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Evaluation of aquifer parameters and groundwater quality in Doon Valley, Uttarkhand

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ABSTRACT
Doon valley forms part of Dehradun District, Uttarakhand in the Himalayan Mountain Belt. Doon valley area is drained by the mighty rivers, Ganga, Yamuna and their tributaries prominent of which are Asan, Tons, Rispana and Song rivers. Though the area is bestowed with plenty of surface water resource, the major drinking and irrigation requirements of the valley are met through groundwater. Therefore, it becomes imperative to know the scientific attributes of the ground water bearing formations so that the ground water may be developed and managed in an objective and controlled manner. There are two aquifers in the valley, shallow aquifer under unconfined conditions and deeper with confined conditions. Pumping tests are carried out, one in each of the aquifers, to estimate the aquifer parameters and well characteristics. These values infer that these aquifers are with high potential. Groundwater quality is also analyzed through hydrochemical data obtained from 20 samples covering the area. Ninety five percent of the samples fall in field 5 of the Richard's diagram where alkaline earths dominate over the alkalies and weak acids exceed the strong acids. The data suggests that the groundwater in Doon Valley is potable and suitable for domestic and irrigation purposes.

INTRODUCTION

Doon Valley forms part of Dehradun District in the Northwestern part of Uttarakhand. The valley extends NW-SE and has a length of about 80 km with an average width of 18 km. Doon valley is bound by Lesser Himalaya on the north and Siwalik hills on the south. The eastern and western limits are formed by Ganga and Yamuna rivers, respectively. The valley has defined boundaries on all the four sides and hence it is also known as intermontane valley. The study area is shown in location map of Fig.1.

Though the area is bestowed with plenty of surface water resources, groundwater is the main source for drinking and irrigation requirements in the area. It becomes necessary to know scientific attributes of the groundwater bearing formations so that groundwater may be developed and managed in an objective and controlled manner. The objective of the present study is to estimate the aquifer parameters and well characteristics for the evaluation of groundwater potential supplemented by quality of the groundwater. Drainage pattern of an area has a direct bearing on the flow of surface water and infiltration/recharge to groundwater and for that motive the drainage pattern has been studied. To estimate the aquifer parameter of the deeper aquifer a pumping test has been conducted on a borehole located at village Rani Pokhri. Another pumping test has been conducted on a dug well tapping shallow aquifer located at village Kalimati. Hydrochemical data from groundwater samples are generated, plotted and classified. Data are analyzed and inferences are made in the light of groundwater potential and its quality. The suitability of groundwater for domestic and irrigation purposes has been studied by using the guidelines given by Bureau of Indian Standards (BIS 2003).

GEOLOGY

Doon Valley has distinct geological attributes with a wide spectrum of rock types ranging in age from Proterozoic to Quaternary (Thakur 1981). The area lies in the foot hills of the Himalayan Mountain Belt. The Main Boundary Thrust (MBT) brought the Neo-Proterozoic rocks of the Lesser Himalayan zone to over ride the Siwalik Group whereas a sudden topographic rise of Siwalik range demarcate the Himalayan Frontal Thrust (HFT), locally called as Mohand Thrust which separates the Siwalik Group from the Recent alluvium of the plains. The Mohand anticline, a growing fold

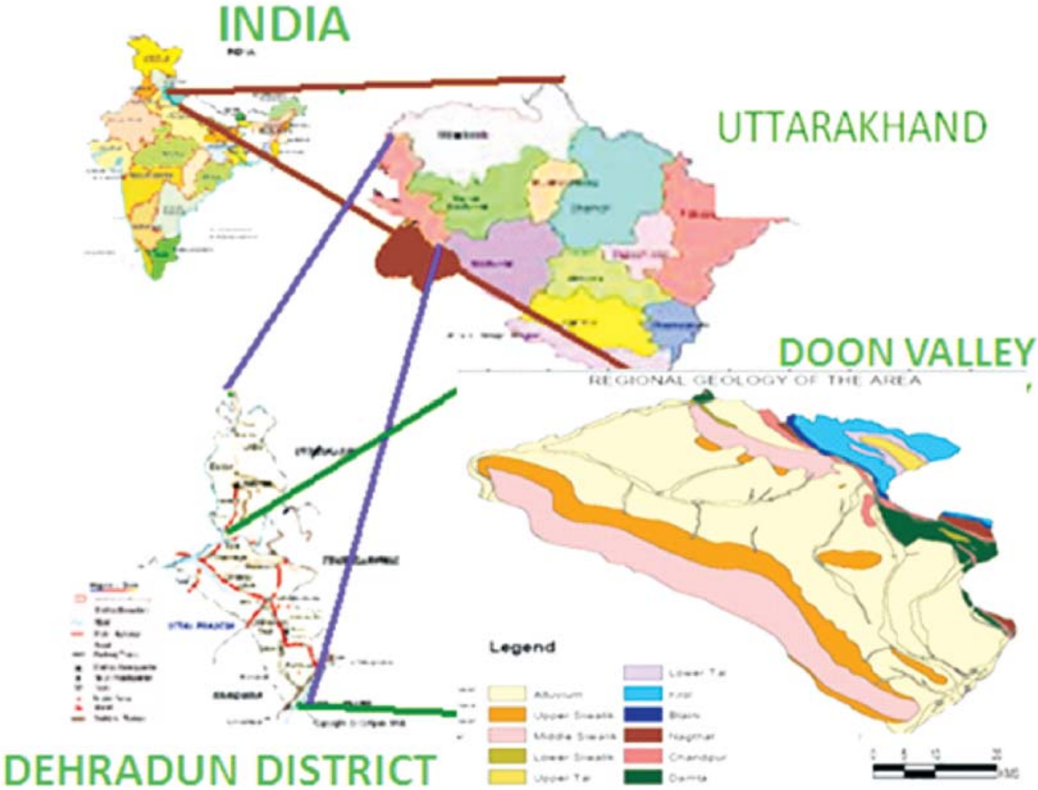

Figure 1. Location map and details of the study area.

structure, uplifted the Siwalik range and restricted the drainage within Doon Valley. The schematic interpretation for Doon Valley and tectonic control for drainage (Thakur 1995) is shown in Fig.2.

HYDROGEOLOGY

A wide variation in geology and landforms of the area gave rise to varied hydrogeological set-up. The area is broadly divided into three hydrological units namely, the Himalayan mountain belt, the Siwaliks and the Doon alluvial fill (Doon gravels). The details of the formations (CGWB 2010) are given in the succession Table 1.

Himalayan Mountain Belt

Ground water in this zone occurs as disconnected local bodies under both confined and unconfined conditions. Quartzite, schist, shale, phyllite, compact sandstone, limestone and dolomite of Jaunsar, Baliana, Krol and Tal groups have secondary porosity and permeability. The formations are characterized by fissures, veins, fractures and joints. The zone of lineament, fault and main boundary thrust shows area of high secondary porosity. The weathered veneer found on hilltops, ridges, spurs etc. give rise to large ground water repositories under perched conditions. Significant variation in the yield for short distances is common. The alluvial deposits of fluvial origin in the lower reaches of the streams/ rivers in the form of fans and terraces are highly porous and permeable and hold promising areas for groundwater exploration. The springs and seepages are the main source of water for hilly areas. The springs show wide variation in their discharge from 1400 to 1507000 liters per day (CGWB 2009).

Siwalik zone

Groundwater occurs in confined conditions and the depth to water level is comparatively deep. Though boulder-conglomerate bed of upper Siwaliks formation is highly porous and permeable, much of the water runs-off due to steep slopes and sediment forming piedmont fans dip into the intermontane valley. About 70 gravitational type springs have been reported which have a discharge varying from less than a litre per second to 113 litre per second (0.002 m^3/min). Pebble gravel conglomerate- boulder beds in the upper Siwaliks, when underlain by the Bhabhar or Doon Gravels, act as good groundwater reservoirs and serve

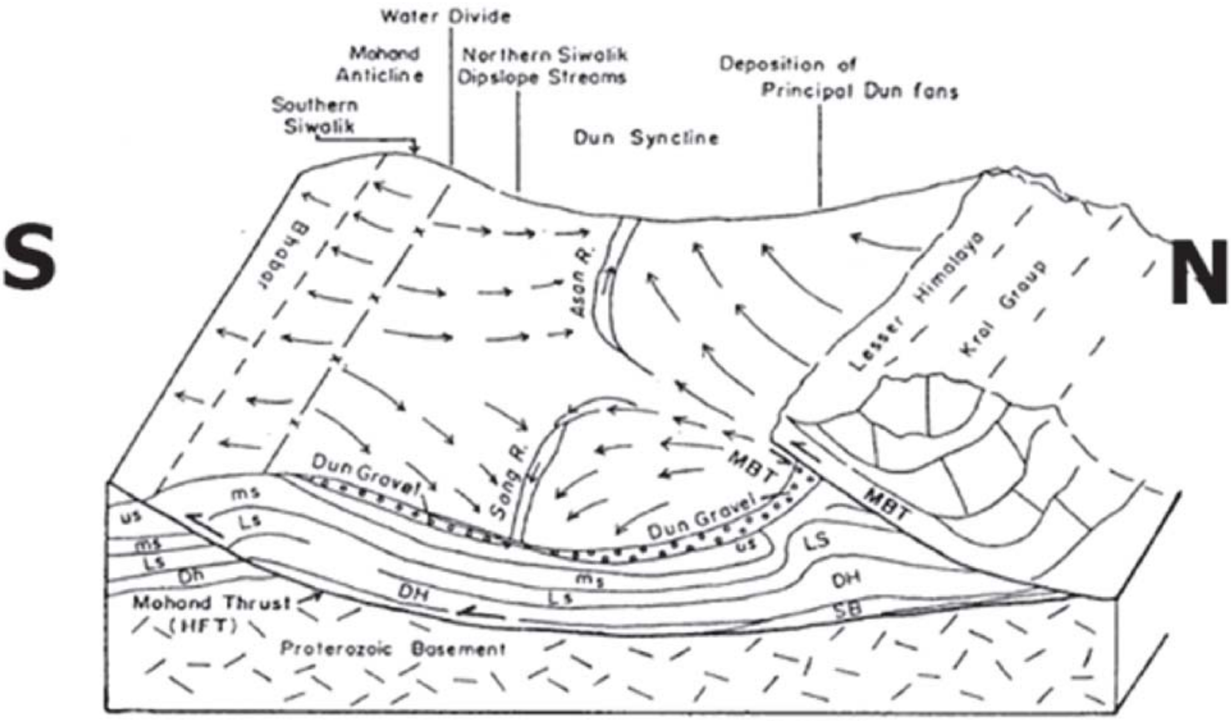

Figure 2. Schematic interpretation for evolution of Doon Valley and tectonically controlled Drainage . SB-Subathu, DH-Dharmashala, LS-Lower Siwalik, MS-Middle Siwalik,US-Upper Siwalik (Thakur 1995).

Table 1. Geological succession of Doon Valley.

Formation	Group	Lithology	Period
Fan Alluvium	**Alluvium**	**Sand**	**Holocene- Recent**
Doon Gravel		**Yellow brown clay, sand, gravel, pebbles and boulders.**	**Late Pleistocene to Holocene**
Upper Siwalik	**Siwalik Group**	**Coarse sandstone, boulder conglomerate, clay and grit.**	**Pliocene to lower Pleistocene**
Middle Siwalik		**Grey micaceous sandstone, clay and shale.**	**Miocene- Pliocene**
Lower Siwalik		**Micaceous sandstone with clay and mudstone intercalations.**	**Miocene**

as fresh water bearing zones. Exploration revealed that these are capable of yielding copious volume of water.

Doon gravels

Gravels descend from the Lesser Himalayan front as well as the north facing Siwaliks slopes called as "Doon Gravels" characterized by very coarse boulders embedded in sandy and silty matrix. The clasts are mainly composed of quartzite, limestone, sandstone and phyllite which are derived mainly from the Krol belt of the Himalayas. Pebbles from Siwalik conglomerates are also present in Doon gravels. The Doon gravels are composed of three units namely Older, Younger and Youngest Doon gravels. The older Doon Gravels are characterized by the clasts eroded from the Upper Siwalik conglomerates. These conglomerates are massive, supported by the matrix represent debris flow deposits. The Younger Doon Gravel are characterized by rounded clasts of quartzite, limestone, sandstone, phyllite and shale derived from the Lesser Himalayas and Siwalik provinces. Calcification is prominent due to the availability of carbonate material from the Krol belt. The youngest of Doon Gravels consist of very large boulders representing debris flow and braided river system. Recent alluvial deposits formed by rivers overlie this unit.

METHODOLOGY

Drainage Map for Doon Valley

Drainage map for Doon Valley area is prepared using IRS data (LISS III, FCC-321) and Survey of India Toposheets Nos. 53 E,F,G,J,K and drainage pattern is analysed. Drainage pattern of Doon valley is shown in Fig.3. Major and Minor streams along with their bifurcations are marked. Third order streams form the major stream channels in the area.

Pumping Tests for evaluation of aquifer parameters

Two pumping tests are conducted to estimate the aquifer parameters and well characteristics. A deep bore hole, located at Rani Pokhri and tapping the deeper aquifer, has been tested. To know the characteristics of the wells tapping shallow aquifer a pumping test has been conducted on a large dimension dug well located near village Kalamati.

Aquifer Performance Test at Rani Pokhri

To plan groundwater development and management, it is essential to know the transmission and storage parameters of the aquifer. Drilling through the Doon gravels which are boulder dominated is very difficult and costly. Aquifer Performance Test (APT) has been conducted on a single bore hole tapping the deeper aquifer. It doen't have an observation well and hence with the available bore hole data it is possible to estimate only the transmission parameter i.e., the transmissivity (T) of the aquifer. The storage parameter cannot be estimated due to the limitation of not having an observation well.

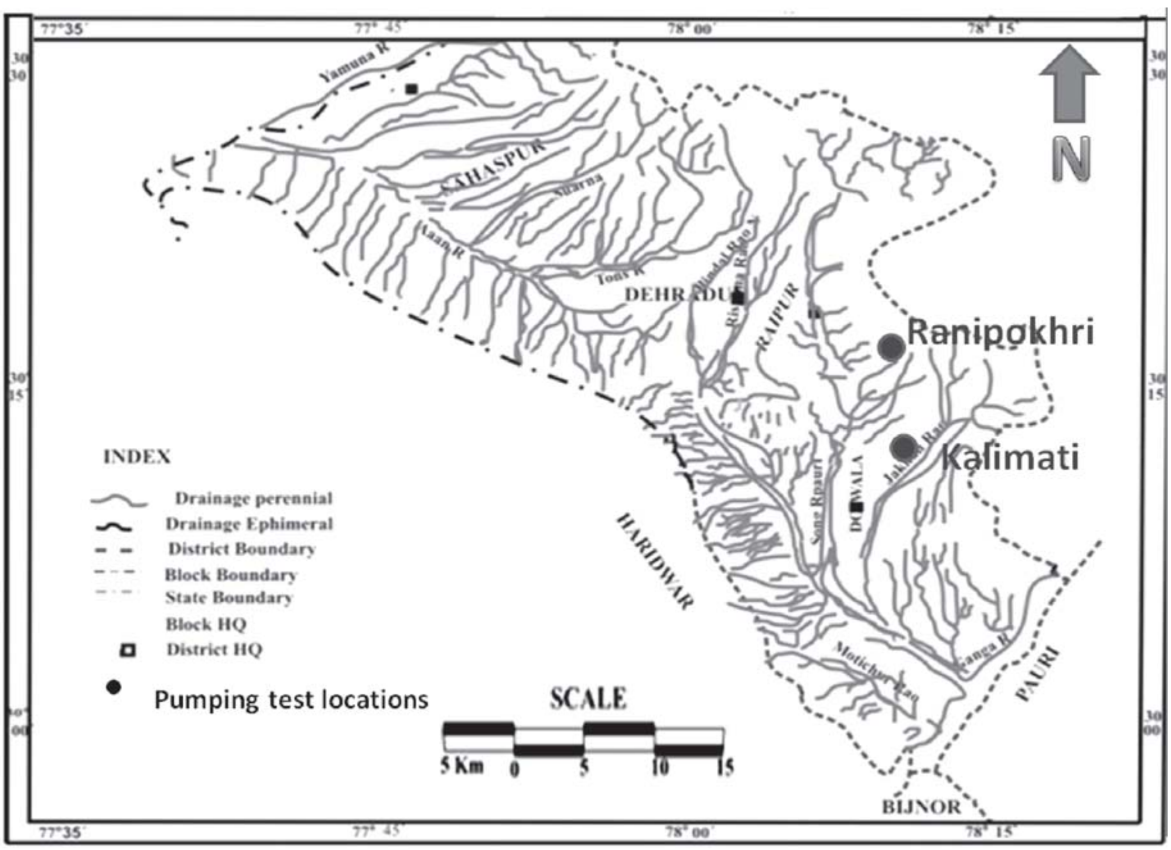

Figure 3. Drainage map of Doon Valley area.

The static water level at Ranipokhri has been measured as 86.23 m bgl(Period: Premonsoon, 2010). The tube well was given 24 hours rest before commencing the pumping test to maintain its natural static level. Pumping test is conducted at constant discharge of 2739 lpm for 240 minutes. Drawdown is noted at specified intervals of time. During the initial stage of pumping, up to the first 10 minutes, drawdown is noted for every 2 minutes. Time interval is increased to 5 minutes for the next 50 minutes. From one-hour to one-hour forty minutes the drawdown is noted for every 10 minutes. For the next 80 minutes the time interval is 20 minutes and thereafter 30 minutes. The draw-down curve is shown in Fig.4. Immediately after stopping the pumping, recuperation readings are noted at every 1 minute in the initial 8 minutes, then time interval is increased to 2 minutes. The well reached its stable static water level in 28 minutes since the pumping stopped. The residual drawdown with respect to time is shown in Fig.5.

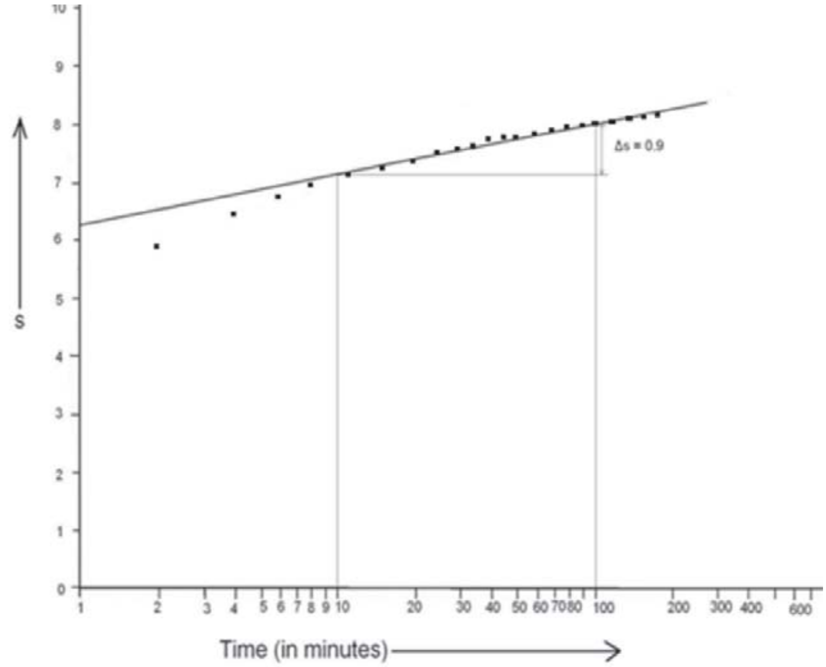

Figure 4. Time-Drawdown graph for the solution of Jacob's equation.

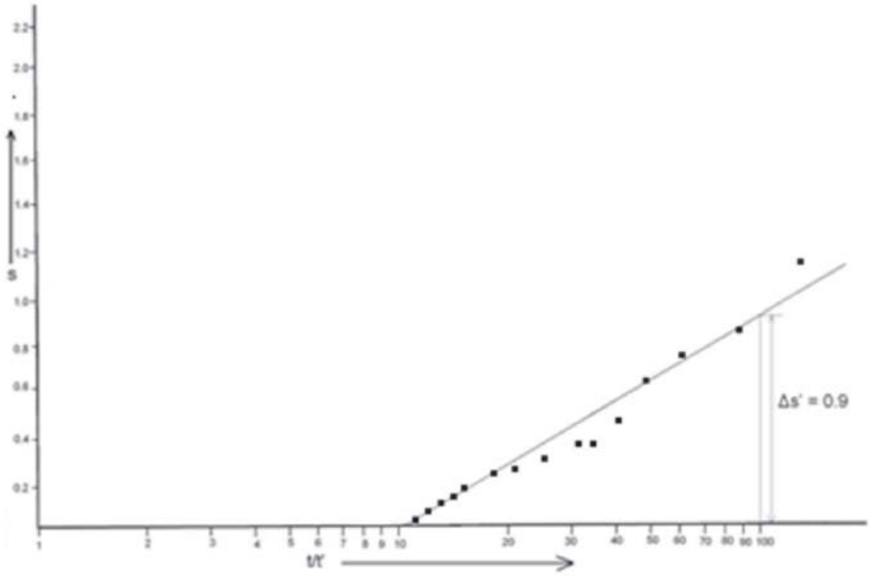

Figure 5. Graph for recoupment of the well tapping deeper aquifer.

Well Test in a large dimension dug well at Kalimati

The surface area of the dugwell is 108.62 sq. m. and saturated thickness is 0.8 m. The well was continuously pumped at constant discharge to get maximum drawdown. Immediately after the pumping stopped, the recovery of the well was observed continuously at every 5 minutes interval for 30 minutes and then at 10 minutes interval up to 3 hours. The recuperation data are analysed. The specific capacity of a well is the measure of its productivity. The specific capacity has been estimated using Slitcher's formula (Slitcher, 1906) which is as given below:

$$C = 2303^{*} (A/t)^{*} \log (S1/S2)$$

Where, C = specific capacity of the well in lpm/ minute of drawdown,

A=area of cross section of the well (sq.m),
t =time in minutes,
S1=total drawdown in metre,
S2=residual drawdown in metre

The data are plotted on a semi-log paper. The S1/ S2 values are plotted on the logerthmic scale (Y-axis) and time on the arithmetic scale (X-axis). The time-drawdown plot is given in Fig.6. A straight line is obtained. The values of log(S1/S2) are obtained for different times and accordingly the values of the specific capacity are estimated. Various well characteristics as well as aquifer parameters namely, specific capacity (of dugwell), unit area specific capacity, yield factor (specific capacity index), unit specific capacity, transmissivity and permeability are then calculated.

Groundwater quality evaluation

Groundwater samples from 20 locations covering the whole district are collected and analysed for their hydrochemical data using standard analytical procedures. The variability of groundwater hydrochemical data is evaluated. Piper's trilinear diagrams are prepared and the groundwater quality in the area is evaluated for the use of domestic purposes and compared with the standards given by Bureau of Indian Standards as well as irrigation purposes. Hydrochemical data are analysed for irrigation purposes using Richard's diagram.

RESULTS AND DISCUSSION

Along the eastern extremity of Doon Valley, the river Ganga flows SW de'bouches Gangetic plain at Haridwar, and along western extremity the river Yamuna flows SW, S and again SW. The change in orientation of the Yamuna River was due to tectonic movements along N - S trending Yamuna tear fault. Similarly the Ganga tear fault, trending NE - SW controls the drainage pattern of river Ganga. The Doon Valley is bounded in the South by high and very young topographic relief of the Siwalik ranges. This topographic elevation acts as a water divide, separating the NE flowing consequent streams from the SW flowing consequent streams. The Asan and Song are the two principal rivers in the Doon Valley, the former joining the river Yamuna and the latter the river Ganga. A water divide, running NE - SW from Clement Town city to Rajpur, separates the NW flowing river Asan from the SE flowing river Song. The tributaries of river Asan emerge from the southern slopes of Mussoorie hill range flows towards S and SW, and joining the NS flowing main river. The river Rispana flows SSW, takes right angle turn and then joins SW flowing river Suswa, which further continue its journey until it meets river Song. The river Song emerges from the Mussoorie range flowing southward and is joined by SW flowing tributaries. Subsequently it changes its course to SE and finally joins the river Ganga. Both the Asan and Song rivers system and their consequent tributaries (streams) are tectonically controlled. The Asan and Song rivers were initiated on the rising southern slopes of the Mussoorie range, but trend from SW to NW flowing in the former case i.e., river Asan and from S-SSW to SE flowing the latter case i.e., river Song were affected by uplift of the frontal Siwalik range that acted as a shutter ridge. The Asan, Song and Suswa rivers, in their lower parts of the drainage, after taking right angle turn, run along NW-SE regional alignment occupying in the center of the valley. This NW - SE alignment of these rivers appears to be tectonically controlled.

The Mussoorie mountain-front drainage initiates either from the Mussoorie range or beyond in the Lesser Himalaya and debouche into the Doon Valley deeply incise the fan gravels at three or more terrace levels. A sharp loss of gradient from Mussoorie range to Doon Valley is characterized by sharp knee that coincides with the trace of Main Boundary Thrust. The drainage that has developed on the main fans in northern part of the Doon and flowing southwestward is younger than the mountain front drainage. To the south the drainage system in the Siwalik range is controlled by the growing Mohand anticline. A water divide demarcating the highest elevation in the Siwaliks divides the drainage system of the northern Siwalik from that of the southern Siwalik. Dip-slope of the northern Siwalik dipping Northeast controls the drainage. All the streams flow sub-parallel, towards NE on the dip-slope and join the SE flowing river Song in the eastern part of the Doon Valley. To the south of divide the drainage over the southern Siwalik flow opposite to dip of the strata i.e., towards SW debouching on the Bhabar alluvial plains.

The maximum drawdown is 5.9 m during the first 2 minutes of pumping at constant discharge of 2739 lpm. There after the drawdown gradually increased up to 160 minutes and then it reached a stable level (i.e. the rate of drawdown is equal to the rate of recoupment from the aquifer). The pump was run for 240 minutes to obtain a significant drawdown with the constant discharge of 2739 lpm. Transmissivity (T) of the aquifer is calculated using Jacob's straight line method (Jacob, 1947) and the T value estimated is 802.5 **m^2/day.** As the transmissivity value is considerably high, it may be concluded that the aquifer has a good groundwater potential in Rani Pokhri area**.**

Immediately after stopping the pumping, recovery (recuperation) test was started. The recuperation data is plotted in Fig.5. It is observed that maximum recovery took place during the first minute and then its gradually decreased and reached the stability in 28 minutes. Time-drawdown plot has been interpreted for aquifer parameters. Transmissivity is calculated and its value is 802.5 m^2/day and the value is suggestive of the fact that the aquifer has good potential of groundwater. Further, in both the above procedures, the same value is obtained for the transmissivity which indicates the accuracy of the tests conducted.

The performance of shallow aquifer's dug well is also studied. Before pumping started, the initial water level was 1.29 m bgl. In one hour of pumping the water level is reached to a depth of 2 m bgl, which is maximum drawdown. Hence the total drawdown caused by pumping was 0.71 m. The drawdown-time data is plotted in Fig.6. As soon as pumping stopped, the recuperation of the well started. The total recoupment measured in 3 hours was 0.17 m.

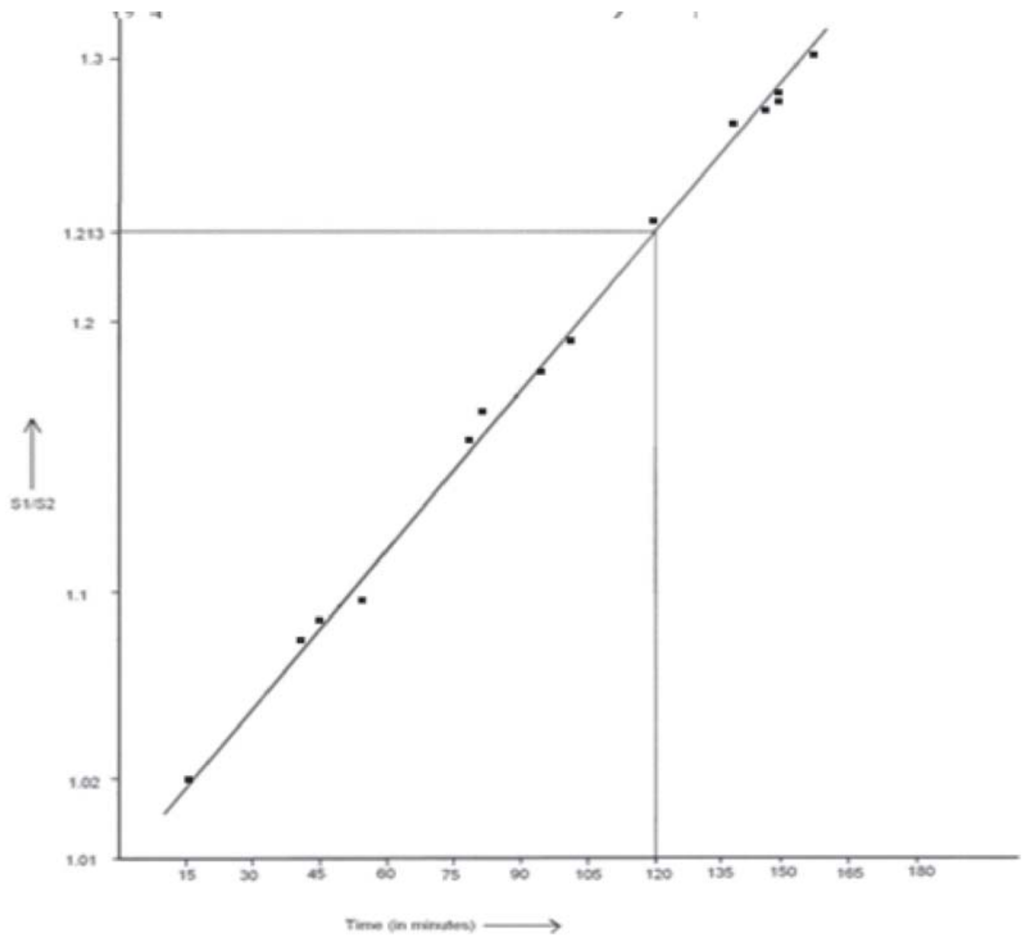

Figure 6. Shallow aquifer performance test in a dug well.

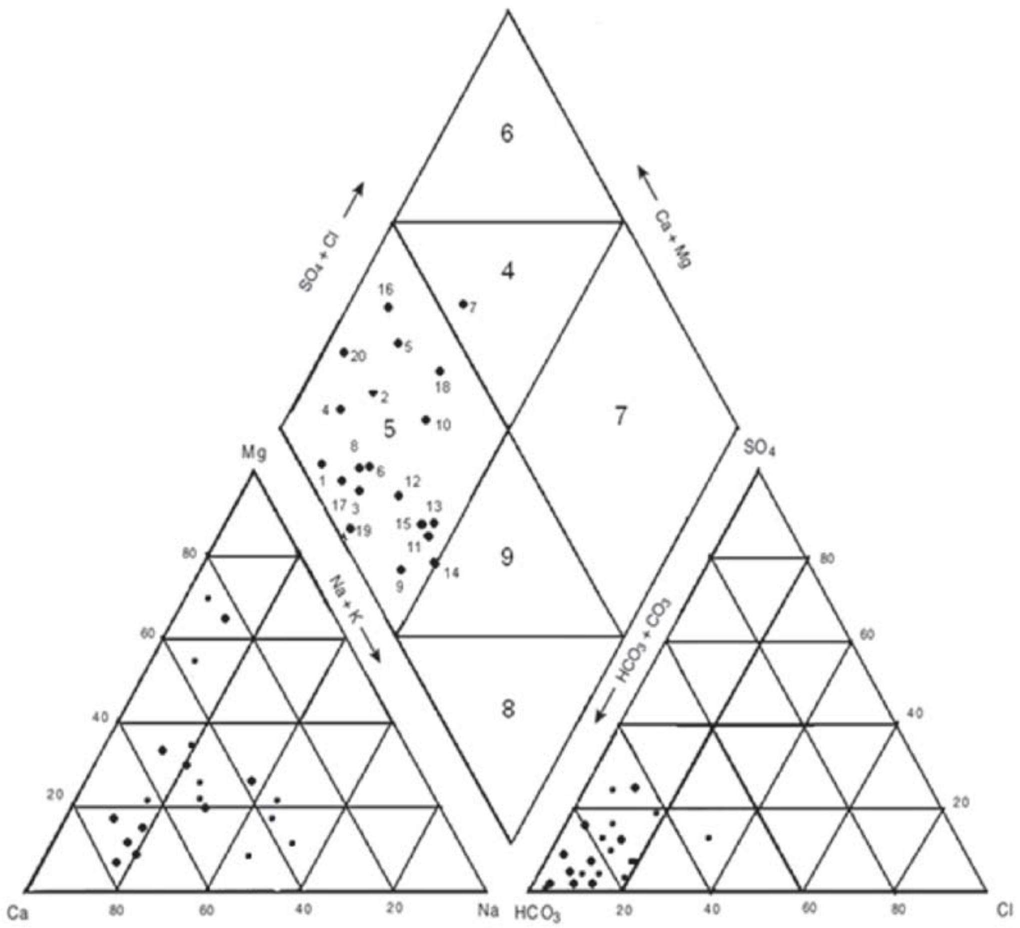

Figure 7. Trilinear Diagram showing Groundwater water quality of Doon Valley.

The specific capacity of the dug well tapping shallow aquifer is 2528.62 lpm/m drawdown. The Unit specific capacity and specific capacity index values arrived from the test are 23.3 lpm/m^3 and 3160.8 lpm/m^2, respectively. Modified Theis equation (Theis 1935) has been used to estimate the Permeability and Transmissivity of the shallow aquifer. The values of Permeability and Transmissivity of the shallow aquifer respectively are 0.042 darcy and 0.221 lpm/m. These values help inferring that the aquifer is with high potential.

Hydrochemical data from 19 locations out of 20 locations in the Doon Valley fall in field-5 of trilinear plot (Piper 1944) in Fig. 7. This shows that the alkaline earths (Ca + Mg) exceed by 50% and dominate over alkali metals (Na + K). The weak acids (HCO_3 + CO_3) dominate over strong acids (SO_4 + Cl). Chemical properties of groundwater in these locations are dominated by carbonate hardness. At one location namely, Lal Taper, exactly contrary conditions are observed where strong acids dominate weak acids and alkali metals dominate alkaline earths, this is local and may due to human activities. On comparison of data presented in Table 2, it can be concluded that pH of Groundwater from different localities of Dehradoon District varies from 8.01 to 8.55. All other parameters are under permissible limits. Groundwater in the district is slightly basic in nature and fit for drinking purposes.

Groundwater quality also plays a significant role in irrigation. Improper management of water quality for agriculture use especially when it carries high amounts of salt loads affects directly plant growth and crop yield. The dissolved excessive solid contents reach and settle at various parts of the plants through the roots due to osmotic pressure and difficult to leach or dissolve them out. The adverse of this are observable in crop as stunted growth, low yield, discoloration and leaf burns at margins or top. Groundwater quality for irrigation purposes is evaluated using Richards (1954) diagram. The diagram uses data of pH values, Electrical

Table 2. Drinking water characteristics of BIS (IS:10500:2001).

S. No.	Characteristic Parameters	Desirable Limits (mg/l)	Permissible Limits (mg/l)	Present work (mg/l)
1.	pH	6.85-8.5	No relaxation	8.01 – 8.55
2.	Total Hardness	300	600	111 - 583
3.	Chloride	250	1000	0.19 - 35
4.	Fluoride	1.0	1.5	0.015 – 0.074
5.	Dissolved solids	500	2000	66.6 – 342.6
6.	Calcium	75	200	8.4 - 64
7.	Magnesium	30	100	1.5 - 41
8.	Sulphate	200	400	0.05 - 95
9.	Nitrate	45	100	0.62 - 64

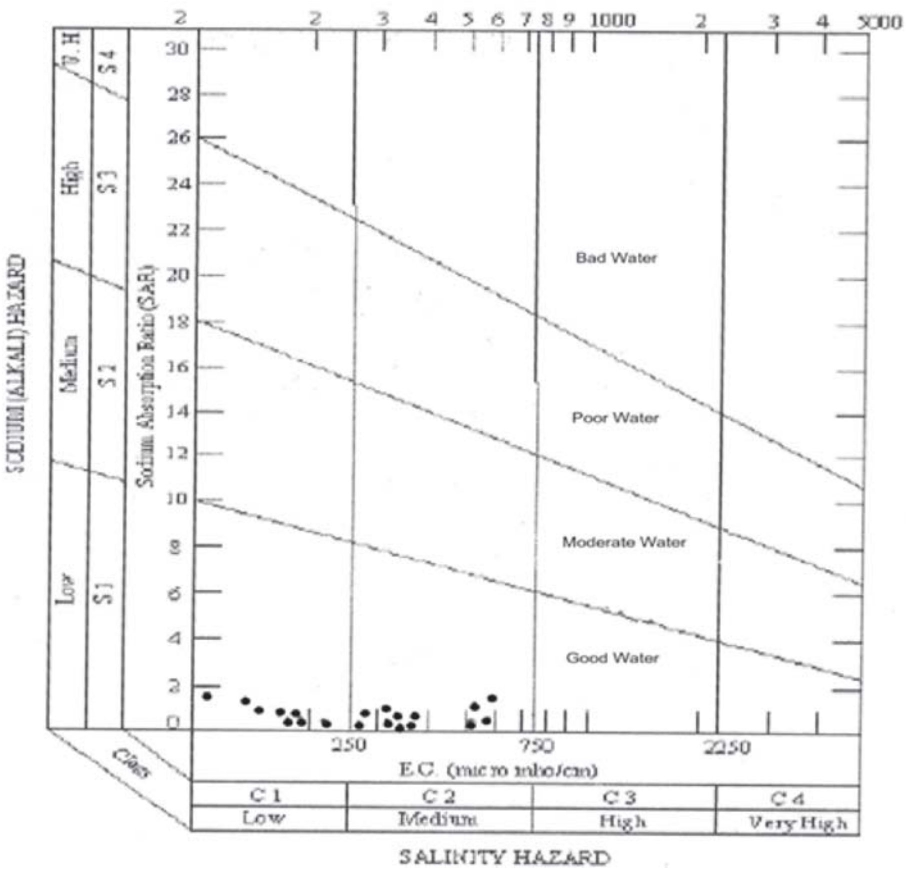

Figure 8. Richard's USSL Diagram for suitability of water for irrigation.

Conductivity in micro Siemens/cm at 25° C and Sodium Absorption Ratio (SAR=Na/(Ca+Mg)/2) at each locality. The data is plotted in the Richards diagram and is presented in Fig. 8. As mentioned earlier, the pH of the water samples range from 8.01 to 8.55 and quality of water is slightly basic nature. Electrical Conductivity values are varying from 111 to 583 micro Siemens/cm. SAR values are ranging between 0.052 and 1.8. From the data and their position in the US salinity diagram (Richards 1954) it can be inferred that the Salinity Hazard is very low to medium and Sodium Hazard is very low. Groundwater is of C1S1 type which is suitable for irrigation for all type of crops.

CONCLUSIONS

The hydrogeological investigations carried out in the intermontane Doon Valley are suggestive of the fact that the shallow as well as the deeper aquifer are with high groundwater potential. The domestic and irrigation needs are met from the deeper aquifer which is under stress. Hence it becomes imperative to use this precious resource judiciously. It is recommended that groundwater management studies should be parallelly taken up along with development. The hydrochemical studies indicate that the water is potable and may be safely used for domestic purposes. The plots drawn for the assessment are suitable for irrigation purpose which categorically suggest that the water is of C1S1 type and may be used for all type of crops.

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Dr.U.Kedareswarudu has been working as Associate Professor at University of Petroleum and Energy Studies, Dehradun for the last three years. He obtained his M.Sc.(Tech) Degree in Applied Geophysics and Ph.D. Degree in Mineral Exploration from Andhra University and also M.Tech. Degree in Computer Science Engineering from Allahabad University. He published 20 research papers in reputed journals and presented 15 papers in National and International Seminars and put up 24 years of teaching experience at various levels. Apart from his profession as a Teacher in University, he is also interested in Mineral worked in various geological environments from fundamental properties to development of exploration strategies for various mineral deposits and geotechnical problems in the country and abroad. He executed three major projects funded by UGC, CSIR and DST from each one. He is a member of various Scientific Societies. He is currently looking after the Petroleum Exploration Programs of B.Tech. and M.Tech. courses in the University. His present research interest is to establish a base in India for 9-component Seismic Surveys and its expertise.

Dr.R.P.Singh got his M.Tech. and Master of Hydrology Degrees from Indian Institute of Technology, Roorkee and Ph.D. Degree from University of Rajasthan, Jaipur. Since his inception in the Central Ground Water Board in 1983, he has been working in different terrains, Basalts of Maharashtra to Himalayan terrain of Uttarakhand. Some of his reputed works are Hydrochemistry, Conjunctive use of Surface and Groundwater, Mathematical Modeling , Groundwater Exploration and Technology Mission. Dr.R.P.Singh also published 20 research papers in various journals presented 26 papers in seminars on various themes. He is interested in Artificial Recharge of Groundwater. He is now working as Scientist-D and Head of Office of CGWB, Dehradun, Uttarakhand.