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Research Article

ESTIMATION OF CONTRIBUTION OF SPRINGS TO ASAN RIVER WATERSHED OF DOON VALLEY THROUGH BASEFLOW-HYDROGRAPH METHOD

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ABSTRACT
Asan River Watershed is a prominent catchment area in Doon valley at foot hills of Siwalik ranges in the Dehradun District of Uttarakhand. The catchment area is the surface of an asymmetric syncline and Asan River flows along its axis. It has a length of about 40 km and width 18 km. The Asan River is a third-order drainage system which charges with surface run-off during monsoon and base-flow during non-monsoon period. The drainage system produces 150 MW of Electricity at Dhalipur Barrage before merging into Yamuna River. Though the area bestowed with number of streams, domestic and irrigation needs are met through Groundwater only. Aquifer parameters evaluation and their monitoring are imperative. Groundwater storage is replenished mainly due to springs existing all around the Doon Valley. Groundwater recharge through rainfall is $1.3396*10^9$ m^3/y. The contribution of springs to the groundwater storage in Asan river watershed is estimated using Baseflow- hydrograph method. Baseflow is calculated using daily discharge data at the Barrage. Daily discharge data is collected consecutively for 11 years. Significantly the contribution of the system of springs to Asan river watershed is very high and is estimated to be $4.66944*10^9$ m^3/y which is 77.8% of the total groundwater recharge in the area. Groundwater recharge is estimated using monitoring wells data. Groundwater budget equation is balanced with inflow and outflow stakes. The excess water storage in the watershed is attributed to the contribution of the springs to Asan River.

Key Words: *Asan River, Watershed, Baseflow, Springs, Groundwater Recharge*

INTRODUCTION
Asan river watershed is a prominent part of Doon valley in Dehradun District of Uttarakhand. It has a length of about 40 km and width 18 km. Rainfall is moderate to heavy in this area. Asan River is a third order stream and most of rainfall flows as surface run-off or flash-floods. The drainage system is controlled by major and minor faults and lineaments. There exists a system of springs all around the catchment area. The objective of the present study is to estimate the contribution of springs to groundwater recharge of Asan river watershed.

Doon valley is drained by two drainage systems with a drainage divider passing through Mussori, Dehradun and Mohand anticline in the South. One drainage in the system flows towards North-West forming a river system with Asan as a major stream and hence the drainage system is called Asan river watershed. It merges with the major river Yamuna at Dhalipur. The second drainage system flows towards South-East of Doon valley with Song river as a major stream and finally merges with Ganga river at Rishikesh. Asan watershed is situated in the western part of doon valley between $77^o38'$E and $78^o06'$E longitudes and $30^o14'$N and $30^o31'$N latitudes. The location of the watershed and its details are given in Fig.1. Asan watershed is bounded by Main Boundary Thrust of Lesser Himalayan range in the North and Mohand Thrust of Lower Siwaliks in the South. Yamuna River forms a barrier on the West and drainage divider on the East. Hence Asan watershed is formed in the intermontane valley of Dehradun District. Asan watershed consists of smaller watersheds around the major streams as shown in Fig.1. Analysis of Base-flow and evaluation of unconfined aquifer characteristics of Asan river watershed are under the scope of discussion

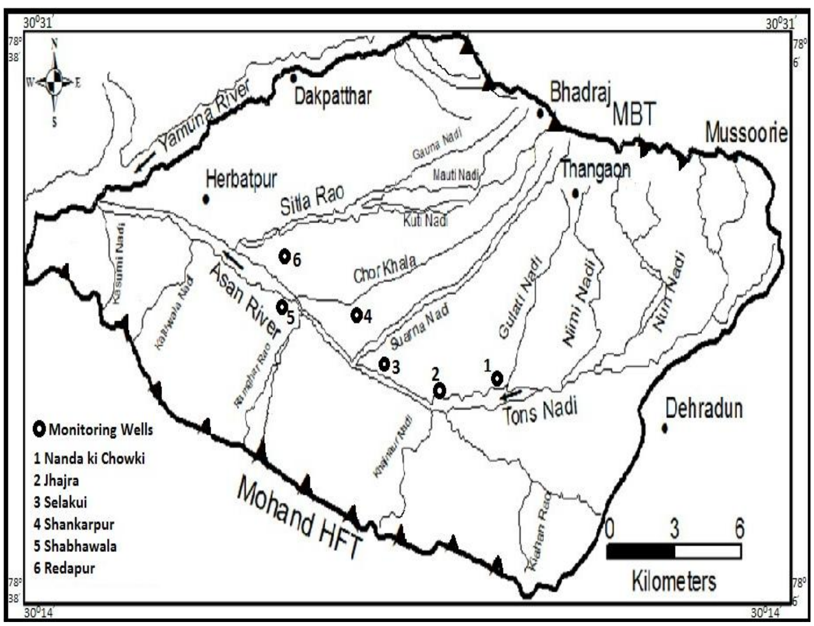

Figure 1: Location map, drainage pattern and details of Asan Watershed area

Asan watershed forms an asymmetrical synclinal valley which flows North-Westwards and joins with Yamuna river. The physiographic units are extended NW-SE to ENE-WSW. The major drainage pattern in the area is mostly dendritic to sub-dendritic, parallel to sub-parallel, trellis, angular, rectangular, intermittent and braided. Though the area is bestowed with plenty of surface water resources, groundwater is the main source for drinking and irrigation requirements. It becomes necessary to know scientific attributes of the groundwater bearing formations so that groundwater may be developed and managed in controlled manner. Estimation of base flow indices for its discharge data, analysis of aquifer parameters and estimation of contribution of springs to Asan river watershed are under the scope of the present discussion.

Geology of the Area

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

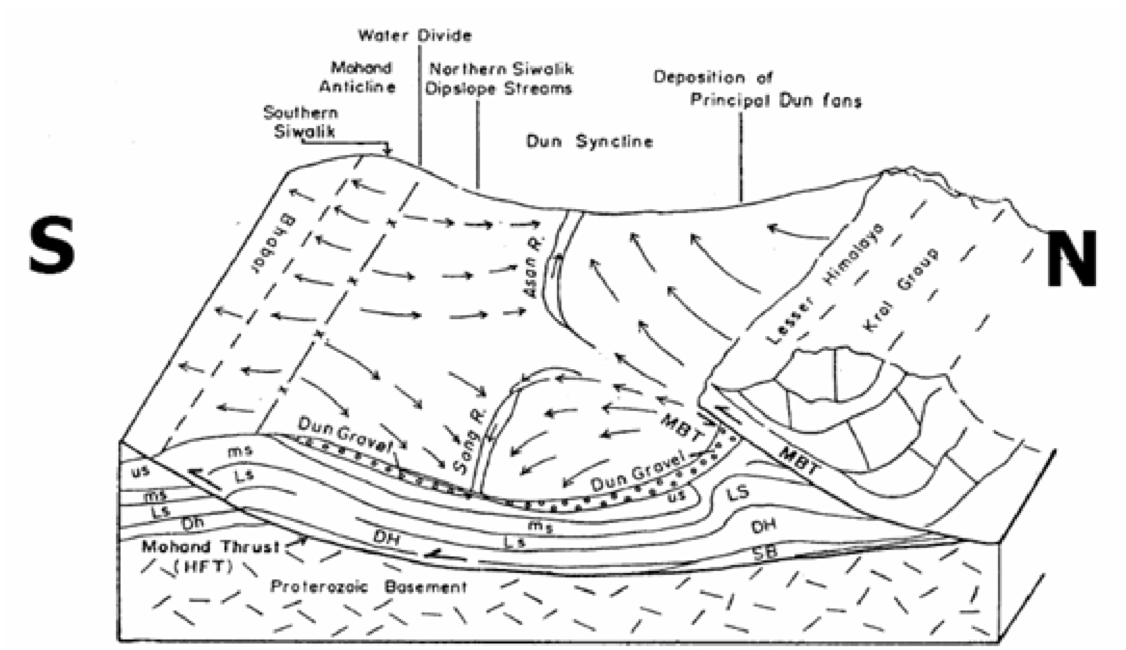

Figure 2: Schematic interpretation for evolution of Doon Valley and tectonically controlled Drainage. SB-Subathu, DH-Dharmashala, LS-Lower Siwalik, MS-Middle Siwalik, US-Upper Siwalik (Thakur, 1995).

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 geological succession and their details are given in the geological 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 areas 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 15, 07,000 liters per day (CGWB, 2009).

Table-1: Geological succession of unconfined aquifer 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		Coarse sandstone, boulder conglomerate, clay and grit.	Pliocene to lower Pleistocene
Middle Siwalik	Siwalik	Grey micaceous sandstone, clay and shale.	Miocene- Pliocene
Lower Siwalik	Group	Micaceous sandstone with clay and mudstone intercalations.	Miocene

Siwalik Zone

Groundwater occurs in both confined and unconfined 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 from Dehradun district 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 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 Gravels is 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.

Structure and Tectonics of Asan Watershed

Watershed is a landform defined by high points and ridge lines that descend onto lower elevations and valleys. As a result precipitation is carried as run-off towards one focused output point. Precipitation in a watershed finds its way into the soils, groundwater, springs and streams and ultimately forms into a major channel or river. In the present case study, Tons Nadi, Suarna Nadi, Sitla Rao Nadi are contributed to form the Asan river which joins finally Yamuna river at Dhalipur as a single output. Further, land forms characterize the landscape of a watershed. Asan watershed is characterized by rough mountainous terrain in the Northern and Southern parts, valleys and high altitude plateaus in the middle portions with accompanied streams.

Geomorphology of the Area

Nossin (1971) divided the area into Siwalik range, Doon Valley and Himalayan front. Sangeetha (2000) identified the Doon valley as five geomorphic units. The major geomorphic units in Asan watershed are Denudo-structural hills, structural hills, Residual hills, Piedmont zone, River terraces, Flood plains, Lineaments and settlements (Sangeeta, 2000). Residual hills of Doon Gravels control the drainage pattern in the area. River terraces of Asan, Sitla Rao, Suarna streams are gentle to flat in nature.

Precipitation and Land Cover

Asan watershed covers an area of 1400 km^2. The area receives heavy rainfall from South-West Monsoon from early July to the end of September. The monsoon is active hardly 100 days. The average rainfall vary from 90 to 240 cm with an average of 1700 mm/y. Malavika (2010) reported that the volume of rainfall in the area is 94.62 bcm out of which 17.5% is lost as evaporation, 29.5% is absorbed in to soil, 15.5% infiltrates in to groundwater and 37.5% reaches river Asan. The area is near the foothills of Siwaliks and valleys and has minimal forest cover and more of urbanization, industries and agriculture. The dominant species of Forest Cover is Sal under tropical to subtropical followed by Pine. Glaciers in the Himalayan range gives rise to Ganga and Yamuna. Rainfed seasonal reivers are Sitla Rao, Suarna, Tons, Nun, Rao and Asan. Flash flood in these seasonal rivers is a common phenomenon and causes high level erosion and modifies geomorphology of the area. There is a considerable loss of groundwater. Evaporation along the seasonal river systems and evapotranspiration through forest cover are the major concerns of water losses in the watershed where as springs are contributing to groundwater potential storage in the Doon valley.

Base Flow

Groundwater seepage in to a stream channel is known as Baseflow. During most of the year, stream flow is composed of both groundwater discharge and surface run-off. When groundwater provides the entire flow of a stream, baseflow conditions are said to exist (Keith, 2001). After the rainfall has replenished the groundwater supply does the water table rise sufficiently to intersect the stream bed and resume baseflow discharge? The amount of base-flow a stream receives is closely linked to the permeability of rock or soil and hydraulic gradient of the watershed. In watersheds generally, the formations exposed to the recharge and get tapered in the stream channel along which groundwater seepages or baseflow conditions prevail. Because of which stream flow periods are to be extended between rainfalls. In Assan watershed, from Selaqui onwards, the stream becomes perennial and has a high base-flow component. Baseflow measurements are tedious and also need baseflow measuring instruments. An alternative approach is stream hydrograph method. For a gaining stream where groundwater is contributing to stream flow, analysis of the stream hydrograph can indicate the magnitude and timing of this contribution. Analysis of stream hydrograph also separates the baseflow component and provides characteristics of the unconfined aquifer and natural storages feeding the stream (Smakhtin, 2001). Other storages like glaciers, caverns in karst terrain and springs can also contribute to the baseflow (Griffiths and Clausen, 1997). In the present case, it is found that springs contribute much to the groundwater potential and hence in turn to base-flow. Hydrograph essentially represents the net balance between gains to and losses from the stream. The losses include direct evaporation from the stream channel or from any connected surface water features, springs, watersheds etc., transpiration from riparian vegetation, evapotransiration from source, groundwater seepages and leakage to the underlying aquifer or rewetting of stream bank and alluvial deposits (Smakhtin, 2001).

A hydrograph is a time-series record of water level, water flow or other hydraulic properties and can be used to gain insights in to the relationship between streams and aquifers. Baseflow is long-term discharge derived from natural storages, mostly assumed to be groundwater discharge from the shallow unconfined aquifer. Base flow separation techniques use the time series record of stream flow to derive the baseflow signature. The common separation methods are either graphical which tend to focus on defining the points where baseflow intersects the rising and falling limbs of the quickflow response or involve filtering where data processing of the entire stream hydrograph derives a baseflow hydrograph.

This stream flow can be divided into two components such as run-off and base-flow. Baseflow or groundwater discharge to streams is an important constituent of lean period stream flows. Because of low velocities of groundwater, baseflow does not fluctuate rapidly; they are mainly controlled by the hydrogeological conditions and climatological factors. The baseflow may be divided into two components, bank and basin storage discharges. The important components of groundwater releases being basin storage ie.. The groundwater released from the main basin. Depending upon the hydrogeology of the stream channel the bank storage may also contribute significantly to the total lean period stream flow. During the floods the stream flow is composed primarily of runoff and once the river stage is higher than the adjacent groundwater levels there is no affluent flow to the river ie… no baseflow contribution even in the gaining river reaches. The interplay of flood flow, bank storage will depend upon the hydrogeology of the river channel. The baseflow studies require regular monitoring of the stream flow for eatimation of the baseflow. If the baseflow records of a basin are available for a long period, meaningful conclusion can be drawn about the general ground water scenario of the basin. Studies have established that the release from groundwater reservoir to the stream is attenuation of a linear reservoir represented by an empirical relation. The recession can be approximated by exponential relation of the form

$$\mathbf{Q_t = Q_o\, e^{-\alpha t}} \quad \text{............} \quad \mathbf{(1)}$$

Where Q_o and Q_t are the discharge at the beginning of the measurement period and after time t respectively, and α is a constant governed by the drainage characteristic. This paper presents the analysis of various characteristics necessary to describe the aquifer system of the Asan watershed. It also discusses about the trends of changes in discharge, surface runoff, baseflow, precipitation and probable causes for the variations being shown by it and their cumulative effect.

MATERIALS AND METHODS

Drainage Map of 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. Drainage pattern of Doon valley is shown in Fig.1. Major and Minor streams along with their bifurcations are marked. Third order streams form the major stream channel, called Asan River. Drainage pattern in Asan river watershed shows high degree of lithological control, slope control as well as structural control. The most common patterns observed in the watershed are dendritic to sub-dendritic and parallel to sub-parallel. There are minor watersheds within the major Asan river watershed such as Tons Nadi watershed, Suarna Nadi watershed Sitla Rao Nadi watershed etc. All the streams in the area are lithologically and structurally controlled flowing along the lineaments.

Baseflow Calculation

Baseflow is calculated using Web based Hydro Office-2010. It calculates baseflow index as a time series for the catchment discharge. Baseflow index is the ratio of baseflow to total flow calculated from the hydrograph. The baseflow index is considered as a measure of the run off of the stream that derives from storage of the basin and as a catchment descriptor to assess groundwater recharge and sustainability (Sloto and Crouse, 1996). Several methods are in practice to calculate BFI. Baseflow separation procedures are described by Nathan and McMohan (1990), Tallaksen and Lanen (2004). Base flow as a time series is useful as a measure of the behavior of groundwater in catchment where as baseflow indices infer the catchment's ability to store groundwater during the monsoon period and release of water during non-monsoon period (Hall, 1968). Web based Hydrograph Analysis Tool (WHAT) is used to calculate the filter coefficients of various models of baseflow separations (Lim et al., 2006). WHAT acts as an interface to the USGS HydroOffice software? It's takes daily discharge database as input and calculates filter coefficients for various methods and separate baseflow from stream flow. Out of several methods available to calculate BFI, BFLOW method indices are shown with the time series discharge data in Fig.3 and Table-2 because BFLOW indices are stable and smooth. Day-wise discharge indices of base-flow for the year 2006 in various methods are shown in the insert of Fig. 3. Quantification of shallow groundwater aquifers is important for sustainable groundwater and surface water exploitation. Aquifer parameters are estimated from stream discharge data.

Table 2: Summary of Base-flow estimates using BFLOW filter

Year	**Average Base-flow in cusecs during**		
	Monsoon	**Non-Monsoon**	**Annual Average**
2001	349.58	338.74	332.38
2002	323.12	652.28	309.85
2003	443.15	428.26	401.31
2004	453.18	449.79	431.90
2005	415.38	443.82	408.75
2006	451.77	441.45	427.47
2007	425.24	395.25	338.41
2008	485.31	418.72	416.77
2009	365.98	369.90	354.90
2010	288.48	439.19	364.37
2011	544.33	481.70	494.47
Average bflow over a decade data			**389.1436**

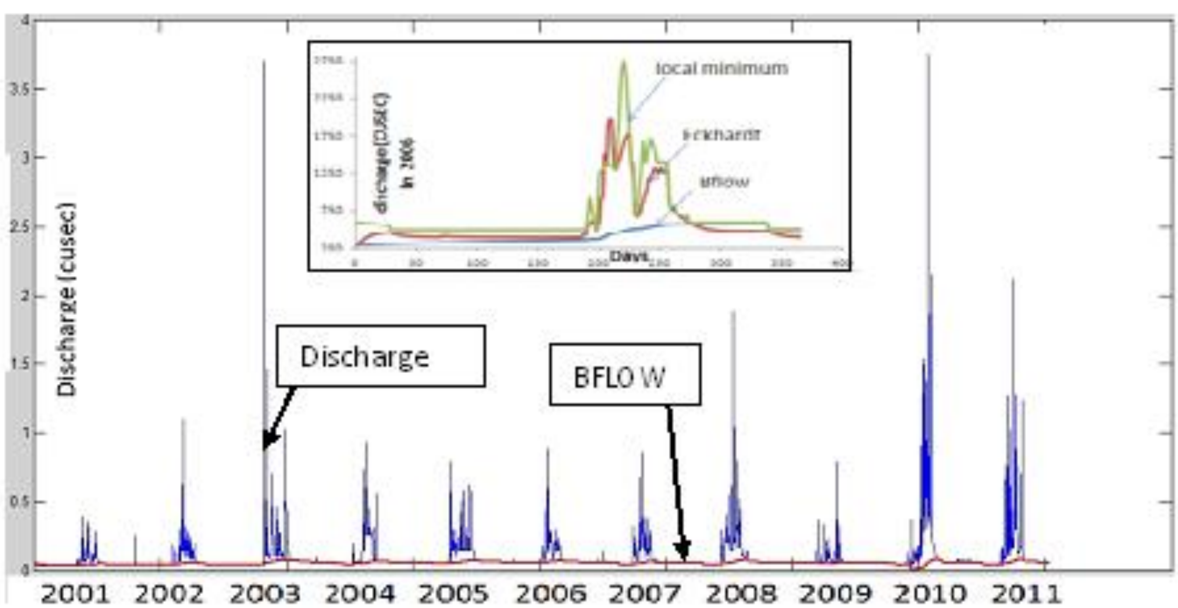

Figure 3: BFLOW filter response on discharge data

Rainfall Data Analysis

Rainfall data are collected from Selaqui observatory of Central Soil and Water Conservation Department, Dehradun which is centrally located in the watershed. Monthly mean rain fall data are collected for the period 2004-2011. Precipitation in pre monsoon, monsoon, post monsoon are calculated and the summery is shown in Figs. 4 and 5. Amount of water infiltered in to the unconfined aquifer is calculated.

Monitoring Wells Data

Groundwater Table levels during pre-monsoon and post-monsoon are collected from nine locations. Data of monitoring wells have been collected from nine stations distributed over the Asan Watershed are for the pre-monsoon, monsoon and post-monsoon seasons from Central Ground Water Board (CGWB,2010), Dehradun, Uttarakhand. Depth to the water table data is used to assess the groundwater storage and other characteristics. Relative elevations of water table in those locations are shown in Fig.6 with reference to Nanda ki Chowki location. Water-table at two locations is relatively depressed.

RESULTS AND DISCUSSION

Asan river watershed is an asymmetric syncline which is spread along normal to the synclinal axis. In the higher reaches the gradient of the streams is very steep varying from 30 to 35. In the middle portions of streams, the gradient varies from 0.46 to 0.35 and then gradually decreases to the planar. Stream Length Index varies between 1166 (Tons Nadi) and 130 (Nun Nadi). Third order streams forms the river Asan.

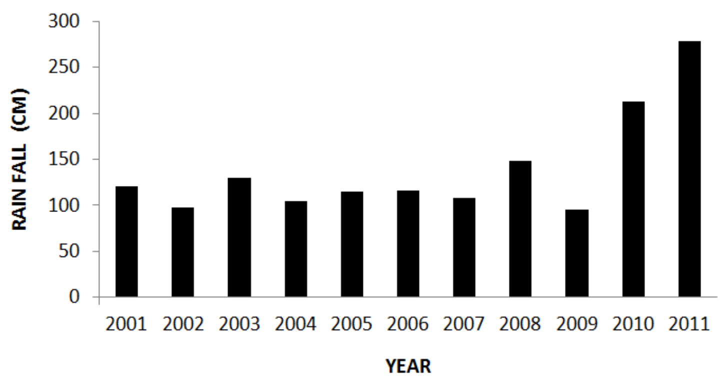

Figure 4: Annual Rainfall in the Asan watershed

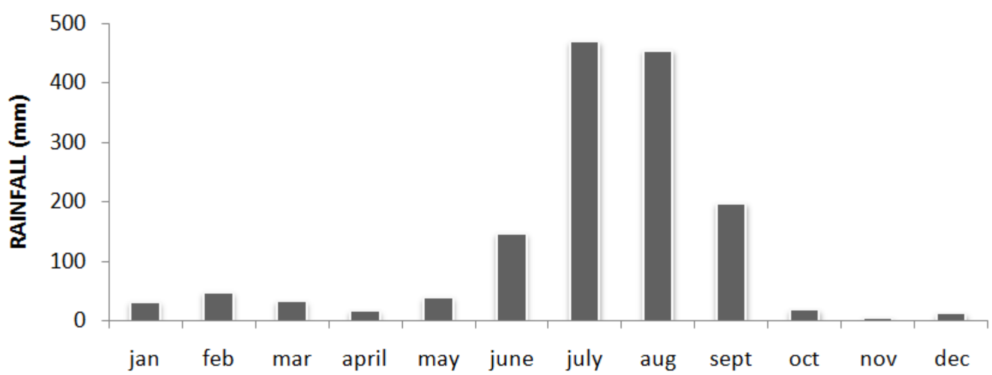

Figure 5: Mean Monthly Rainfall

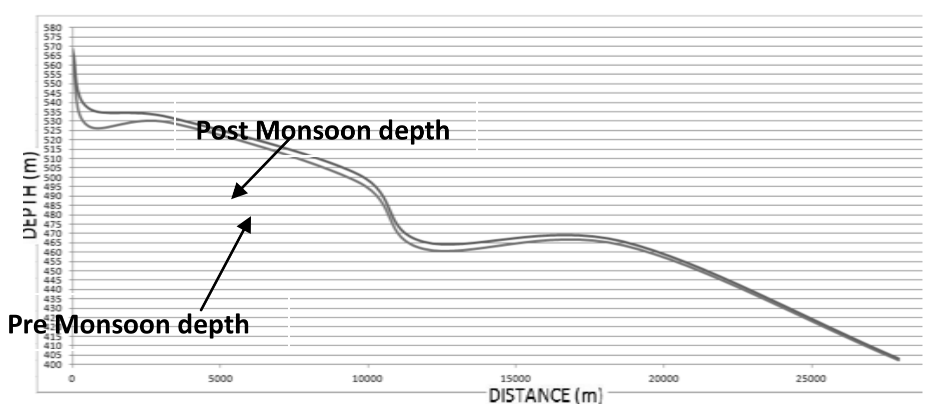

Figure 6: Depth of Water-Table (MSL) in monitoring wel (Location marked w.r.t. Nanda ki Chowki)

Discharge is the amount of water which flows through a stream or a river channel. Measurement of the physical observations along the streams using a gauge is very difficult procedure. Further, the Asan watersheds contain many minor watersheds. Hence the procedure becomes cumbersome. Therefore hydrograph method is adopted. In this case the discharge data have been collected from the Asan Barrage at Dhalipur Power House, Uttarakhand for the period 2001-2011. Baseflow Index (**BFI**) and other characteristics of the watershed are calculated using the discharge data.

Separation of Base-Flow from Discharge Data

The stream hydrograph and base flow curve obtained using the BFLOW filter, developed by Lyne and Hollick (1979), used for base flow separation in WHAT is given as (Lim et al., 2005):

$$\mathbf{b_t = [\ (1 - BFI_{max})*\alpha + b_{t-1} + (1-\alpha)*BFI_{max}*Q_t\ ]/\ (1 - \alpha*BFI_{max})\ \ \ldots.\ (2)}$$

Where, b_t = base flow at the t time step, b_{t-1} = base flow at the t-1 time step, BFI_{max} = maximum value of long term ratio of base flow to the total stream flow (assumed 0.8, for perennial streams with porous aquifer), α = filter parameter (taken as 0.999), Q_t = total stream flow at the t time step.

Time series discharge data and baseflow characteristics are shown in Fig.3. A summary of base flow estimates obtained using the BFLOW Filter is presented in Table 2. The estimated base flow during non-monsoon period (November to May, average of 11 hydrologic years obtained using Filters range from 338.74 to 652.28 cusec, the average being about 441.73 cusec. Whereas, in the monsoon period (June to October), average of 11 hydrologic years, it ranges from 228.48 to 544.33 cusec, the average being about 413.23 cusec. The annual base flow (monsoon base flow and non-monsoon base flow) ranges between 309.85 and 494.47 cusec, the average being 389.14 cusec.

During the monsoon period and post monsoon period also, hilly/mountainous parts of the watershed contribute to the total base flow of Asan River. Therefore, the minimum annual base flow contribution to the main piedmont aquifer system has been estimated assuming the minimum base flow rate in the monsoon period will be the same as that of the non-monsoon period (i.e. 40 cusec for BFLOW filter). With this assumption, the minimum average annual base flow from the piedmont aquifer system is estimated to be between 40 and 802.15 cusec (average of about 486.26 cusec). Table-2 shows a summary of base flow estimates obtained from digital filtering method of hydrograph separation. Stream discharge data of 11 hydrologic years (2001 to 2011) are used. The average annual base-flow is calculated from discharge data comes to 0.434 X 10^9 m^3/year. The summery of average annual base-flow for the last decade is shown in Fig.7.

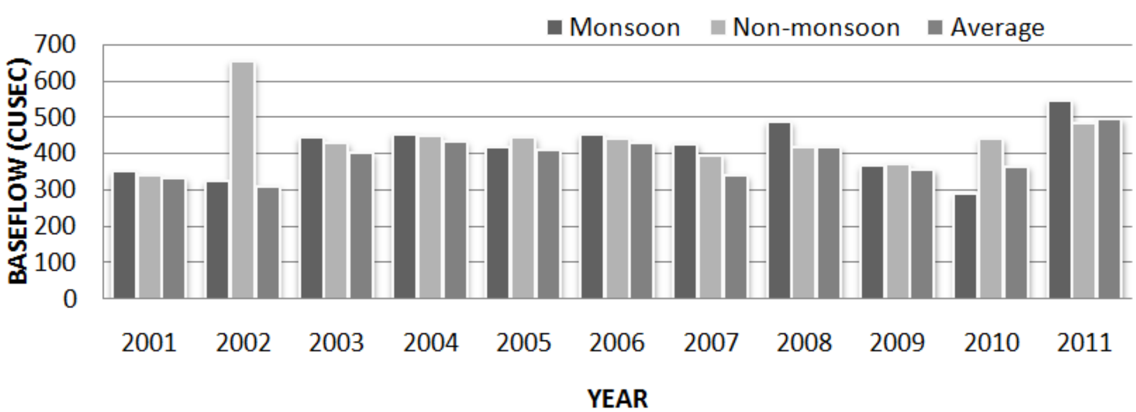

Figure 7: Comparison of Average annual Base-flow

On an average the baseflow has been increased which shows that the storage has been increased in the Asan watershed. Separation of base-flow from discharge data for the year 2006 using Local Minimum and Eckhardt methods along with Bflow method is shown in insert of Fig.3. Base flow calculated other than BFLOW follows the variations in the discharge data and BFLOW indicates a clear separation of baseflow. Further it shows a rise in the groundwater storage when compared to the non-monsoon period and considerable resident time of about 160 days during monsoon and post-monsoon period.

Groundwater Potential

There are different monitoring wells distributed throughout the Asan basin. Depth to water-table in those wells during pre and post monsoon periods has been collected from CGWB, Dehradun. The data are plotted as shown in Fig. 6. The distance is taken from Nanda ki chowki to Asan barrage and water table depth in each locality is measured from mean sea level of respective of monitoring well location. Average difference in water-table depth in those monitoring wells between monsoon and non-monsoon periods is 4.31m which is available for base flow and recorded as discharge at Asan barrage, the end point of Asan watershed. This average thickness is get multiplied by the area of basin, 1400 km^2, which amounts to 6.034 $km^{3.}$ This represents the total groundwater recharge due to infiltration of precipitation including the recharge of groundwater due to system of springs. Further the local depressions in the water table consistently during monsoon and non-monsoon periods indicate the over draw of groundwater at two point sources. Such sources will greatly damage the sustainable conditions of groundwater potential in the Asan river catchment area.

Aquifer Parameters

Further proceeded to analyse the unconfined aquifer parameters. Average base-flow is used to calculate specific storage which is equal to 2825.62 lpm/m drawdown. Formation factor is 0.00123. If the difference in water table depth between monsoon and non-monsson, which is 4.31 m, is taken aquifer thickness which is available for base-flow. Transmissivity amounts to 0.221 lpm/m and permeability is equal to 51.3 mdarcy. The aquifer parameters shows that the doon gravel formation is serving as a good unconfined aquifer with sustainable aquifer parameters which can cater the domestic as well as irrigation needs.

Rainfall

The rainfall for a period of 2001 to 2011 has been plotted yearly wise and monthly wise as in figure 4 and 5 respectively. From rainfall data, the rate of infiltration (ϕ-index) can be calculated on the basis of rainfall and runoff correlations,

$$\mathbf{R = k_b I} \text{ (Barlow formula) .... (3)}$$

$$\text{and } \mathbf{\phi = I\text{-}R} \text{ .... (4)}$$

Where, R= runoff in cm from a 24-hr rainfall of intensity I cm/day k_b= a coefficient which depends upon the type of catchment and nature of monsoon rainfall (taken as 0.35)

The average rainfall intensity (I) taken as 0.433 cm/day. Runoff (R) is 0.16816 cm/day and so rate of infiltration becomes 0.2621 cm/day. The total infiltration over the catchment is calculated by multiplying the rate of infiltration by area of catchment and which comes to 1.3395 X 10^9 m^3/year.

Evaporation

There is evaporation phenomenon takes place through the stream coarse and it depends on the following factors-a) The temperature of the water at air-water surface, b) The humidity of the air, c) The area of the air-water surface, d) The temperature of air, e) water currents convecting heat and the ability to keep the temperature constant at 100^o F, f) Airfllow past the water/air surface. The rate of evaporation from the stream has been calculated with the help of Irvin Langmuir formula stated as-

$$\mathbf{V= [(\text{vapor pressure - ambient partial pressure})*sqrt((m)/(2*\pi*R*T))]/1000 \ldots (5)}$$

Where, V = (volume of water loss rate)/ (unit area), m = molecular weight of water, i.e. .018 kg/mole and ambient partial pressure is related to relative humidity(ϕ) and saturated vapour pressure (p_w) as

Ambient partial pressure = relative humidity * saturated vapour pressure

$$\mathbf{Pw = [\exp(77.345 + 0.0057*T - 7235/T)] / T^{8.2} \ldots. (6)}$$

Where, T= temperature in terms of Kelvin.

The different parameters required for calculating the rate of evaporation is given in table 3.

The average values have been taken for each month of the period 2001 to 2011.

The average loss during a year due to evaporation is given by volume loss rate per year per unit area and the area of stream flowing is $22.8*10^4$ m^2 and which is equal to $4.38*10^9$ m^3/ year. The value of rate of evaporation is calculated by assuming the stream in static condition but in practically the stream is in dynamic condition so the rate of evaporation should be always greater than the value which is calculated in static condition.

Table 3: Mean monthly water loss due to Evaporation

Month	**Relative humidity**	**Saturation vapour pressure of water (pa)**	**Ambient partial pressure (pa)**	**Vapour pressure of water (pa)**	**Volume rate loss per unit area (m3/sec/m2)**
January	0.91	1300.085	1183.077	1306.56	0.000136
February	0.83	1522.758	1263.889	1546.54	0.00031
March	0.69	1993.885	1375.781	1999.836	0.00068
April	0.53	2750.653	1457.846	2719.777	0.001362
May	0.49	3234.571	1584.94	3253.067	0.001793
June	0.65	3575.971	2324.381	3559.708	0.001324
July	0.86	3177.371	2732.539	3173.073	0.000474
August	0.89	3215.405	2861.711	3253.067	0.000421
September	0.83	3011.032	2499.156	2986.422	0.000525
October	0.74	2404.372	1779.235	2399.803	0.000672
November	0.82	1778.278	1458.188	1759.856	0.00033
December	0.89	1398.308	1244.494	1402.818	0.000174
Average	0.76	2331.215	1771.723	2333.142	0.000609

Evapotranspiration

There is a loss of moisture through land plants by the phenomenon called transpiration and directly due to evaporation through the soil, together called evapotranspiration. The rate of evapotranspiration is calculated by the Penman's equations. This equation is based on some theoretical reasoning and is obtained by a combination of energy-balance and mass-transfer approach.

$$\mathbf{PET = (A*H_n + E_a*\Upsilon) / (A + \Upsilon) \quad .... \quad .... (7)}$$

Where, PET = daily potential evapotranspiration in mm per day

A = slope of the saturation vapour pressure *vs* temperature curve at the mean air

Temperature (mm of mercury/ degree C) =1.05 mm/degree C

E_a = parameter including wind velocity and saturation deficit

Υ = psychrometric constant, i.e. 0.49 mm of mercury / degree C

H_n = net radiation in mm of evaporable water per day and given as

$$\mathbf{H_n = H_a*(1-r)*(a + b*n/N) - \sigma*T_a^4*(0.56 - 0.092*\, sqrt(e_a)*(0.1 + 0.9*n/N) \quad .... (8)}$$

Where, H_a = incident solar radiation outside the atmosphere on a horizontal surface, expressed in mm of evaporable water per day (function of the latitude) = 12.69 mm/day

a = a constant depending upon the latitude ϕ and is given as a = $0.29*\cos(30^0 15')$ = 0.1142

b = a constant with an average value of 0.52

n = actual duration of bright sunshine in hours = 7.33 hrs

N = maximum possible hours of bright sunshine (function of latitude) = 12.17 hrs

r = reflection coefficient, depending upon surface, here taken as 0.25

σ = Stefan-Boltzmann constant = $2.01 * 10^{-9}$ mm/day

T_a = mean air temperature in degree Kelvin = 293 degree kelvin

e_a = actual mean air temperature in the air in mm of mercury.

The parameter E_a is estimated using

$$E_a = 0.35*(1+ u_2/160)*(e_w – e_a) \quad .... \quad .... \quad (9)$$

Where u_2 = mean wind speed in km/day = 60 km/day
e_w = saturation vapour pressure at mean air temperature in mm of mercury = 17.54 mm of Hg
e_a = actual vapour pressure = e_w * average relative humidity = 13.33 mm of Hg
E_a = 2.026
And the value of H_n is to be 1.935 mm/day. Consequently the value of PET (daily potential evapotranspiration) becomes 1.964 mm/day. The total loss due to evapotranspiration per year is calculated by multiplying the value of PET over the area of watershed (excluding the area of main stream) and which is equal to 1.0034 *10^9 m^3/year.

Groundwater Balance Equation

The estimation of the groundwater balance of a region requires quantification of all individual inflows to or outflows from a groundwater system and change in groundwater storage over a given time period (Karanth, 1987; Kumar and Seethapathi, 2002). The basic concept of the water balance is

Change in storage of the system = input to the system - outflow from the system

(Over a period of time)

Considering the various inflow and outflow components in a given area, the groundwater balance equation can be written as

$$Rr + Rc + Ri + Rt + Si + Ig = Et + Tp + Se + Og + S$$

Where Rr = recharge from rain fall,
Rc = recharge from canal seepage,
Ri = recharge from field irrigation,
Rt = recharge from tanks,
Si = influent seepage from rivers,
Ig = inflow from other basins,
Et = evapotranspiration from groundwater,
Tp = draft from groundwater,
Sc = effluent seepage to rivers,
Og = outflow to other basins,
S = change in groundwater storage.

It is not always possible to compute all individual components of the groundwater balance equation separately. Some components can be lumped and account only for their net value in the equation.
In the above equation,
Rr = 1.3396 *10^9 m^3/year
Rc + Ri + Rt + Si = 0.056 *10^9 m^3/year
Ig = 0 = **Tp + Se** (assumed to be minimum of minimum)
Og = base flow = 6.034 *10^9 m^3/year
Et = 5.978 *10^9 m^3/year
S = 4.6384 which is 76.87% of 6.034 *10^9 m^3/year

Contribution of springs to Groundwater

From the monitoring wells data, on an average the total groundwater recharge is 6.034 * 10^9 m^3/year. This much groundwater is available to flow as base-flow. Similarly the rate of infiltration calculated from precipitation in the area is 1.3396 * 10^9 m^3/year. The total losses of water through the watershed which includes evaporation, evapotranspiration and base-flow comprises to a total volume of 5.978 * 10^9 m^3/year. But from well monitoring data it is calculated as 6.034 * 10^9 m^3/year of water is lost annually on average. Even without considering the groundwater losses due to pumping out of groundwater for domestic and irrigation, the remaining water which is 4.66944 * 10^9 m^3/year (which is nearly 77.8%) is contributed by the springs existing all around the Asan watershed in the higher altitudes of the watershed. Further North of MBT, Lesser Himalayas with Krol formation on top are tectonically highly disturbed and consists of major, minor faults and lineaments which enhance the porosity and permeability. North to

Mussorie a synclinorium of large dimension also exists. Glaciers in the Lesser Himalayas in addition to precipitation recharge the formations which are at higher levels to the catchment area of Asan watershed. Hence probably during the monsoon these formations contribute to the Asan watershed in the form of surface run-off through springs and as base-flow during the non-monsoon.

Conclusion

Asan river watershed consists of a thick pile of doon gravels serving as a good unconfined aquifer. The Asan River and all the other streams are structurally as well as lithologically controlled and followed the axis of asymmetric syncline, lineaments and major or minor faults. The entire Asan basin is tectonically under control. The hydrogeological conditions in the intermontane doon valley are under sustainable conditions with high groundwater potential. The aquifer potential groundwater is not withdrawn in any year during the last decade. The BFI for the last decade shows a steady state condition of the aquifer with considerable residence time. The recession level in any year of the preceding decade had never come down below the depth of water table during non-monsoon in the area. The aquifer parameters are under sustainable conditions. The formation, namely doon gravel, is serving as a good unconfined aquifer in Doon Valley meeting the needs of domestic as well as irrigation. But it becomes imperative to use the resource judiciously. The very interesting fact found in the present study is that the contribution to the aquifer by the system of springs in the higher reaches of the Asan watershed is higher than that due to precipitation. Hence obviously it can be recommended that construction of bunds across the steams and springs in the higher reaches of the watershed will greatly improve the aquifer storage. Groundwater management studies shall parallelly be taken up along with the development. Sources of over draw of groundwater storage should properly be monitored.

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