FINAL REPORT

of

APPLYING ISOTOPE TECHNIQUES TO INVESTIGATE GROUNDWATER DYNAMICS AND RECHARGE RATE FOR SUSTAINABLE GROUNDWATER RESOURCE MANAGEMENT IN THAL DOAB, PAKISTAN.

NATIONAL PROJECT COORDINATORS

MUBARIK ALI
May 2014 To December 2015

DR. M. AZAM TASNEEM
June 2012 To April 2014

TECHNICAL OFFICER
Dr. MANZOOR AHMED
ISOTOPE HYDROLOGY SECTION, IAEA

ISOTOPE APPLICATION DIVISION
PAKISTAN INSTITUTE OF NUCLEAR SCIENCE &TECHNOLOGY
P. O. NILORE ISLAMABAD, PAKISTAN

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SUMMARY

Determination of recharge rate and dynamics of groundwater using isotope techniques for sustainable management of aquifer in the area of Thal Doab was the objective this project. To understand the recharge mechanism in Thal Doab, water samples were collected from the whole doab area for ^{18}O, ^{2}H and ^{3}H measurement. Isotopic data of recharge sources indicated that rivers/canals and rainfall have quite different signatures. Four zones were identified with the help of $\delta^{2}H$ vs. $\delta^{18}O$ plot that were recharged from the river system, precipitation, mixing of precipitation and river water and a small portion with evaporated precipitation.

Data of groundwater clearly demonstrated spatial variation of isotopic composition illustrating recharge from different sources and in varying proportions. Rain appears to be the main source of recharge in upper eastern part of the doab. Rest of the area is mainly recharged by surface water. $\delta^{18}O$ values of shallow and deep groundwater showed similar spatial distribution proving that they are interconnected and have same recharge mechanism. Tritium activity is found in most of the analyzed samples, which indicates that aquifers are nourished by fresh recharge over most of the doab. Groundwater has different age/residence time in various zones ranging from fresh to more than 50 years.

Based on the results, a small area recharged by river system was selected in the Thal Doab that was easily manageable and accessible for $^{3}H/^{3}He$ sampling and pumping test. The site with a total area of 40 km^2 is located at the confluence of Chashma-Jhelum link canal and Thal canal and extends up to river Indus. The land is agricultural and is irrigated by tube wells penetrating to depths of about 80 meters below the ground surface. The depth to water table varies from 9 to 13 meters.

Tritium concentrations and $^{3}H/^{3}He$ ratio were used to calculate the age of groundwater. Chlorofluorocarbons (CFC) and ^{222}Rn were also measured to estimate the residence time. Tritium concentration is used to address groundwater dynamics.

Four sampling locations were selected in recharge area and four locations in discharge area. Deep wells penetrating up to about 83 m depth were available in this study area. The

shallow wells ranging in depth from 15-25 m were drilled using manual drilling system. At each location at least two depths were made available for taking samples. Additional boreholes were drilled for measuring the water table. The water table contours show that the groundwater flow direction is from north-east to south-west that is from the recharge area to the discharge area towards Indus River. Sampling campaigns were carried out in Feb/March 2011, October 2011, September 2012 and June 2014. The samples were collected for analyses of $\delta^{18}O$, $\delta^{2}H$, chemical composition, ^{3}H and $^{3}H/^{3}He$ measurements. The Cu tubes and necessary information for $^{3}H/^{3}He$ sampling technique were provided by IAEA.

The saturated flow velocity was determined using single well dilution technique and it came to be 0.35 m/day. The porosity was determined as 30%. Generally the age increases with increase in depth (except in discharge area in 3rd sampling) which is in good agreement with the conceptual model. The aquifer parameters like hydraulic conductivity, porosity, transmissivity and storage coefficient play an important role in recharge rate, therefore a pumping test was performed to determine these parameters. The pumping test data was analyzed using Jacob, Chow and Theis recovery methods. The average values of transmissivity, hydraulic conductivity and storage coefficient came to be 4724 m^2/day, 94.3 m/day and 0.30 respectively. The flow velocity and pumping test data show that the aquifer is highly transmissive. The average recharge rate came to be 1.36 m/year.

Ages calculated from CFC's concentrations (pmol/kg) do not match with each other i.e. ages calculated from CFC-11, CFC-12 and CF113 are different. Generally, ^{222}Rn is low in recharging area and relatively high in discharging area.

APPLYING ISOTOPE TECHNIQUES TO INVESTIGATE GROUNDWATER DYNAMICS AND RECHARGE RATE FOR SUSTAINABLE GROUNDWATER RESOURCE MANAGEMENT IN THAL DOAB, PAKISTAN.

1. INTRODUCTION

Regarding the groundwater resources, the most important and critical concern is the safe exploitation. Thus, the problem of origin and distribution of groundwater becomes a matter of defining the time, place and amount of replenishment and distinguishing lateral and vertical differences in groundwater movement from points of recharge to points of discharge. Base flow is an important component of the water in rivers/streams. This generally comes from shallow unconfined aquifers. Quality of river water is deteriorated due to discharge of poor quality groundwater from saline zones, industrial effluents and urban contamination.

Groundwater is being used increasingly to provide fresh drinking water for the world's ever growing population. Its rising use for agriculture and industrial processes places further stress on available resources. The growing pressure on groundwater resources requires detailed characterization and quantification of groundwater dynamics, from the time it recharges aquifers to its drainage into rivers, lakes and the ocean, with the aim of managing these limited groundwater resources in a sustainable manner. The complexity of interactions between water bodies poses questions which can be answered in the context of a consolidated integrated approach using tools and techniques from geology, geography, hydrogeology and hydrology.

Since the turnover time of groundwater in an aquifer is directly related to volume and sustainable yield, this parameter which is directly accessible through evaluation of environmental tracers is of high importance. In the context of land use changes, population growth and climate change, a direct evaluation of the replenishment rate of groundwater on short time scales is very important information for water resources management.

Techniques tracing groundwater flow are particularly important for tackling hydrological systems, ranging from small local catchment areas to very large regional basins. Methodologies based on the use of environmental tracers provide promising possibilities in this respect, with intrinsic relative advantages compared to traditional hydrological methods. Environmental isotope tracers contribute to solve the problems dealing with groundwater recharge qualitatively and quantitatively.

The most prominent groundwater dating tools such as tritium concentration is applied to assess the dynamics of groundwater. Tritium/^{3}He (^{3}H/^{3}He) technique which depends on tritium decay into ^{3}He was applied to age the groundwater. This approach is best applied in recharge areas using depth profiles to derive groundwater ages as well as to investigate discharge areas where groundwater seeps out into rivers, creeks, springs and lakes in the downstream area. The ^{222}Rn is suitable to calculate residence time of very young water. Other tracers such as CFCs, SF_6 and ^{85}Kr complement the ^{3}H/^{3}He approach. Additionally, δ^{2}H, δ^{18}O, ^{14}C and ^{39}Ar in groundwater can be used to refine recharge age distribution.

In addition, the ^{3}H/^{3}He technique can be used to investigate discharge areas where groundwater seeps out into rivers, creeks, springs or lakes. Under such conditions, groundwater flow lines of different ages discharge together at one site, thus integrating the natural variability of water flow patterns in just one sample. This enables one to obtain estimates of groundwater residence time in a larger catchment area by measuring a few samples at the discharge area. A common difficulty in studies of rivers as discharge areas is the potential mixing of groundwater with surface waters in the first thin layer of river sediment.

A lot of isotopic data (δ^{18}O, δ^{2}H, CFCs) is available from different on-going CRPs and also from completed in the past, in the river Indus command area. So the ^{3}H/^{3}He technique with other data of δ^{18}O, ^{2}H, CFCs, may help improve information on the groundwater recharge and discharge rates through dating and direct assessment of groundwater turnover time. The ^{3}H/^{3}He technique may be used to amend and supplement data to synthesize it into conceptual flow models.

2. PROJECT TEAM:

Dr. M. Azam Tasneem, Mubarik Ali, Zahid Latif, Dr. Saira Butt, Dr. Abdul Ghaffar, M. Fazil and Ms. Fariha Malik.

3. END-USERS/STAKEHOLDERS AND COLLABORATING INSTITUTES:

Main beneficiaries will be IAD itself, other establishments of PAEC, end users like universities, water policy and decision makers, water development and management authorities, research organizations and agriculture sector such as Pakistan council of research in water resources (PCRWR), Water and Power Development Authority (WAPDA) and Public Health Engineering.

4. BACKGROUND

Study was commenced in Thal Doab which is situated in Punjab, Pakistan. The vast expanse is located between the Jhelum and Sindh rivers, with a total length from north to south 305 km, and a maximum breadth of 110 km and minimum breadth 32 km as shown in figure 1. Thal Doab covers the districts of Bhakkar, Khushab, Mianwali, Layyah, Muzaffargarh as well as Jhang. Samples were collected from the whole Doab for environmental isotopes of oxygen and hydrogen. It was realized that it was very difficult to cover the whole area of the Doab to perform this study and subsequently the area was reduced as shown in figure 2.

4.1 Description of the Study Area

Thal Doab that is situated between Indus and Jhelum Rivers was selected for this study. It is underlain by unconsolidated aeolian and alluvial deposits of Quaternary age. Unconsolidated sediments were deposited on semi-consolidated Tertiary rocks or on a basement of metamorphic and igneous rocks of Precambrian age. Sand formations are intercalated with lenses of silt and clay of variable thickness and aerial extent. The subsequently reduced area for this study lies tectonically within the Mianwali Re-entrant representing part of the northwestward dipping Punjab platform. It is located near the Chashma Barrage on the left bank of the river Indus in the district of Mianwali about 32 km south of Mianwali and 280 km south-west of Islamabad.

The project site is located in between the confluence of Chashma-Jhelum link canal and Thal canal and extends up to river Indus and covers an area of about 40 sq. km. There is no population in the area. The land is agricultural and is irrigated by tube wells penetrating to shallow depths of about 40 meters below the ground surface.

4.2 Hydrogeology of the Study Area

The exploratory bore holes (160 to 366 meters), drilled by water and power development authority (WAPDA) in and around the study area bottomed in alluvium. Hence no definite information is available regarding the total thickness of alluvial deposits. However, deep bore holes drilled by WAPDA in the Punjab reveal that unconsolidated sediments have been deposited on semi-consolidated Tertiary rocks or on a basement of metamorphic and igneous rocks of Precambrian age and their thickness is generally more than 300 m.

The alluvial sediments were deposited in a subsiding trough by the present and ancestral tributaries of the river Indus. The trough was developed due to orogenic movements in the Himalayan Ranges. Contemporaneous filling and subsidence of the trough gave rise to a thick accumulation of alluvial sediments which generally exceed 300 m. In accordance with the mode of deposition i.e. by large streams in constantly shifting courses, the alluvial complex is heterogeneous in both vertical and lateral extent. The drilling indicates that the sand formations are intercalated with lenses of silt and clay of variable thickness and aerial extent [NESPAK, 1992].

The groundwater recharging sources may be the local rains, the river Indus itself (higher reaches), Chashma reservoir, Thal canal system and Chashma-Jhelum Link Canal [Sajjad et al., 1993]. The depth to water table varies from 9 to 13 meters. The groundwater flow direction is towards river Indus. The discharging and recharging areas can be clearly identified.

4.3 Climate of the Area

The climate of the project area and its surroundings is, in general, arid to semiarid and hot. The study area is about 200 m above mean sea level, and is located in the direction of north-east, at a distance of about 1120 km from the Arabian Sea. Towards the west and immediately on the right side of the river Indus are the hills of the Khisor range with an average elevation of 950 m above mean sea level. These hills are devoid of any vegetation. On the north of the site, the land is generally flat and extends up to the foot-hills of the salt range. High mountain ranges lie farther to the north and north-west of the area, which provide an effective barrier, during the winter, to cool-air-masses moving southward from the central Asia. The mean maximum and minimum temperatures recorded over a long period are 33°C and 16°C respectively. Annual average relative humidity is about 66 % and the annual precipitation is 322.5 mm [NESPAK, 1992], about 60-70 % of which falls during the monsoon.

4.4 Problem Statement:

Issues related to groundwater contamination, aquifer potential for sustainable exploitation, impacts of climate change and land use may be addressed by understanding the process of recharge mechanism, groundwater dynamics and its residence time.

5. AIMS and OBJECTIVES

- Main objective of this study was the determination of recharge rate and dynamics of groundwater using isotope techniques for sustainable management of an aquifer.
- Contribution to sustainable management of groundwater resources and in establishing hydrological baseline for evaluating land use and climate change effects in future.
- Additionally, it will help in capacity building for environmental tracers for groundwater dating by conducting such studies.
- The project will also contribute to IAEA GNIP & GNIR data base.

6. METHODOLOGY ADAPTED:

Environmental isotope were employed because of their unique 'fingerprinting' of sources that are often preserved within the subsurface water, and the radioactive natural isotopes provide a time scale of subsurface flow. ^{3}H-^{3}He technique was used as dating tool of young groundwater. Conventional techniques were also used to strengthen the results.

7. EXPERIMENTAL

In the project area, multi depth sampling points were available at some locations. The samples were collected from those locations. At some locations, drilling of bore holes was arranged to get samples from different depths. The depth of wells varies from 15 meters to 83 meters. The location of sampling points of recharging and discharging area is shown in Fig. 3 (recharging and discharging areas are shown in the figure 9 & 10). The sampling system/equipment for $^{3}H/^{3}He$ samples was provided by the Isotope Hydrology Laboratory, International Atomic Energy Agency (IAEA), Vienna, Austria. The sampling system consists of copper tubes in Aluminum frame with clamps on both sides.

For monitoring of water table, in addition to the sampling points for $^{3}H/^{3}He$, additional bore holes were drilled. The water table and the elevations of all the observation wells were measured using leveling equipment "Total Station". The water table contours are given in Fig. 11.

8. SAMPLING CAMPAIGNS

In early stages of the project approximately two hundred samples were collected to determine the concentrations of heavy isotopes of oxygen and hydrogen (^{18}O, ^{2}H and ^{3}H) from the whole area of the Doab. Due to certain constraints, it was very difficult to continue the study covering the whole area of the Doab. Area was reduced and north-western portion of the Doab, near Chashma reservoir, was selected to continue this study. Limited sampling points were selected including 14 groundwater and two surface water (canal water) sampling points, for the measurement of Noble gases, $^{3}H/^{3}He$ and isotopes of oxygen hydrogen. Seven groundwater sampling points were selected in discharging area and the same numbers of sampling points were selected in recharging area.

The first, second and third sampling campaigns were completed in February/March 2011 October 2011 and September 2012 respectively. 4th, 5th and 6th sampling campaigns were carried out in April, June and October, 2014 respectively.

The samples No. 1A/B-BH/TW, 2A/B-BH/TW, 3-TW and 4-TW are located in discharging area and the sampling points RFO, China Town, Chascent and WRP are located in recharging area. The distance between the recharging and discharging areas is approximately 5 km. The samples were collected for measurement of $^{3}H/^{3}He$ and tritium (Sampling 1st, 2nd, 3rd and 5th). The physico-chemical parameters like electrical conductivity (EC), TDS, pH, temperature and dissolved oxygen were measured in the field. Samples for ^{18}O and ^{2}H analysis were also collected for all the six samplings. The coordinates of the sampling points were recorded using GPS.

For measurement of $^{3}H/^{3}He$, the samples were collected in Cu tubes provided by the Isotope Hydrology Laboratory (IHL), IAEA, Vienna, Austria. The collected samples were sent to Isotope Hydrology Laboratory, IAEA. All sampling results were received. Radon was measured in the field (Sampling 4th & 5th in April & June 2014 respectively). CFC's, samples were collected in 4th, 5th & 6th sampling, 2014.

9. RESULTS and DISCUSSIONS

Sampling campaign was commenced in whole area of the Doab to determine $\delta^{18}O$, $\delta^{2}H$ and tritium concentrations in the water samples. Later on, the study was focused in the north-western portion of the Doab. In this area, six sampling campaigns were performed during Feb/March, October 2011, September 2012, April, June and October, 2014. Physico-chemical parameters like EC, pH, Temperature and DO were measured in the field. Water samples from recharging and discharging areas were collected for analysis of $\delta^{18}O$ and $\delta^{2}H$, Chemical analysis and $^{3}H/^{3}He$ analysis. Depth to water table was also measured at selected points. The field data is given in Tables 2-7.

9.1. Stable Isotopes:

Concentrations of heavy isotopes of oxygen and hydrogen i.e. ^{18}O and ^{2}H in the water samples were determined relative to a reference material, Vienna Standard Mean Oceanic Water (VSMOW). To understand the recharge mechanism in Thal Doab, water samples were collected from the whole doab area. The isotopic index of river Indus has been determined at Tarbela as -12.57 ‰ and -87.35 ‰ for $\delta^{18}O$ and $\delta^{2}H$ respectively from ten years data. The isotopic index of rain has been determined as -4.47 ‰ and -22.82 ‰ for $\delta^{18}O$ and $\delta^{2}H$ respectively. These isotope indices were used to identify the recharge sources of the aquifer. Four zones were identified with the help of $\delta^{2}H$ vs. $\delta^{18}O$ plot that were recharged from the river system, precipitation, mixing of precipitation and river water and a small portion with evaporated precipitation as shown in fig.4. Isotopic results are summarized in Table No.1.

The $\delta^{18}O$ compositions of shallow and deep ground waters range from -12.2 to -2.2‰ (average = -8.4‰) and -11.8 to -4.8‰ (average = -8.7‰) respectively, and the $\delta^{2}H$ compositions range from -87.4 to -17.6‰ (average = 61.4‰) and -84.2 to -34.3‰ (average = -65.6‰) respectively. Interestingly, the average $\delta^{18}O$ and $\delta^{2}H$ compositions of shallow and deep ground waters are close to each other and to the surface water but entirely different (highly negative) than the weighted average rainfall values (-4.47‰ and -22.82‰).

In general, groundwater in Thal Doab can be divided into four main categories depending upon their isotopic composition viz. Category-1 (enriched isotopic values, $\delta^{18}O$ > -3.9‰), Category-2 (isotopic values in between, $\delta^{18}O$ = -5.9 to -4.0‰), Category-3 (isotopic values in between, $\delta^{18}O$ = -8.9 to -6.0‰) and the Category-4 (depleted isotopic values, $\delta^{18}O$ < -9.0‰).

Geographical distribution of these categories in shallow groundwater is presented in Figure 5. Category-1 and Category-2 waters are found in a narrow zone in the upper eastern part of the doab between Grot, Distt. Khushab and Hyderabad Thal, Distt. Bhakar. Their isotopic composition reflects that shallow groundwater in this zone is recharged by the rain and there is no contribution of river water. As we move vertically and laterally away from the rain fed area, isotropic values go on depleting suggesting the decreasing role of rain and increasing role of surface waters in groundwater recharge. Shallow groundwater at sampling points surrounding the rain-fed area show intermediate isotopic values suggesting mixing of varying fractions of rain water and river water. At sampling points immediately below the rain-fed area, shallow groundwater has $\delta^{18}O$ composition in between - 5.5 and - 6.5‰. These values reveal that rain is the dominant source of recharge at these locations and contribution of surface water is very low. In the area shown in yellow colour in Figure 5 (Mixed recharge zone), groundwater isotopic composition is relatively depleted (between -6.5 and -7.5‰) reflecting more contribution of surface water as compared to the rain. All the sampling points located along the Indus River right from the start of the doab to the very end show highly negative $\delta^{18}O$ values (< -9‰), which signify that these sites are fed by isotopically depleted surface water.

Spatial distribution of various categories of deep groundwater is shown in Figure 6. Unfortunately, deep groundwater samples from the upper part of the study area were not available because the tube wells were either not existing or not in operation during the field sampling period. $\delta^{18}O$ values in shallow and deep groundwater show similar distribution pattern proving that they are interconnected and influenced by the same recharge mechanism.

The isotopic data belonging to experimental site show that shallow as well as deep groundwater is being recharged by the river Indus and its tributaries flowing in this area. A few shallow and deep sampling points show mixing of rain water. The results of isotope analysis are given in Table No. 8-14. The $\delta^{18}O$ values of groundwater have a range of -11.84 ‰ to -8.22 ‰ and $\delta^{2}H$ values vary from -81.32 ‰ to -53.77 ‰. The plots of $\delta^{2}H$ vs $\delta^{18}O$ all the samplings are given in figure No. 12 - 16. Temporal variation of $\delta^{18}O$ of each sampling point in the experimental site is shown in fig. 17.

9.2. Radioisotopes:

To study the dynamics of the groundwater, age of the groundwater was estimated with the help of tritium. Tritium values of rivers range from 10 to 12 TU which could be considered as the present day tritium content in precipitation in the study area. Tritium values in groundwater range from 0 to 21.2 TU. Tritium activity is found in most of the analyzed samples, which indicates that aquifers are nourished by fresh recharge over most of the doab. In general, groundwater can be divided into following main categories depending upon the tritium values.

a. *0 to 1 TU:* Areas having tritium content in the range of 0 to 1 TU were recharged before atmospheric thermonuclear tests in 1960s releasing a large quantity of tritium into the atmosphere. This is old water having mean residence time (MRT) of more than 50 years.

b. 1 to 4 TU: Tritium content of 1 to 4 TU suggests the mixing of fresh recharge with old water. However, only a small amount of modern water has infiltrated at these locations. The mean residence time of groundwater at these locations is likely to have been longer (40-50 years).

c. *4 to 8 TU:* Groundwater having tritium in the range of 4 to 8 TU is relatively young and contains major fraction of post-1960s water. Areas with groundwater having tritium in this range are related to modern recharge and the groundwater MRT is 20-30 years.

d. > *8 TU:* Areas where groundwater tritium values are more than 8 TU are associated with recent recharge and groundwater is recent in origin. Mean residence time of such waters is only few years.

Geographical distribution of above mentioned four categories of water is represented in Figures 7 and 8. These figures show that sampling locations along the river Indus and in the confluence area generally contain modern to recent groundwater indicating quick recharge. Groundwater in upper middle part of the doab has no or very little tritium. The reason might be the long travel time from a distant area or very slow movement in the unsaturated zone resulting in the loss of tritium activity due to radioactive decay before recharging the aquifer. Hence, groundwater in this zone is old (residence time more than 50 years). Mostly the ground water seems to be young and at some points the groundwater is relatively older.

9.3. Tritium – Helium Isotopes

The water samples 23 in number from first sampling campaign in Feb/March 2011, 14 samples from 2nd sampling campaign in October 2011, 14 samples from 3rd sampling campaign in September 2012 and 16 samples from 4th sampling campaign in June 2014 collected in Cu tubes, were dispatched to Isotope Hydrology Laboratory IAEA for $^{3}H/^{3}He$ and noble gas analyses. The results of $^{3}H/^{3}He$ and noble gases have been received from IHL, IAEA, are given in Tables 14 to 25. The T-^{3}He ages of groundwater with excess air by He/Ne=air & NGT vary from 0 years to 56.4 years for 1st sampling, from 1.4 years to 28.7 years for the 2nd sampling, from 2.1 years to 45.5 years for the 3rd sampling and from 3.3 years to 50.6 years for the 4th sampling. The T-^{3}He ages of groundwater with modeled excess air & NGT vary from 2.8 years to 58.2 years for 1st sampling and 1.4 years to 28.7 years for 2nd sampling. The ages through both the procedures are same.

The ages have been plotted against depth of groundwater samples in Fig. 18-25. Generally the age of groundwater increases with depth which is in good agreement with the conceptual model. The recharge rates were calculated using 06 data sets of age and depth from all the samplings excluded outliers. The average recharge rate came to be 1.36 m/year as shown in Table 26 [P. B. MacMahon et. al. 2011].

9.4. Chemistry of groundwater

9.4.1 Physico-chemical Parameters

Results of field measurements (Samplings 2011, 2012 & 2014) show that EC values of groundwater vary from 269 to 1270 μS/cm. EC values of shallow groundwater range from 356 to 1270 μS/cm (average = 863.9 μS/cm) while those of deep groundwater range from 269 to 1077 μS/cm (average = 752 μS/cm) respectively. EC range and average for shallow groundwater are higher as compared to the deep groundwater. Majority of the shallow samples (60%) and all deep groundwater samples except a few have EC less than 1000 μS/cm indicating that groundwater in this area generally has low mineralization. EC is consistent and high in discharge area as compare to recharge area due to the dissolution of salts from their path as shown in Fig. 26. Groundwater temperature is consistent in discharge area as compare to recharge area (Fig. 27). pH values of shallow and deep groundwater vary from 7.2 to 8.18 (average = 7.62) and 7.1 to 8.3 (average = 7.7), respectively. Average pH of shallow and deep groundwater is almost same. These values suggest that groundwater is neutral to slightly alkaline and the alkalinity is mainly due to HCO_3^- content. pH is consistent and low in discharge area as compare to recharge area due to the dissolution of salts from their path as shown in Fig. 28. Dissolved oxygen is slightly low in discharge area as compare to recharge area due to the interaction of minerals from their path as shown in Fig. 29.

9.4.2 Major Ion Chemistry

In shallow groundwater, concentrations of Na^+ show variation in the range of 3.5 to 93.3 mg/L with an average of 45.3 mg/L. The values of Ca^{2+} and Mg^{2+} range from 10.1 to 56.7 mg/L (average = 22.6 mg/L) and 15.7 to 61.9 mg/L (average = 32.3 mg/L), respectively. The concentrations of K^+ are varying from 7.2 to as high as 126.5 showing average of 23.5 mg/L. In case of anions, HCO_3^- is dominant in all shallow groundwater samples. Its values range from 205 to 387 mg/L with an average of 283 mg/L. As regards the concentrations of Cl^- and SO_4^{--}, their values vary from 15 to 82 mg/L and 14 to 161 mg/L. Average concentrations of these constituents are 37.7 mg/L and 58.8 mg/L, respectively (Table 27).

In deep groundwater, Na^{+}, K^{+}, Ca^{++} and Mg^{++} concentrations (mg/L) vary from 8.9 to 85.1, 3.3 to 14.3, 11.8 to 26.4 and 13.5 to 33.3 respectively. Average concentrations (mg/L) of these constituents are 48.1, 8.3, 18.4 and 26.0 respectively. HCO_3^{-} values are much higher as compared to other anions (Cl^{-} and SO_4^{--}) and vary between 113 - 301 mg/L (average = 235 mg/L). Concentrations of Cl^{-} and SO_4^{--} lie in the range of 20 to 69 mg/L and 13 to 103 mg/L, respectively. Average values of these anions are 40 mg/L and 54.6 mg/L, respectively.

Water chemistry data reveals that ranges and average values of all major cations and anions in shallow groundwater are higher than in the deep groundwater. In case of cations, Na^{+} has the highest average value in shallow as well as deep groundwater followed by Mg^{++} and Ca^{++}. In case of anions, HCO_3^{--} is predominant in both shallow and deep groundwater.

9.4.3 Groundwater Types

Based on the Piper diagram (Fig. 30), the groundwater is classified into different distinct (where concentration of individual cation and anion is at least 50% of the total cations and anions, respectively) and mixed / transitional (where no individual cation and anion has concentration more than 50% of the total cations and anions, respectively) types. These types are Ca-HCO_3, K-HCO_3, Mg-HCO_3, Na-HCO_3, Mg-Ca-HCO_3, Mg-Na-HCO_3, Na-Mg-HCO_3 and Mg-HCO_3-SO_4. Distinct type waters are found at 8 out of 18 locations (Ca-HCO_3 type = 1, K-HCO_3 = 1, Mg-HCO_3 = 4, Na-HCO_3 type = 2). Groundwater at 10 surveyed locations shows mixed character in terms of cations (n = 8) or anions (n = 2). Number of samples falling in various mixed types are; Mg-Ca-HCO_3 = 1, Mg-Na-HCO_3 = 4, Na-Mg-HCO_3 = 3 and Mg-HCO_3-SO_4 = 2. In case of shallow groundwater samples (n = 10), 4 samples show distinct types and 6 show mixed types. Distinct and mixed types are equally abundant in case of deep groundwater. Two samples of canal water show Ca-HCO_3 type.

9.5. CFC of water samples from project area

CFC's concentrations (pmol/kg), year of recharge and apparent age (years) of the April, June and October, 2014 samplings are tabulated in Table 27-29. Data is compared with Helium-Tritium Isotopes. Though the results obtained from the above mentioned techniques, as shown in fig.31, are not in good agreement but it can be inferred from the data that ground water is relatively young in age.

9.6. Radon of water samples from project area

9.6.1 Health risk

Drinking-water is one of the most essential and indispensable element for human and all kinds of life. The safety of drinking-water is often of the highest priority for public health and environmental protection. The Environmental Protection Agency of the United Nations estimates that radon in drinking water causes about 168 cancer deaths per year: 89% from lung cancer caused by breathing radon released to the indoor air from water and 11% from stomach cancer caused by consuming water containing radon. Hence the public concern for radioactivity of drinking-water has been increasing in recent years after the rapid development of nuclear power plants. The radioactivity of water samples collected in the vicinity of nuclear facilities from the Kundian area surrounding the Chashma Nuclear Power plants was measured. A systematic study was carried on by collecting the water samples from different locations. These samples of water were from bore holes, tube wells, canals as well as of hand pumps. The activity was measured in water samples by using RAD-7 radon detector. The results obtained from the activity of radon, ranged from 4.1 pCi/l to 232.8 pCi/l with a mean value of 133.00 pCi/l (Table 31 & 32). The annual mean effective dose calculated from the measured activity varies from 0.1μSv-a^{-1} to 3.1μSv-a^{-1} with a mean value of 1.74 μSv.a^{-1}. According to the recommendations made by the International Commission of Radiological Protection (ICRP) all the water samples collected are within the permissible level of 3–10 μSv a^{-1} [ICRP Publication 60 Ann. ICRP, Oxford Pergamon (1990)].

9.6.2 Groundwater discharge

Groundwater discharge can be determined by measuring Radon concentration and rate of flow in surface/groundwater using mass balance approach. In discharge area, it was observed that Radon concentration is high as compare to recharge area, especially that area where 2A (HP) exits. Secondly, it was observed that shallow groundwater have high Radon concentration as compare to deep groundwater.

10. CONCLUSIONS:

Isotopic data clearly demonstrate spatial variations of the isotopic composition of groundwater in Thal Doab indicating different recharge sources. Converging of all evidences based on environmental isotopes, following conclusions are drawn.

- Shallow groundwater in a small zone in the upper eastern part of the doab is mainly recharged by the rain. Sampling points surrounding the rain fed area show intermediate waters indicating the mixed recharge from rain and surface waters. As we move downwards from the rain-fed area, contribution of rain to groundwater recharge decreases while the rivers/canals contribution increases. At the remaining locations, shallow groundwater is mainly recharged by the rivers and their distributaries flowing in this area.
- Deep groundwater at most of the surveyed locations is recharged by the rivers/canals. As in shallow groundwater, rain influence is limited. Rain appears to be the main source of recharge in upper eastern part of the doab.
- $\delta^{18}O$ values in shallow and deep groundwater show similar geographical distribution pattern proving that they are interconnected and have same recharge mechanism.
- Tritium activity is found in most of the analyzed samples, which indicates that aquifers are nourished by fresh recharge over most of the doab.
- Groundwater (shallow and deep) has different age / residence time at various locations. The river recharged areas generally contain young groundwater indicating relatively quick recharge.

Experimental Site:

1. Stable isotope data indicate that the groundwater is being recharged by canals and River Indus and seasonal variation of stable isotopes in surface water is reflected in shallow ground water in recharge area (which is near to the recharging source)..
2. Hydraulic conductivity and storage coefficient, determined with the help of pumping test, came to be 94.42 m/day and 0.30 respectively.
3. The groundwater flow direction is from north-east to south-west i.e. from recharge area to discharge area.
4. Recharge rate was calculated 1.36 m/year with the help of $^{3}H/^{3}He$ data.

Table 1: Sampling Locations and Isotopic Data of water samples.

Sr. No.	Type	Latitude	Longitude	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	^{3}H (T.U)	Sr. No.	Type	Latitude	Longitude	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	^{3}H (T.U)
1	H.P.	32.66	71.52	-12.02	-82.61		29	H.P.	31.79	71.82	-4.4	-26.13	5.6
2	H.P.	32.81	71.48	-11.86	-80.11	0.9	30	H.P.	31.87	71.73	-2.75	-22.91	
3	T.W.	32.81	71.47	-11.76	-78.01	2.9	31	H.P.	31.96	72.21	-3.47	-19.84	
4	H.P.	32.85	71.50	-11.03	-75.63		32	H.P.	31.85	72.11	-3.09	-21.34	
5	H.P.	32.95	71.56	-6.94	-42.26	3.9	33	H.P.	31.77	72.07	-8.85	-62.15	1.7
6	H.P.	32.79	71.58	-12.06	-84.83	1.6	34	H.P.	31.63	72.11	-6.64	-39.98	
7	T.W.	32.66	71.70	-5.75	-32.31		35	H.P.	31.81	72.18	-2.15	-19.77	10.4
8	H.P.	32.60	71.60	-9.4	-60.25	1.8	36	H.P.	32.02	71.82	-7.85	-52.85	0.6
9	T.W.	32.47	71.69	-9.42	-67.02		37	H.P.	32.06	71.69	-11.57	-80.2	
10	T.W.	32.55	71.72	-6.09	-42.85	1.1	38	H.P.	32.09	71.9	-3.25	-21.92	
11	M.P.	32.39	71.53	-10.13	-69.7	4.5	39	H.P.	32.16	72	-7.51	-56.16	21.2
12	M.P.	32.29	71.52	-10.78	-74.14		40	H.P.	32.19	71.82	-8.3	-55.86	1
13	M.P.	32.29	71.36	-12.16	-80.22		41	H.P.	32.26	71.88	-10.58	-73.58	
14	H.P.	32.13	71.49	-10.77	-73.59		42	H.P.	32.38	71.93	-5.64	-39.16	1.2
15	H.P.	32.20	71.51	-10.1	-69.97		43	H.P.	32.36	72.38	-9.77	-66.21	
16	H.P.	32.46	71.46	-10.76	-75.6	11	44	M.P.	32.46	72.43	-5.87	-37.12	0.9
17	H.P.	32.29	71.69	-9.83	-67.58	9.7	45	T.W.	32.5	72.46	-5.58	-35.16	
18	H.P.	32.22	71.66	-6.33	-37.9	11.9	46	H.P.	30.89	71.07	-10.46	-75.5	
19	H.P.	32.39	71.77	-8.43	-52.33	9.4	47	H.P.	30.74	71.09	-8.64	-65.66	
20	H.P.	32.30	72.08	-11.25	-76.08		48	H.P.	30.82	71.2	-10.1	-75.91	3.2
21	H.P.	32.29	72.27	-11.2	-79.04		49	H.P.	30.96	71.21	-7.93	-53.66	1.9
22	H.P.	32.10	72.26	-4.69	-29.61	21.2	50	H.P.	30.87	71.31	-11.55	-87.37	
23	H.P.	32.20	72.22	-7.72	-51.25	11	51	H.P.	30.76	71.36	-10.29	-69.34	7.4
24	H.P.	32.08	72.10	-4.14	-23.25		52	H.P.	30.69	71.45	-8.3	-59.1	
25	H.P.	32.01	72.03	-9.4	-59.98	11.7	53	H.P.	30.85	71.41	-9.9	-70.1	
26	H.P.	31.88	71.91	-3.35	-17.58		54	H.P.	30.91	71.51	-7.42	-47.73	
27	H.P.	31.79	71.91	-4.4	-26.13	5.6	55	H.P.	30.76	71.55	-7.39	-50.51	2
28	H.P.	31.72	71.87	-3.35	-17.58		56	H.P.	30.66	71.66	-8.29	-59.73	

Table 1. Cont. from previous page

Sr. No.	Type	Latitude	Longitude	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	^{3}H (T.U)	Sr. No.	Type	Latitude	Longitude	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	^{3}H (T.U)
57	H.P.	30.61	71.52	-8.62	-59.22	5.9	86	H.P.	30.58	71.15	-9.53	-73.41	9.5
58	H.P.	31.05	71.31	-7.09	-45.97		87	H.P.	30.68	71.24	-7.37	-51.27	
59	H.P.	31.05	71.27	-6.34	-41.87	3.8	88	HP	32.12	71.5	-9.14	-70.92	3.3
60	H.P.	31.19	71.61	-6.34	-41.87	3.8	89	TW	32.15	71.36	-9.19	-72.91	4.9
61	H.P.	31.14	71.74	-6.23	-44.57	3.7	90	MP	32.16	71.28	-9.47	-72.17	4.1
62	H.P.	31.12	71.68	-6.7	-46.35		91	MP	31.98	71.17	-7.78	-53.43	3
63	H.P.	31.17	71.43	-7.32	-48.51	3.9	92	TW	31.14	71.21	-8.52	-61.76	
64	H.P.	31.18	71.21	-8.78	-60.81	4.8	93	TW	31.22	71.21	-9.09	-66.02	3.4
65	H.P.	31.09	71.12	-8.72	-61.18		94	HP	31.5	71.24	-9.56	-70.07	2.8
66	H.P.	31.02	71.00	-10.28	-72.82	7.7	95	TW	31.5	71.24	-8.82	-63.13	1.8
67	H.P.	31.06	71.52	-7.35	-60.92		96	HP	31.66	71.33	-7.68	-58.54	2.6
68	H.P.	30.99	71.74	-7.49	-59.38	4.8	97	HP	31.72	71.57	-5.9	-44.16	1.3
69	H.P.	30.92	71.71	-7.87	-56.4		98	HP	31.55	71.53	-5.29	-40.16	4.1
70	H.P.	30.85	71.78	-8.54	-58.47		99	TW	31.45	71.48	-5.1	-40.35	3.5
71	H.P.	30.81	71.69	-7.97	-57.24	5.3	100	HP	31.39	71.44	-6.15	-45.49	2.1
72	H.P.	30.97	71.61	-7.47	-50.3	1.6	101	HP	31.35	71.69	-6.31	-51.7	3.9
73	T.W.	30.95	70.87	-10.75	-74.18	13.9	102	TW	31.39	71.72	-4.79	-39.49	2.6
74	H.P.	31.08	70.94	-10.78	-77.21		103	HP	31.51	71.74	-3.33	-24.88	4.8
75	H.P.	31.21	71.04	-11.03	-80.62	4.8	104	HP	31.3	71.43	-6.5	-47.47	5.9
76	H.P.	31.34	71.08	-9.17	-63.15		105	TW	31.43	71.24	-10.65	-71.14	6.6
77	H.P.	31.4	71.01	-9.71	-70.67	5.3	106	TW	30.94	71.31	-9.38	-66.92	10.1
78	H.P.	31.33	70.9	-9.99	-73.66		108	TW	30.76	71.8	-8	-54.99	2.4
79	T.W.	31.33	70.9	-10.66	-76.35		109	HP	30.69	71.73	-8.38	-60.55	1.9
80	H.P.	31.22	70.85	-9.87	-74.56	3	110	HP	30.94	71.92	-8.13	-55.95	1.7
81	T.W.	30.89	70.92	-9.88	-74.51	4.6	111	MP	31.06	72.01	-7.87	-57.91	10.3
82	H.P.	30.81	70.99	-10.43	-75.69	4.6	112	TW	31.07	72.02	-6.76	-50.72	13.5
83	H.P.	30.72	70.92	-10.32	-74.82		113	TW	31.17	72.08	-7	-50.36	13.4
84	H.P.	30.64	70.95	-10.98	-76.98	5.8	114	HP	31.33	72.06	-8.17	-52.63	12.4
85	H.P.	30.57	70.94	-9.82	-72.12	6.7	115	HP	31.48	72.07	-7.21	-49.86	13.4

Table 1. Cont. from previous page

Sr. No.	Type	Latitude	Longitude	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	^{3}H (T.U)	Sr. No.	Type	Latitude	Longitude	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	^{3}H (T.U)
116	HP	31.25	71.91	-7.07	-51.15	11.4	149	HP	30.3	71.08	-9.03	-66.29	4.7
117	TW	31.01	70.98	-9.89	-77.45	11.6	150	TW	30.67	70.95	-10.46	-70.52	4.7
118	TW	31.23	70.96	-10.59	-75.54	12.9	151	HP	30.27	70.97	-9.81	-76.44	4.4
119	HP	31.52	71.05	-8.22	-62.29	14.5	152	TW	30.26	70.97	-9.03	-70.63	9
120	HP	31.79	71.11	-9.12	-74.61	11.5	153	HP	29.79	70.91	-10.82	-76.36	14
121	TW	31.79	71.15	-10.3	-81.48	10.8	154	HP	29.79	70.91	-9.55	-75.83	15
123	HP	31.54	70.92	-10.75	-83.56	10.2	154	TW	29.79	70.91	-9.55	-75.83	15
124	TW	31.53	71.05	-10.27	-75.72	9.2	155	HP	29.66	70.86	-9.89	-77.77	6.8
125	TW	30.97	71.01	-10.66	-74.62	10.6	157	HP	29.49	70.88	-10.26	-74.99	3.4
126	TW	30.66	71.24	-5.58	-48.07	3.7	157	TW	29.49	70.88	-10.26	-74.99	3.4
127	HP	30.56	71.39	-5.75	-50.15	2	159	HP	29.29	70.86	-10.07	-70.47	5.4
128	HP	30.54	71.45	-11.37	-75.46	7	159	TW	29.29	70.86	-10.07	-70.47	5.4
129	TW	30.54	71.46	-8.19	-56.43	3.4	161	HP	29.3	70.78	-8.78	-71.36	4.2
130	TW	30.53	71.51	-7.4	-55.25	1.9	161	TW	29.3	70.78	-8.78	-71.36	4.2
131	HP	30.57	71.6	-7.89	-65.14	13	163	TW	29.35	70.79	-7.11	-50.22	4.3
132	HP	30.43	71.47	-6.42	-48.77	5	164	TW	29.46	70.96	-10.83	-84.04	3.1
133	TW	30.42	71.46	-6.81	-45.98	9	165	HP	29.48	70.96	-10.58	-77.93	3.8
134	HP	30.32	71.36	-7.66	-56.54	2	165	TW	29.48	70.96	-10.58	-77.93	3.8
137	HP	30.27	71.23	-8.73	-72.75	1.9	167	HP	29.61	71.02	-10.85	-78.16	4.7
138	HP	30.42	71.24	-10.1	-70.34	4.4	167	TW	29.61	71.02	-10.85	-78.16	4.7
139	TW	30.48	71.23	-8.48	-62.88	3.1	169	HP	29.97	70.97	-10.84	-81.17	2.8
140	HP	30.48	71.23	-10.05	-67.86	2.6	169	TW	29.97	70.97	-10.84	-81.17	2.8
141	TW	30.74	71.23	-9.36	-65.7	4.4	170	HP	29.93	70.97	-8.63	-71.33	3.1
142	TW	30.89	70.94	-9.51	-70.59	4.8	172	TW	29.88	71.12	-7.99	-59.02	3.1
143	TW	30.73	70.94	-9.47	-70.72	5.2	173	HP	29.79	71.07	-8.35	-59.72	4.5
144	TW	30.5	70.96	-10.63	-71.82	3.4	173	TW	29.79	71.07	-8.35	-59.72	4.5
145	HP	30.5	70.96	-10.88	-76.69	4.9	174	HP	29.78	71.07	-8.08	-63.89	2.8
146	TW	30.33	70.93	-9.6	-77.07	2.9	176	TW	30.8	71.23	-8.09	-60.21	3.4
147	HP	30.33	70.93	-9.63	-72.07	5.3	177	TW	31.09	71.08	-7.78	-58.57	2.6
148	TW	30.3	71.08	-10.12	-74.84	4.6	178	HP	31.12	70.98	-9.92	-75.88	2.2

Table 1. Cont. from previous page

Sr. No.	**Type**	**Latitude**	**Longitude**	**$\delta^{18}O$ (‰)**	**$\delta^{2}H$ (‰)**	**^{3}H (T.U)**	**Sr. No.**	**Type**	**Latitude**	**Longitude**	**$\delta^{18}O$ (‰)**	**$\delta^{2}H$ (‰)**	**^{3}H (T.U)**
178	TW	31.12	70.98	-9.92	-75.88	2.2	190	TW	31.05	71.42	-7.48	-48.75	0
180	TW	31.33	71.08	-10.13	-72.46	6.6	191	TW	31.19	71.51	-6.35	-44.78	1
181	TW	31.32	71.2	-10.03	-75.12	4.7	192	TW	31.12	71.63	-6.15	-43.76	0.5
182	TW	31.2	71.09	-9.89	-74.35	10.6	193	TW	30.94	71.71	-6.43	-46.99	1
183	TW	31.13	71.32	-7.47	-49.5	0.6	196	HP	31.84	71.45	-8.39	-55.99	0
184	TW	30.8	70.97	-11.08	-78.79	0.5	194	TW	30.86	71.52	-7.42	-52.05	2
185	TW	30.72	71.08	-10.4	-70.8	2.9	195	HP	31.78	71.4	-7.79	-55.09	0.2
187	TW	30.86	71.74	-7.76	-54.36	1.4	196	HP	31.84	71.45	-8.39	-55.99	0
188	TW	30.82	71.42	-8.25	-55.85	4.5	197	HP	31.97	71.36	-8.01	-67.9	4.3
189	TW	31.04	71.22	-8.42	-60.93	1.4	198	HP	31.98	71.55	-2.56	-19.88	11.6

Table 2: Field data along with location, depth, coordinates, physico-chemical parameters (Feb/March 2011 sampling)

Sr. No.	Sample Code	Sample Collection Date	Sample depth	Coordinates		Altitude	Field data				Time of Collection
	(local name)			Latitude	Longitude		Cond	Temp.	pH	DO	
1			(m)	N DD,MM,SS	E DD,MM,SS	(m)	µS/cm	^{o}C		mg/l	
2	1A-BH	03-02-2011	15	32,23,05.0	071,25,47.0	189.89	740	23.1	7.30	6.8	1800 hrs
3	1B-BH	03-02-2011	25	32,23,05.0	071,25,47.0	189.89	836	23.1	7.30	7.4	1850 hrs
4	1C-TW	03-02-2011	50	32,23,05.0	071,25,47.0	189.89	850	24.0	7.30	2.5	1730 hrs
5	2A-HP	04-02-2011	18	32,22,54.50	071,24,41.20	194.77	1091	24.2	7.20	7.9	1045 hrs
6	2B-TW	04-02-2011	50	32,22,54.50	071,24,41.20	194.77	950	24.6	7.10	1.9	1030 hrs
7	3-TW	04-02-2011	35	32.22.28.5	071.25.21.60	203.00	911	24.5	7.40	2.1	1145 hrs
8	4-TW	04-02-2011	50	32,22,31.00	071,24,50.00	196.60	775	23.8	7.50	2.8	1215 hrs
9	1A-BH	31-03-2011	15	32,23,05.0	071,25,47.0	189.89	561	24.2	7.70	6.2	0830 hrs
10	1B-BH	31-03-2011	25	32,23,05.0	071,25,47.0	189.89	830	24.6	7.40	9.5	0850 hrs
11	1C-TW	30-03-2011	50	32,23,05.0	071,25,47.0	189.89	832	25.5	7.65	3.5	1515 hrs
12	2A-HP	31-03-2011	18	32,22,54.50	071,24,41.20	194.77	956	25.3	7.65	7.5	1055 hrs
13	2B-TW	31-03-2011	50	32,22,54.50	071,24,41.20	194.77	740	25.3	7.77	2.7	1135 hrs
14	3-TW	31-03-2011	35	32.22.28.5	071.25.21.60	203.00	769	25.4	7.60	2.9	1235 hrs
15	4-TW	30-03-2011	50	32,22,31.00	071,24,50.00	196.60	728	25.3	7.58	3.1	1419 hrs
16	WRP Deep	30-03-2011	83	32,23,28.10	071,27,55.60	208.48	269	20.9	8.22	2.6	0858 hrs
17	WRP Shallow	30-03-2011	20	32,23,25.40	071,28,02.10	193.24	407	24.0	8.03	9.5	1055 hrs
18	China town Deep	30-03-2011	83	32,23,22.10	071,27,27.40	199.95	561	25.1	7.97	8.1	0950 hrs
19	China town Shallow	30-03-2011	20	32,23,27.50	071,27,37.50	211.23	608	26.9	7.55	8.4	1030 hrs
20	RFO Deep	30-03-2011	83	32,23,03.60	071,27,27.40	199.95	642	24.8	7.69	8.0	1147 hrs
21	Chascent Deep	31-03-2011	83	32,23,29.90	071,27,20.20	207.26	421	25.3	8.00	6.2	1445 hrs
22	Chascent Shallow	31-03-2011	20	32,23,29.90	071,27,20.20	207.26	1075	27.1	7.67	8.5	1415 hrs
23	Thal Canal	07-05-2011	02	32,21,27.60	071,27,40.60	209.09	330	21.7	7.85	8.9	0755 hrs

Table 3: Field data along with location, depth, coordinates, physico-chemical parameters (October 2011 sampling).

No.	Sample Code (local name)	Sample Collection Date	Sample depth (m)	Coordinates		Altitude (m)	Field data				Time of Collection
				Latitude N DD,MM,SS	Longitude E DD,MM,SS		Cond. µS/cm	Temp. °C	pH	DO mg/l	
1	1A-BH	13-10-2011	15 m	32,23,05.0	071,25,47.0	189.89	1099	26.0	7.35	7.8	1040 hrs
2	1B-BH	13-10-2011	25 m	32,23,05.0	071,25,47.0	189.89	1129	26.1	7.52	4.4	1000 hrs
3	1C-TW	08-12-2011	50 m	32,23,05.0	071,25,47.0	189.89	966	24.7	7.29	3.3	1100 hrs
4	2A-HP	08-12-2011	18 m	32,22,54.50	071,24,41.20	194.77	1270	25.4	7.43	6.2	1330 hrs
5	2B-TW	08-12-2011	50 m	32,22,54.50	071,24,41.20	194.77	1053	25.6	7.33	4.1	1400 hrs
6	3-TW	09-12-2011	35 m	32.22.28.5	071.25.21.60	203.00	993	26.3	7.40	4.2	1300 hrs
7	4-TW	13-10-2011	50 m	32,22,31.00	071,24,50.00	196.60	840	26.4	7.45	4.7	1215 hrs
8	WRP Deep	12-10-2011	83 m	32,23,28.10	071,27,55.60	208.48	302	26.2	8.32	3.7	1430 hrs
9	WRP Shallow	12-10-2011	20 m	32,23,25.40	071,28,02.10	193.24	626	26.1	7.85	6.0	1500 hrs
10	China town Deep	12-10-2011	83 m	32,23,22.10	071,27,27.40	199.95	624	26.0	7.93	4.0	1600hrs
11	China town Shallow	13-10-2011	20 m	32,23,27.50	071,27,37.50	211.23	645	26.2	7.51	5.8	1400hrs
12	RFO Deep	13-10-2011	83 m	32,23,03.60	071,27,27.40	199.95	740	26.1	7.75	3.0	1430hrs
13	Chascent Deep	13-10-2011	83 m	32,23,29.90	071,27,20.20	207.26	480	26.2	7.86	3.6	1530 hrs
14	Chascent Shallow	13-10-2011	20 m	32,23,29.90	071,27,20.20	207.26	848	26.1	7.79	4.0	1500 hrs
15	Thal Canal	13-10-2011	2 m	32,21,27.60	071,27,40.60	209.09	215	21.8	8.47	11.7	1600 hrs
16	C.J Link Canal	13-10-2011	2 m	32,24,27.30	071,27,04.10	212.75	223	22.2	8.30	10.2	1700 hrs

Table 4. Field data along with location, depth, coordinates, physico-chemical parameters (September 2012 sampling)

Sr. No.	Sample Code (local name)	Sample Collection Date	Sample depth	Coordinates		Altitude	Field data				Time of Collection
				Latitude	Longitude		Cond	Temp.	pH	DO	
			(m)	N DD,MM,SS	E DD,MM,SS	(m)	µS/cm	°C)		mg/l	Hrs.
1	1A-BH	26-09-2012	15	32,23,05.0	071,25,47.0	189.89	1123	25.2	7.40	6.16	11:52
2	1B-BH	26-09-2012	25	32,23,05.0	071,25,47.0	189.89	1025	25.1	7.56	4.80	12:00
3	1C-TW	26-09-2012	50	32,23,05.0	071,25,47.0	189.89	965	25.1	7.47	2.04	09:45
4	2A-HP	26-09-2012	18	32,22,54.50	071,24,41.20	194.77	968	26.6	7.50	2.63	13:00
5	2B-TW	28-09-2012	50	32,22,54.50	071,24,41.20	194.77	1077	26.0	7.51	2.13	09:30
6	3-TW	27-09-2012	35	32.22.28.5	071.25.21.60	203.00	1046	25.2	7.44	1.33	08:30
7	4-TW	26-09-2012	50	32,22,31.00	071,24,50.00	196.60	910	25.1	7.26	2.75	14:00
8	WRP Deep	27-09-2012	83	32,23,28.10	071,27,55.60	208.48	301	22.2	8.05	2.13	10:00
9	WRP Shallow	27-09-2012	20	32,23,25.40	071,28,02.10	193.24	478	25.2	7.76	2.70	16;00
10	China town Deep	27-09-2012	83	32,23,22.10	071,27,27.40	199.95	654	25.6	7.79	3.34	15:15
11	China town Shallow	27-09-2012	20	32,23,27.50	071,27,37.50	211.23	627	27.2	7.45	3.45	12:40
12	RFO Deep	27-09-2012	83	32,23,03.60	071,27,27.40	199.95	732	25.1	7.74	3.11	1;00
13	Chascent Deep	27-09-2012	83	32,23,29.90	071,27,20.20	207.26	457	25.2	7.69	2.93	1;30
14	Chascent Shallow	27-09-2012	20	32,23,29.90	071,27,20.20	207.26	792	26.4	7.75	1.96	11;00

Table 5. Field data along with location, depth, coordinates, physico-chemical parameters (April 2014 sampling)

Sr. No.	Sample Code (local name)	Sample Collection Date	Sample depth	Coordinates		Altitude	Field data				Time of Collection
				Latitude	Longitude		Cond	Temp.	pH	DO	
			(m)	N DD,MM,SS	E DD,MM,SS	(m)	µS/cm	^{o}C)		mg/l	Hrs.
1	1A-BH	9/4/2014	15	32,23,05.0	071,25,47.0	189.89	1118	26	7.47	0.83	10:40
2	1B-BH	9/4/2014	25	32,23,05.0	071,25,47.0	189.89	1121	24	7.37	5.11	9:30
3	1C-TW	9/4/2014	50	32,23,05.0	071,25,47.0	189.89	981	25	7.582	1.22	10:40
4	2A-HP	9/4/2014	18	32,22,54.50	071,24,41.20	194.77	1027	26	7.65	1.36	11:40
5	2B-TW	9/4/2014	50	32,22,54.50	071,24,41.20	194.77	998	26	7.57	2.05	14:20
6	3-TW	9/4/2014	35	32.22.28.5	071.25.21.60	203.00	1012	26	7.63	1.70	14:00
7	4-TW	9/4/2014	50	32,22,31.00	071,24,50.00	196.60	802	25	7.62	2.38	13:00
8	WRP Deep	10/4/2014	83	32,23,28.10	071,27,55.60	208.48	296	26	8.17	2.12	9:20
9	WRP Shallow	10/4/2014	20	32,23,25.40	071,28,02.10	193.24	419	26	7.90	1.83	9:45
10	China town Deep	10/4/2014	83	32,23,22.10	071,27,27.40	199.95	920	27	7.71	8.89	11:00
11	China town Shallow	10/4/2014	20	32,23,27.50	071,27,37.50	211.23	663	26	7.79	1.69	10:15
12	RFO Deep	10/4/2014	83	32,23,03.60	071,27,27.40	199.95	772	27	7.83	1.44	12:15
13	Chascent Deep	10/4/2014	83	32,23,29.90	071,27,20.20	207.26	432	27	7.93	1.32	12:50
14	Chascent Shallow	10/4/2014	20	32,23,29.90	071,27,20.20	207.26	907	27	7.66	0.79	12:40
15	Thal Canal	10/4/2014	2	32,21,27.60	071,27,40.60	209.09	295	27	8.23	7.30	19:00
16	C.J Link Canal	10/4/2014	2	32,24,27.30	071,27,04.10	212.75	395	26	8.39	8.30	18:00

Table 6. Field data along with location, depth, coordinates, physico-chemical parameters June 2014 sampling)

Sr. No.	Sample Code (local name)	Sample Collection Date	Sample depth	Coordinates		Altitude	Field data				Time of Collection
				Latitude	Longitude		Cond	Temp.	pH	DO	
			(m)	N DD,MM,SS	E DD,MM,SS	(m)	µS/cm	°C)		mg/l	Hrs.
1	1A-BH	18/6/2014	15	32,23,05.0	071,25,47.0	189.89	1152	25.8	7.72	4.25	9.00
2	1B-BH	18/6/2014	25	32,23,05.0	071,25,47.0	189.89	1117	25.9	7.58	4.86	10.00
3	1C-TW	18/6/2014	50	32,23,05.0	071,25,47.0	189.89	1004	26.2	7.57	1.7	8.00
4	2A-HP	18/6/2014	18	32,22,54.50	071,24,41.20	194.77	1151	26.9	7.75	2.28	11.00
5	2B-TW	19/6/2014	50	32,22,54.50	071,24,41.20	194.77	946	25.7	7.68	1.91	7.00
6	3-TW	18/6/2014	35	32.22.28.5	071.25.21.60	203.00	1048	26.3	7.72	2.10	19.00
7	4-TW	18/6/2014	50	32,22,31.00	071,24,50.00	196.60	809	25.8	7.64	2.67	19:45
8	WRP Deep	19/6/2014	83	32,23,28.10	071,27,55.60	208.48	312	21.9	8.17	1.92	10:15
9	WRP Shallow	19/6/2014	20	32,23,25.40	071,28,02.10	193.24	370	23.9	8.14	4.98	10:45
10	China town Deep	19/6/2014	83	32,23,22.10	071,27,27.40	199.95	891	27.4	7.71	8.71	12:30
11	China town Shallow	19/6/2014	20	32,23,27.50	071,27,37.50	211.23	748	28.8	7.67	6.28	13:00
12	RFO Deep	19/6/2014	83	32,23,03.60	071,27,27.40	199.95	771	25.2	7.89	3.53	14:30
13	Chascent Deep	19/6/2014	83	32,23,29.90	071,27,20.20	207.26	436	24.9	7.91	2.53	15:30
14	Chascent Shallow	19/6/2014	20	32,23,29.90	071,27,20.20	207.26	827	27.1	7.79	4.64	15:00
15	Thal Canal	20/6/2014	2	32,21,27.60	071,27,40.60	209.09	171.9	23.2	8.36	7.95	11:15
16	C.J Link Canal	20/6/2014	2	32,24,27.30	071,27,04.10	212.75	176	25.5	8.2	7.57	10:15

Table 7. Field data along with location, depth, coordinates, physico-chemical parameters (October 2014 sampling)

Sr. No.	Sample Code (local name)	Sample Collection Date	Sample depth	Coordinates		Altitude	Field data				Time of Collection
				Latitude	Longitude		Cond	Temp.	pH	DO	
			(m)	N DD,MM,SS	E DD,MM,SS	(m)	µS/cm	°C)		mg/l	Hrs.
1	1A-BH	15/10/2014	15	32,23,05.0	071,25,47.0	189.89	1250	24.7	7.5	2.83	9:40
2	1B-BH	15/10/2014	25	32,23,05.0	071,25,47.0	189.89	1155	24.0	7.43	5.43	9:15
3	1C-TW	15/10/2014	50	32,23,05.0	071,25,47.0	189.89	1003	24.1	7.6	1.85	9:00
4	2A-HP	15/10/2014	18	32,22,54.50	071,24,41.20	194.77	1037	24.9	7.62	2.14	10:10
5	2B-TW	15/10/2014	50	32,22,54.50	071,24,41.20	194.77	998	25.6	7.50	3.08	11:40
6	3-TW	15/10/2014	35	32.22.28.5	071.25.21.60	203.00	1036	25.0	7.6	2.23	10:45
7	4-TW	15/10/2014	50	32,22,31.00	071,24,50.00	196.60	802	24.8	7.66	2.3	10:30
8	WRP Deep	15/10/2014	83	32,23,28.10	071,27,55.60	208.48	307	22.5	8.16	1.82	14:10
9	WRP Shallow	15/10/2014	20	32,23,25.40	071,28,02.10	193.24	356	23.4	8.18	1.85	14:15
10	China town Deep	15/10/2014	83	32,23,22.10	071,27,27.40	199.95	750	25.4	7.82	3.64	14:30
11	China town Shallow	15/10/2014	20	32,23,27.50	071,27,37.50	211.23	756	26.9	7.62	6.5	15:10
12	RFO Deep	15/10/2014	83	32,23,03.60	071,27,27.40	199.95	763	24.5	7.6	2.6	16:00
13	Chascent Deep	15/10/2014	83	32,23,29.90	071,27,20.20	207.26	427	24.6	7.98	5.14	15:40
14	Chascent Shallow	15/10/2014	20	32,23,29.90	071,27,20.20	207.26	784	26.2	7.78	2.35	15:30
15	Thal Canal	16/10/2014	2	32,21,27.60	071,27,40.60	209.09	229	18.6	8.08	8.84	8:00
16	C.J Link Canal	15/10/2014	2	32,24,27.30	071,27,04.10	212.75	296	20.7	8.25	8.62	16:30

Table No.8. Stable Isotope data of water samples from project area (Feb/March 2011 sampling).

No.	Sample Code	Sample Collection Date	Sample depth	Coordinates		Altitude	Isotopic data	
	(local name)			Latitude	Longitude		$\delta^{18}O$	$\delta^{2}H$
			(m)	N DD,MM,SS	E DD,MM,SS	(m)	‰	‰
1	1A-BH	03-02-2011	15	32,23,05.0	071,25,47.0	189.89	-10.61	-69.59
2	1B-BH	03-02-2011	25	32,23,05.0	071,25,47.0	189.89	-10.77	-73.44
3	1C-TW	03-02-2011	50	32,23,05.0	071,25,47.0	189.89	-11.01	-74.30
4	2A-HP	04-02-2011	18	32,22,54.50	071,24,41.20	194.77		-64.36
5	2B-TW	04-02-2011	50	32,22,54.50	071,24,41.20	194.77	-10.58	-72.43
6	3-TW	04-02-2011	35	32.22.28.5	071.25.21.60	203.00	-11.25	-77.55
7	4-TW	04-02-2011	50	32,22,31.00	071,24,50.00	196.60	-11.15	-77.00
8	1A-BH	31-03-2011	15	32,23,05.0	071,25,47.0	189.89	-11.05	-71.31
9	1B-BH	31-03-2011	25	32,23,05.0	071,25,47.0	189.89	-10.75	-72.56
10	1C-TW	30-03-2011	50	32,23,05.0	071,25,47.0	189.89	-10.88	-75.12
11	2A-HP	31-03-2011	18	32,22,54.50	071,24,41.20	194.77	-10.36	-68.14
12	2B-TW	31-03-2011	50	32,22,54.50	071,24,41.20	194.77	-11.31	-73.87
13	3-TW	31-03-2011	35	32.22.28.5	071.25.21.60	203.00	-11.22	-75.05
14	4-TW	30-03-2011	50	32,22,31.00	071,24,50.00	196.60	-11.20	-75.52
15	WRP Deep	30-03-2011	83	32,23,28.10	071,27,55.60	208.48	-10.96	-72.57
16	WRP Shallow	30-03-2011	20	32,23,25.40	071,28,02.10	193.24	-10.76	-72.18
17	China town Deep	30-03-2011	83	32,23,22.10	071,27,27.40	199.95	-10.86	-75.08
18	China town Shallow	30-03-2011	20	32,23,27.50	071,27,37.50	211.23	-8.22	-53.77
19	RFO Deep	30-03-2011	83	32,23,03.60	071,27,27.40	199.95	-10.80	-70.92
20	Chascent Deep	31-03-2011	83	32,23,29.90	071,27,20.20	207.26	-11.27	-76.26
21	Chascent Shallow	31-03-2011	20	32,23,29.90	071,27,20.20	207.26	-10.71	-72.69
22	Thal Canal	07-05-2011	02	32,21,27.60	071,27,40.60	209.09	-10.68	-69.67
23	C.J Link Canal	07-05-2011	02	32,24,27.30	071,27,04.10	212.75	-10.65	-71.70

Table No.9. Stable Isotope data of water samples from project area (October 2011 sampling).

No.	Sample Code (local name)	Sample Collection Date	Sample depth (m)	Coordinates Latitude N DD,MM,SS	Coordinates Longitude E DD,MM,SS	Altitude (m)	Isotopic data $\delta^{18}O$ ‰	Isotopic data $\delta^{2}H$ ‰	Time of collection
1	1A-BH	13-10-2011	15 m	32,23,05.0	071,25,47.0	189.89	-9.55	-63.78	1040 hrs
2	1B-BH	13-10-2011	25 m	32,23,05.0	071,25,47.0	189.89	-10.96	-71.50	1000 hrs
3	1C-TW	08-12-2011	50 m	32,23,05.0	071,25,47.0	189.89	-11.29	-79.56	1100 hrs
4	2A-HP	08-12-2011	18 m	32,22,54.50	071,24,41.20	194.77	-9.12	-62.60	1330 hrs
5	2B-TW	08-12-2011	50 m	32,22,54.50	071,24,41.20	194.77	-10.89	-74.25	1400 hrs
6	3-TW	09-12-2011	35 m	32.22.28.5	071.25.21.60	203.00	-11.84	-78.74	1300 hrs
7	4-TW	13-10-2011	50 m	32,22,31.00	071,24,50.00	196.60	-11.77	-75.65	1215 hrs
8	WRP Deep	12-10-2011	83 m	32,23,28.10	071,27,55.60	208.48	-11.40	-71.84	1430 hrs
9	WRP Shallow	12-10-2011	20 m	32,23,25.40	071,28,02.10	193.24	-11.18	-72.10	1500 hrs
10	China town Deep	12-10-2011	83 m	32,23,22.10	071,27,27.40	199.95	-11.29	-73.50	1600hrs
11	China town Shallow	13-10-2011	20 m	32,23,27.50	071,27,37.50	211.23	-9.63	-60.84	1400hrs
12	RFO Deep	13-10-2011	83 m	32,23,03.60	071,27,27.40	199.95	-11.29	-74.99	1430hrs
13	Chascent Deep	13-10-2011	83 m	32,23,29.90	071,27,20.20	207.26	-11.69	-77.13	1530 hrs
14	Chascent Shallow	13-10-2011	20 m	32,23,29.90	071,27,20.20	207.26	-11.76	-75.18	1500 hrs
15	Thal Canal	13-10-2011	2 m	32,21,27.60	071,27,40.60	209.09	-13.33	-89.94	1600 hrs
16	C.J Link Canal	13-10-2011	2 m	32,24,27.30	071,27,04.10	212.75	-13.14	-87.39	1700 hrs

Table 10. Stable Isotope data of water samples from project area (September 2012 sampling)

Sr. No.	Sample Code (local name)	Sample Collection	Sample Depth	Coordinates		Altitude	$\delta\ ^{18}O$	$\delta\ ^{2}H$	d-excess
				Latitude	Longitude				
		Date	(m)	N DD,MM,SS	E DD,MM,SS	(m)	‰	‰	
1	1A-BH	26-09-2012	15	32,23,05.0	071,25,47.0	189.89	-10.16	-70.61	10.63
2	1B-BH	26-09-2012	25	32,23,05.0	071,25,47.0	189.89	-11.14	-73.88	15.25
3	1C-TW	26-09-2012	50	32,23,05.0	071,25,47.0	189.89	-11.05	-74.64	13.76
4	2A-HP	26-09-2012	18	32,22,54.50	071,24,41.20	194.77	-10.81	-73.80	12.68
5	2B-TW	28-09-2012	50	32,22,54.50	071,24,41.20	194.77	-11.00	-73.58	14.39
6	3-TW	27-09-2012	35	32.22.28.5	071.25.21.60	203.00	-11.34	-75.48	15.25
7	4-TW	26-09-2012	50	32,22,31.00	071,24,50.00	196.60	-10.82	-72.85	13.71
8	WRP Deep	27-09-2012	83	32,23,28.10	071,27,55.60	208.48	-11.38	-74.86	16.14
9	WRP Shallow	27-09-2012	20	32,23,25.40	071,28,02.10	193.24	-10.98	-73.00	14.81
10	China town Deep	27-09-2012	83	32,23,22.10	071,27,27.40	199.95	-10.81	-74.07	12.42
11	China town Shallow	27-09-2012	20	32,23,27.50	071,27,37.50	211.23	-10.71	-72.32	13.36
12	RFO Deep	27-09-2012	83	32,23,03.60	071,27,27.40	199.95	-11.15	-75.81	13.40
13	Chascent Deep	27-09-2012	83	32,23,29.90	071,27,20.20	207.26	-11.37	-75.80	15.16
14	Chascent Shallow	27-09-2012	20	32,23,29.90	071,27,20.20	207.26	-11.27	-75.54	14.62

Table 11. Stable Isotope data of water samples from project area (April 2014 sampling)

Sr. No.	Sample Code (local name)	Sample Collection Date	Sample Depth (m)	Coordinates Latitude N DD,MM,SS	Longitude E DD,MM,SS	Altitude (m)	δ ^{18}O ‰	δ ^{2}H ‰	d-excess
1	1A-BH	9/4/2014	15	32,23,05.0	071,25,47.0	189.89	-10.94	-73.91	13.61
2	1B-BH	9/4/2014	25	32,23,05.0	071,25,47.0	189.89	-10.74	-69.55	16.38
3	1C-TW	9/4/2014	50	32,23,05.0	071,25,47.0	189.89	-11.22	-76.80	12.92
4	2A-HP	9/4/2014	18	32,22,54.50	071,24,41.20	194.77	-10.76	-71.16	14.92
5	2B-TW	9/4/2014	50	32,22,54.50	071,24,41.20	194.77	-10.97	-75.13	12.63
6	3-TW	9/4/2014	35	32.22.28.5	071.25.21.60	203.00	-11.36	-78.27	12.58
7	4-TW	9/4/2014	50	32,22,31.00	071,24,50.00	196.60	-11.47	-78.97	12.79
8	WRP Deep	10/4/2014	83	32,23,28.10	071,27,55.60	208.48	-11.72	-75.90	17.86
9	WRP Shallow	10/4/2014	20	32,23,25.40	071,28,02.10	193.24	-11.52	-74.59	17.53
10	China town Deep	10/4/2014	83	32,23,22.10	071,27,27.40	199.95	-10.23	-67.85	14.00
11	China town Shallow	10/4/2014	20	32,23,27.50	071,27,37.50	211.23	-11.42	-75.90	15.46
12	RFO Deep	10/4/2014	83	32,23,03.60	071,27,27.40	199.95	-10.97	-76.56	11.17
13	Chascent Deep	10/4/2014	83	32,23,29.90	071,27,20.20	207.26	-11.73	-81.32	12.53
14	Chascent Shallow	10/4/2014	20	32,23,29.90	071,27,20.20	207.26	-11.10	-78.70	10.06
15	Thal Canal	10/4/2014	2	32,21,27.60	071,27,40.60	209.09	-8.20	-49.73	15.83
16	C.J Link Canal	10/4/2014	2	32,24,27.30	071,27,04.10	212.75	-8.56	-50.02	18.43

Table 12. Stable Isotope data of water samples from project area (June 2014 sampling)

Sr. No.	Sample Code (local name)	Sample Collection	Sample Depth	Coordinates		Altitude	δ ^{18}O	δ ^{2}H	d-excess
				Latitude	Longitude				
		Date	(m)	N DD,MM,SS	E DD,MM,SS	(m)	‰	‰	
1	1A-BH	18/6/2014	15	32,23,05.0	071,25,47.0	189.89	-10.98	-73.30	14.55
2	1B-BH	18/6/2014	25	32,23,05.0	071,25,47.0	189.89	-11.11	-73.91	14.97
3	1C-TW	18/6/2014	50	32,23,05.0	071,25,47.0	189.89	-11.36	-75.14	15.75
4	2A-HP	18/6/2014	18	32,22,54.50	071,24,41.20	194.77	-10.13	-69.16	11.89
5	2B-TW	19/6/2014	50	32,22,54.50	071,24,41.20	194.77	-11.46	-76.68	14.97
6	3-TW	18/6/2014	35	32.22.28.5	071.25.21.60	203.00	-11.64	-78.74	14.34
7	4-TW	18/6/2014	50	32,22,31.00	071,24,50.00	196.60	-11.73	-79.19	14.66
8	WRP Deep	19/6/2014	83	32,23,28.10	071,27,55.60	208.48	-11.55	-78.19	14.17
9	WRP Shallow	19/6/2014	20	32,23,25.40	071,28,02.10	193.24	-11.66	-75.87	17.42
10	China town Deep	19/6/2014	83	32,23,22.10	071,27,27.40	199.95	-10.23	-71.24	10.56
11	China town Shallow	19/6/2014	20	32,23,27.50	071,27,37.50	211.23	-10.05	-69.39	11.02
12	RFO Deep	19/6/2014	83	32,23,03.60	071,27,27.40	199.95	-11.11	-75.22	13.67
13	Chascent Deep	19/6/2014	83	32,23,29.90	071,27,20.20	207.26	-11.68	-79.85	13.59
14	Chascent Shallow	19/6/2014	20	32,23,29.90	071,27,20.20	207.26	-11.57	-78.13	14.43
15	Thal Canal	20/6/2014	2	32,21,27.60	071,27,40.60	209.09	-12.16	-79.71	17.58
16	C.J Link Canal	20/6/2014	2	32,24,27.30	071,27,04.10	212.75	-11.95	-79.05	16.51

Table 13. Stable Isotope data of water samples from project area (October 2014 sampling)

Sr. No.	Sample Code (local name)	Sample Collection	Sample Depth	Coordinates		Altitude	δ ^{18}O (‰)	δ ^{2}H (‰)	d-excess
				Latitude	Longitude				
		Date	(m)	N DD,MM,SS	E DD,MM,SS	(m)	‰	‰	‰
1	1A-BH	15/10/2014	15	32,23,05.0	071,25,47.0	189.89	-10.75	-75.03	10.97
2	1B-BH	15/10/2014	25	32,23,05.0	071,25,47.0	189.89	-10.32	-72.91	9.65
3	1C-TW	15/10/2014	50	32,23,05.0	071,25,47.0	189.89	-10.74	-73.90	11.98
4	2A-HP	15/10/2014	18	32,22,54.50	071,24,41.20	194.77	-10.49	-74.81	9.11
5	2B-TW	15/10/2014	50	32,22,54.50	071,24,41.20	194.77	-10.45	-72.36	11.24
6	3-TW	15/10/2014	35	32.22.28.5	071.25.21.60	203.00	-11.05	-77.98	10.38
7	4-TW	15/10/2014	50	32,22,31.00	071,24,50.00	196.60	-10.85	-76.71	10.09
8	WRP Deep	15/10/2014	83	32,23,28.10	071,27,55.60	208.48	-11.02	-76.33	11.83
9	WRP Shallow	15/10/2014	20	32,23,25.40	071,28,02.10	193.24	-11.21	-77.71	11.97
10	China town Deep	15/10/2014	83	32,23,22.10	071,27,27.40	199.95	-10.29	-71.74	10.58
11	China town Shallow	15/10/2014	20	32,23,27.50	071,27,37.50	211.23	-9.16	-62.36	10.92
12	RFO Deep	15/10/2014	83	32,23,03.60	071,27,27.40	199.95	-10.78	-76.06	10.14
13	Chascent Deep	15/10/2014	83	32,23,29.90	071,27,20.20	207.26	-11.22	-75.43	14.30
14	Chascent Shallow	15/10/2014	20	32,23,29.90	071,27,20.20	207.26	-11.32	-76.50	14.06
15	Thal Canal	16/10/2014	2	32,21,27.60	071,27,40.60	209.09	-12.34	-86.30	12.42
16	C.J Link Canal	15/10/2014	2	32,24,27.30	071,27,04.10	212.75	-12.14	-85.30	11.82

Table 14. Noble gas concentrations of samples (Feb/March 2011 sampling)

Sequence ID	Sample ID	Methods	He [x 10^{-8} cm^3STP/g]	Ne [x 10^{-7} cm^3STP/g]	Ar [x 10^{-4} cm^3STP/g]	Kr [x 10^{-8} cm^3STP/g]	Xe [x 10^{-8} cm^3STP/g]
418	1A-BH	Cu-Tube	4.48 ±0.05	1.92 ±0.01	3.56 ±0.04	8.30 ±0.18	1.37 ±0.07
450	1A-BH Feb Sampling)	Cu-Tube	5.39 ±0.07	2.20 ±0.01	3.55 ±0.04	8.10 ±0.13	1.10 ±0.06
423	1B-BH	Cu-Tube	5.88 ±0.04	2.35 ±0.01	3.26 ±0.04	7.10 ±0.15	0.94 ±0.04
451	1B-BH (Feb Sampling)	Cu-Tube	5.83 ±0.04	2.34 ±0.01	3.30 ±0.03	7.05 ±0.12	0.93 ±0.04
418	1C-TW	Cu-Tube	5.36 ±0.05	2.17 ±0.01	3.28 ±0.04	7.11 ±0.15	0.96 ±0.04
442	1C-TW (Feb Sampling)	Cu-Tube	4.98 ±0.04	2.07 ±0.01	3.26 ±0.06	7.02 ±0.17	0.89 ±0.05
451	2A-HP(Feb Sampling)	Cu-Tube	4.20 ±0.03	1.76 ±0.01	2.80 ±0.03	6.05 ±0.10	0.79 ±0.04
444	3-TW	Cu-Tube	5.46 ±0.06	2.18 ±0.01	3.28 ±0.04	6.89 ±0.11	0.85 ±0.04
418	3-TW(Feb Sampling)	Cu-Tube	5.00 ±0.05	2.04 ±0.01	3.15 ±0.04	6.72 ±0.14	0.98 ±0.05
445	4-TW	Cu-Tube	4.70 ±0.05	1.93 ±0.01	3.08 ±0.03	6.65 ±0.11	0.79 ±0.04
444	4-TW(Feb Sampling)	Cu-Tube	5.60 ±0.06	2.24 ±0.01	3.26 ±0.04	7.00 ±0.11	0.86 ±0.04
442	C.J. Link Canal	Cu-Tube	4.25 ±0.04	1.77 ±0.01	3.01 ±0.05	6.71 ±0.16	0.80 ±0.04
412	Chascent Deep	Cu-Tube	3.79 ±0.02	1.59 ±0.01	2.62 ±0.03	5.15 ±0.49	0.72 ±0.05
442	Chascent Shallow	Cu-Tube	4.68 ±0.04	1.94 ±0.01	3.02 ±0.05	6.69 ±0.16	0.84 ±0.04
445	China town Deep	Cu-Tube	5.47 ±0.06	2.18 ±0.01	3.24 ±0.03	6.89 ±0.11	0.81 ±0.04
422	China town Shallow	Cu-Tube	3.06 ±0.02	1.25 ±0.00	2.44 ±0.04	5.49 ±0.12	0.71 ±0.04
423	RFO Deep	Cu-Tube	6.03 ±0.04	2.28 ±0.01	3.30 ±0.04	6.99 ±0.15	0.95 ±0.04
422	Thal Canal	Cu-Tube	4.55 ±0.03	1.88 ±0.01	3.17 ±0.05	7.05 ±0.15	0.98 ±0.05
445	Duplicate	Cu-Tube	4.62 ±0.05	1.89 ±0.01	3.11 ±0.03	6.70 ±0.11	0.80 ±0.04
423	WRP Deep	Cu-Tube	4.35 ±0.03	1.83 ±0.01	3.29 ±0.04	7.46 ±0.16	1.08 ±0.05
444	WRP Shallow	Cu-Tube	2.62 ±0.03	1.10 ±0.01	2.50 ±0.03	6.46 ±0.10	0.93 ±0.05

Noble gas temperatures and other parameters shown in this table are calculated based on the Uncertainties are resulted from the root-finding method to fit the randomly varied noble gas concentrations within their respective 1 sigma uncertainties (included elements are listed in this table) by varying temperature, excess air and fractionation factor. Equilibrium concentrations of noble gases are calculated by assuming a barometric pressure of 1000 (±10%) mbar and its uncertainties were also included in the model calculation. closed-system equilibrium model with entrapped air by Aeschbach-Hertig et al., (2000).

Table 15. Noble gas temperatures (Feb/March 2011 sampling)

Sequence ID	Sample ID	Methods	Noble Gas Temp.		Excess Air	χ^2	*F*	Model	Data included to the calc.
			[°C]		[cm^3STP/kg]				
418	1A-BH	Cu-Tube	10.41	±0.13	0.34±0.01	5.02	0	CE (Aeschbach)	Ne, Ar, Kr, Xe
450	1A-BH (Feb Sampling)	Cu-Tube	12.71	±0.13	2.08±0.03	0.41	0	CE (Aeschbach)	Ne, Ar, Kr, Xe
423	1B-BH	Cu-Tube	18.93	±0.13	3.82±0.03	0.41	0.076	CE (Aeschbach)	Ne, Ar, Kr, Xe
451	1B-BH (Feb Sampling)	Cu-Tube	18.57	±0.14	3.92±0.09	0.41	0.115	CE (Aeschbach)	Ne, Ar, Kr, Xe
418	1C-TW	Cu-Tube	17.42	±0.07	2.69±0.03	0.38	0.105	CE (Aeschbach)	Ne, Ar, Kr, Xe
442	1C-TW (Feb Sampling)	Cu-Tube	17.71	±0.17	2.13±0.03	3.26	0.146	CE (Aeschbach)	Ne, Ar, Kr, Xe
451	2A-HP(Feb Sampling)	Cu-Tube	22.59	±0.28	0.48±0.01	1.37	0.061	CE (Aeschbach)	Ne, Ar, Kr, Xe
451	2B-TW(Feb Sampling)	Cu-Tube	20.54	±0.16	0.52±0.01	3.45	6.00E-05	CE (Aeschbach)	Ne, Ar, Kr, Xe
444	3-TW	Cu-Tube	24.53	±0.11	66.16±0.55	0.52	0.721	CE (Aeschbach)	Ne, Ar, Kr, Xe
418	3-TW(Feb Sampling)	Cu-Tube	18.4	±0.23	1.91±0.04	2.32	0.078	CE (Aeschbach)	Ne, Ar, Kr, Xe
445	4-TW	Cu-Tube	19.29	±0.12	1.47±0.03	11.35	0.151	CE (Aeschbach)	Ne, Ar, Kr, Xe
444	4-TW(Feb Sampling)	Cu-Tube	19.05	±0.16	6.05±0.19	2.71	0.406	CE (Aeschbach)	Ne, Ar, Kr, Xe
442	C.J. Link Canal	Cu-Tube	18.88	±0.15	0.33±0.01	8.37	0.086	CE (Aeschbach)	Ne, Ar, Kr, Xe
412	Chascent Deep	Cu-Tube	27.66	±0.25	0.00±0.00	23.96	0	CE (Aeschbach)	Ne, Ar, Kr, Xe
442	Chascent Shallow	Cu-Tube	19.65	±0.13	1.37±0.03	1.96	0.061	CE (Aeschbach)	Ne, Ar, Kr, Xe
445	China town Deep	Cu-Tube	24.43	±0.06	58.55±0.45	2.81	0.717	CE (Aeschbach)	Ne, Ar, Kr, Xe
422	China town Shallow	Cu-Tube	60.99	±0.22	0.00±0.01	####	0	CE (Aeschbach)	Ne, Ar, Kr, Xe
423	RFO Deep	Cu-Tube	18.23	±0.14	4.15±0.08	0.73	0.204	CE (Aeschbach)	Ne, Ar, Kr, Xe
422	Thal Canal	Cu-Tube	16.38	±0.25	0.71±0.02	0.31	0.037	CE (Aeschbach)	Ne, Ar, Kr, Xe
445	Thal Canal Duplicate	Cu-Tube	18.4	±0.15	1.10±0.02	14.65	0.161	CE (Aeschbach)	Ne, Ar, Kr, Xe
423	WRP Deep	Cu-Tube	13.86	±0.17	0.23±0.01	0.47	0	CE (Aeschbach)	Ne, Ar, Kr, Xe
444	WRP Shallow	Cu-Tube	55.33	±0.85	0.00±0.02	####	0	CE (Aeschbach)	Ne, Ar, Kr, Xe

Table 16. $^3He/^4He$ ratios & T - ^3He ages (Feb/March 2011 sampling)

Sequence ID	Sample ID	Methods	He		$^3He/^4He$		[^{3}He]trit		Tritium		T-^{3}He age
			[x 10^{-8} cm^3STP/g]		[x10^{-6}]		[TU]		[TU]		[Years]
418	1A-BH	Cu-Tube	4.48	±0.05	1.54	±0.02	1	±0	10.3	±0.80	1.7
450	1A-BH (Feb Sampling)	Cu-Tube	5.39	±0.07	1.47	±0.01	1	±0	10.3	±0.80	1.6
423	1B-BH	Cu-Tube	5.88	±0.04	13.93	±0.08	296	±2	11.7	±0.80	58.1
451	1B-BH (Feb Sampling)	Cu-Tube	5.83	±0.04	12.85	±0.11	268	±2	11.7	±0.80	56.4
418	1C-TW	Cu-Tube	5.36	±0.05	3	±0.04	34	±1	11	±0.80	25
442	1C-TW (Feb Sampling)	Cu-Tube	4.98	±0.04	3.37	±0.02	38	±1	11	±0.80	26.7
451	2A-HP(Feb Sampling)	Cu-Tube	4.2	±0.03	1.53	±0.01	2	±0	8.5	±0.80	3.5
451	2B-TW(Feb Sampling)	Cu-Tube	4.35	±0.03	2.13	±0.02	12	±0	7.2	±0.80	18
444	3-TW	Cu-Tube	5.46	±0.06	1.59	±0.01	4	±0	4.6	±0.70	11.2
418	3-TW(Feb Sampling)	Cu-Tube	5	±0.05	1.47	±0.02	1	±0	4.6	±0.70	3.2
445	4-TW	Cu-Tube	4.7	±0.05	1.86	±0.01	8	±0	7.1	±0.70	13.7
444	4-TW(Feb Sampling)	Cu-Tube	5.6	±0.06	1.87	±0.02	10	±1	7.1	±0.70	15.9
442	C.J. Link Canal	Cu-Tube	4.25	±0.04	1.38	±0.01	0	±0	15.5	±0.90	0
412	Chascent Deep	Cu-Tube	3.79	±0.02	1.63	±0.01	3	±0	2.2	±0.70	14.9
442	Chascent Shallow	Cu-Tube	4.68	±0.04	4.01	±0.02	48	±1	10.2	±0.80	31
445	China town Deep	Cu-Tube	5.47	±0.06	2.1	±0.01	16	±1	10.95	±0.80	15.7
422	China town Shallow	Cu-Tube	3.06	±0.02	1.87	±0.03	1	±0	10.5	±0.80	1.1
423	RFO Deep	Cu-Tube	6.03	±0.04	2.56	±0.01	30	±0	2.8	±0.70	44
422	Thal Canal	Cu-Tube	4.55	±0.03	1.39	±0.02	0	±0	16.5	±0.80	0
445	Thal Canal Duplicate	Cu-Tube	4.62	±0.05	1.36	±0.01	0	±0	16.5	±0.80	0
423	WRP Deep	Cu-Tube	4.35	±0.03	1.63	±0.01	4	±0	11.4	±0.80	5.2
444	WRP Shallow	Cu-Tube	2.62	±0.03	1.58	±0.02	0	±0	12.6	±0.80	0

T-^{3}He ages are calculated by assuming a terrigenic $^3He/^4He$ ratio of 2x10-8. Amount of excess helium is based on the neon mean with respect to the solution under pressure and temperature observed in the field. Uncertainties are obtained by repeating age calculation for 100 times with parameters randomly varied within their respective uncertainties.

Table 17. Noble gas concentrations of samples (October 2011 sampling)

Sequence ID	Sample ID	Methods	He [x 10^{-8} cm^3STP/g]		Ne [x 10^{-7} cm^3STP/g]		Ar [x 10^{-4} cm^3STP/g]		Kr [x 10^{-8} cm^3STP/g]		Xe [x 10^{-8} cm^3STP/g]	
563	1-C depth 50m	Cu-Tube	5.2	±0.06	2.1	±0.01	3.15	±0.06	0.68	±0.02	0.91	±0.07
565	2-A depth 18m	Cu-Tube	4.1	±0.05	1.67	±0.01	2.82	±0.05	0.64	±0.01	0.91	±0.07
553	2-B depth 50m	Cu-Tube	4.45	±0.07	1.81	±0.02	3.06	±0.03	0.67	±0.01	1.03	±0.06
552	3-TW depth	Cu-Tube	5.04	±0.08	2.04	±0.02	3.18	±0.03	0.69	±0.01	0.85	±0.05
550	WRP deep	Cu-Tube	4.38	±0.05	1.85	±0.03	3.16	±0.04	0.71	±0.02	0.96	±0.07
559	WRP shallow	Cu-Tube	4.29	±0.06	1.72	±0.01	2.99	±0.04	0.66	±0.01	0.9	±0.08
559	Chascent deep	Cu-Tube	5.19	±0.08	2.06	±0.02	3.26	±0.05	0.71	±0.02	0.87	±0.08
552	Chaina Town deep	Cu-Tube	5.85	±0.10	2.34	±0.02	3.39	±0.03	0.71	±0.01	1.03	±0.06
546	C.J Link Canal	Cu-Tube	3.99	±0.05	1.68	±0.03	2.95	±0.04	0.67	±0.01	0.9	±0.07
550	Thal Canal	Cu-Tube	4.66	±0.06	1.93	±0.03	3.19	±0.04	0.72	±0.02	0.92	±0.07
550	4TW depth 50m	Cu-Tube	4.9	±0.06	1.9	±0.02	11.14	±0.41	10.5	±0.5	11.8	±0.5
552	1-A, BH 15m	Cu-Tube	4.53	±0.07	1.43	±0.03	15.61	±0.43	1.3	±0.6	1.4	±0.6
546	R.F.O deep	Cu-Tube	5.09	±0.07	2.34	±0.09	5.1	±0.24	20.5	±1.7	28.7	±1.4

Noble gas temperatures and other parameters shown in this table are calculated based on the Uncertainties are resulted from the root-finding method to fit the randomly varied noble gas concentrations within their respective 1 sigma uncertainties (included elements are listed in this table) by varying temperature, excess air and fractionation factor. Equilibrium concentrations of noble gases are calculated by assuming a barometric pressure of 1000 (±10%) mbar and its uncertainties were also included in the model calculation. Closed-system equilibrium model with entrapped air by Aeschbach-Hertig et al., (2000).

Table 18. Noble gas temperatures (October 2011 sampling)

Sequence ID	Sample ID	Methods	Noble Gas Temp. [°C]		Excess Air [cm^3STP/kg]	χ^2	*F*	Model	Data included to the calc.
563	1-C depth 50m	Cu-Tube	19.04	±0.19	2.31±0.04	0.12	0.1	CE (Aeschbach)	Ne, Ar, Kr, Xe
565	2-A depth 18m	Cu-Tube	22.17	±0.20	0.00±0.02	8.02	0	CE (Aeschbach)	Ne, Ar, Kr, Xe
553	2-B depth 50m	Cu-Tube	18.1	±0.21	0.46±0.01	5.38	0.08	CE (Aeschbach)	Ne, Ar, Kr, Xe
552	3-TW depth	Cu-Tube	18.14	±0.18	2.11±0.04	5.56	0.16	CE (Aeschbach)	Ne, Ar, Kr, Xe
550	WRP deep	Cu-Tube	16.13	±0.28	0.59±0.02	0.48	0.11	CE (Aeschbach)	Ne, Ar, Kr, Xe
559	WRP shallow	Cu-Tube	18.73	±0.21	0.00±0.0	0.69	0	CE (Aeschbach)	Ne, Ar, Kr, Xe
559	Chascent deep	Cu-Tube	16.85	±0.14	2.38±0.04	2.7	0.23	CE (Aeschbach)	Ne, Ar, Kr, Xe
552	Chaina Town deep	Cu-Tube	17.2	±0.17	4.00±0.1	3.3	0.12	CE (Aeschbach)	Ne, Ar, Kr, Xe
550	Thal Canal	Cu-Tube	16.23	±0.18	1.03±0.02	0.97	0.07	CE (Aeschbach)	Ne, Ar, Kr, Xe
550	4TW depth 50m	Cu-Tube	19.36	±0.06	1.65±0.01	0.03	0	CE (Aeschbach)	Ne, Ar, Kr, Xe
552	1-A, BH 15m	Cu-Tube	19.58	±0.15	0.80±0.02	0.53	0.12	CE (Aeschbach)	Ne, Ar, Kr, Xe
546	R.F.O deep	Cu-Tube	21.88	±0.25	2.36±0.03	1.64	0.24	CE (Aeschbach)	Ne, Ar, Kr, Xe

Table 19. $^3He/^4He$ ratios & T - ^3He ages (October 2011 sampling)

with modeled excess air &NGT **with excess air by He/Ne=air &NGT**

Sequence ID	Sample ID	Methods	He		$^3He/^4He$		Tritium		$[^3He]_{trit}$		T-^{3}He age		$[^3He]_{trit}$	T-^{3}He age
			[x 10^{-8} cm^3STP/g]		[x10^{-6}]		[TU]		[TU]		[Years]		[TU]	[Years]
563	1-C depth 50m	Cu-Tube	5.2	±0.06	4.06	±0.04	15.36	±0.53	56.3	±1.2	27.4	±0.5	56.32±1.21	27.4±0.55
565	2-A depth 18m	Cu-Tube	4.1	±0.05	1.5	±0.03	8.96	±0.34	2.3	±0.5	4	±0.8	2.27±0.51	4.0±0.81
553	2-B depth 50m	Cu-Tube	4.45	±0.07	1.89	±0.03	8.11	±0.26	9.9	±0.8	14.2	±0.9	9.90±0.82	14.2±0.94
552	3-TW depth	Cu-Tube	5.04	±0.08	1.4	±0.03	2.25	±0.18	0.7	±0.6	5	±3.5	0.71±0.61	4.9±3.47
550	WRP deep	Cu-Tube	4.38	±0.05	1.58	±0.01	14.68	±0.40	3.9	±0.3	4.2	±0.3	3.91±0.33	4.2±0.33
559	WRP shallow	Cu-Tube	4.29	±0.06	2	±0.05	32.33	±1.03	11.7	±0.9	5.5	±0.4	11.72±0.90	5.5±0.39
559	Chascent deep	Cu-Tube	5.19	±0.08	1.68	±0.04	4.65	±0.23	7.3	±0.8	16.7	±1.3	7.23±0.85	16.7±1.38
552	Chaina Town deep	Cu-Tube	5.85	±0.10	2.09	±0.04	10.95	±0.40	16.9	±1.1	16.6	±0.8	16.93±1.06	16.6±0.77
546	C.J Link Canal	Cu-Tube	3.99	±0.05	1.33	±0.05	20.04	±0.69	0	±0.4	0	±0.3	0.00±0.37	0.0±0.32
550	Thal Canal	Cu-Tube	4.66	±0.06	1.37	±0.01	13.63	±0.47	0.1	±0.3	0.1	±0.3	0.11±0.35	0.1±0.40
550	4TW depth 50m	Cu-Tube	4.9	±0.06	1.9	±0.02	11.14	±0.41	10.5	±0.5	11.8	±0.5	10.53±0.47	11.8±0.50
552	1-A, BH 15m	Cu-Tube	4.53	±0.07	1.43	±0.03	15.61	±0.43	1.3	±0.6	1.4	±0.6	1.29±0.60	1.4±0.60
546	R.F.O deep	Cu-Tube	5.09	±0.07	2.34	±0.09	5.1	±0.24	20.5	±1.7	28.7	±1.4	20.55±1.81	28.7±1.40

T-^{3}He ages are calculated by assuming a terrigenic $^3He/^4He$ ratio of 2x10^{-8}. Amount of excess helium is based on the neon mean with respect to the solution under pressure and temperature observed in the field. Uncertainties are obtained by repeating age calculation for 100 times with parameters randomly varied within their respective uncertainties.

Table 20. Noble gas concentrations of samples (October 2012 sampling)

Sequence ID	Sample ID	Methods	He [x 10^{-8} cm^3STP/g]		Ne [x 10^{-7} cm^3STP/g]		Ar [x 10^{-4} cm^3STP/g]		Kr [x 10^{-7} cm^3STP/g]		Xe [x 10^{-8} cm^3STP/g]	
664	1A-BH	Cu-Tube	6.53	±0.12	2.38	±0.03	3.23	±0.02	0.69	±0.02	0.87	±0.07
690	1B-BH	Cu-Tube	9.99	±0.08	3.18	±0.04	3.2	±0.36	0.69	±0.02	0.89	±0.07
681	1C-TW	Cu-Tube	6.08	±0.05	2.32	±0.03	3.43	±0.01	0.73	±0.02	0.98	±0.08
681	2A-HP	Cu-Tube	4.24	±0.04	1.74	±0.02	3	±0.01	0.67	±0.02	0.91	±0.07
681	3-TW	Cu-Tube	4.86	±0.04	1.98	±0.03	4.32	±0.02	0.93	±0.02	1.16	±0.09
681	4-TW	Cu-Tube	4.63	±0.05	1.91	±0.03	3.38	±0.01	0.71	±0.02	1.12	±0.09
755	WRP Deep	Cu-Tube	4.53	±0.06	1.87	±0.01	3.33	±0.04	0.78	±0.02	1.1	±0.06
747	WRP Shallow	Cu-Tube	4.24	±0.07	1.68	±0.01	2.82	±0.04	0.67	±0.02	0.83	±0.05
681	China town Deep	Cu-Tube	5.26	±0.05	2.17	±0.03	3.31	±0.01	0.71	±0.02	0.99	±0.08
690	China town Shallow	Cu-Tube	5.76	±0.04	2.15	±0.03	2.7	±0.31	0.58	±0.02	0.73	±0.06
744	RFO Deep	Cu-Tube	6.09	±0.08	2.32	±0.02	3.41	±0.05	0.69	±0.02	0.84	±0.05
690	Chascent Shallow	Cu-Tube	5.26	±0.04	2.02	±0.03	3.04	±0.36	0.65	±0.02	0.88	±0.07
684	Chascent Deep	Cu-Tube	5.62	±0.05	2.16	±0.03	4.28	±0.02	0.95	±0.03	1.53	±0.12

Table 21. Noble gas temperatures (October 2012 sampling)

Sequence ID	Sample ID	Methods	Noble Gas Temp. [°C]		Excess Air [cm^3STP/kg]		χ^2	*F*	Model	Data included to the calc.
664	1A-BH	Cu-Tube	22.19	±0.09	3.32	±0.05	0.31	4.00E-06	CE (Aeschbach)	Ne, Ar, Kr, Xe
690	1B-BH	Cu-Tube	25.12	±0.22	7.93	±0.11	0.8	0	CE (Aeschbach)	Ne, Ar, Kr, Xe
681	1C-TW	Cu-Tube	17.94	±0.09	3.52	±0.06	1.19	0.1902	CE (Aeschbach)	Ne, Ar, Kr, Xe
681	2A-HP	Cu-Tube	20.17	±0.07	0.33	±0.01	0.01	2.1855	CE (Aeschbach)	Ne, Ar, Kr, Xe
681	3-TW	Cu-Tube	4.64	±0.06	0	±0.02	59.19	0	CE (Aeschbach)	Ne, Ar, Kr, Xe
681	4-TW	Cu-Tube	15.39	±0.07	0.26	±0.00	8.8	0.0215	CE (Aeschbach)	Ne, Ar, Kr, Xe
755	WRP Deep	Cu-Tube	15.5	±0.21	0	±0.02	1.02	0	CE (Aeschbach)	Ne, Ar, Kr, Xe
747	WRP Shallow	Cu-Tube	25.3	±0.30	0	±0.01	32.85	0	CE (Aeschbach)	Ne, Ar, Kr, Xe
681	China town Deep	Cu-Tube	18.54	±0.09	2.18	±0.04	1.11	0.1022	CE (Aeschbach)	Ne, Ar, Kr, Xe
690	China town Shallow	Cu-Tube	29.39	±0.25	2.52	±0.05	0.1	1.00E-05	CE (Aeschbach)	Ne, Ar, Kr, Xe
744	RFO Deep	Cu-Tube	28.03	±0.10	102.6	±0.96	0.84	0.7106	CE (Aeschbach)	Ne, Ar, Kr, Xe
690	Chascent Shallow	Cu-Tube	22.54	±0.30	1.35	±0.04	0.02	0	CE (Aeschbach)	Ne, Ar, Kr, Xe
684	Chascent Deep	Cu-Tube	5.41	±0.06	0.74	±0.03	9.02	0.1664	CE (Aeschbach)	Ne, Ar, Kr, Xe

Table 22. $^3He/^4He$ ratios & T - ^3He ages (October 2012 sampling)

Sequence ID	Sample ID	He		$^3He/^4He$		Tritium		With Modeled Excess Air & NGT				With Excess Air by He/Ne = air & NGT.			
								$[^3He]$trit		T-^{3}He age		$[^3He]$trit		T-^{3}He age	
		[x 10^{-8} cm^3STP/g]		[x10^{-6}]		[TU]		[TU]		[Years]		[TU]		[Years]	
664	1A-BH	6.53	±0.12	5.83	±0.08	23.13	±1.02	119.3	±3.5	32.3	±0.8	119.33	±3.54	32.3	±0.78
690	1B-BH	9.99	±0.08	9.41	±0.12	27.73	±1.21	330.5	±5.1	45.5	±0.8	330.54	±5.14	45.5	±0.78
681	1C-TW	6.08	±0.05	2.97	±0.04	11.63	±0.53	40.6	±1.0	26.7	±0.7	40.54	±1.11	26.7	±0.74
681	2A-HP	4.24	±0.04	1.82	±0.02	3.25	±0.21	8	±0.4	22.1	±1.1	7.68	±0.28	21.5	±1.03
681	3-TW	4.86	±0.04	1.48	±0.02	1.85	±0.15	3.4	±0.3	18.7	±1.4	3.45	±0.34	18.7	±1.44
681	4-TW	4.63	±0.05	1.49	±0.02	7.79	±0.37	2.6	±0.5	5	±0.9	2.71	±0.65	5.3	±1.08
755	WRP Deep	4.53	±0.06	1.66	±0.02	10.57	±0.50	5.5	±0.6	7.4	±0.7	5.47	±0.6	7.4	±0.7
747	WRP Shallow	4.24	±0.07	1.78	±0.02	9.91	±0.48	6.8	±0.3	9.2	±0.5	6.76	±0.3	9.2	±0.5
681	China Town Deep	5.26	±0.05	2.01	±0.03	8.04	±0.40	13.4	±0.7	17.4	±0.8	13.39	±0.7	17.4	±0.8
690	China Town Shallow	5.76	±0.04	2.64	±0.02	204.7	±8.83	26.1	±0.5	2.1	±0.1	26.12	±0.6	2.1	±0.1
744	RFO Deep	6.09	±0.08	2.21	±0.01	3.33	±0.20	21.8	±0.9	36	±1.1	20.72	±0.8	35.2	±1.1

Table 23. Noble gas concentrations of samples (June-2014 sampling)

LIMS ID (SID)	SubSample Name	He (cm^3STP/g)	Erorr	Ne (cm^3STP/g)	Error	Ar (cm^3STP/g)	Error	Kr (cm^3STP/g)	Error	Xe (cm^3STP/g)	Error
67200	1A-BH	6.55E-08	1.28E-09	2.57E-07	2.93E-09	3.40E-04	6.08E-06	6.62E-08	2.03E-09	8.78E-09	5.04E-10
67201	1B-BH	4.78E-08	3.66E-10	1.90E-07	2.13E-09	3.05E-04	5.84E-06	6.40E-08	1.64E-09	9.29E-09	5.69E-10
67202	1C-TW	4.87E-08	3.27E-10	1.97E-07	2.20E-09	3.02E-04	5.80E-06	6.28E-08	1.60E-09	9.30E-09	5.69E-10
67203	2A-HP	4.77E-08	3.63E-10	1.95E-07	2.23E-09	2.94E-04	5.04E-06	6.17E-08	1.65E-09	9.45E-09	6.51E-10
67204	2B-TW	4.96E-08	7.04E-10	1.99E-07	3.21E-09	3.14E-04	5.68E-06	6.26E-08	1.76E-09	9.09E-09	7.54E-10
67205	3-TW	4.39E-07	7.20E-09	1.39E-06	1.66E-08	8.52E-04	1.64E-05	1.15E-07	4.17E-09	1.13E-08	5.07E-10
67206	4-TW	5.80E-08	8.04E-10	2.25E-07	2.71E-09	3.47E-04	6.69E-06	6.79E-08	2.38E-09	9.46E-09	4.23E-10
67207	WRP Deep	4.53E-08	6.49E-10	1.87E-07	3.01E-09	3.33E-04	6.02E-06	7.00E-08	1.97E-09	9.88E-09	8.30E-10
67208	WRP Shallow	5.05E-08	4.48E-10	2.08E-07	1.59E-09	3.38E-04	5.19E-06	7.73E-08	2.31E-09	1.03E-08	5.07E-10
67209	China town Deep	8.04E-08	1.56E-09	3.04E-07	3.48E-09	4.08E-04	7.30E-06	7.62E-08	2.35E-09	9.71E-09	5.59E-10
67210	China town Shallow	6.26E-08	6.02E-10	2.41E-07	2.60E-09	3.05E-04	5.81E-06	6.23E-08	1.66E-09	8.56E-09	6.47E-10
67211	RFO Deep	6.48E-08	5.76E-10	2.45E-07	2.64E-09	3.49E-04	6.69E-06	6.68E-08	1.78E-09	9.38E-09	7.11E-10
67212	Chascent Shallow	5.54E-08	8.06E-10	2.16E-07	3.49E-09	3.26E-04	5.91E-06	6.68E-08	1.88E-09	9.24E-09	7.76E-10
67213	Chascent Deep	3.06E-07	6.71E-09	8.35E-07	8.98E-09	6.09E-04	1.16E-05	9.26E-08	2.51E-09	1.13E-08	8.66E-10
67214	Thal Canal	4.59E-08	6.66E-10	1.88E-07	3.03E-09	3.17E-04	5.75E-06	6.54E-08	1.84E-09	8.88E-09	7.38E-10
67215	C.J Link Canal	4.37E-08	3.42E-10	1.78E-07	2.04E-09	2.87E-04	4.92E-06	6.08E-08	1.62E-09	9.94E-09	6.86E-10

Table 24. Noble gas temperatures (June-2014 sampling)

LIMS ID (SID)	Sample Name	Sample Medium	NGT	Error	Excess Air (cc/kg)	Error	Sum (Chi^2)	F values	model1	Model2
67200	1A-BH	Cu-Tube	26.6	0.2	22.0	0.4	1.1	0.5	CE (Aeschbach)	T, Ex-A, F or R varied
67201	1B-BH	Cu-Tube	21.8	0.3	0.7	0.0	2.4	0.1	CE (Aeschbach)	T, Ex-A, F or R varied
67202	1C-TW	Cu-Tube	22.8	0.2	1.2	0.0	3.1	0.1	CE (Aeschbach)	T, Ex-A, F or R varied
67203	2A-HP	Cu-Tube	23.8	0.4	1.0	0.0	3.4	0.0	CE (Aeschbach)	T, Ex-A, F or R varied
67204	2B-TW	Cu-Tube	22.0	0.4	1.5	0.0	7.0	0.2	CE (Aeschbach)	T, Ex-A, F or R varied
67205	3-TW	Cu-Tube	43.2	0.3	68.9	0.9	1.4	0.0	CE (Aeschbach)	T, Ex-A, F or R varied
67206	4-TW	Cu-Tube	23.7	0.2	58.3	0.7	3.6	0.7	CE (Aeschbach)	T, Ex-A, F or R varied
67207	WRP Deep	Cu-Tube	17.3	0.2	0.2	0.0	5.0	0.1	CE (Aeschbach)	T, Ex-A, F or R varied
67208	WRP Shallow	Cu-Tube	16.3	0.2	1.2	0.0	0.5	0.0	CE (Aeschbach)	T, Ex-A, F or R varied
67209	China town Deep	Cu-Tube	28.2	0.3	64.7	0.7	1.7	0.5	CE (Aeschbach)	T, Ex-A, F or R varied
67210	China town Shallow	Cu-Tube	26.4	0.3	3.8	0.1	0.7	0.0	CE (Aeschbach)	T, Ex-A, F or R varied
67211	RFO Deep	Cu-Tube	28.4	0.1	57.4	0.6	4.0	0.6	CE (Aeschbach)	T, Ex-A, F or R varied
67212	Chascent Shallow	Cu-Tube	24.3	0.2	35.3	0.5	1.0	0.8	CE (Aeschbach)	T, Ex-A, F or R varied
67213	Chascent Deep	Cu-Tube	32.5	0.2	40.0	0.6	3.8	0.0	CE (Aeschbach)	T, Ex-A, F or R varied
67214	Thal Canal	Cu-Tube	20.1	0.3	0.6	0.0	5.6	0.2	CE (Aeschbach)	T, Ex-A, F or R varied
67215	C.J Link Canal	Cu-Tube	23.5	0.2	0.1	0.0	6.4	0.0	CE (Aeschbach)	T, Ex-A, F or R varied

Table 25. $^3He/^4He$ ratios & T - ^3He ages (June-2014 sampling)

Sample Name	$^3He/^4He$	Error	Tritium (TU)	Tritium Error (TU)	$[^3He]trit$ (NGT)	Error	T-^3He age (NGT)	Error	Terrigenic ^4He	Error	$^3He/^4He$ (at sampling)	Error
1A-BH	1.25E-05	1.50E-07	29.68	0.35	292.2	7.2	42.4	0.4	2E-10	1.4667E-09	1.25E-05	1.50E-07
1B-BH	2.41E-06	1.58E-08	9.47	0.20	20.5	0.5	20.5	0.4	8E-10	3.7901E-10	2.41E-06	1.58E-08
1C-TW	3.33E-06	2.08E-08	8.66	0.31	38.4	0.5	30.1	0.5	-3E-10	3.5457E-10	3.32E-06	2.08E-08
2A-HP	1.72E-06	1.28E-08	4.26	0.11	6.9	0.3	17.1	0.5	-1E-09	4.1307E-10	1.72E-06	1.28E-08
2B-TW	1.94E-06	1.57E-08	4.48	0.15	11.4	0.5	22.5	0.7	-2E-10	7.4211E-10	1.93E-06	1.57E-08
3-TW	1.30E-06	1.75E-08	0.59	0.09	9.6	5.8	50.6	13.0	4E-08	8.9112E-09	1.30E-06	1.75E-08
4-TW	1.73E-06	2.56E-08	4.88	0.14	9.7	0.9	19.5	1.2	2E-09	1.0376E-09	1.73E-06	2.56E-08
WRP Deep	1.65E-06	1.17E-08	8.44	0.24	5.2	0.4	8.6	0.5	2E-10	6.5242E-10	1.64E-06	1.17E-08
WRP Shallow	1.60E-06	1.53E-08	9.04	0.14	4.4	0.3	7.1	0.4	5E-11	4.7983E-10	1.58E-06	1.53E-08
China town Deep	1.62E-06	2.02E-08	8.81	0.20	9.6	1.2	13.1	1.2	3E-09	1.7005E-09	1.62E-06	2.02E-08
China town Shallow	5.79E-06	5.64E-08	509.81	2.30	102.5	1.9	3.3	0.1	-1E-10	8.2105E-10	5.44E-06	5.64E-08
RFO Deep	2.14E-06	1.77E-08	2.82	0.18	21.5	0.8	38.3	1.2	3E-09	8.9942E-10	2.14E-06	1.77E-08
Chascent Shallow	4.45E-06	2.83E-08	24.42	0.19	69.5	1.5	23.9	0.3	2E-09	9.0421E-10	4.44E-06	2.83E-08
Chascent Deep	1.72E-06	1.46E-08	6.70	0.17	81.3	5.3	45.8	1.1	7E-08	7.1321E-09	1.72E-06	1.46E-08
Thal Canal	1.40E-06	1.48E-08	9.42	0.23	0.6	0.3	1.0	0.5	-1E-10	6.7877E-10	1.39E-06	1.48E-08
C.J Link Canal	1.41E-06	1.12E-08	12.85	0.22	0.7	0.2	0.9	0.3	-1E-10	3.4259E-10	1.40E-06	1.12E-08

Table 26. Calculation of recharge rates from T-^{3}He ages of Chashma site samplings

T-^{3}He age (years)						
Sample code	**Water Depth (m)**	**Mar-11 Sampling**	**Oct. -2011 Sampling**	**Sep-12 Sampling**	**Jun-14 Sampling**	**Average Age (years)**
WRP Deep	73	6.2	4.2	5.2	8.6	6.0
WRP Shallow	10	2.8	5.5	4.2	7.1	4.9
China town Deep	73	16.2	16.6	16.4	13.1	15.6
China town Shallow	10	8.2		8.2	3.3	6.6
RFO Deep	73	44.1	28.7	36.4	38.3	36.8
Chascent Deep	73	18.7	16.7		45.8	27.1
Chascent Shallow	10	20	31.5	24.4		23.9
Average		16.6	17.2	15.8	19.3	17.3
Recharge (m/year)						
Sample code	**Water Depth (m)**	**Mar-11 Sampling**	**Oct. -2011 Sampling**	**Sep-12 Sampling**	**Jun-14 Sampling**	**Average Recharge**
WRP Deep	73	3.53	5.21	4.21	2.55	3.88
WRP Shallow	10	1.07	0.55	0.72	0.42	0.69
China town Deep	73	1.36	1.32	1.34	1.67	1.42
China town Shallow	10	0.37		0.37	0.92	0.55
RFO Deep	73	0.50	0.76	0.60	0.57	0.61
Chascent Deep	73	1.17	1.31		0.48	0.99
Chascent Shallow	10	0.15	0.10	0.12		0.12
Average Recharge Rate		1.33	1.83	1.45	1.10	1.36

Table 27: Chemical data of water samples from project area.

Sample Code	**EC** µS/cm	**TDS** mg/l	**pH**	**CO_3^{--}** (ppm)	**HCO_3^-** (ppm)	**SO_4^{--}** (ppm)	**Cl^-** (ppm)	**Ca^{++}** (ppm)	**Mg^{++}** (ppm)	**Na^+** (ppm)	**K^+** (ppm)	**Cations** (meq)	**Anions** (meq)
1A-BH	1099	703.4	7.35	0	220	103	63	11.77	40.40	52.52	12.21	6.55	7.54
1B-BH	1129	722.6	7.52	0	387	111	44	13.64	43.23	93.34	15.84	8.75	9.90
1C -TW	966	618.2	7.30	0	291	78	52	25.74	31.01	79.99	12.87	7.68	7.87
2A -HP	1270	812.8	7.20	0	266	161	82	24.97	61.91	74.24	12.43	9.95	10.05
2B -TW	1053	673.9	7.10	0	301	103	52	26.4	24.75	85.04	14.30	7.45	8.55
3- TW	993	635.5	7.40	0	254	82	69	22.11	31.31	66.05	11.88	6.89	7.80
4-TW	840	537.6	7.45	0	279	68	41	11.99	33.30	42.89	8.58	5.46	7.14
WRP Deep	302	193.3	8.32	0	113	13	20	11.77	13.46	8.87	3.27	2.18	2.68
WRP Shallow	620	396.8	7.85	0	315	14	21	10.12	15.66	20.45	126.50	5.94	6.05
China Town Deep	624	399.4	7.93	0	215	22	27	12.76	23.21	42.59	5.50	4.56	4.75
China Town Shallow	645	412.8	7.51	0	215	16	20	16.72	22.54	25.45	7.15	4.00	4.43
RFO Deep	740	473.6	7.75	0	236	48	39	21.12	33.00	29.68	5.50	5.24	5.97
Chascent Shallow	848	542.7	7.79	0	205	24	27	14.3	30.14	23.36	7.70	4.44	4.64
Chascent Deep	480	307.2	7.86	0	190	23	20	15.18	17.75	28.56	4.07	3.58	4.15
Thal Canal	215	137.6	8.47	0	82	19	24	20.13	4.90	9.13	2.39	1.87	2.41
C.J.Link Canal	223	142.7	8.30	0	82	15	14	19.91	4.54	6.73	2.44	1.73	2.04
Ch-8	828	529.9	7.53	0	278.8	39.7	37.5	15.07	21.01	78.88	11.66	6.23	6.45
Ch-10	1068	683.5	7.41	0	352.6	77	47.5	22.22	39.49	56.46	18.04	7.32	8.72
Ch-11	621	397.4	7.36	0	254.2	22	15	56.65	18.69	3.54	7.92	4.75	5.05
Ch-12	760	486.4	7.27	0	336.2	20	18.7	40.48	29.39	24.85	15.40	5.95	6.46

Table 28. CFC data of water samples from project area (April 2014 sampling)

Sr. No.	Sample Code	Sample Collection Date	Concentration (pmol/kg)			Recharge Year			Apparent Age (Years)		
			CFC-12	CFC-11	CFC-113	CFC-12	CFC-11	CFC-113	CFC-12	CFC-11	CFC-113
1	1A-BH	9/4/2014	0.5	1.33	0.05	1974	1977	1979	40	37	35
2	1B-BH	9/4/2014	5.95	121	0.3	C	1976	C		38	
3	1C-TW	9/4/2014	0.11	0.13	0.01	1962	1962	1964	**52**	**52**	**50**
4	2A-HP	9/4/2014	2.48	2.71	0.1	C	C	1984			30
5	2B-TW	9/4/2014	0.91	0.93	0.04	1983	1974	1978	31	40	36
6	3-TW	9/4/2014	0.14	0.14	0.01	1963	1962	1964	**51**	**52**	**50**
7	4-TW	9/4/2014	0.55	0.3	0.05	1975	1966	1978	39	48	36
8	WRP Deep	10/4/2014	1.95	0.31	0.03	C	1966	1975		**48**	**39**
9	WRP Shallow	10/4/2014	1.88	4.41	0.17	C	C	1988			26
10	China town Deep	10/4/2014	2.09	3.12	0.35	1987	1981	1988	27	33	26
11	China town Shallow	10/4/2014	2.95	1.55	0.57	C	1982	C		32	
12	RFO Deep	10/4/2014	1.4	1.99	0.08	C	1986	1983		28	31
14	Chascent Deep	10/4/2014	0.67	0.21	0.02	C	1964	1973	C	50	41
13	Chascent Shallow	10/4/2014	0.75	0.18	0.04	1979	1964	1977	35	50	37
15	Thal Canal	10/4/2014	5.52	C	0.36	C	C	C			
16	C.J Link Canal	10/4/2014	2.22	1.86	0.21	C	1985	1992		29	22

Table 29. CFC data of water samples from project area (June 2014 sampling)

Sr. No.	Sample Code	Sample Collection Date	Concentration (pmol/kg)			Recharge Year			Apparent Age (Years)		
			CFC-12	CFC-11	CFC-113	CFC-12	CFC-11	CFC-113	CFC-12	CFC-11	CFC-113
1	1A-BH	18/6/2014	1.27	8.65	0.02	1990	C	1973	24	C	41
2	1B-BH	18/6/2014	C	C	0.27	C	C	C	C	C	C
3	1C-TW	18/6/2014	2.29	39.05	0.02	C	C	1972	C	C	42
4	2A-HP	18/6/2014	13.52	203.87	0.09	C	C	1984	C	C	30
5	2B-TW	19/6/2014	C	13.32	0.03	C	C	1974	C	C	40
6	3-TW	18/6/2014									
7	4-TW	18/6/2014	C	99.43	0.24	C	C	C	C	C	C
8	WRP Deep	19/6/2014	C	30.57	0.35	C	C	C	C	C	C
9	WRP Shallow	19/6/2014	3.52	24.9	0.14	C	C	1986	C	C	28
10	China town Deep	19/6/2014	C	C	C	C	C	C	C	C	C
11	China town Shallow	19/6/2014	C	65.5	0.25	C	C	C	C	C	C
12	RFO Deep	19/6/2014	0.94	C	0.01	1982	C	1969	32	C	45
14	Chascent Deep	19/6/2014	2.25	0.45	0.04	C	1969	1976	C	45	38
13	Chascent Shallow	19/6/2014	6.31	249.5	0.06	C	C	1980	C	C	34
15	Thal Canal	20/6/2014	5.6	16.75	0.28	C	C	C	C	C	C
16	C.J Link Canal	20/6/2014	6.45	17.6	0.29	C	C	C	C	C	C

Table 30. CFC data of water samples from project area (October 2014 sampling)

Sr. No.	Sample Code	Sample Collection Date	Concentration (pmol/kg)			Recharge Year			Apparent Age (Years)		
			CFC-12	CFC-11	CFC-113	CFC-12	CFC-11	CFC-113	CFC-12	CFC-11	CFC-113
1	1A-BH	15/10/2014	0.53	0.61	0.03	1974	1971	1975	40	43	39
2	1B-BH	15/10/2014	3.09	3.71	0.25	C	C	C	C	C	C
3	1C-TW	15/10/2014	0.19	0.65	0.01	1965	1971	1969	49	43	45
4	2A-HP	15/10/2014	1.12	1.31	0.05	1987	1977	1978	27	37	36
5	2B-TW	15/10/2014	1.66	1.28	0.05	1988	1977	1978	26	37	36
6	3-TW	15/10/2014	0.31	0.27	0.03	1969	1966	1975	45	48	39
7	4-TW	15/10/2014	0.6	0.43	0.02	1975	1968	1973	39	46	41
8	WRP Deep	15/10/2014	2.06	0.14	0.02	C	1962	1972	C	52	42
9	WRP Shallow	15/10/2014	2.32	2.72	0.12	C	C	1985	C	C	29
10	China town Deep	15/10/2014	2.52	2.87	0.4	C	C	C	C	C	C
11	China town Shallow	15/10/2014	0.38	0.24	0.01	C	C	C	C	C	C
12	RFO Deep	15/10/2014	1.46	1.26	0.02	1971	1965	1968	43	49	46
14	Chascent Deep	15/10/2014	1.46	1.26	0.02	C	1976	1972		38	42

Table 31. Radon data of water samples from project area (April 2014 sampling)

Sr. No.	Sample Code	Sample Collection Date	Sample Depth	Altitude (m)	Temp. (°C)	RH (%) Mean	Battery Voltage (V)	Collection Time	Analysis Time	Time (Hours)	Activity (Mean)	Activity (SD)	DCF	Corrected Activity (pCi/l)	Annual effective doses (μSv-a^{-1})
1	1A-BH	9/4/2014	15	189.89	26	11	7.18	10:40	19:20	8.667	157	46.3	1.068	167.6	2.3
2	1B-BH	9/4/2014	25	189.89	24	15	7.18	9:30	17:10	7.667	178	15.2	1.060	188.6	2.5
3	1C-TW	9/4/2014	50	189.89	25	12	7.18	10:40	18:25	7.75	112	14	1.060	118.8	1.6
4	2A-HP	9/4/2014	18	194.77	26	10	7.18	11:40	20:22	8.7	218	25	1.068	232.8	3.1
5	2B-TW	9/4/2014	50	194.77	26	8	7.18	14:20	23:25	9.083	146	26.2	1.071	156.4	2.1
6	3-TW	9/4/2014	35	203.00	26	9	7.18	14:00	22:35	8.583	142	20.1	1.067	151.5	2.0
7	4-TW	9/4/2014	50	196.60	25	9	7.18	13:00	21:30	8.5	162	16.2	1.066	172.7	2.3
8	WRP Deep	10/4/2014	83	208.48	26	12	7.24	9:20	15:21	6.017	105	16.9	1.046	109.9	1.5
9	WRP Shallow	10/4/2014	20	193.24	26	10	7.22	9:45	16:25	6.667	182	16.00	1.052	191.4	2.6
10	China town Deep	10/4/2014	83	199.95	27	9	7.19	11:00	18:14	7.233	154	15.2	1.056	162.6	2.2
11	China town Shallow	10/4/2014	20	211.23	26	10	7.22	10:15	17:15	7	162	9.95	1.054	170.8	2.3
12	RFO Deep	10/4/2014	83	199.95	27	9	7.22	12:15	19:10	6.917	121	30.2	1.054	127.5	1.7
14	Chascent Deep	10/4/2014	83	207.26	27	9	7.22	12:50	20:54	8.067	83	14.7	1.063	88.2	1.2
13	Chascent Shallow	10/4/2014	20	207.26	27	9	7.20	12:40	20:04	7.4	160	18.3	1.057	169.2	2.3
15	Thal Canal	10/4/2014	2	209.09	27	8	7.21	19:00	1:33	6.55	5.02	5.05	1.051	5.3	0.1
16	C.J Link Canal	10/4/2014	2	212.75	26	8	7.18	18:00	22:40	4.667	10	5.18	1.036	10.4	0.1

Table 32. Radon data of water samples from project area (June 2014 sampling)

Sr. No.	Sample Code	Sample Collection Date	Sample Depth	Altitude (m)	Temp. (°C)	RH (%) Mean	Battery Voltage (V)	Collection Time	Analysis Time	Time (Hours)	Activity (Mean)	Activity (SD)	DCF	Corrected Activity (pCi/l)	Annual effective doses ($\mu Sv\text{-}a^{-1}$)
1	1A-BH	18/6/2014	15	189.89	27	18	7.18	9:00	14:00	5.000	146	28	1.038	151.6	2.0
2	1B-BH	18/6/2014	25	189.89	26	12	7.16	10:00	16:23	6.383	157	39.3	1.049	164.8	2.2
3	1C-TW	18/6/2014	50	189.89	27	14	7.15	8:00	15:20	7.333	120	22.6	1.057	126.8	1.7
4	2A-HP	18/6/2014	18	194.77	25	13	7.18	11:00	21:00	10.000	199	26.4	1.078	214.6	2.9
5	2B-TW	19/6/2014	50	194.77	27	12	7.18	7:00	8:52	1.867	167	14	1.014	169.4	2.3
6	3-TW	18/6/2014	35	203.00	26	10	7.18	19:00	22:00	3.000	169	25.2	1.023	172.9	2.3
7	4-TW	18/6/2014	50	196.60	26	9	7.18	19:45	23:41	3.933	129		1.030	132.9	1.8
8	WRP Deep	19/6/2014	83	208.48	27	13	7.19	10:15	17:30	7.250	91.8	18	1.056	97.0	1.3
9	WRP Shallow	19/6/2014	20	193.24	26	11	7.19	10:45	18:30	7.750	143	14.3	1.060	151.6	2.0
10	China town Deep	19/6/2014	83	199.95	26	10	7.19	12:30	19:30	7.000	134	13.5	1.054	141.3	1.9
11	China town Shallow	19/6/2014	20	211.23	27	10	7.20	13:00	20:30	7.500	136	26.2	1.058	143.9	1.9
12	RFO Deep	19/6/2014	83	199.95	26	9	7.19	14:30	21:30	7.000	118	19.3	1.054	124.4	1.7
14	Chascent Deep	19/6/2014	83	207.26	26	12	7.20	15:00	6:00	15.000	66.4	12.7	1.120	74.4	1.0
13	Chascent Shallow	19/6/2014	20	207.26	26	9	7.18	15:30	23:45	8.250	145	21.3	1.064	154.3	2.1
15	Thal Canal	20/6/2014	2	209.09	26	8	7.22	11:15	15:38	4.383	4.01	4.63	1.034	4.1	0.1
16	C.J Link Canal	20/6/2014	2	212.75	26	12	7.22	10:15	13:45	3.500	8.03	6.56	1.027	8.2	0.1

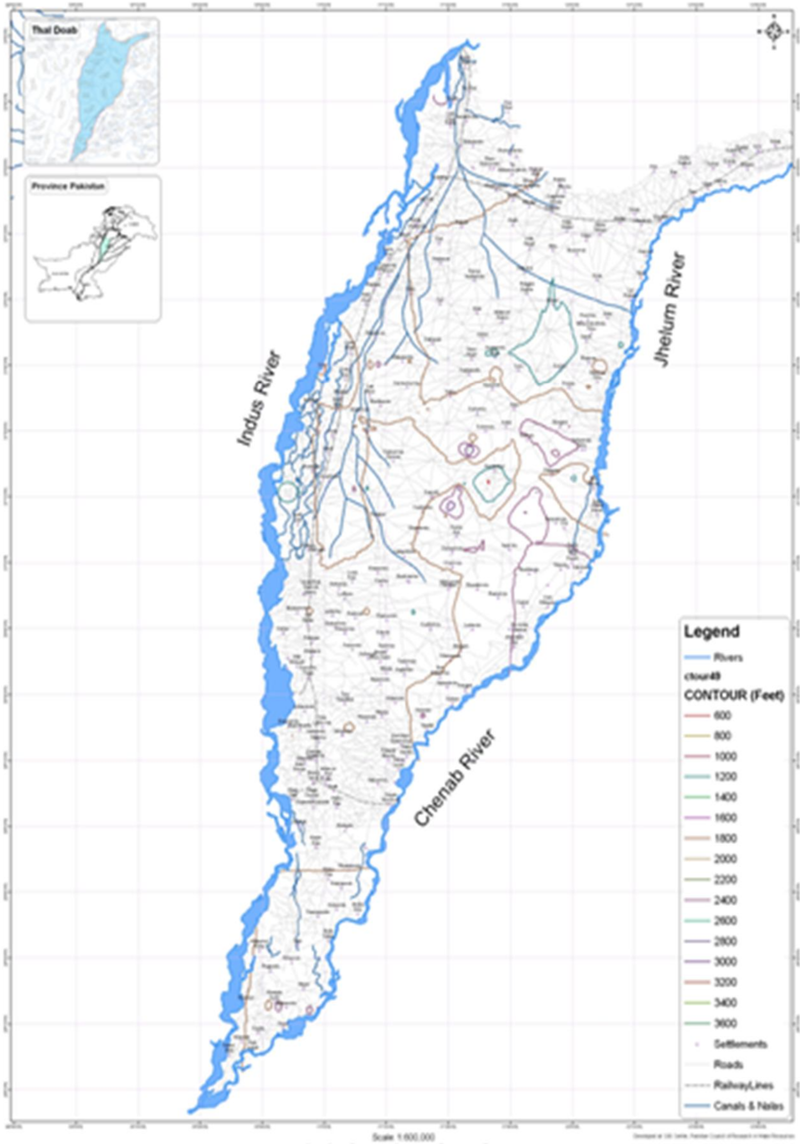


Fig. 1 Map of Thal doab.

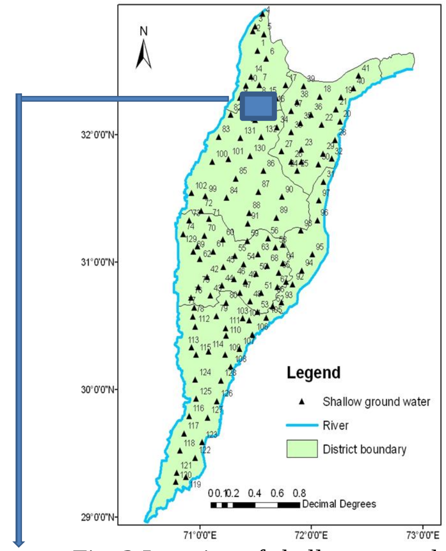


Fig. 2 Location of shallow groundwater sampling points in the whole area of Thal doab

Fig. 3. Location of sampling points in the reduced area of recharging and discharging zones.

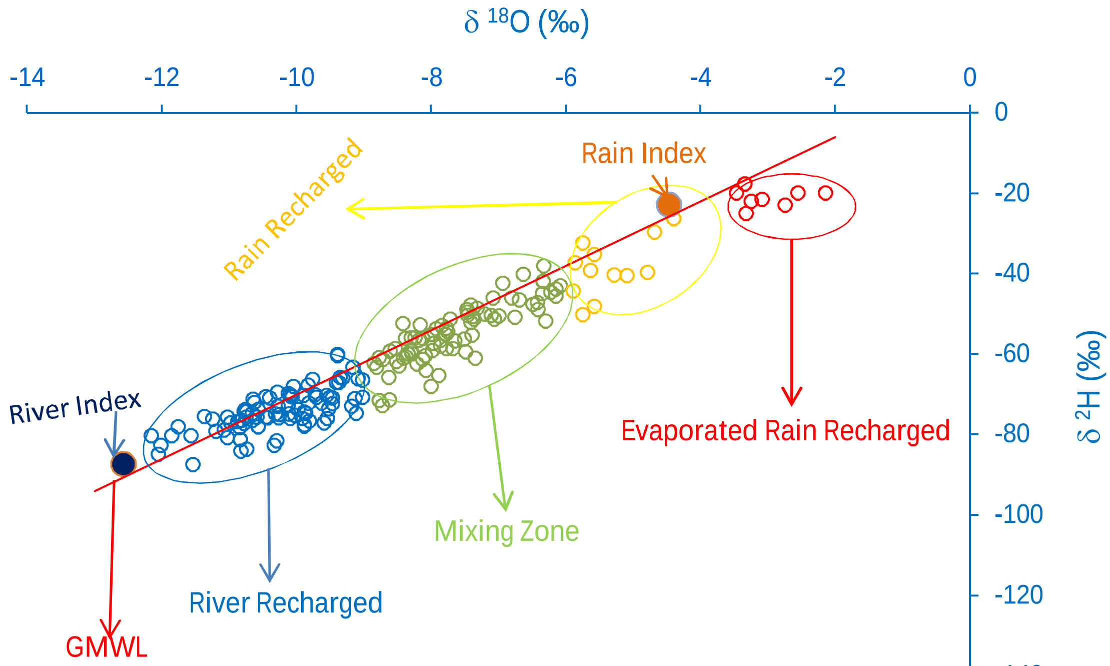
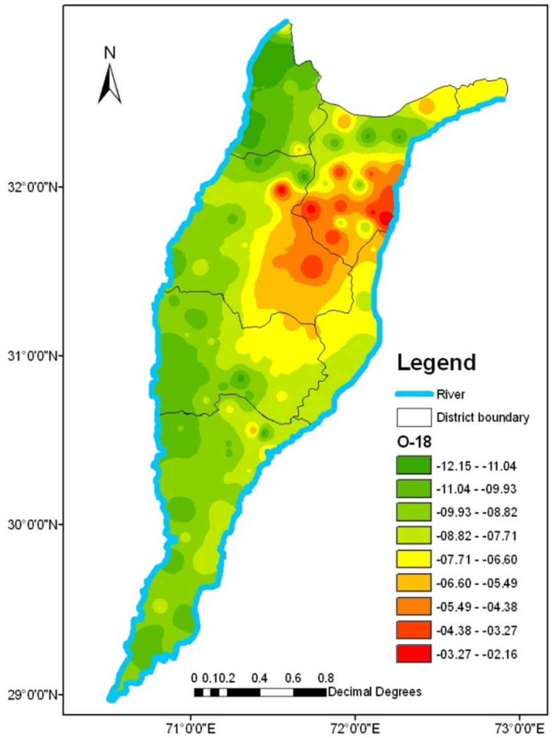


Fig. 4. Plot of δ^2H vs δ^{18}O of groundwater samples from the whole area of the Doab.



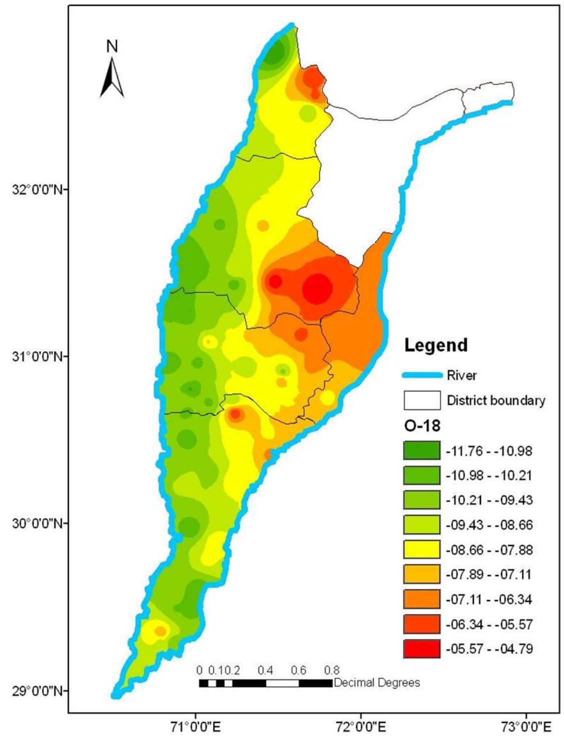
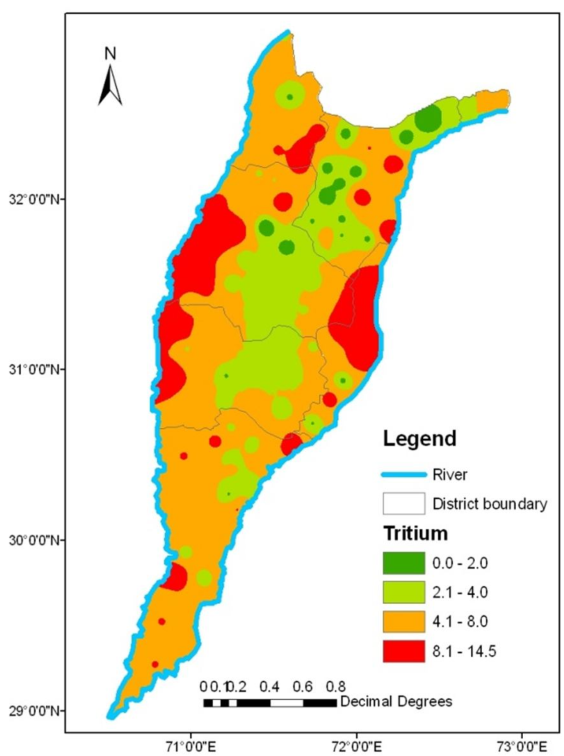


Fig. 5. Spatial distribution of $\delta^{18}O$ in shallow groundwater. Fig. 6. Spatial distribution of $\delta^{18}O$ in deep groundwater



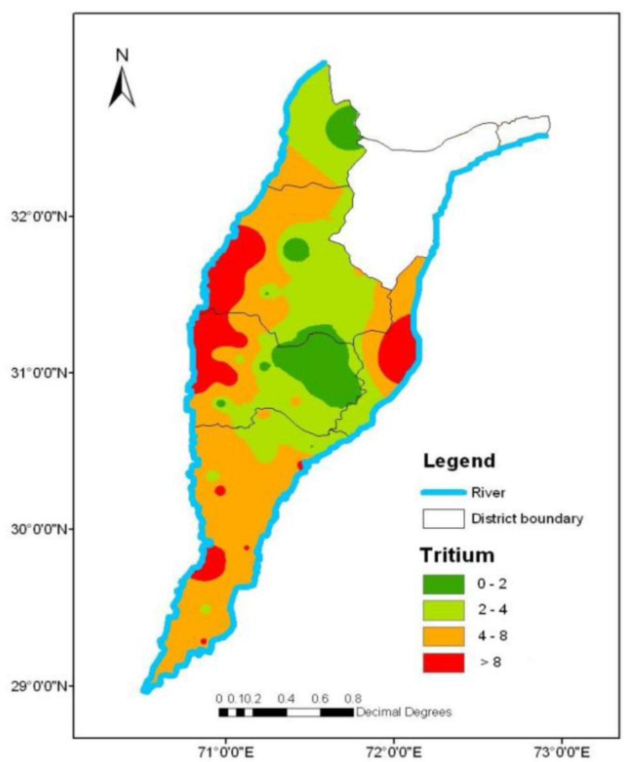


Fig. 7. Spatial distribution of tritium in shallow groundwater. Fig. 8. Spatial distribution of tritium in shallow groundwater

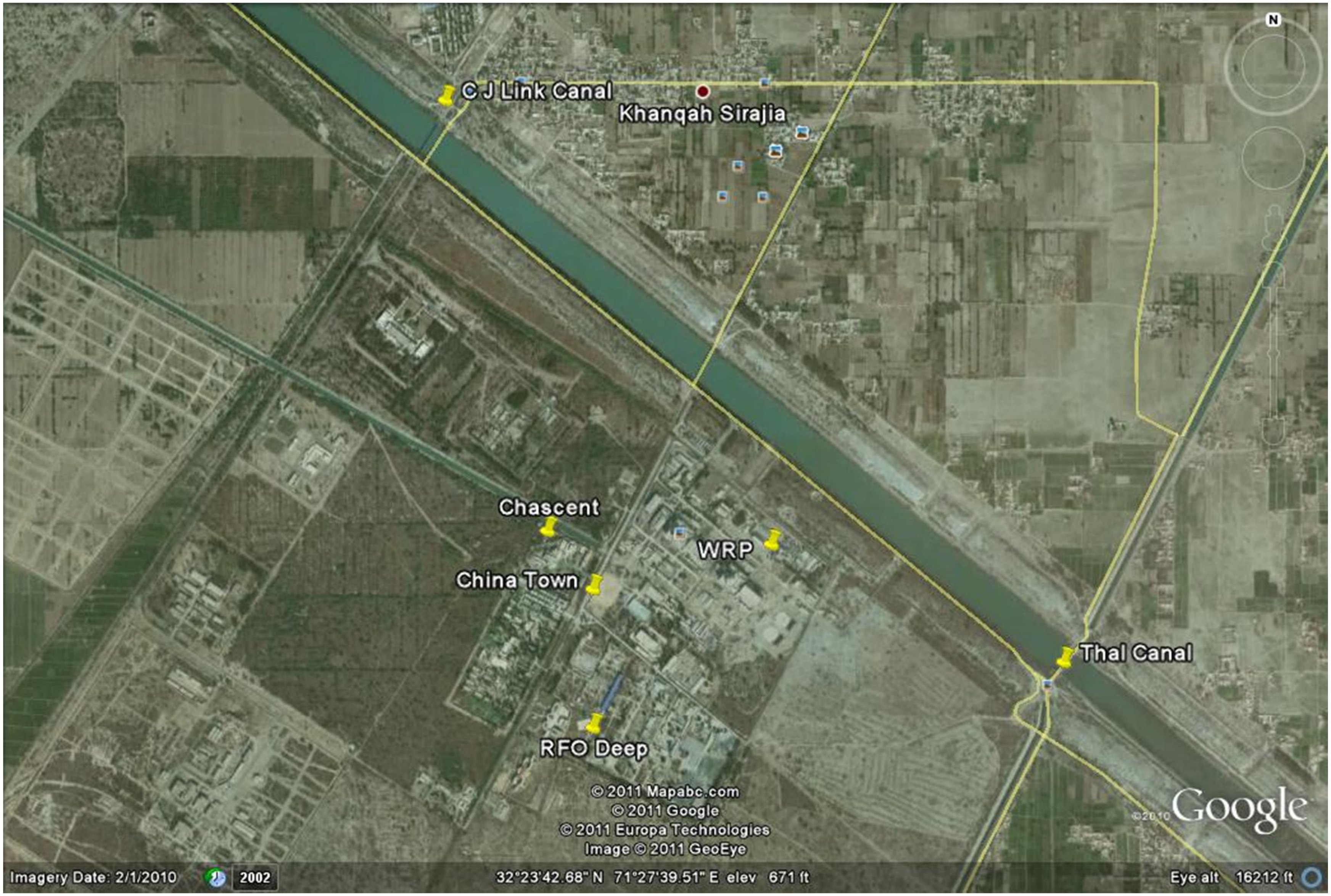


Figure 9. Location of sampling points in Recharge area.

Figure 10. Location of sampling points in discharge area.

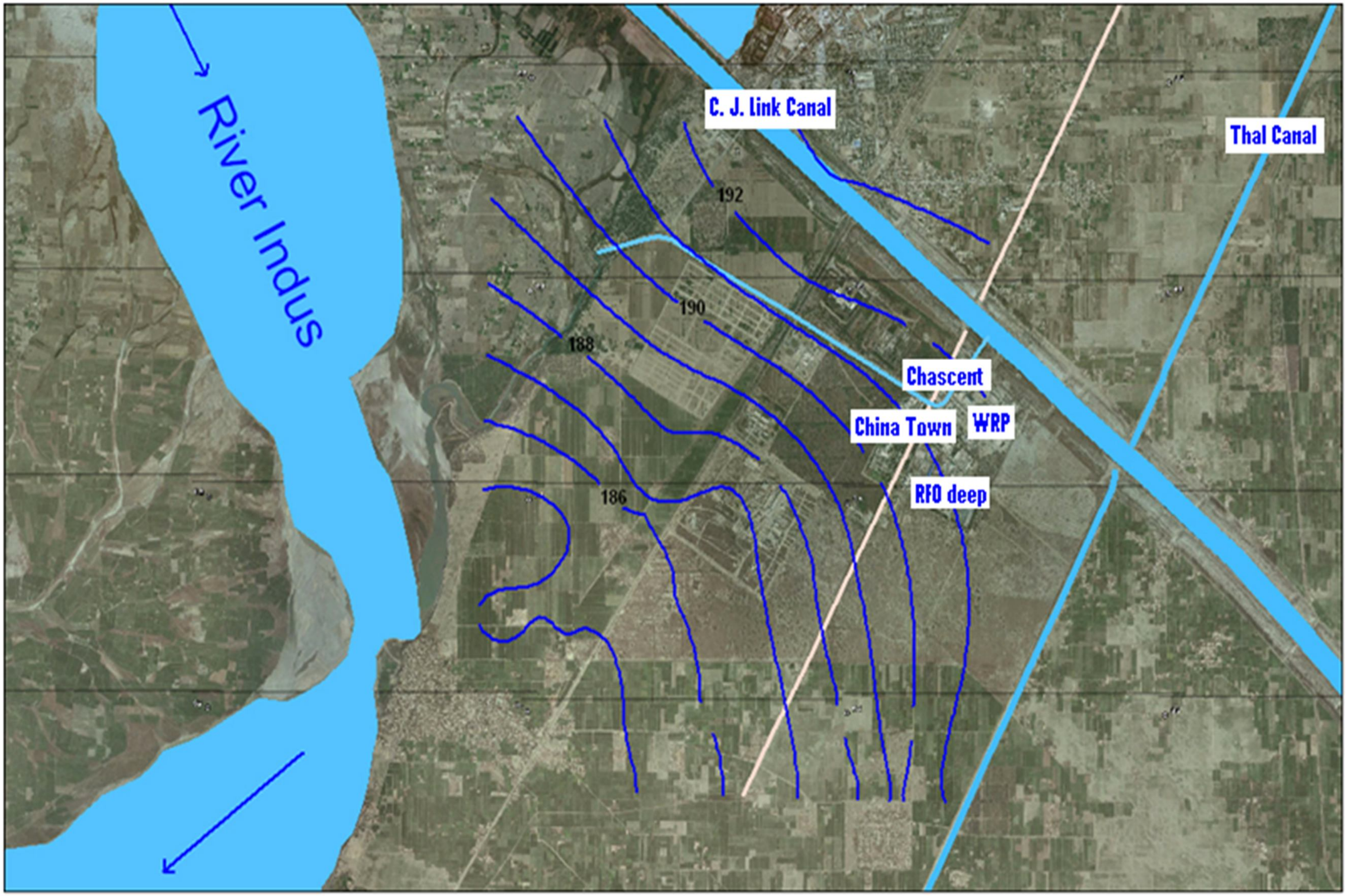


Figure 11. Water table contours of groundwater (meters) at CHASHMA NPPs site

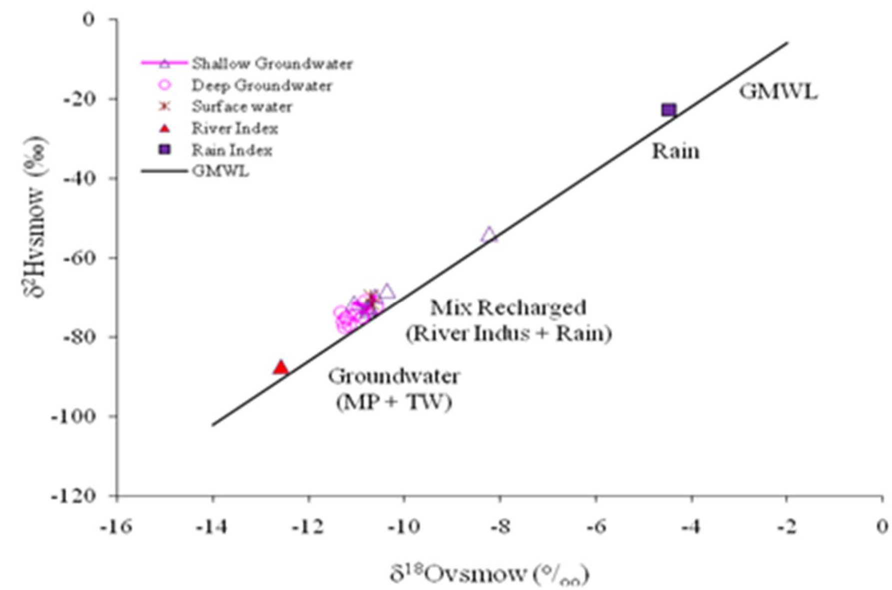


Figure 12. Plot of δ^{18}O vs. δ^{2}H of water samples (Chashma Sampling-Feb./March, 2011)

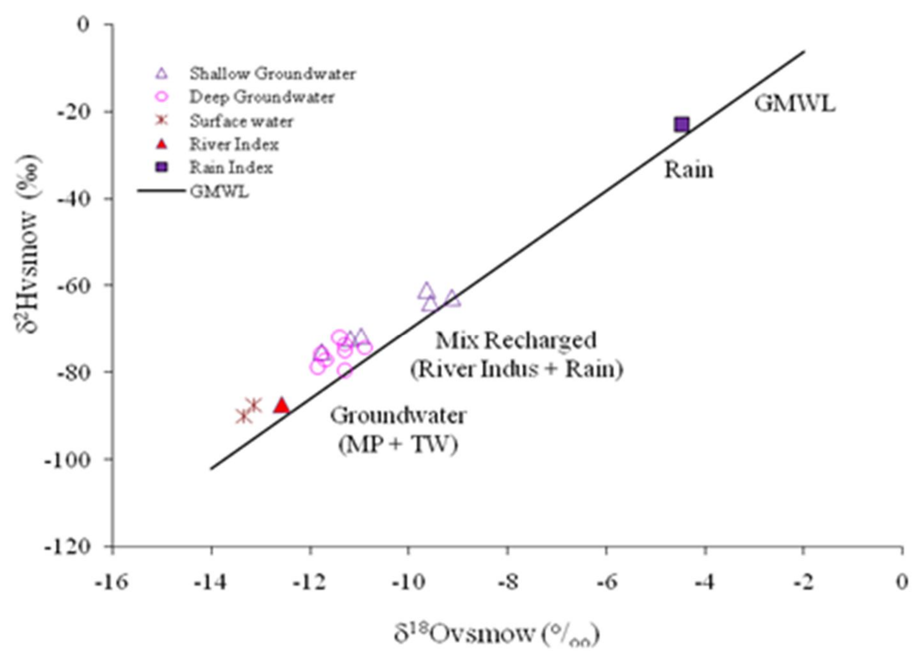


Figure 13. Plot of δ^{18}O vs. δ^{2}H of water samples (Chashma Sampling-October, 2011)

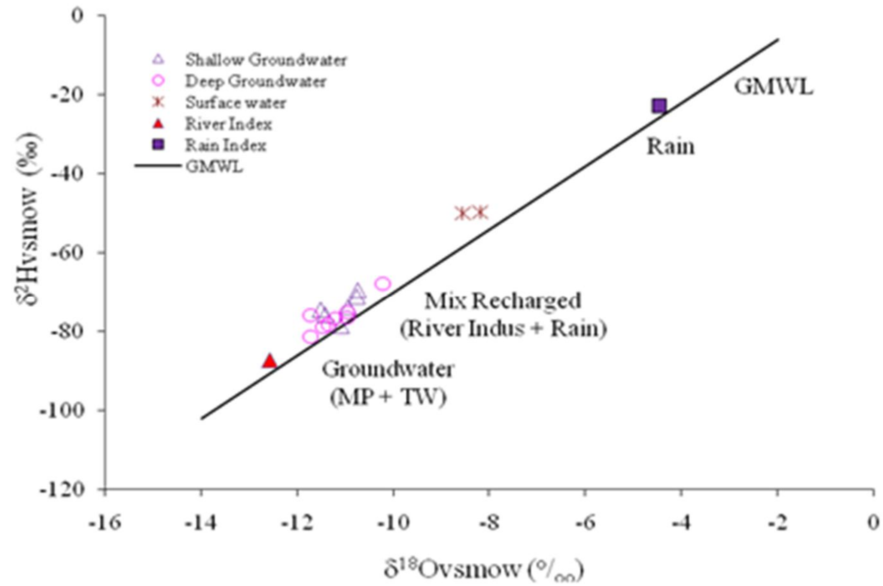


Figure 14. Plot of $\delta^{18}O$ vs. $\delta^{2}H$ of water samples (Chashma Sampling-April, 2014)

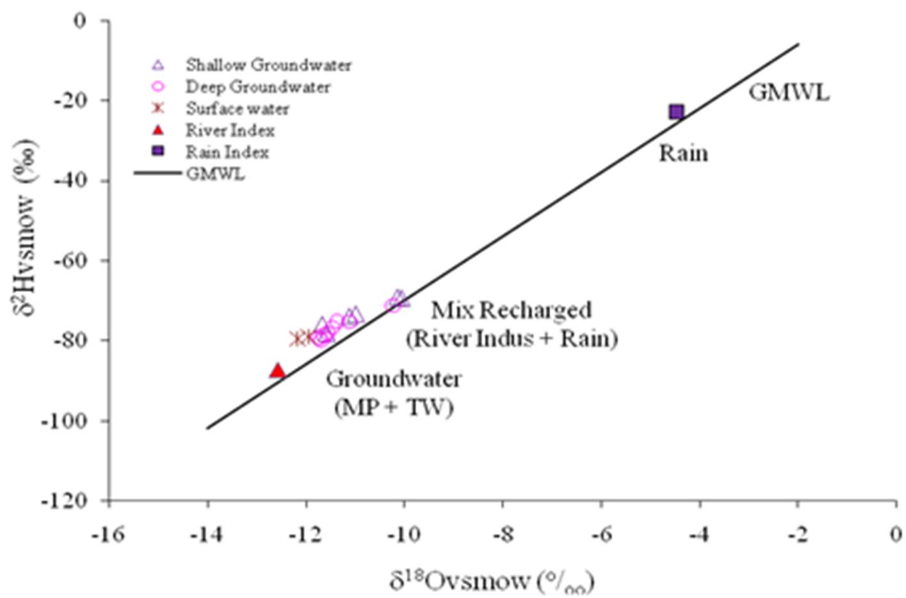


Figure 15. Plot of $\delta^{18}O$ vs. $\delta^{2}H$ of water samples (Chashma Sampling-June, 2014)

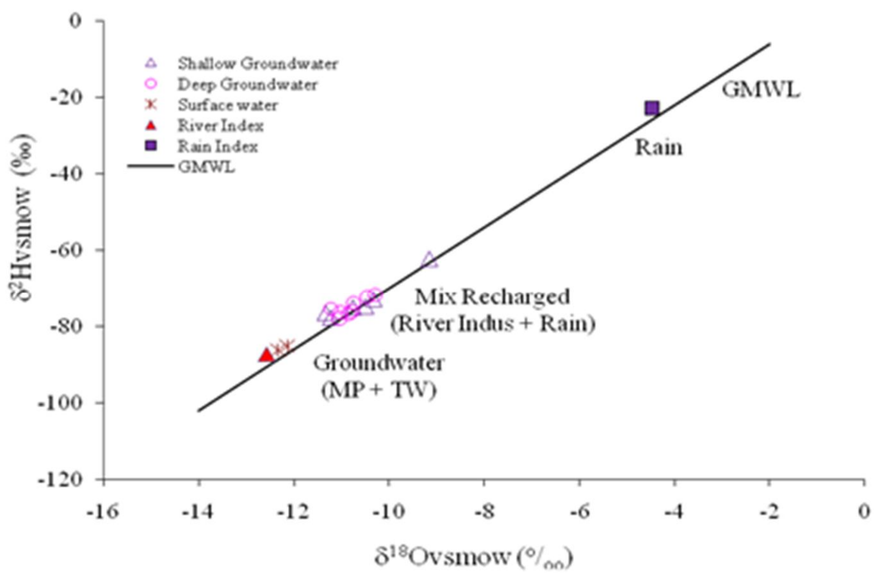


Figure 16. Plot of $\delta^{18}O$ vs. $\delta^{2}H$ of water samples (Chashma Sampling-October, 2014)

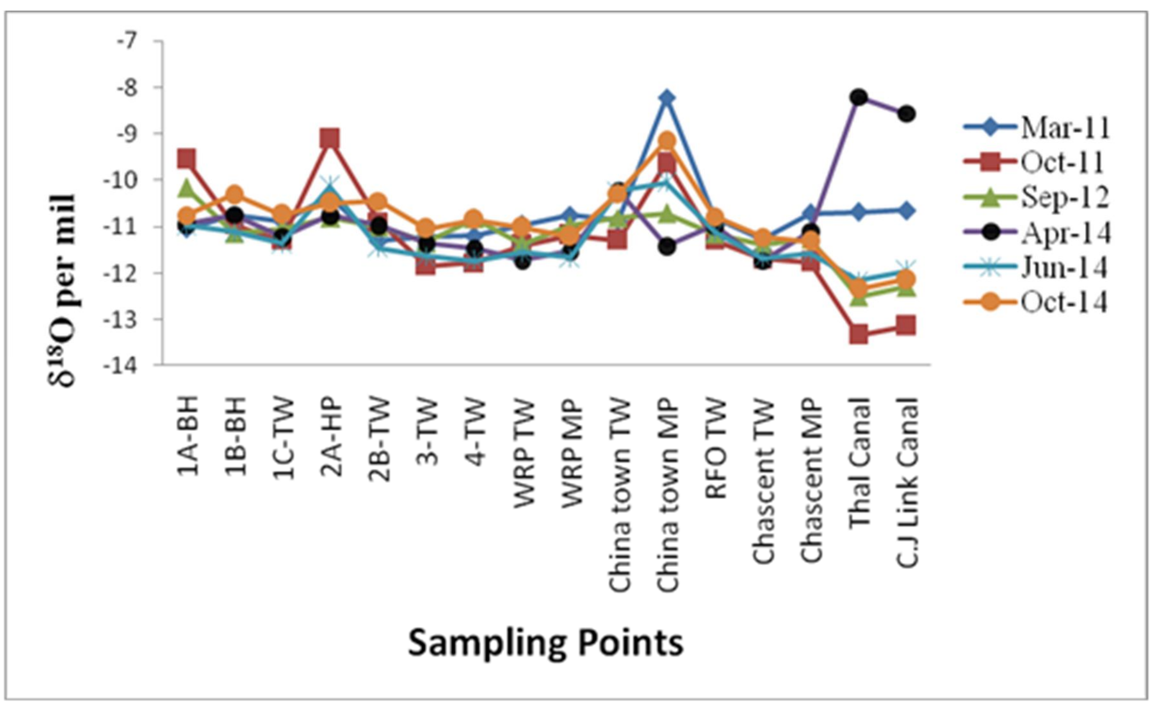


Fig. 17. $\delta^{18}O$ of Aqueous sampling of Chashma area at different time period

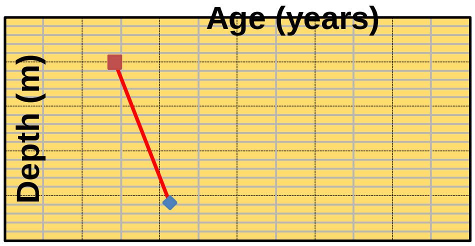


Fig.18 The age vs depth in recharge area (1st sampling)

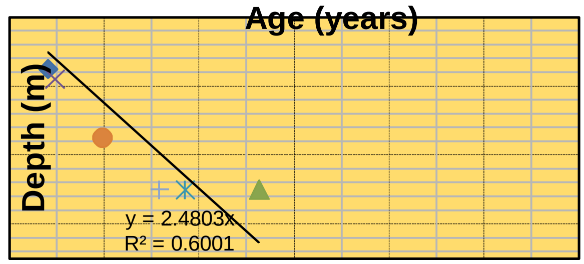


Fig.19 The age vs depth in discharge area (1st sampling)

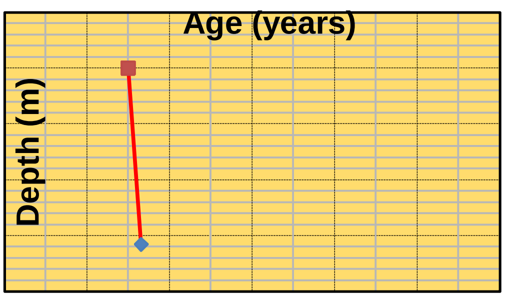


Fig.20 The age vs depth in recharge area (2nd sampling)

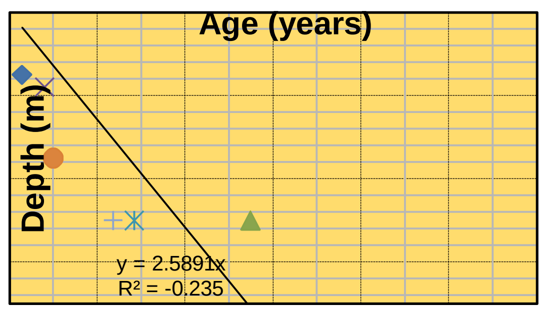


Fig.21 The age vs depth in discharge area (2nd sampling)

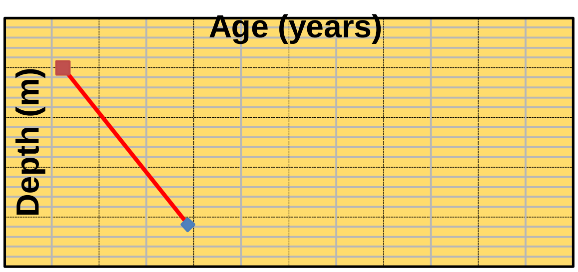


Fig.22 The age vs depth in recharge area (3rd sampling)

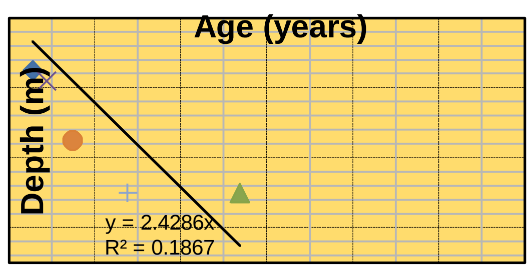


Fig.23 The age vs depth in discharge area (3rd sampling

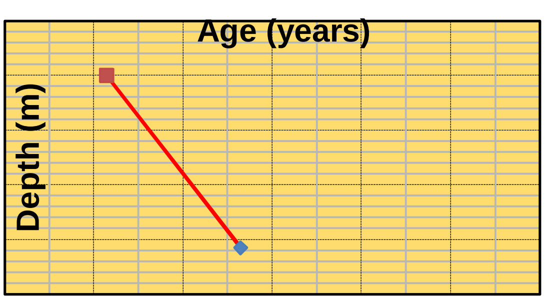


Fig. 24 The age vs depth in recharge area (4th sampling)

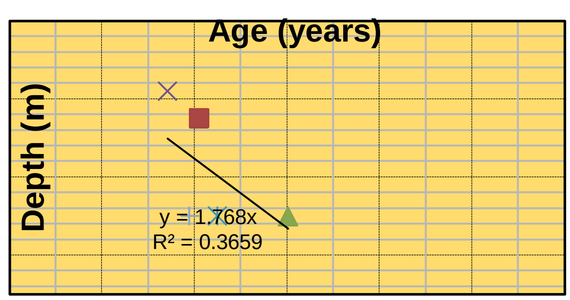


Fig.25 The age vs depth in discharge area (4th sampling

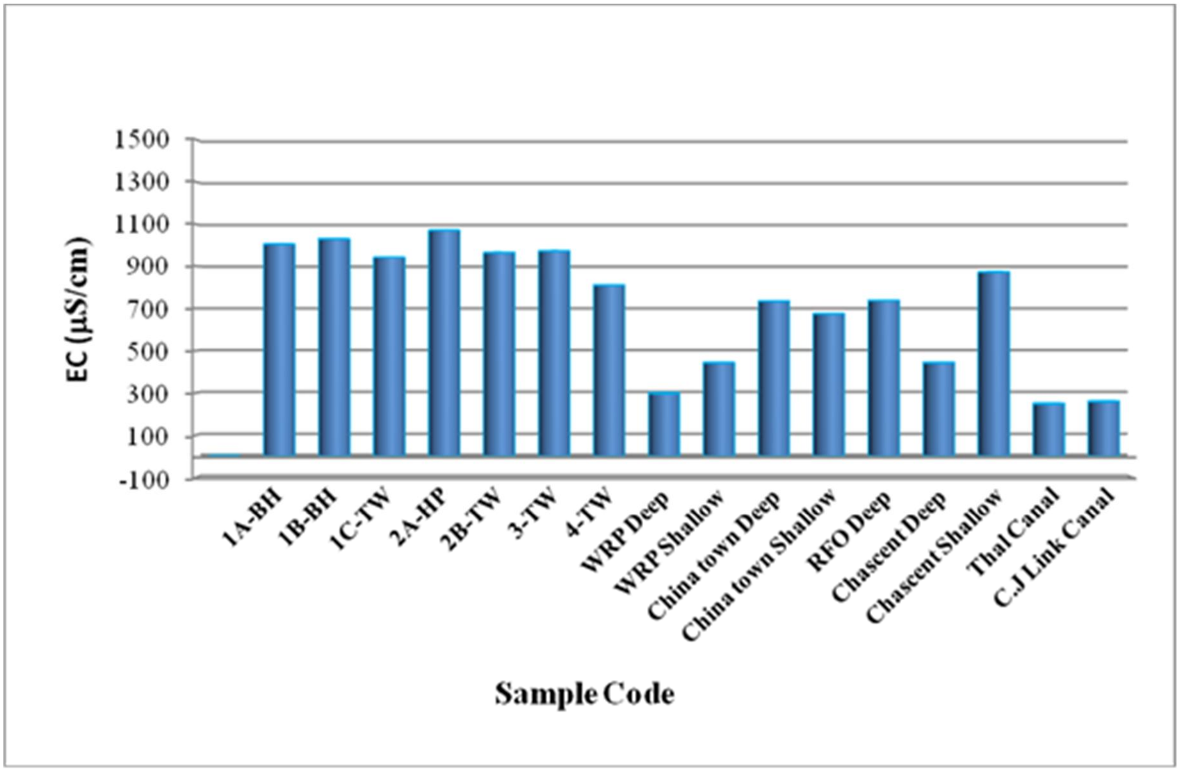


Fig. 26. Electrical conductivity of groundwater and surface water samples at Chashm site

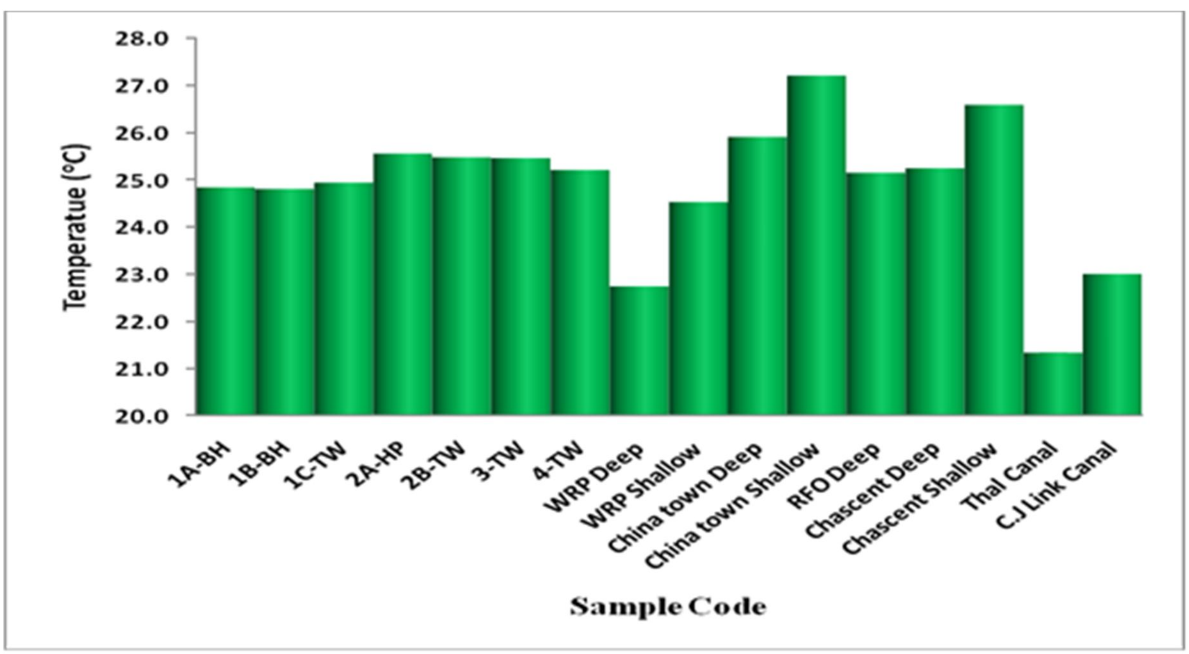


Fig. 27. Temperature of groundwater and surface water samples at Chashma site

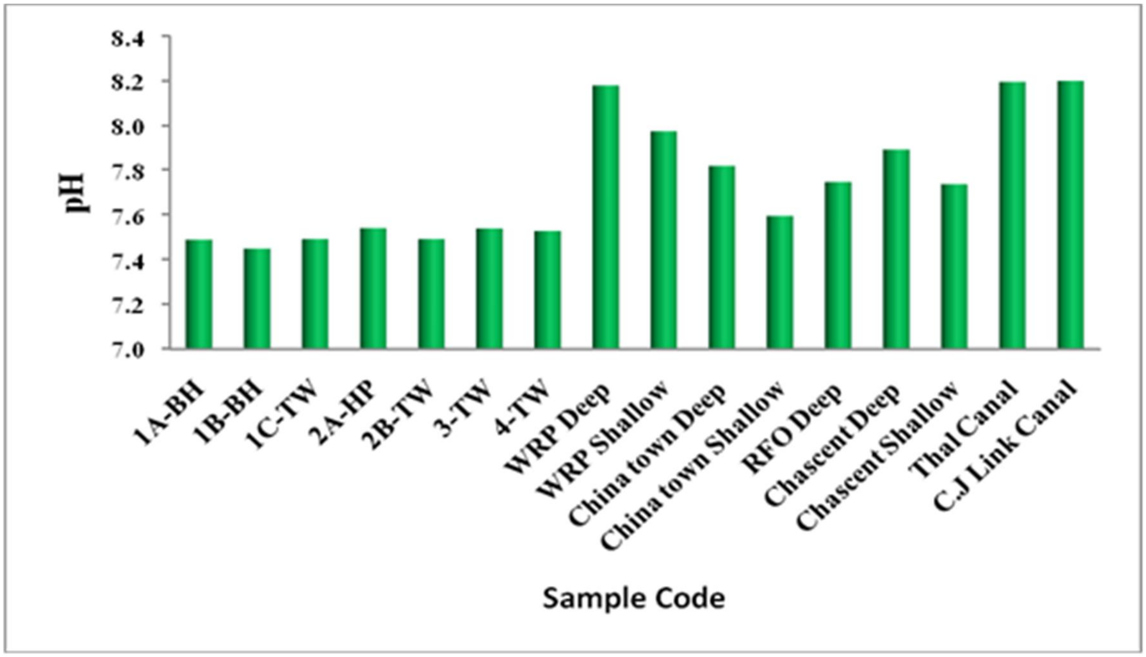


Fig. 28. pH of groundwater and surface water samples at Chashma site

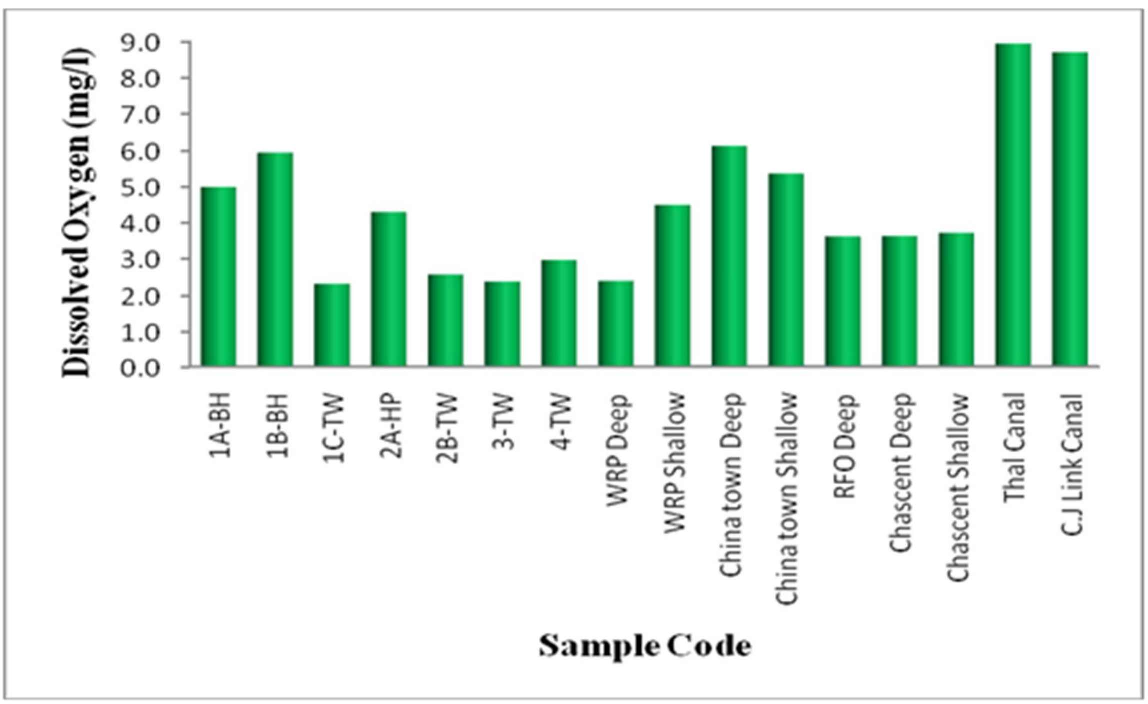


Fig. 29. Dissolved Oxygen of groundwater and surface water samples at Chashma site

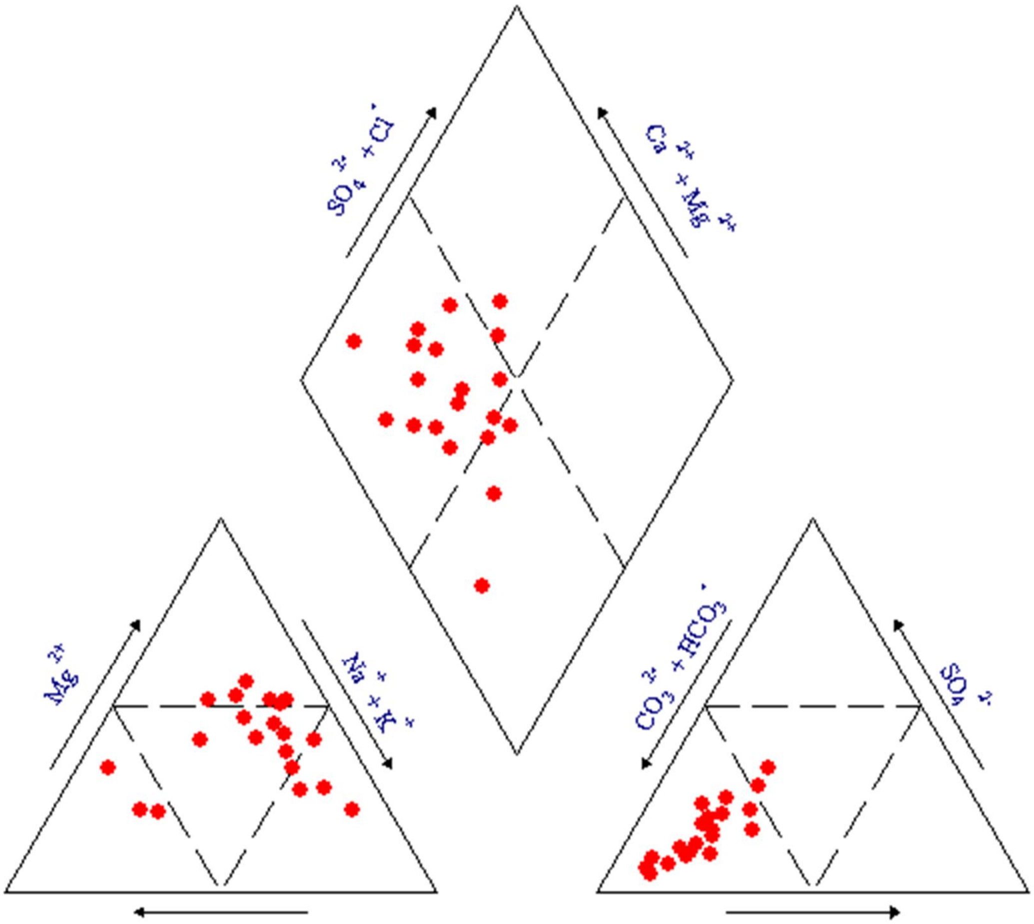
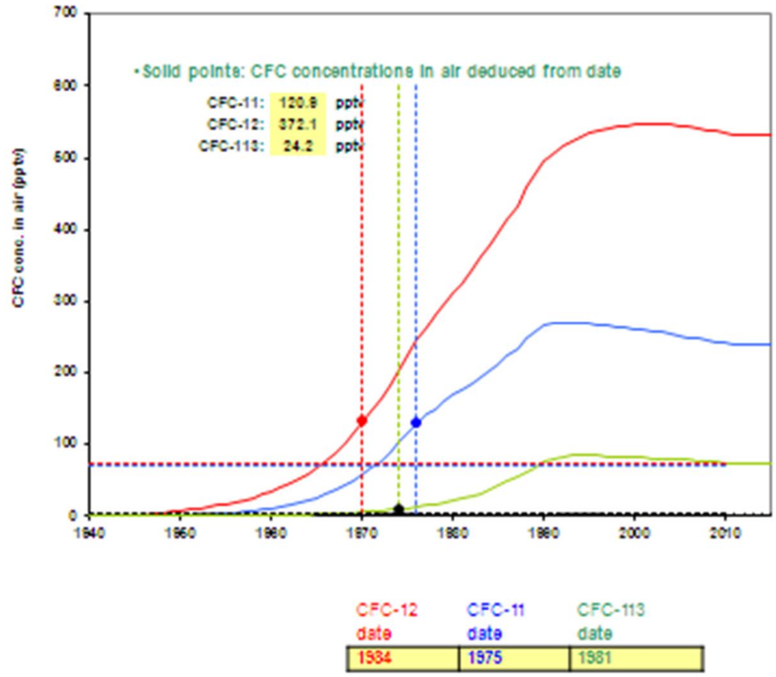


Figure 30. Piper diagram showing the chemical composition of groundwater.



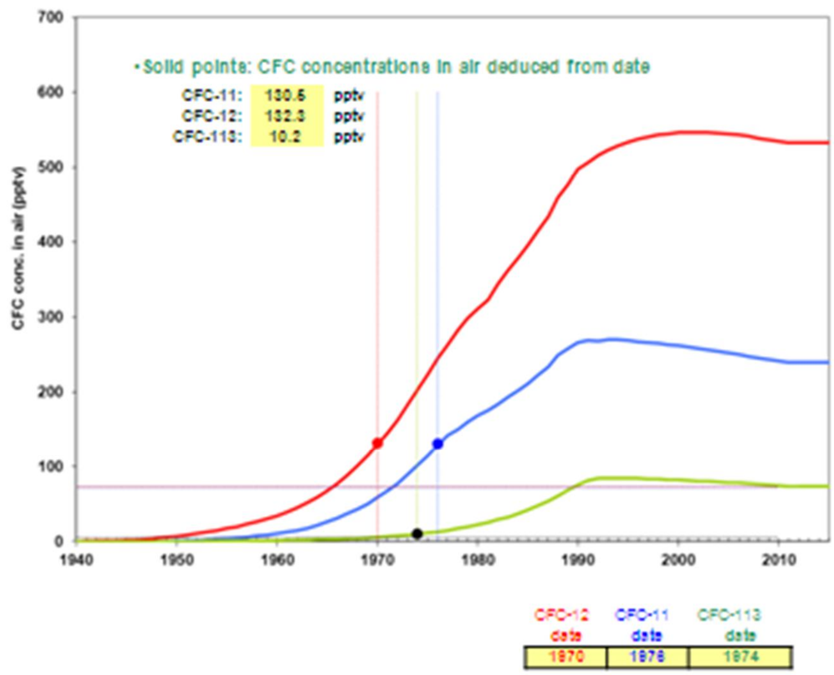


Figure.31: Graphs of Chlorofluorocarbons to determine the age of samples.

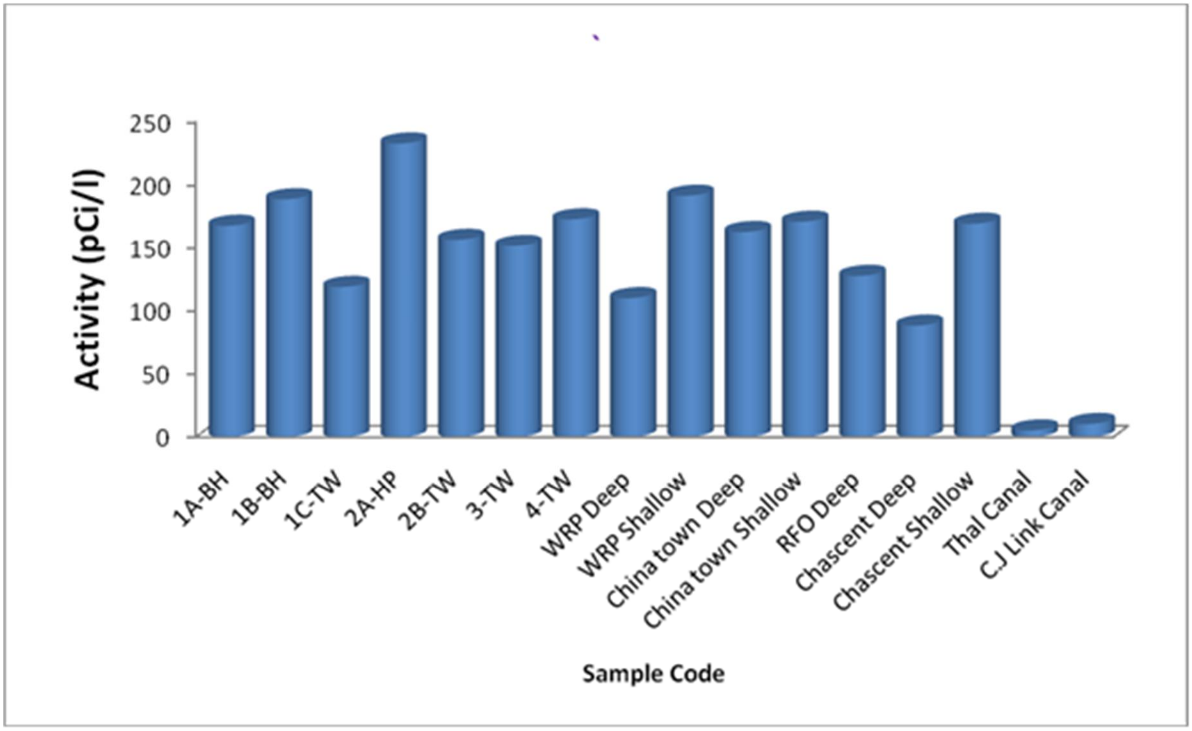


Fig. 32. Radon Activity of Groundwater and Surface water Samples at Chashma site (April 2014)

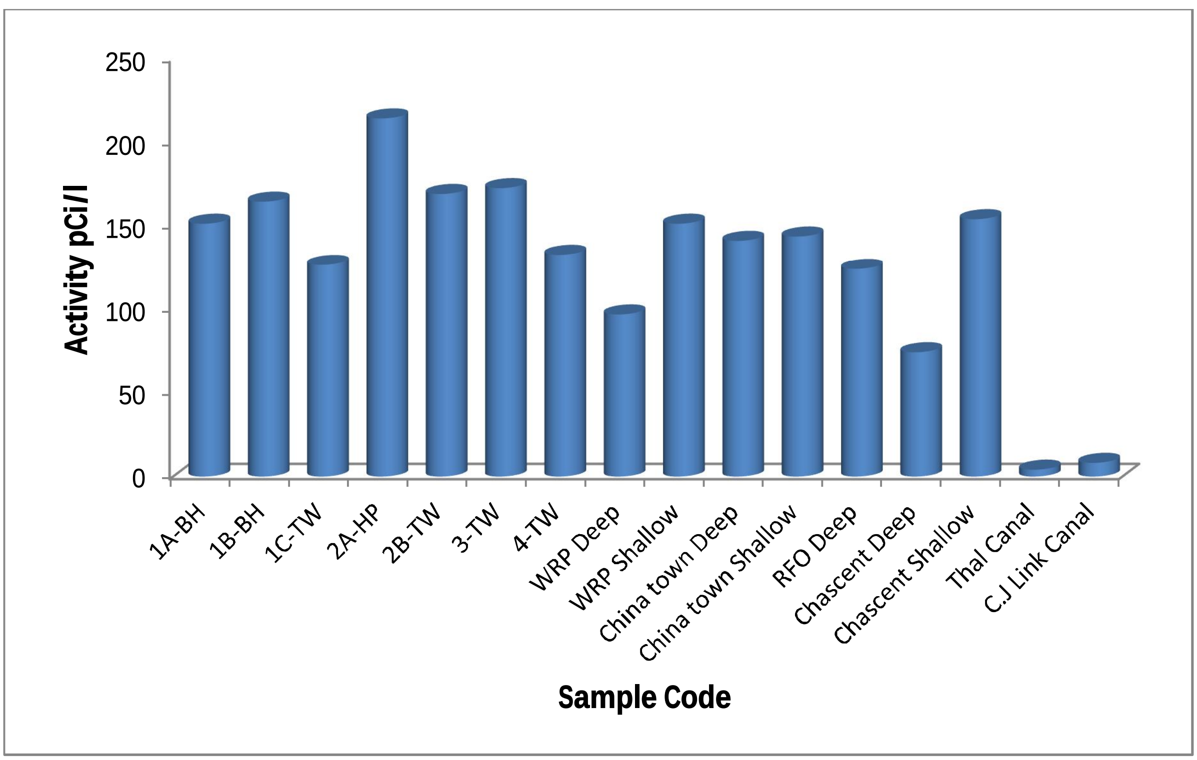


Fig. 33. Radon Activity of Groundwater and Surface water Samples at Chashma site (June 2014)

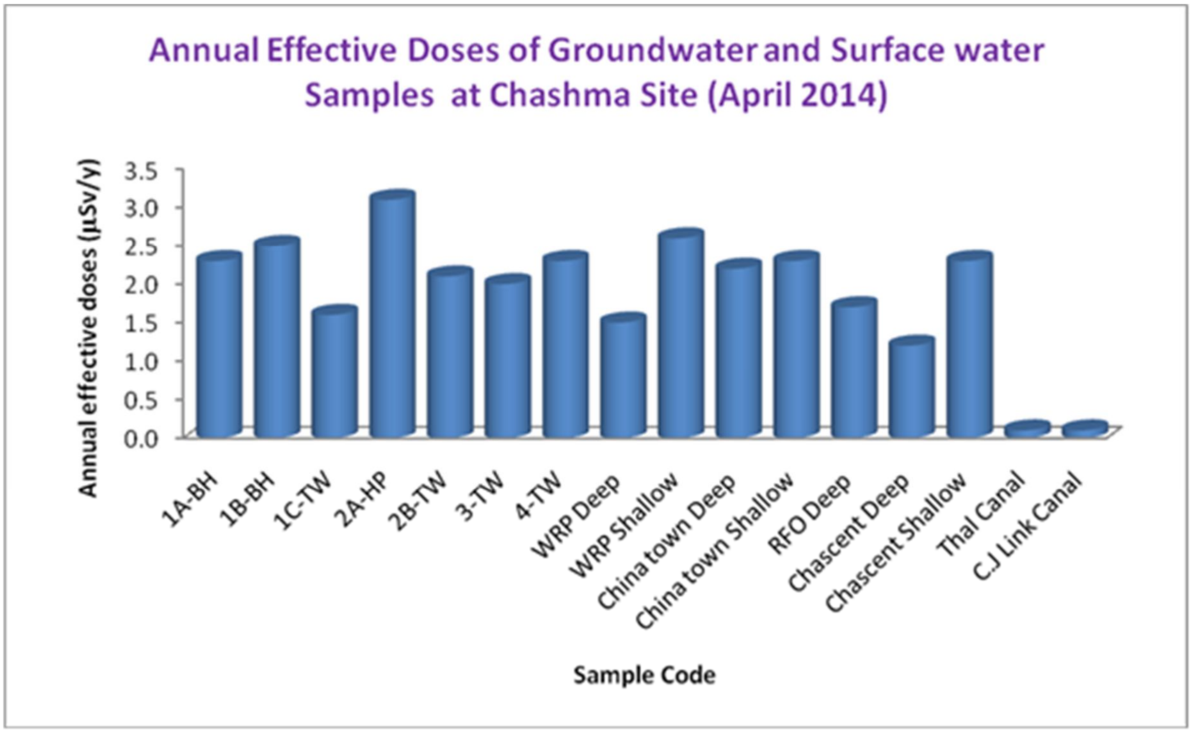


Fig. 34. Annual Effective Doses of Groundwater and Surface water Samples at Chashma site (April 2014)

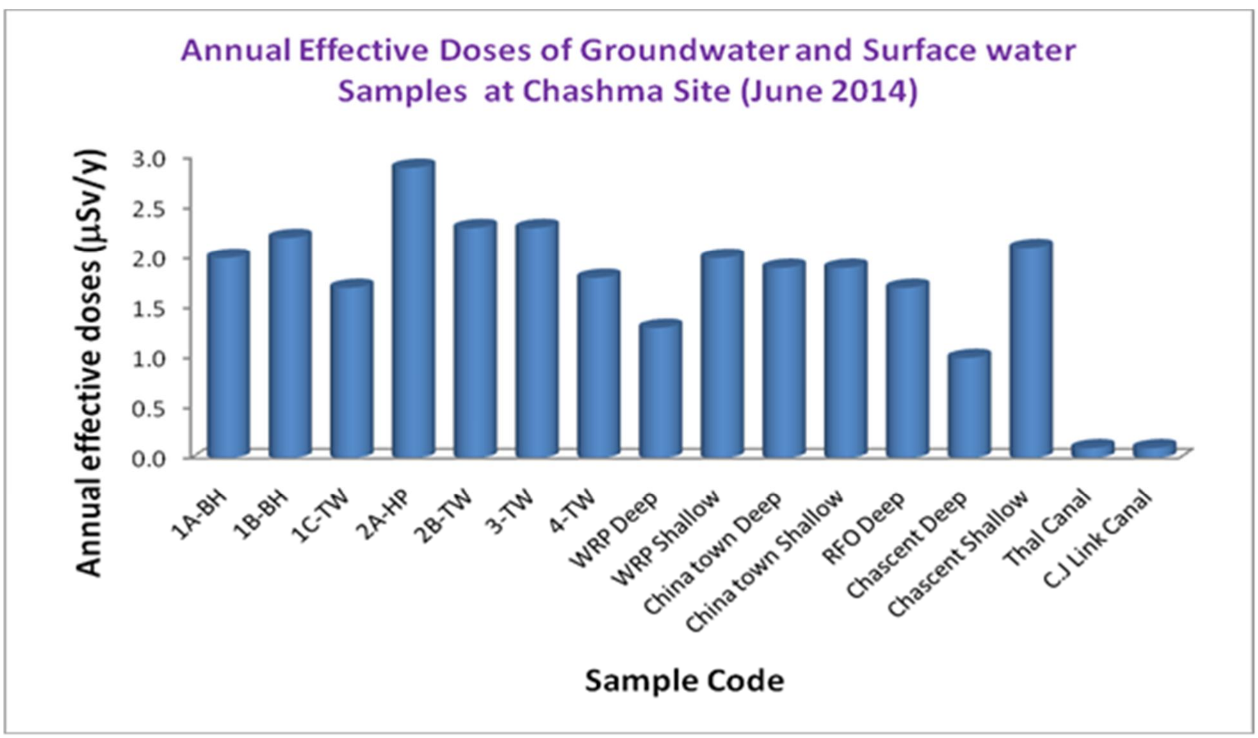


Fig. 35. Annual Effective Doses of Groundwater and Surface water Samples at Chashma site (June 2014)

Some photographs showing the field activities of drilling, pumping test and $^{3}H/^{3}He$ sampling.

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