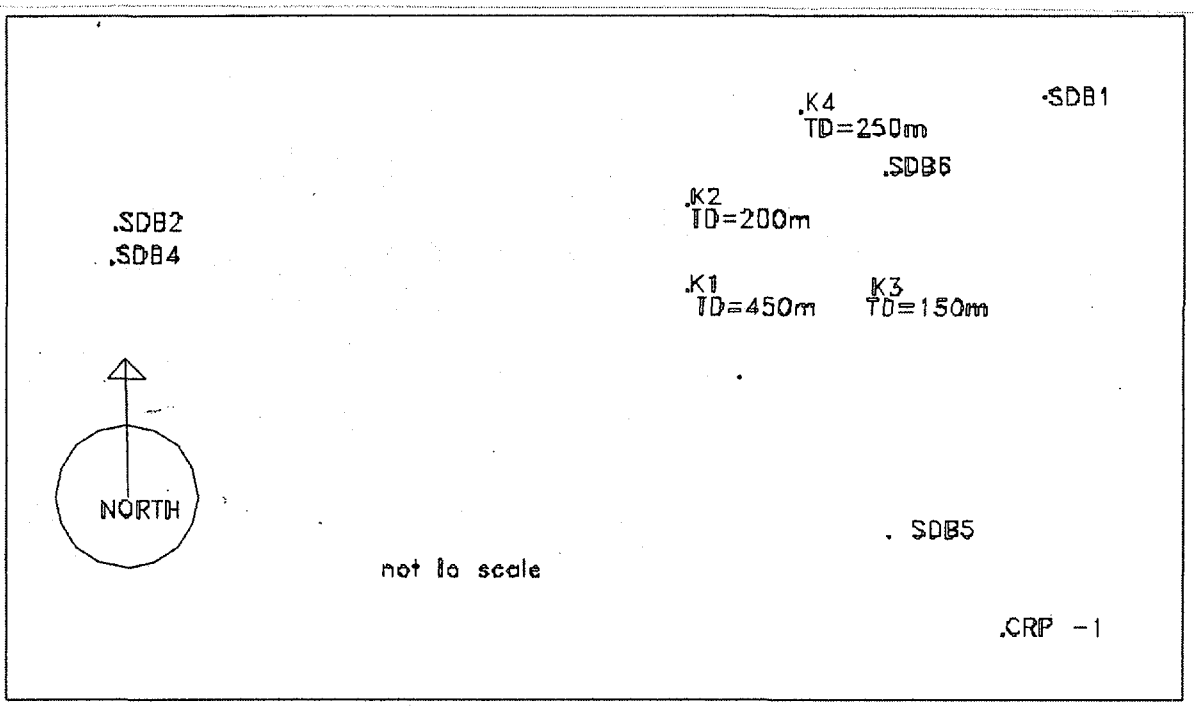

FIG. 1. Sand dune Augering sites in Oassim area (Oct. 95), KACSI research station.

Field work

Drilling at the dune site (CRP-1) commenced at ~7.00am on April 16, 1997 with Al-Sagaby, Allafouza, Moallim and two locally hired laborers in attendance. As only Al-Sagaby and Moallim had used the sand-drill previously, progress was slow and it took nearly the whole day to drill the hole. Rainfall had fallen on the previous days and the surface soils were relatively moist. Three soil samples for the interval 0.3-1.15 of the upper surface were taken prior auguring. To prevent collapse of the upper levels of the hole a 2-m length of PVC tube was inserted in the ground. Coring with sand-drill commenced and was generally carried out at 1-m intervals. When soil collapsed into the hole between samples, only core from the lower portion of the core barrel was used. Coring was carried out successfully until a hard gravely layer was reached at 17.10 m and no further drilling was possible. For all sampling intervals soil was placed in both a 1-L airtight glass jar and 0.75-L airtight steel can. Another trip was

attempted last May 1999 with new drilling machine called Power Probe Auger. The new instrument was mounted on a small truck and can be easily operated by four persons. The power probe soil sampler has a capability of preventing soil contamination and collecting undisturbed sample. This last trip with this instrument was not successful due to certain constraints.

Table 1. Rainfall data (mm) for last six years from the study area

(data were collected from kacst and the agricultural research center meteorological stations in qassim)

Month	1993	1994	1995	1996	1997	1998	Average
January	-	16.6	3.8	38	4	22.8	
February	-	1.0	36.7	5.3	0.0	1.0	
March	-	9.8	57.2	13.5	59.9	52.6	
April	-	46.6	34.2	29.9	4.6	10.7	
May	-	7.6	1.2	2.8	2.0	13.0	
June	-	-	0	0	0	-	
July	-	-	0	0	0	-	
August	-	-	0	0	0	-	
September	-	-	0	0	0	-	
October	4.8	15.7	-	-	-	-	
November	0.8	26.7	2.8	4.0	107	-	
December	1.6	21.6	118	0.8	16.1	-	
Total =	**7.2**	**146**	**254**	**94.3**	**193.6**	**100.1**	**133**

Some separate field trips were made for rainwater collection from some stations in the region, giving priority the study area. This has helped the knowledge of chloride input and its magnitude in rainwater. The updated rainfall data available is up to May 1998 (the end of the rainy season).

1. 2. Sample analyses

The following analyses were made at the KACST laboratory: gravimetric water content (0_g), matric suction and $[Cl^-]$ in the soil water. In addition, water from the soil was azeotropically distilled using the methods described in the previous report [2]. The chloride analyses were carried out by titration using a digital burette capable of dispensing aliquots of $AgNO_3$ as small as 0.03 ml.

Azeotropic distillations were carried out using ~500 g aliquots of soil in 1 L flasks and were heated for 75 (wet samples) to 90 minutes (dry samples). Yields of about 100% were obtained in all cases. Up to two aliquots of soil per sample (approximately the whole sample was used) were distilled to obtain maximum water available in the sample for stable isotope and tritium analyses (at least 15 ml). The water extracted by azeotropic distillation was sent to the British Geological Survey (BGS) laboratory in Wallingford for oxygen-18, deuterium and tritium analyses, but Deuterium result was received.

2. Results and discussion

2.1. Water content and matric suction

The water content and matric suction profile for CRP-1 are shown in Figure 2. There is an evidence of slightly wetter conditions, in the upper 2 m of the profile, presumably due to residual rainfall from storms during the previous years which was much wetter (average ~ 133mmy^{-1}) than the average rainfall (~110mmy^{-1}) in the Kingdom of Saudi Arabia. Collected rainfall data during the previous years is shown in Table 1. The water contents are relatively low (< 0.010g/g) in the depth between 2.7 and 5.6m, as are the matric suctions (< 70 kPa). The highest metric suction peak is located at depth of 6.5m below the surface, representing dry period. In between 13 and 17m, there is a peak in water content of up to 1.5%, presumably due to increased clay content (high capacity of water retention) as the matric suction in this zone decreased. The profile, generally, shows a shift of water content towards the deeper parts of hole (fig. 2.). Descending below 9.7m, there is a monotonic increase in water content. Moreover, the water content in the profile shows that the total water stored in the profile is 300mm (fig. 3.).

2.2. Chloride

The Chloride concentration for CRP-1 is shown in figure 4. Concentration increases monotonically from values of about 3169 mg L^{-1} near the surface to about 20000 mg L^{-1} at about 16m. A distinct peak with a maximum value of about 10,000 mgL^{-1} is found at about 9.2m below the surface.The contrasting zones of low and high chloride concentrations are suggestive of distinct intervals of dry and wet season. This can be further illustrated by plotting cumulative chloride versus depth for the entire profile (Fig. 4). The differing slopes could also be a result of changes in the chloride input to the profile (by rainfall or dryfall) or some combination of these and changes in recharge regime.

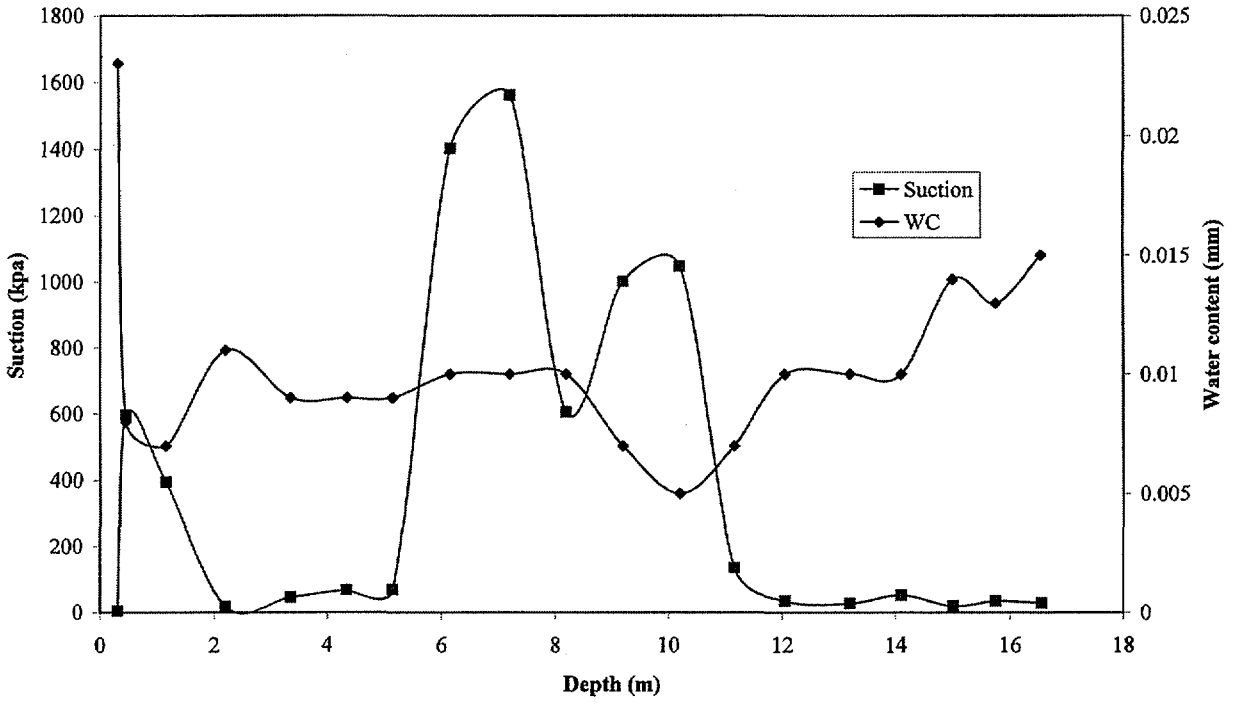

Fig. 2. Water content and suction with depth.

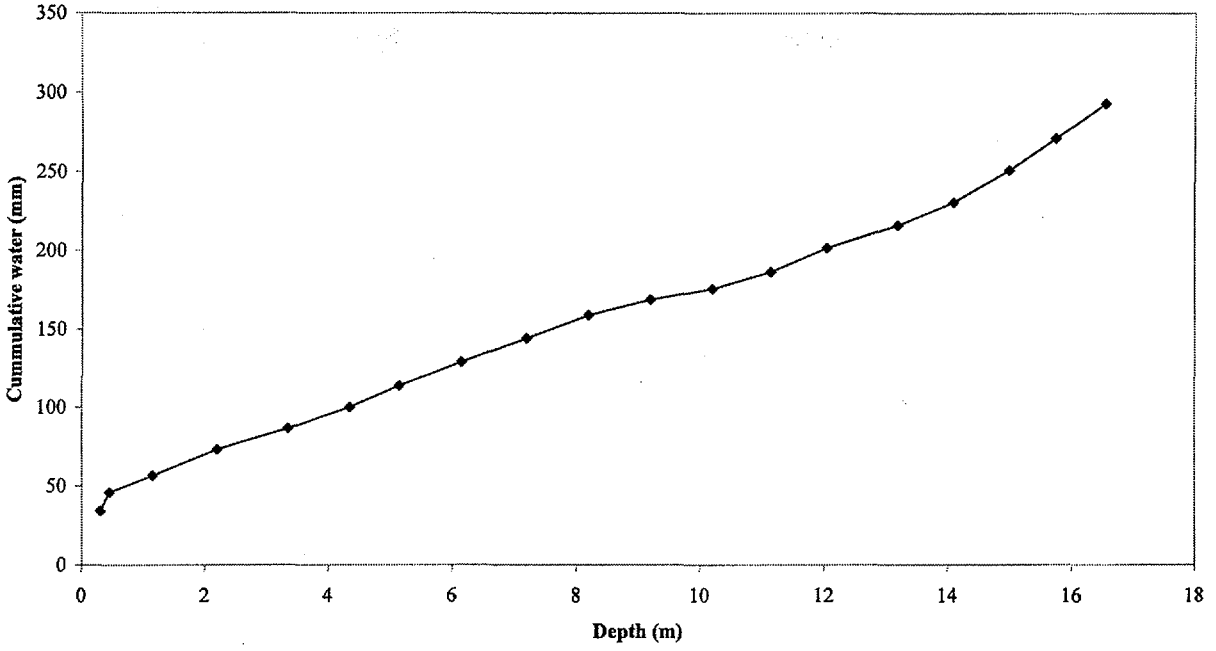

FIG. 3. Cummulative water within the profile.

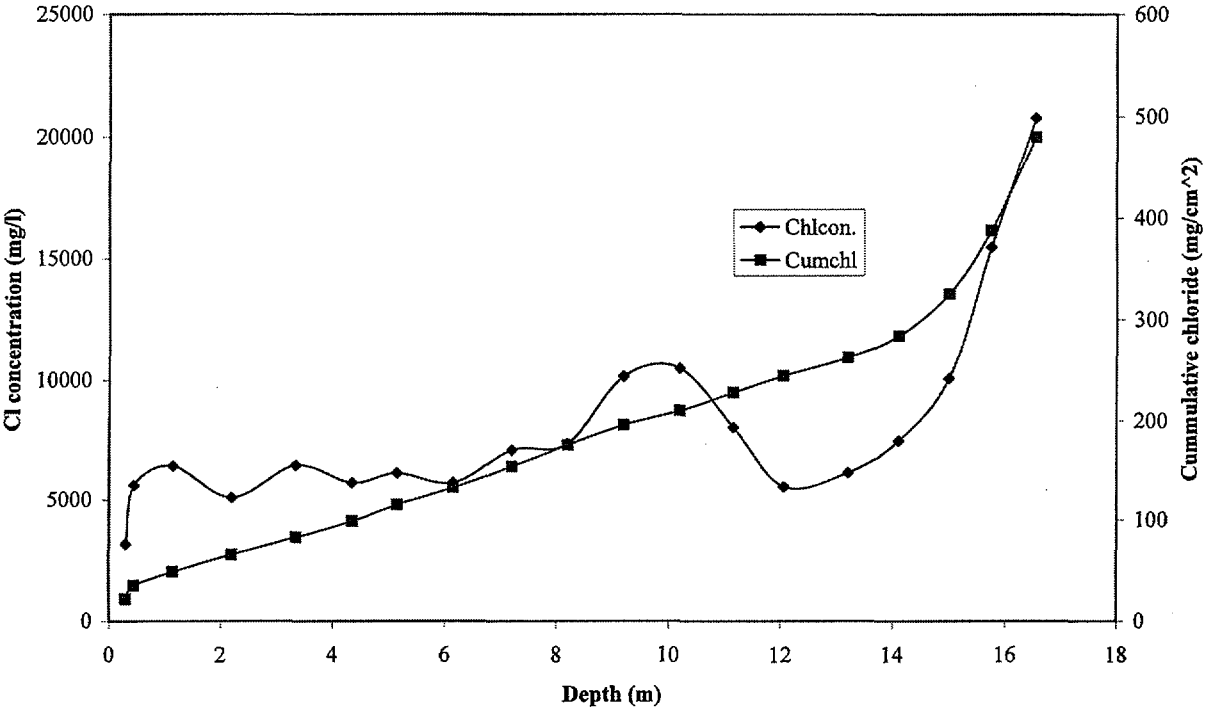

FIG. 4. Chloride concentration along the profile of the dune.

2.3. Deuterium

The deuterium data varies from 14 to -33 per mill within the profile (Fig. 5). Typical enrichment was encountered near the surface followed by depletion of isotope. Approximately the depth between 2 and 9m, a steady state condition was nearly prevailed. This indicates continuous and homogeneous shift of isotope input through the profile resulting

in a relatively constant environment condition. The trend between 9 and 12m within the profile, oscillation of isotope has prevailed, indicating inconsistent condition with a trend of enrichment and depletion, which could have been resulted from the status, and nature of the recharge condition. Beyond 12m in depth, a trend of enrichment has came back indicating present day recharge.

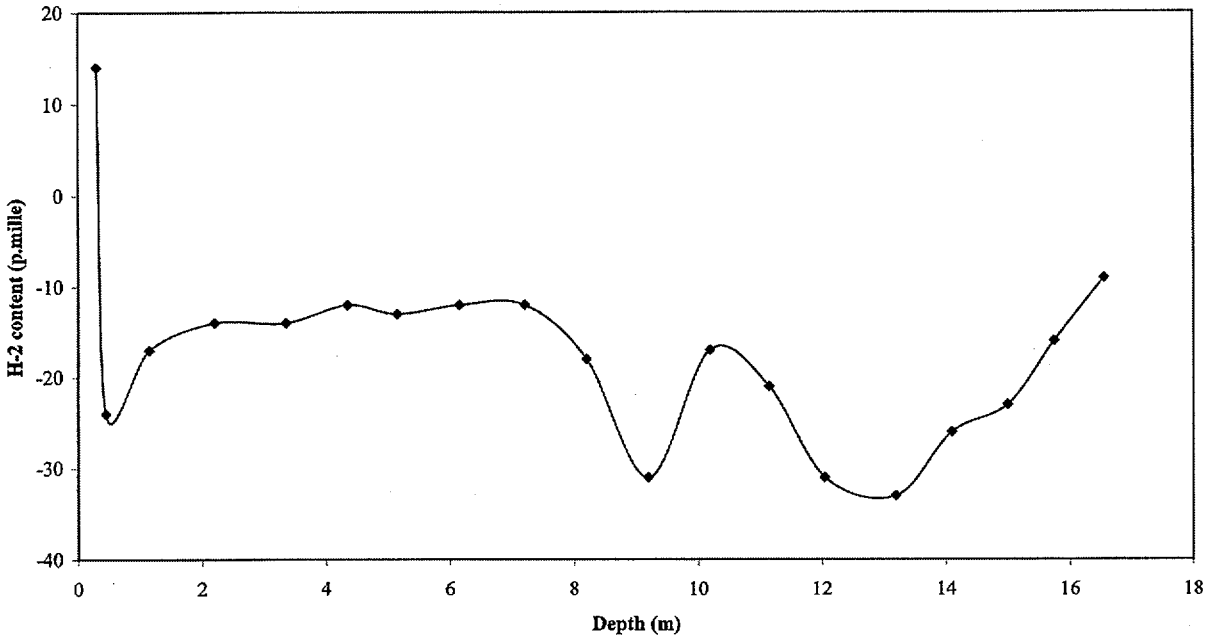

FIG. 5. Deuterium concentration with depth.

2.4. Recharge assessment

Evaluation of water volume recharged in the sand dune was conducted using the weighted precipitation in the study area (Table 1), weighted chloride concentration in rainwater and chloride concentration in groundwater (Table 2).

Table 2. Chloride concentration in rainfall data

Sources	Date	Cl- Rainwater (mgl^{-1})	Average (mgl^{-1})
BRGM	1982-83	12.22	
Wood &Bazuhair	1996	9.0	
KACST	1997	7.0	
KACST	1998	25	
Average for All			**13.31**

The weighted chloride concentration in shallow groundwater in the study area was found to be 960 mgl^{-1} [3]. Chloride- mass balance method [4] was applied and presented in this way:

$\mathbf{R_w = (P * CL_p) / CL_{gw}}$ where R_w = Recharge rate

P = Weighted annual precipitation

CL_p = Chloride concentration in rainwater

Cl_{gw} =chloride concentration in groundwater

The recharge rate result obtained with the application of chloride mass balance method is about 1.84mmy^{-1} in the dune site (CRP-1). In the first progress report of the same study, the volume of water recharged in the dune site was about 1.80mmy^{-1}[1]. Both recharge rates are still very low compared to recharge rates reported in 1994 (30mmy^{-1} in the dune site and 5mmy^{-1} in the swale site.) and 1996 (13.4mmy^{-1} in the dune site) in same area using Tritium method for other projects. Applications of both methods for evaluation of recharge rate in same area at different times have shown inconsistent recharge rates although the last two events are approximately consistent. The main reasons for the lower recharge rate with the application of chloride mass-balance method could be:

- Chloride concentration in groundwater is not purely from the precipitation because it is higher than what can be expected in rainwater.
- The presence of high evaporation and precipitation of chloride salts is more likely in the study area.
- It is Likely that the dry fallout from sabkha material is the source of chloride input.
- The application of chloride mass-balance method may not be proper for this site as long as the basic assumptions for the equation are not completed.

2.5. Soil and groundwater isotope relationship

To correlate and evaluate the isotopic relationship between overlying soil and Groundwater in the various aquifers in the study area, groundwater sampling on Saq, Qassim and shallow aquifers in Qassim region was conducted. This sampling helps and makes clear the hydraulic continuity between the aquifers and rainfall. Figure 6 shows oxygen-18 against deuterium for groundwater in Qassim region. The pattern of isotope has shown spatial variation and scattering. Oxygen-18 ranges from ~0.45 per mille to about -7 per mille while

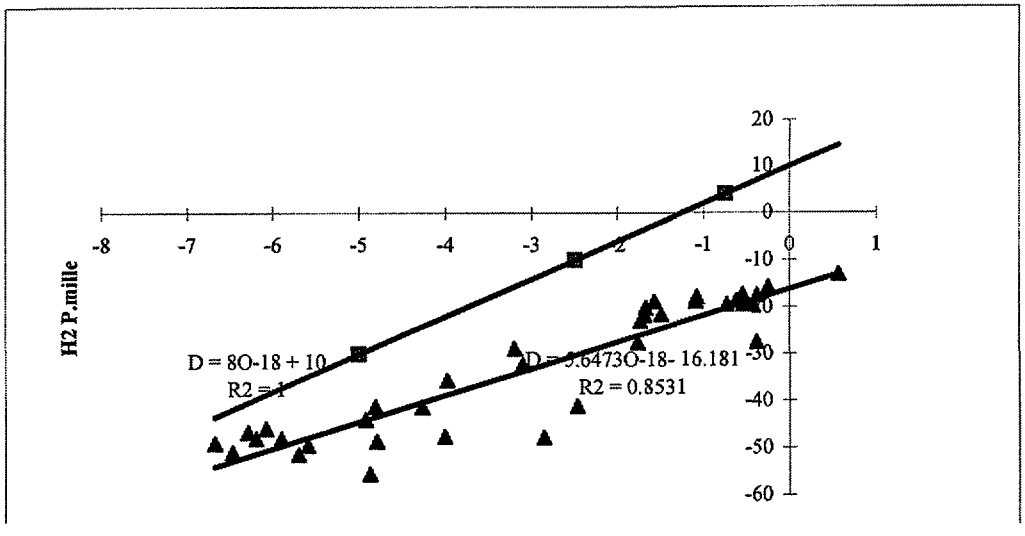

FIG. 6. Groundwater isotope in central Qasim area.

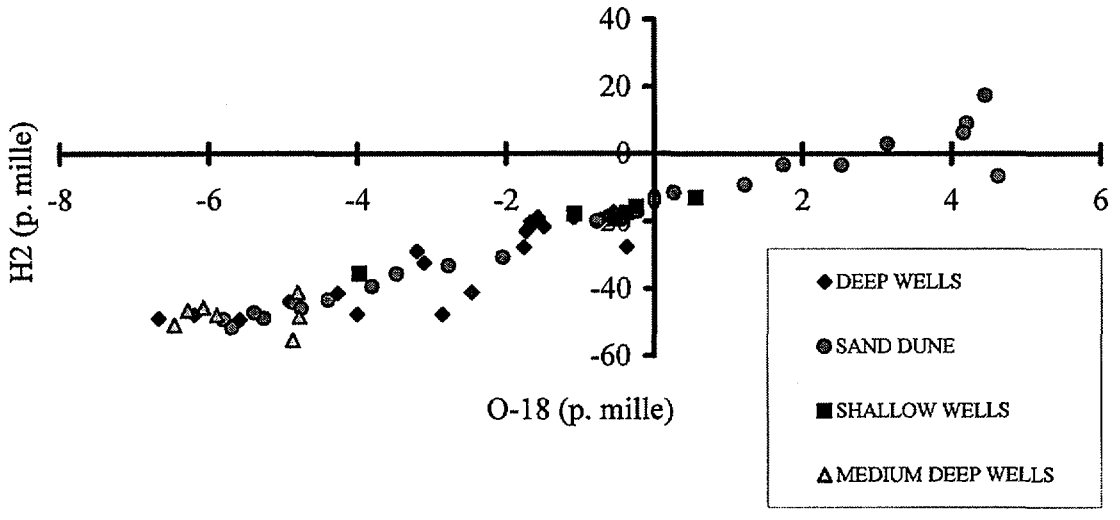

FIG. 7. Isotope comparison for deep, medium & shallow wells with sand dune waters

deuterium ranges from about -55 per mille to about -15 per mille. Comparison of isotope for deep aquifer (Saq), medium aquifers (Qassim) and shallow wells with sand dune waters are presented in figure 7. Oxygen-18 and deuterium for Saq aquifer range from -6.3 per mille to about 0.43 per mille and -55 per mille to about -15 per mille respectively. Some deep wells have oxygen-18 values lying in the range of modern precipitation (-3.5 to -2.5 per mille). For shallow wells, oxygen-18 ranges from ~ 0.56 to about -1.5 per mille and -13 to about -19.4 per mille for deuterium. This shows isotopic relationship between some deep wells tapping Saq aquifer and shallow wells tapping alluvial aquifers in the study area. There is also clear evidence of isotopic relationship between the samples of sand dune and shallow wells indicating recharge phenomena. Such phenomena are not continuous in the study area but it is confined in certain locations. This could be due to hydraulic continuity within the aquifers and between the aquifers and overlying sand dune. Oxygen-18 for medium wells (Qassim aquifer) range from -6.4 to -4.4 per mille and deuterium value range from -55 to about -40 per mille. It is likely that during the recharge there were a condensation process (cold environment) that might have caused the lighter isotope enrichment and depletion of heavy isotope [3].

In the outcrop area of Saq sand aquifer, the oxygen-18 content was -2.5 per mille, and in the deep area the oxygen-18 content was -6.5 per mille [7]. Similar values (4.62 to -5.81 per mille for oxygen-18) have also been observed in sand dune samples while shallow aquifers have similar magnitude of isotope values. Therefore, due to isotope similarities the connection between the sand dune samples and some of the aquifers like alluvial and Saq in the study area is obvious.

3. Conclusion

The area under investigation has shown variability in chloride concentration and isotopic content along the dune profile. Both radicals (chloride and isotopes) have shown monotonic patterns, indicating recharge season and dry season. Moreover, chloride mass balance method was applied in order to estimate the volume of water recharged through sand dune profile in Qasim, Saudi Arabia. The volume of water infiltrated in to the sand dunes (dune site) was very low ($1.84 mmy^{-1}$) compared to the recharge rates ($30 mmy^{-1}$, $13.4 mmy^{-1}$ in the dune site and $5 mmy^{-1}$ in the swale site) calculated in same area by applying tritium peak method in the previous years (1994 and 1996). Many factors like the source of chloride input, soil compaction, rain intensity and high evaporation in the area could cause the recharge rate variation.

REFERENCES

[1] Al- Sagaby, I.A., M.A. Moallim and.Lafouza, O.M,A., 1997, "Isotopes Based Assessment of Groundwater Renewal and Related Anthropogenic Effects in Water Scarce Areas: Sand Dune Study in AL-Qassim Area, Saudi Arabia," Open File Report No. 147-18-ES, NRERI, KACST, Riyadh, Saudi Arabia.

[2] Al-Sagaby, I.A. and Moallim, M.A., (1994), "Use of Isotope to Study Groundwater Recharge through Sand Dunes in Qassim Area, Saudi Arabia," Proceeding of the Final Coordination Meeting of a Regional Technical Cooperation Project Held in Ankara, Turkey, 12–15, Nov. 1994, IAEA, TECDCO-890,.11–32.

[3] Al-Sagaby, I.A. and Moallim, M.A., (1996), "Use of Isotope to Study Groundwater Recharge through Sand Dunes in Qassim Area, Saudi Arabia,"2nd Progress Report, No. 117-18-ES, NRERI, KACST, Riyadh, Saudi Arabia.

[4] Wood, W.W. and Sandford, W.E., 1995, Chemical and Isotopic Methods for Quantifying Groundwater Recharge in a Regional, Semiarid Environment: Groundwater V. 33, No. 3. 458–486.

[5] Williams, P.J., Edmund, W.M and Darling, W.G , 1997, British Geological Survey Survey Report on Isotope: Technical Report WD/97/36, Hydrogeology Series: British Geological Survey, U.K.

[6] Warren, W.W. and Bazuhair A.S. (1996) " Chloride Mass-Balance Method for Estimating Groundwater Recharge in Arid Areas: Examples from Western Saudi Arabia" J. Hydrol., V. 186, 153–159.

[7] Shampine, W.J., et. al. (1979), "An Evaluation of Isotope Concentrations in the Groundwater of Saudi Arabia", Isotope Hydrology 1978, Vol. 2. 443–463, IAEA, Vienna.