The Nucleus **51**, No. 1 (2014) 63-74

The Nucleus

A Quarterly Scientific Journal of Pakistan Atomic Energy Commission

NCLEAM, ISSN 0029-5698

HYDROLOGICAL INVESTIGATION OF GROUNDWATER UNDER SALT AFFECTED LAND IN SHORKOT AREA WITH SPECIAL EMPHASIS ON SEEPAGE FROM LINK CANALS

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(Received January 16, 2014 and accepted in revised form February 27, 2014)

Groundwater studies were carried out at Rechna Doab near the confluence of the rivers Chenab and Ravi, around the two link canals (HC and TSLC). The effects of canals on groundwater recharge was investigated with stable and radioactive isotope tracer technique by taking 39 spatial samples and 20 vertical profile samples at two locations . The studies show that about half of the study area receives more than 50% contribution from the canals in the groundwater recharge. The age of groundwater base flow without any contribution from the canals is more than 50 years, while the canal water component moves faster having residence time within few years. However, it seems that the hydraulic pressure due to contribution of the canals, hinders the movement of base flow coming from the northeast direction (eastern bank) and as a result, salt contents of groundwater and soil salinity increase very significantly in the area receiving little or no contribution from the canals. The study looks at horizontal and vertical extent of ground water quality at head-end of the canals. The findings of the study can help policy makers to devise policies to remove inequity due to variation in surface flow and resulting ground water quality at head and tail-ends of canal. The future studies can look at willingness to pay by low-enders for head-enders using groundwater and vice versa.

Keywords: Groundwater, Twin canals, Salinity, Isotopes

1. Introduction

Deterioration of groundwater quality, water logging and soil salinity are among the main causes of destruction of the biological potential of land and lead ultimately to desert-like conditions. The quality of irrigation water depends upon type and quantity of salts. These salts, though present in small quantities but their net effect is very significant [1]. Wherever the irrigation water is used, the crop removes much of the applied water from the soil to meet its evapo-transpiration demand (ET) but leaves most of the salts behind. More salts are added with irrigation and ultimately reached to such concentration which is fatal for some crops. Poor land management and increasing population are factors that promote increased irrigation, improper cultivation or over-cultivation, and increased numbers of livestock. These events alter the land and the soil, diminish the resources, and increase the chances of desertification. Drought, a period of unusually dry weather, can cause loss of vegetation, which in turn leads to desertification. Nearly all irrigation water contains some salt. If an irrigation system lacks a good drainage system, the salt accumulates in the soil. Eventually, the salt reaches toxic levels to most plants. This problem is now jeopardizing about one-third of the world's irrigated land [2].

Integration of nuclear techniques with the conventional techniques can help prevent the degradation of farmlands and point the way towards more productive harvests. Isotopes are being used for water, soil, and plant studies. Both stable and radioactive isotopes help scientists to analyze groundwater resources, providing information about the quality and quantity of groundwater recharge and thus the sustainability of its use. Isotope techniques in hydrology have been proven to be highly advantageous in terms of their sensitivity, reliability, precision and applicability especially when applied in conjunction with conventional techniques [3].

Nuclear characteristics of various elements are used in isotope hydrology. The isotopes of hydrogen (^{1}H, ^{2}H and ^{3}H) and oxygen (^{16}O, ^{17}O, ^{18}O) form part of the water molecule and serve as conservative tracers in the hydrologic cycle. Light species respond faster to physical and chemical changes as compared to the heavier ones resulting in fractionation of the isotopes [4]. Inherent characteristics of isotopes such as fractionation and radioactive decay render them extremely useful tools in almost all spheres of scientific endeavor. Tritium concentration in groundwater reflects the concentration of tritium in the atmosphere at the time when the water was last in contact with the atmosphere. Tritium concentration in the atmosphere before 1950s was in the range of 2-8 TU. Atmospheric nuclear bomb testing during 1960s added more than a billion TU in the northern hemisphere with the largest

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peak of tritium concentration in 1963. After global sanction on atmospheric nuclear test, the tritium concentrations have dropped to 12-15 TU [5,6]. The atmospheric tritium strewn in the precipitation enters the hydrological cycle and eventually becomes the part of groundwater. The introduction of man-made tritium into rain enables us to find the age of groundwater in term of being recharged prior to or post the bomb test. By comparison of the tritium concentration in surface and groundwater with that in the local rainfall, recent groundwater recharge can be identified. Given that TU values vary both spatially and temporally, it is important to establish the closest precipitation measurement point to provide a reference to estimate groundwater recharge and travel times.

In Pakistan, the following criteria may be applied

- <0.8 TU indicates submodern water (prior to 1950s)
- 0.8 to 4 TU indicates a mix of submodern and modern water
- 5 to 15 TU indicates modern water (<5 to 10 years)
- 15 to 30 TU indicates some bomb tritium (mixture of recent and 1960s/70s recharges)
- >30 TU: recharge occurred in the 1960s to 1970s [7,8]

Unfavorable seasonal distribution and insufficient quantity of rainfall is the major problem of the area. The canal water from Jhang Branch and lower Goegera Branch Canals is allocated for irrigation, but being at the tail end, the quantity of canal water cannot meet the crop water requirement. Annual rainfall is about 230 mm with more than 70% during monsoon period (July-Sep). Most of the rain water is lost in evaporation and does not contribute much in recharging the groundwater. The gap between availability and demand is met by exploiting groundwater pumped through tube-wells. Like most of the canal commands, pumpage is greater than recharge, thus causing subsidence. Withdrawal of such a huge quantity of low quality water which is either saline or brackish to make up the short fall in irrigation supplies is resulting in increased soil degradation and decreased water productivity and also has a significant impact on soil salinization process. The only major source of recharge is the two link canals between Trimu and Sidhnai Barrages i.e. HC and TSLC.

Generally, the groundwater is saline but due to recharge from the two link canals between Trimu and Sidhnai Barrages (HC and TSLC) and some other minor canals, the quality of groundwater is very good at certain locations. Therefore, it is imperative to investigate recharge mechanism of groundwater with special emphasis to understand effect of these big canals on groundwater quality.

The specific objectives of the present study are to investigate recharge mechanism of groundwater with special emphasis on contribution of seepage from the link canals and to calculate residence time of groundwater. The role of two link canals, Haveli Canal and Trimu Sidhnai Link Canal on recharge and quality of groundwater was investigated by applying isotopic (^{18}O, ^{2}H and ^{3}H) techniques. Furthermore the effect of canals on groundwater quality, soil salinity and the extent of fresh water availability for irrigation purpose were also focused.

2. Materials and Methods

2.1 Study Area

The study site is a part of Rechna Doab near the confluence of the rivers Chenab and Ravi and is located at about 12 km on North-Eastern side from Shorkot city around the two link canals (HC and TSLC). Exact location of the study site lies between 30^{o} 50$^{/}$ to 30^{o} 55$^{/}$ N and 72^{o} 05$^{/}$ to 72^{o} 18$^{/}$ E at an altitude of about 185 m amsl.

The dominant geologic unit is alluvium. The exploratory drilling carried out by Water and Power Development Authority (WAPDA) showed that the alluvium of Quaternary age was deposited on semi-consolidated Tertiary rocks or on a basement of metamorphic and igneous rocks of Precambrian era [9]. The alluvium consists of fine to medium grained sand, silt and minor amounts of gravel and clay. The alluvium is heterogeneous in character and individual strata have little lateral and vertical continuity. The sediments constituting the alluvium were transported and deposited by the present and ancestral tributaries of the river Indus.

The area is subtropical, continental low land, designated as semi-arid. The climate is characterized by large seasonal fluctuation of temperature and rainfall. Summers are long and hot, lasting from April through September with temperatures ranging from 21^{o}C to 49^{o}C. The winter season lasts from December through February; temperatures ranging between 5^{o}C and 25^{o}C.

Although overall climate of the area is dry-subtropical, water logged soils are frequent in the area due to seepage from nearby canals, which keeps the area at a high relative humidity during most parts of the year particularly during summer.

Cotton in summer and wheat in winter (cotton-wheat cropping system) are the major crops. The other crops grown are sugar cane, lucerne and some forage. Rice is also cultivated.

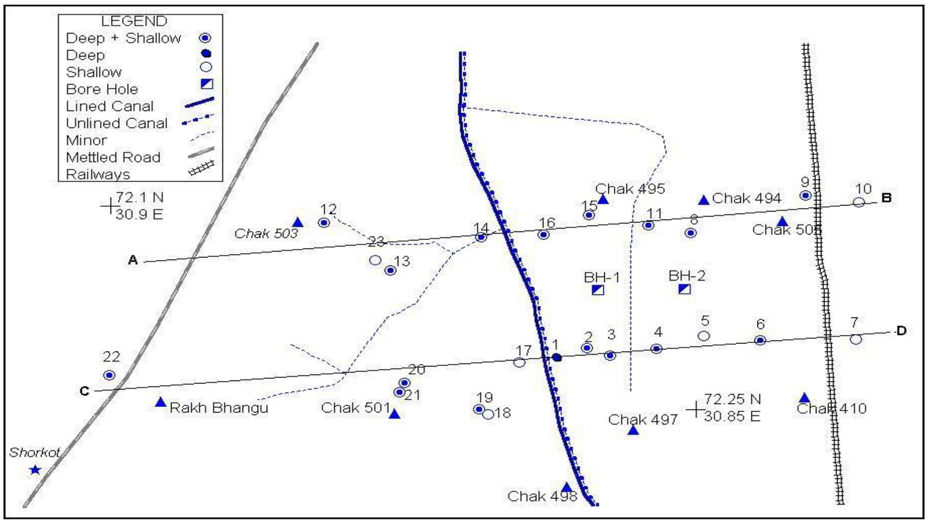

Figure 1. Map of the study area showing sampling locations in two profiles

2.2 *Sample Collection*

Total 39 spatial samples on both sides of canals and 20 samples for vertical profile were collected (Figure 1). Two additional points at about one km and three km distance from the twin canals (HC and TSLC) on eastern side were also collected to investigate vertical extent of ground water quality and isotopic distribution at varying depth upto 100 ft. Shallow groundwater samples (upto 40 ft depth) and deep groundwater samples (100-150 ft depth) were collected from hand pumps and tube wells, respectively (whereas the vertical profile sampling was carried out with the help of depth sampler. Electrical conductivity (EC) of samples was measured in the field with EC meter. Samples for stable isotopes (^{2}H, ^{18}O) and tritium (^{3}H) were collected in pre-cleaned polyethylene bottles for laboratory analysis.

2.3 *Sample Analysis*

The isotopic ratios: ^{2}H/^{1}H and ^{18}O/^{16}O (δ^2H and δ^{18}O) of the water samples were measured on Varian MAT GD-150 mass spectrometers. For determining the oxygen isotopic composition of water samples, CO_2 equilibration method was used [9]. This method involves equilibration of CO_2 with sample water and subsequent mass spectrometric determination of "R" - the ratio of $^{12}C^{16}O^{18}O/^{12}C^{16}O_2$ obtained by suitable corrections from the masses 46 and 44 in CO_2, which have isotopically equilibrated with water sample. This is compared with R_{std} - the isotopic ratio in CO_2 equilibrated with internal laboratory standard at identical temperature. Measurement uncertainty of δ^{18}O is ±0.1‰. For analysis of hydrogen isotope ratio (^{2}H/^{1}H), water samples were first reduced to hydrogen gas using zinc reduction method [1,10, 11]. Quantitative reduction of water to hydrogen gas was achieved by treating water sample with zinc shots of 0.5 – 2.0 mm size under vacuum of the order of 10^{-4} torr. The hydrogen produced was measured on mass spectrometer. Measurement uncertainty of δ^2H is ±1.0‰ [12].

Tritium content of water samples was determined by liquid scintillation counting after electrolytic enrichment [11]. The enrichment was carried out by using cells with stainless steel anodes and phosphated mild steel cathodes. Starting with 250 ml of initial volume, about 17 fold enrichment was done for subsequent counting by liquid scintillation spectrometry. The standard error of measurement is of the order of ±1 TU.

3. Results

3.1 *Isotopic Characteristics*

On regional scale, there are various sources of groundwater recharge in Rechna Doab viz. snow melt on the mountains, rains (mountainous and local), rivers, canals and field irrigation, etc. Considering the study site as localized area, two main components of groundwater are taken into account i.e. the base-flow (groundwater recharged by different sources but not affected by the local canals) and seepage from the two link canals. In order to establish isotope indices of canal water, which is river water diverted from Trimu Barrage, data collected during another study [3,4] have been used.

The mean values of δ^{18}O and δ^2H of canal water are -9.8‰ and -62‰ respectively. Histogram of δ^{18}O (Figure 2) does not show vide variation and its modal class lies at -10‰. δ^2H also follows the similar pattern. Therefore, isotope indices of δ^{18}O and δ^2H can be considered as their mean values. Tritium in canal water varies from 9 to 15 TU.

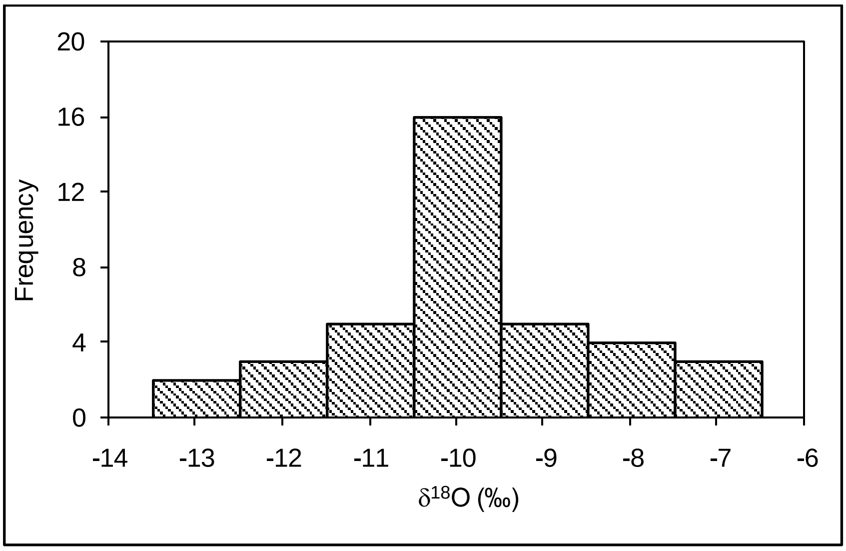

Figure 2. Histogram of $\delta^{18}O$ of water samples collected from Trimu Barrage (source of Haveli Canal and T.S. Link Canal).

Isotopic indices of rains vary spatially. The regional flow of groundwater is from northeastern parts to the southwestern parts and the rains of different isotope indices contribute to the groundwater. For example, $\delta^{18}O$ of rains is depleted than -10‰ in the Himalayan ranges, -6.8‰ at piedmont front (foothills) and -4.0‰ in Faisalabad area, an area located close to the present study area [11]. $\delta^{18}O$ and $\delta^{2}H$ indices of rain of another nearby station (Sargodha) are -4.5‰ and -22.0‰ [12]. For $\delta^{18}O$ and $\delta^{2}H$ indices of base-flow, the samples which are farthest from the canals in northeast direction and their isotopic values are the most enriched indicating no contribution from the canals, are considered.. Although the most enriched $\delta^{18}O$ is -6.9‰ but its $\delta^{2}H$ is -49.3‰ and deuterium excess (d-excess) is 5.7‰, which indicate enrichment of ^{18}O due to evaporation effect [13]. Its tritium value of 7 TU also contradicts the tritium of base flow, which should be very low. It seems that this point is enriched due to evaporation effect. The sampling point No. 10, whose $\delta^{18}O$ and $\delta^{2}H$ values are -7.3 and -45.9 ‰ respectively, is taken as base flow index. Its tritium value (1.1 TU) and d-excess (12.32) also advocate that the enrichment is not due to evaporation. It is also at the maximum distance from the canals. The $\delta^{18}O$ and $\delta^{2}H$ values of shallow groundwater samples vary from -9.7‰ to -6.9‰ and -64.6 ‰ to -45.9‰, respectively, while $\delta^{18}O$ and $\delta^{2}H$ values of deep groundwater samples vary from -9.5‰ to -7.3‰ and -68.3‰ to -50.0‰, respectively. Tritium concentrations of shallow and deep groundwater lie in the ranges of 0.9 to 12.8 TU and 1.8 to 9.3 TU, respectively.

$\delta^{18}O$ and $\delta^{2}H$ values of groundwater samples of bore hole-1 lie between -8.8‰ to -7.0‰ and -55.1‰ to -42.5‰, respectively. $\delta^{18}O$ and $\delta^{2}H$ values of groundwater samples of bore hole--2 vary from -7.7 ‰ to -6.2 ‰ and -50.2 ‰ to -39.4 ‰, respectively. Tritium concentrations of groundwater in bore hole-1 and bore hole-2 lie in the ranges of 1.2 to 6.7 TU and 1.0 to 5.0 TU, respectively.

a. Contribution of the Canals

Isotopic data clearly indicates that isotope ($\delta^{18}O$ and $\delta^{2}H$) indices of the canals are significantly different from those of the groundwater base-flow. Canal water is depleted in $\delta^{18}O$ and $\delta^{2}H$ because the catchment areas of both the rivers (Chenab and Jhelum) are at higher altitudes. Due to altitude effect [14] and cold climate [15,16] the isotopic values of precipitation are more depleted as compared to the base flow having contributions from the precipitation at low lying area/plains. $\delta^{18}O$ and $\delta^{2}H$ of groundwater samples are generally between the canal and base-flow indices showing mixing between these two sources. $\delta^{18}O$ vs. $\delta^{2}H$ plot (Figure 3) shows that groundwater samples lie between the canal and base-flow indices but they are much more scattered, which indicates different contributions of canal water in the groundwater recharge. Downward departure of the points from the local meteoric water line (LMWL) established for Faisalabad area, at about 50 km aerial distance from study site, indicates effect of evaporation at some locations or contribution of evaporated water [11].

In Figure 3, data points of deep water and shallow groundwater form similar scatter, suggesting that the shallow and deep groundwater is well-mixed one aquifer. Lithology of the Rechna Doab also supports the existence of one sandy aquifer with some clay lenses of limited dimensions [13].

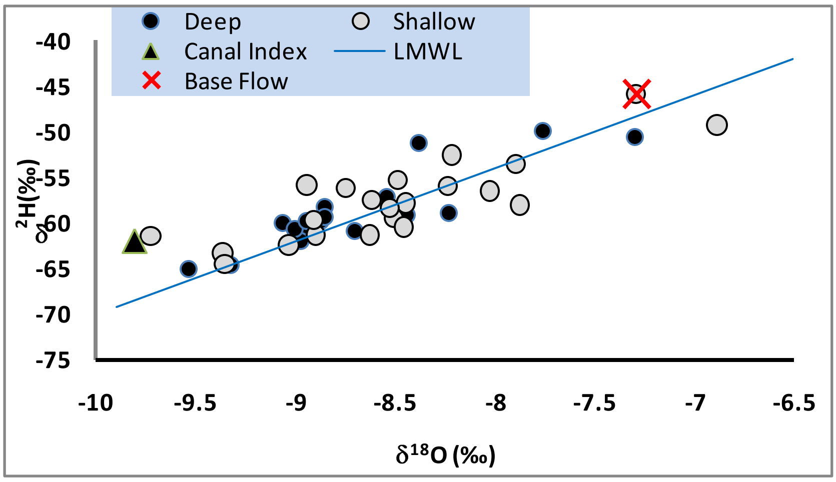

Figure 3. Plot of δ^{18}O vs. δ^{2}H for groundwater samples.

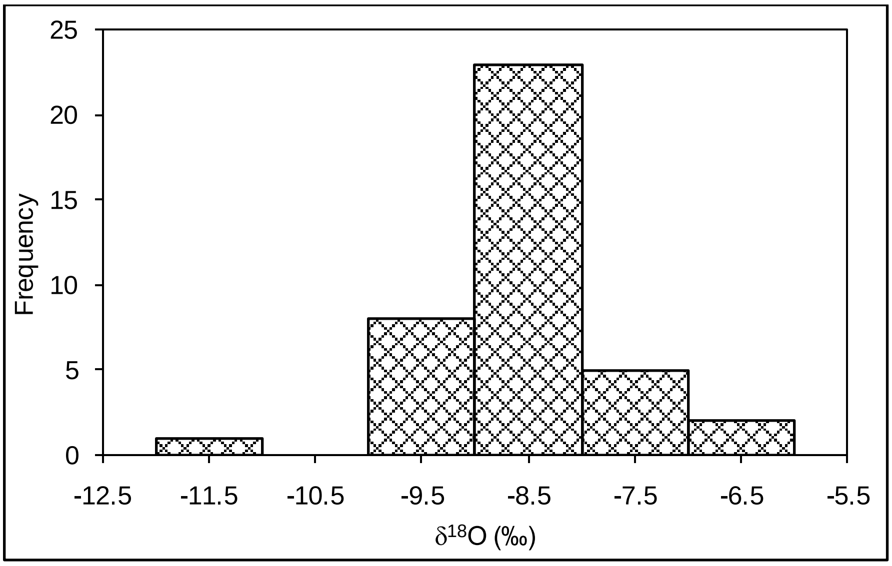

Figure 4. Histogram of δ^{18}O of groundwater samples.

Frequency histogram of δ^{18}O (Fig. 4) shows one population having modal class at -8.5‰, which indicates that most of the groundwater samples (23 out of 39) in the study area have δ^{18}O between -9‰ to -8‰. The following two component mixing equation gives the fraction 'f' of canal water recharged in the groundwater [17,18].

$$F = \frac{\delta^{18}O_M - \delta^{18}O_{B.F}}{\delta^{18}O_{B.F} - \delta^{18}O_R} \quad (1)$$

Where $\delta^{18}O_M$, $\delta^{18}O_{B.F}$ and $\delta^{18}O_R$ are δ^{18}O values of mixed groundwater, base-flow and canal water respectively. Using the above equation, the sampling locations having δ^{18}O around the central value of modal class (-8.5‰) have about 48% contribution from the canals [19, 20]. Twenty-one samples have more than 50% contribution from the canal system, 12 samples have canal contribution from 25 to 50% and rest of the samples [6] do not show significant contribution from canal water.

Spatial distribution of stable isotopes reflects spatial distribution of contribution of canal water in the groundwater. In the study area, on the eastern bank of the canal, δ^{18}O gets enriched while going away from the canals. δ^{18}O of all the samples collected from the sites on eastern bank has been plotted against the distance from the canals (Figure 5). Except the two nearest points to the canals, δ^{18}O increases with distance as shown in Table 1. These nearby points having little-bit enriched δ^{18}O indicate relatively less contribution from canal system is may be due to lateral movement

Table 1. EC and Isotopic data of samples along eastern and western profile of canals.

Sampling Location	Distance (m) approx.	EC (µS/cm)	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	TU	Canal Contribution	EC (µS/cm)	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	TU	Canal Contribution
		Shallow					Deep				
Eastern Bank											
1	190						396	-8.4	-51.2		0.43
2	760	1097	-8.5	-59.6		0.48	625	-8.9	-59.7	9.3	0.63
3	1520	792	-9.7	-61.5		0.97	1490	-9.5	-65.1		0.89
4	2460	1776	-8.9	-61.4	6.6	0.64	2470	-8.9	-58.2		0.62
5	3500	1882	-8.6	-61.4	0.9	0.53					
6	5150	2009	-8.2	-56.0		0.37	3110	-8.7	-60.8	1.8	0.56
7	7300	4185	-7.9	-58.1	2.1	0.23					
8	4000	1320	-8.5	-60.5		0.46	1208	-8.4	-59.2	3.1	0.46
9	6800	2680	-6.9	-49.3	7	-0.17	2270	-8.2	-58.9	5	0.37
10	8000	4276	-7.3	-45.9	1.1	0.00					
11	3100	885	-9.4	-63.4		0.82	980	-9.3	-64.6	3.5	0.81
15	1750	973	-9.0	-62.5		0.69	1088	-9.1	-60.1	7	0.70
16	750	914	-8.0	-56.6		0.29	1085	-8.9	-61.2		0.66
Western bank											
12	3800	694	-9.4	-64.6		0.82	725	-9.0	-62.0		0.67
13	2830	1471	-8.4	-57.9		0.46	930	-8.9	-59.4	3.8	0.62
14	480	1080	-8.9	-59.8		0.64	1327	-9.0	-60.6	5.3	0.68
17	600	860	-8.7	-56.3	12.8	0.58					
18	1700	3190	-8.5	-55.4	4.4	0.47					
19	1500	1977	-8.2	-52.6		0.36	1645	-7.8	-50.0		0.18
20	3250	2570	-8.6	-57.6		0.52	2470	-8.5	-57.2		0.50
21	3450	5100	-7.9	-53.6	5.6	0.24	4980	-7.3	-50.6		0.00
22	10100	2200	-8.9	-55.9		0.66	5050	-8.9	-59.8		0.66
23	3380	1240	-8.5	-58.4		0.49					

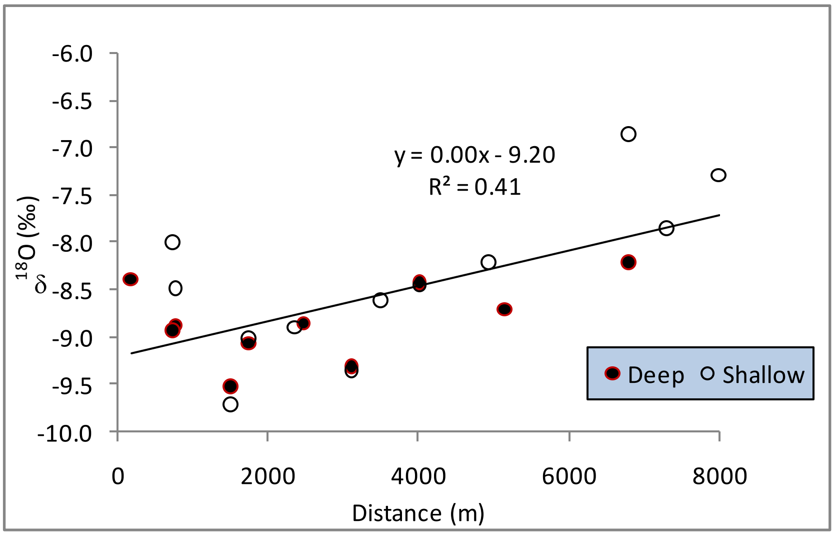

Figure 5. Plot of $\delta^{18}O$ vs. distance from the eastern bank of T. S. L. Canal.

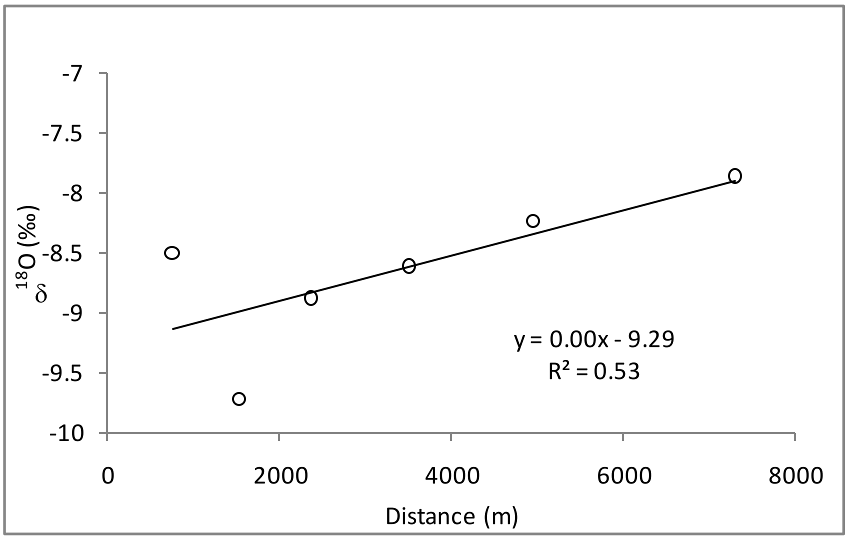

Figure 6. Plot of $\delta^{18}O$ of shallow groundwater vs. distance from canals along profile CD on eastern bank.

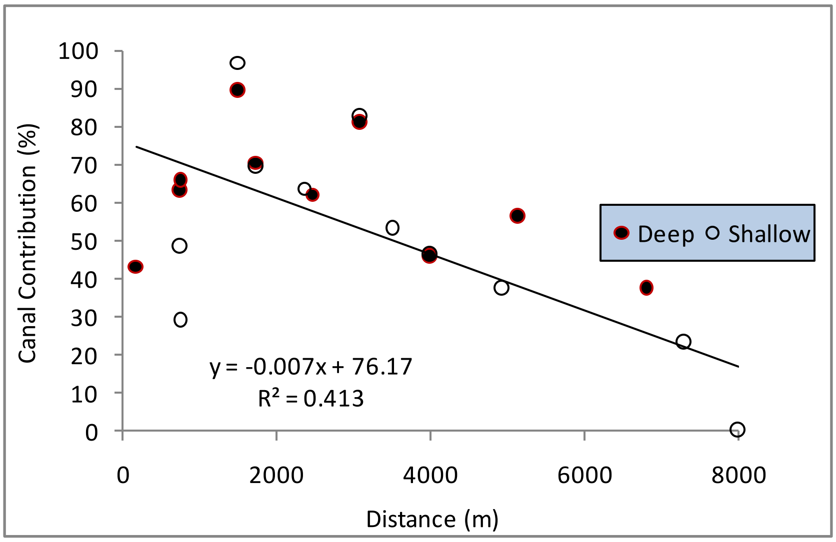

Figure 7. Effect of distance on canal water contribution into groundwater (Eastern side).

during deep circulation of seeping water. Similarly $\delta^{18}O$ of the shallow groundwater samples collected along the profile CD has been plotted against the distance in Figure 6, which shows very good correlation. Contribution of canals in groundwater in the study area estimated by the above-mentioned mixing equation (No. 1) is plotted in Figure 7.

Comparison of water quality of bore holes located at about 1 km and 3 km away from the twin canals on the eastern side shows that the water quality deteriorates as we go deeper. Similarly vertical distribution of stable isotope in two bore holes reflects that as we go deeper, $\delta^{18}O$ and $\delta^{2}H$ become enriched and gradually shift towards delta values of base flow (Figure 8). Tritium values of groundwater in bore hole-1 and bore hole-2 indicate modern water upto the depths of 50 ft and 25 ft respectively, while the water at greater depths is either sub-modern or mix of modern and sub-modern (Figure 9). This trend leads to the conclusion that canal contribution is also gradually deceasing vertically as well as horizontally. The analytical data of bore holes 1 and 2 (Table 2) suggest that the water quality of borehole-1 upto 40 feet depth is comparatively better while for the borehole-2 located at 3 km, 25 feet is the depth to which groundwater shows comparatively better quality. Canal contribution in the borehole at 1 km distance is about 50% in the upper 30 ft which gradually decreased with depth and eventually there is no canal contribution below 60 ft.

Table 2. Isotopic data of bore hole1 and bore hole-2.

Bore Hole-1					
Depth (ft)	EC (mS/cm)	$\delta^{18}O$ (‰)	$\delta^{2}H$(‰)	TU	Canal Contribution
19	3.8	-8.83	-55.1		0.61
24	4.81	-8.49	-53.2	5.9	0.48
29	5.6	-7.97	-47.23		0.27
38	5.8	-8.05	-48.71		0.3
48	9.73	-7.89	-47.6	6.5	0.24
60	12.2	-7.99	-45.9		0.28
72	19.3	-7.17	-42.53	3	-0.05
85	18.5	-6.99	-43.46		-0.12
95	18.92	-7.01	-42.97		-0.12
100	17.45	-7.13	-43.41	1.3	-0.07
Bore Hole-2					
Depth (ft)	EC (mS/cm)	δ18O(‰)	δ2H(‰)	TU	Canal Contribution
23	5.7	-7.74	-48.26		0.18
25	5.4	-7.95	-50.21	5	0.26
33	7.85	-7.68	-44.81		0.15
43	15.6	-7.04	-45.79		-0.10
53	15.5	-7.05	-46.07	3.05	-0.1
63	15	-6.72	-44.18		-0.23
73	19.7	-6.37	-38.51	1.1	-0.37
83	19.6	-6.35	-40.12		-0.38
93	19.7	-6.78	-42.23		-0.21
100	18.7	-6.24	-39.41	1	-0.42
Canal Index		-9.8	-62		
Base Flow		-7.3	-45		

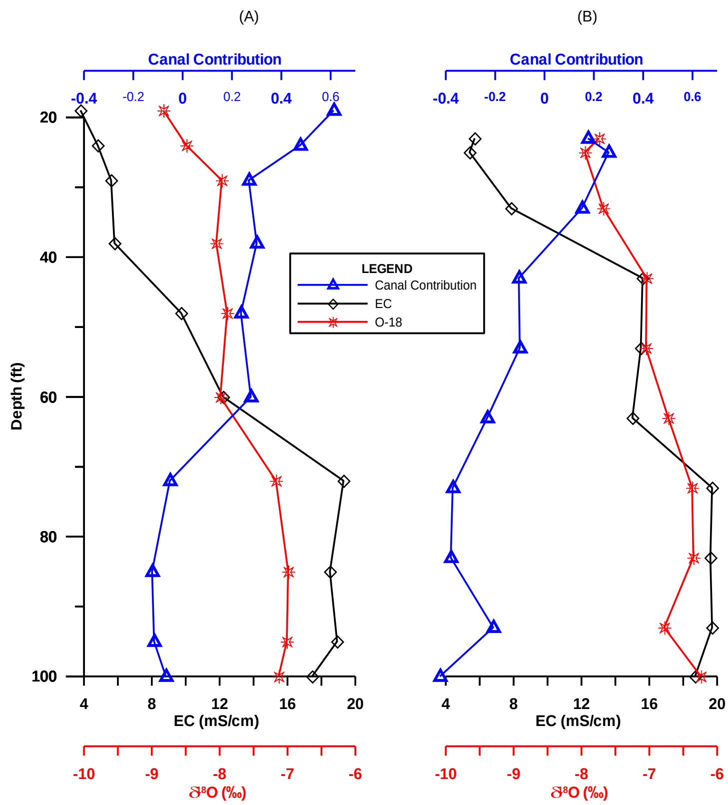

Figure 8. Vertical distribution of EC, $\delta^{18}O$ and canal contribution in bore hole-1(A) and bore hole-2 (B).

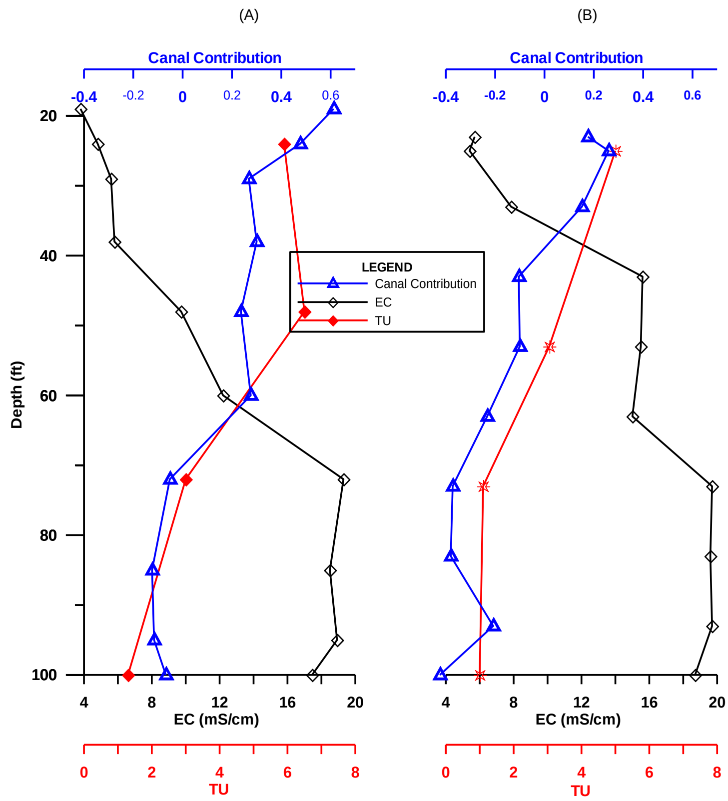

Figure 9. Vertical distribution of EC, tritium and canal contribution in bore hole-1 (Left and borehole-2 (Right).

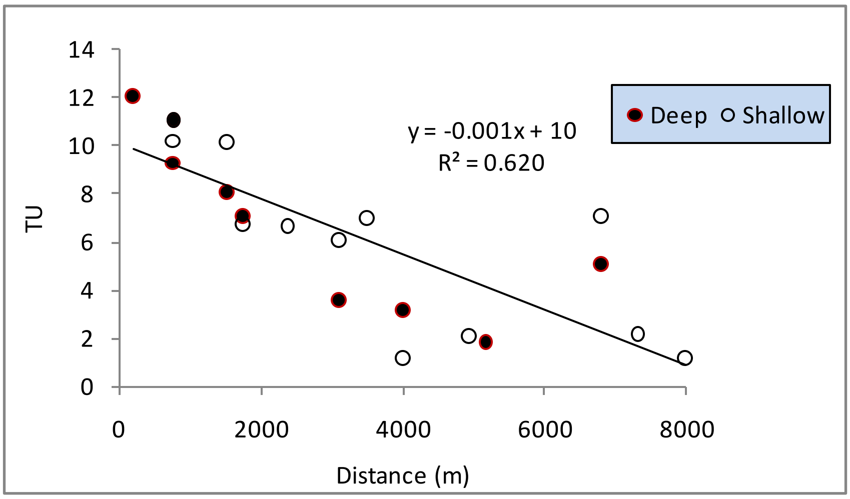

Figure 10. Plot of Tritium vs. distance from the eastern bank of T.S.L. canal.

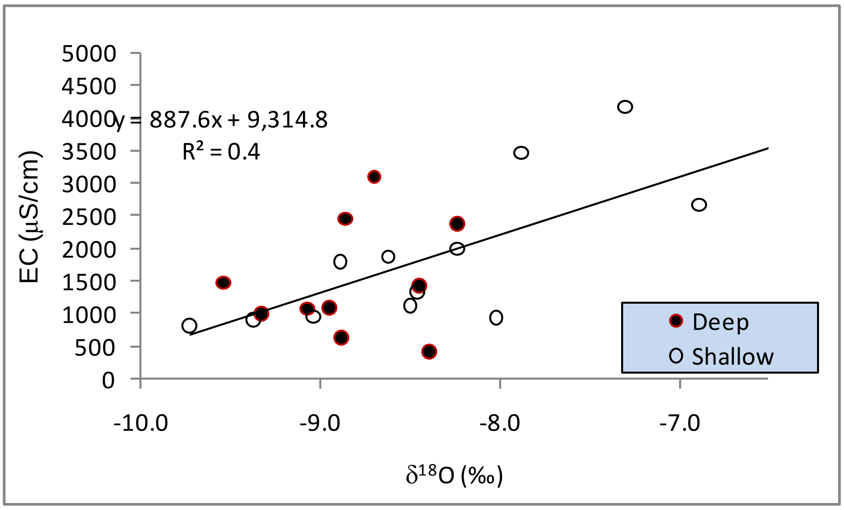

Figure 11. Plot of $\delta^{18}O$ vs. EC of groundwater along eastern bank of TSL canal.

b. Groundwater Dating/Residence Time

The groundwater sampling locations near the canals have high tritium with maximum values of 12.8 TU and 9.3 TU for shallow and deep water respectively, which are almost similar to that of canal water showing quick movement of seeping water. Going away from the canals, the tritium generally decreases (Figure 10) and the lowest values are around 1 TU indicating old water mainly recharged before nuclear weapon testing period i.e. 1953 [13]. It means that the base-flow has long mean residence time (>50 years). Depending on the mixing component of canal water, tritium level of groundwater is re-established. Reduction of tritium is not due to longer residence time but mainly due to mixing of base flow component having low tritium. Therefore, it seems that movement of canal water component in the aquifer is quick having residence time not more than few years. Mean residence time of the mixture will be certainly higher.

c. Effect of Canals on Groundwater Quality

It is obvious that the contribution of canal water having very low salt content will dilute the total dissolved salts (TDS). It is confirmed from the plot of electrical conductivity (EC) of the groundwater samples against their $\delta^{18}O$ (Figure 11) and distance from the canals (Figure 12), which give positive correlations indicating deterioration of water quality going away from the canals due to decrease of canal contribution in the groundwater. It means that the canals play positive role in reducing the salt content of water by dilution process. However, it seems that the hydraulic pressure,

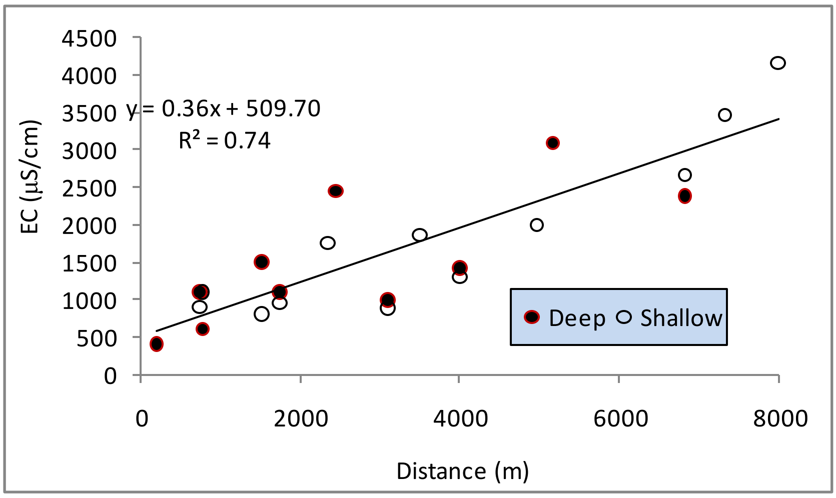

Figure 12. Plot of EC vs. distance from the eastern bank of T.S.L. canal.

due to contribution of the canals, hinders the movement of base-flow in the northeast direction (eastern bank) and as a result, salinity increases significantly in the area which receives little or no recharge from the canals. This phenomenon may also lead to water logging and salinity because the water table will rise and due to evaporation of water through capillaries the salt content will accumulate in the topsoil. High salinity in the northeastern parts of the study area is caused by this process.

4. Conclusions

- Contribution of the two canals in the groundwater recharge is very significant at most of the locations in the study area.
- It decreases with the distance from the canals.
- About half of the area receives more than 50% contribution from the canals in the groundwater recharge.
- Age of groundwater base flow without any contribution from the canals is more than 50 years, while the canal water component moves faster having residence time within few years.
- The canals play positive role in reducing the salt content of water by dilution process. However, it seems that the hydraulic pressure due to contribution of the canals, hinders the movement of base flow coming from the northeast direction (eastern bank) and as a result, salt contents of groundwater and soil salinity increase very significantly in the area receiving little or no contribution from the canals.

5. Recommendations

The policy makers and practitioners may encourage conjunctive use of water with higher recharge and use the saved canal water for surface irrigation in areas with low groundwater recharge. The future work may use these finding on the study site to start a pilot study on how communities in areas with low and high groundwater recharge and subsequent variation in salinity level may negotiate to make conjunctive use of water using game theoretic tools and estimating willingness to pay for fresh water.

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