FINAL REPORT

HYDROLOGICAL INVESTIGATION OF NATURAL WATER SPRING OF BAANGANGA WATERSHED OF JAMMU & KASHMIR

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ABSTRACT

Springs are the natural doors of groundwater from where it emerges on the ground surface and hence common water sources for local community. A gross estimate of nearly 200 million Indians depending upon spring water across the country – mainly the Himalayas, Western Ghats, Eastern Ghats, Aravallis and other such mountain ranges - implies that more than 15% of India's population depends on spring water. A vast majority of the population of Indian Himalayan Region (IHR) is concentrated in the Lower Himalaya in scattered hamlets. This populated stretch of IHR is situated in the zones where the rivers flow in deep valleys and the glaciers are higher up in the mountains, so water from these two sources is generally not available. Additionally, the rooftop rainwater harvesting is feasible only for a part of the year, and springs are the only source for meeting the drinking, domestic and agricultural water needs for both rural and urban communities. In addition to this, these springs drain into and sustain several rivers in the lean season and there is hardly any river that is not feed by the springs. These water pygmies can play a vital role in solving water scarcity in the Himalaya and other mountainous regions of India, wherever large rivers fail to deliver. Thus, springs are the lifeline of mountain people.

Jammu and Kashmir is a Himalayan state that abounds in various springs of which Verinag (source of the Jhelum), Martand (Anantnag), Achhabal (Anantnag), Kukarnag (Anantnag), Chashma-i-Shahi (famous for its fresh and digestive water, situated near Srinagar), Tullamulla or Khirbhawani (a sacred spring), Vicharnag, Sukhnag, Vishnosar and Harmukat Ganga in Srinagar area and Chirnagand Vasaknag in Anantnag are very famous. The primary sources of water in the rural areas of Jammu and Kashmir are springs, streams and rivulets through the surface and sub-surface water flows originating mostly from the unconfined aquifers. Due to mountainous topography of the state, springs are the only feasible source of water in the state especially in rural areas. National Sample Survey Office (NSSO) published a survey in March 2016, which reveals that a household member in rural areas of Jammu and Kashmir spends an average time of 21 minutes a day to fetch drinking water from a source outside their premises. In addition to this, she spends an average waiting time of 12 minutes a day at the principal source of drinking water. Increasing population and unplanned development have adversely affected the recharge processes and resulted in depletion of this prime water resource in the entire state. Furthermore, depletion of these springs is also exacerbated by rising air temperatures, marked decline in winter rainfall and in general, the erratic and torrential rainfall that has replaced the monsoon drizzles of yore. Thus conservation

of seasonal water sources/natural springs by using traditional/ecological/scientific technologies are the immediate interventions required in the area.

Baanganga is a small tributary of Chenab River, the legendary river associated with the miracles and legends of *Mata Vaishno Devi*. It is considered sacred and as is normal Hindu tradition, devotees like to take holy dip before preceding the journey of the holy shrine *Mata Vaishno Devi*. This River is originated from the Trikuta hills and passes from the side of Katra town and joining to *phare khad* before confluence to mighty Chenab River. Since, there is no glacier presented in the Baanganga catchment, hence springs are the only available sources to fulfil the water demand of the livelihood of the surrounding people and also to maintain the flow of the River Baanganga. However, due to ecological degradation in Trikuta mountain range, the discharge of theses springs has significantly reduced and some of the springs have dried-up. Consequently, people of the area are facing acute shortage of water for their livelihood and there is hardly any water flowing in Baanganga. Keeping in view the above points, an internal study entitled "Hydrological Investigation of Natural Water Springs of Baanganga Watershed of Jammu & Kashmir" was taken to study the springs emerging in Baanganga watershed.

In this study the Baanganga River watershed up to Kanjali village (drainage area 20.23 sq. km) was selected for the study. It is a fourth order watershed of elongated shape having 119 streams of different orders. The upper part of the catchment having steep to very steep slope even significant part having more than 100% slopes, while middle part of the watershed having gentle slopes and lower part of the catchment attributed to medium slopes. Geomorphological analysis of the Baanganga watershed indicates that the watershed is prone to produce moderate to high runoff and hence watershed is susceptible to severe erosion.

Fourteen springs (SP1 to SP14) ranging from low discharge (≈1 LPM) to high discharge (≈152 LPM) were identified in Baanganga watershed. Most of the springs are emerging in the upper part of the watershed and in the proximity of Reasi fault and hence characterized as fracture or fault springs. Of fourteen, five springs were selected for the detailed study. Three ordinary raingauge (ORG) stations at different altitudes i.e. Kanjali (388 m), Katra (870 m) and Saanjhichhat (1801 m) were established to record the daily rainfall and collect the rain water samples for isotopic analysis. Annual average rainfall at three stations i.e. Kanjali, Katra and Saanjhichhat was found to be 2126 mm, 2282 mm and 2696 mm, respectively. The annual average weighted rainfall of Baanganga watershed was found to be 2407 mm which is more than twice of the country's average annual rainfall. Five springs (SP1, SP2, SP3, SP4 and SP5) which were selected for the detailed study were monitored for their daily discharge. Discharge variability of springs was estimated using daily spring flow data and it was varied from 53% to 280%. Springs emerging from upstream of Katra town (SP3, SP4, SP5) were found to be more variable in discharge in comparison to the springs emerging from downstream of the Katra towm (SP1 and SP2). Recession curve of spring hydrograph was analyzed and depletion time for Nawai Spring (SP1) and Bhumika Devi Spring (SP3) was found to be 6.96 months and 6.52 months, respectively. It has been found that at present both springs are reliable as they can outlast the most extreme dry spell of 5.2 months for Western Himalaya during 1951-2007. Minimum storage requirement was estimated for theses springs using monthly spring flow and local demand for sustaining the local water demand. It was found that *Bhumika devi* spring can sustain daily water demand of 550 people. However, with the provision of minimum storage capacity of 2877 m^3 this spring can sustain the water demand of 970 people. It was found that minimum storage requirement is quite helpful to make highly variable springs as sustainable source of water for the dependent population.

All springs water is alkaline in nature (pH>7.0) having electrical conductivity (EC) ranging from 300 μS/cm to 700 μS/cm. All spring waters are within the desirable limit of drinking water as per Indian Standard for Drinking Water (IS 10500-2012). Water quality analysis of springs and local streams clearly indicate that source of springs and local streams are similar as having more or less similar values of water quality parameters. Water quality parameters of springs located downstream of Katra town indicated that theses springs to be needed regular monitoring as their water quality parameters are about to crossing the desirable limit of drinking water. Relative proportion of calcium and magnesium ion presence in all springs waters are clear indication that genesis of theses springs are dolostone which contain dolomite and limestone and these springs can be considered karst springs. Since, karst springs are prone to transport the microorganism (viruses, bacteria, protozoa and larger organism produce from sewage and animal waste) due to absence of soil filter, it is recommended to carried-out periodic microorganism testing of all springs water by considering the fact that every day hundreds of ponies are used for transportation of pilgrims of *Maa vaishno devi* pilgrimage.

Local meteoric water line (LMWL) was developed for Baanganga catchment using the isotopic signature (δ^2H and $\delta^{18}O$) of rainfall at three different altitudes viz. Kanjali (388 m), Katra (870 m) and Saanjhichhat (1801 m). When isotopic signatures of studied spring's water were plotted against the LMWL, it was found that local precipitation in the form of rainfall is the sole source of all spring's water. Since, evaporation effect was not observed in the isotopic analysis of the spring's water, altitudes of spring's recharge areas have been obtained directly from the altitudes effect. A mean $\delta^{18}O$ altitude effect of –0.1‰ per 100 m and mean $\delta^{2}H$ altitude effect of –0.8‰ per 100 m were found. With the help of altitude effect, altitudes of probable recharge area for springs SP1, SP2, SP3, SP4 and SP5 have been estimated.

Detailed field mapping was undertaken in and around Katra to identify the fracture systems and the potential recharge areas of the *Baanganga* spring, *Bhoomika Devi*, and *Nomain* springs systems and seepage zones. We report the existence of 3 spring systems in the area that are localized within the Reasi Thrust Zone (RTZ), these springs occur prominently along the (1) hanging-wall imbricate zone, (2) Main Reasi Thrust (MRT), and (3) foot-wall imbricate zone. The lithology consists of the Sirban Limestone Formation (SLFm) in thrusted contact with Quaternary (tectono-sedimentary) breccia accumulations, and the Siwalik Group sandstones. The area is structurally very complex with multiple deformation episodes governed by the MRT, the most prominent structural feature in the area. In the hanging-wall imbricate zone the rocks are intensely fractured, brecciated and the carbonates are extensively karstified, and fracture, breccia and cavern porosity is abundantly observed. Three recharge areas carved by terracing (step-farming) are identified between the hanging-wall imbricate zone and the MRT, the rock fractures act as dominant conduits for the flow of water under the influence of gravity towards the springs and seepages. The *Baanganga* stream in the proximity of the fractured (and karstified) rocks has the potential to recharge the shallow aquifers traversed by the SE, NE and NW dipping 'steep' fractures that from a continuity (fairway) for the movement of water into the fractured aquifers.

The *Bhoomika Devi* spring is located in the proximity of the MRT, and the spring system is located within the Riasi Thrust Zone (RTZ). The lithology consists of the SLFm carbonates in thrusted contact with the Siwalik Group sandstones. The rocks are intensely fractured, and the carbonates are extensively karstified. The fractures are oriented in every direction, six fracture sets (F_1-F_6) were identified, and two fracture sets (F_1 and F_6) (steep, sub-vertical to vertical and dipping towards SE and SW) are very prominent and present throughout the study area. Two recharge areas are identified, and the stream in the proximity of the fractured (and karstified) rocks has the potential to recharge the shallow aquifers traversed by the SE and SW dipping fractures that form a continuity (fairway) for the movement of water into the fractured aquifers. The quaternary accumulation overrides the Siwalik Group sandstones in and around the *Nomain* area where the third spring system occurs. Two recharge areas have been identified here, and the same are feeding the spring system that is dominated by the deformation happening along zone of juxtaposition defined by the foot-wall imbrication.

It has been observed in the field analysis that the fractures in the study area are very mobile and dynamic, and respond to the direction and intensity of movement along the active Riasi Thrust. The intense deformation and gauging of the fractures has rendered the sealing of the older fracture sets and at the same time has opened new fractures. Thereby, it is pertinent to do an overall fracture analysis of the entire region to identify the possible zones that could seal/open in the near future.

Keywords: **Spring, Baanganga River, Karst spring, Limestone, Isotopes, Depletion time**

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CHAPTER - 1
INTRODUCTION

1.1 Background

Surface water, flowing in the form of rivers, and subsurface water, occurring in the form of springs are two main sources of water supply in hilly areas of western Himalayan region. In the high altitude areas, the river flow in deep valley at the toe of slopes and rarely serve any purpose as far as domestic water supply and irrigation are concerned. Thus, in all hilly state of India and even mountainous part of countries such as Turkey, Spain, Greece etc., natural springs are the available major source of water. About 90 per cent of the rural population of this region depends upon natural springs for their water demands. That's why the villages in hills are clustered around the springs. There is hardly any settlement where there is no spring. These springs are locally called "*Chasma*" in Jammu and Kashmir and *"Naula"* and *"Dhara"* in Uttarakhand state of India.

It has been estimated that only less than 15 percent of the rainwater is able to percolate down through deforested slopes to recharge the catchment area of springs. The remaining flows down as runoff and cause floods in plains. In most of the springs in Himalayan area, the springflow has decreased by 50 per cent within last 30 years and the piped drinking water in hill area are failing due to drying up of springs and has adversely affected the water supply in the irrigation channels. Under these circumstances, people will move wherever water moves. Studies indicates that deforestation, grazing and trampling by livestock, erosion of top fertile soil, forest fires and developmental activities (e.g. road cutting, mining, building construction etc.) in the recharge zone of the spring are the causes for diminishing discharge of the springs.

Almost negligible numbers of springs are being monitored presently for their flow and other hydrological parameters and hence no systematic study has been reported till today for developing these springs as dependable and sustainable sources of water for rural population of Himalayan region.

1.2 The Problem Definition

Baanganga, a small tributary of Chenab river, the legendary river associated with the miracles and legends of Mata. It is considered sacred and as is normal Hindu tradition, devotees like to bathe in it before preceding the journey of the holy shrine *Mata Vaishno devi*. This river is originated from the Trikuta hills and passes from the side of Katra town (main base camp for *Mata Vaishno Devi* journey). Baanganga travels 8 km up to Katra town and comprises 13 sq. km catchment area. Since, there is no glacier presented in the Baanganga catchment, hence springs are the only available sources to fulfil the water demand of the livelihood of the surrounding people and also to maintain the flow of the river Baanganga. However, due to ecological degradation in Trikuta mountain range, the discharge of theses springs has significantly reduced and some of the springs have dried-up. Consequently, people of the area are facing acute shortage of water for their livelihood and there is hardly any water flowing in Baanganga.

Keeping in view the above points, there is urgent need to conduct a systematic study on the natural water springs of Baanganga catchment. The output of the study will be helpful for planning augmentation measures for theses springs and ultimately to rejuvenate the mythologically important Baanganga River.

1.3 Objectives

The present investigation is taken up with the following objectives:

a. To characterize the springs on the basis of geomorphological and hydrological features prevailing in the study area.
b. To understand the discharge pattern of springs in relation to recharge zone characteristics and rainfall variation.
c. To study the storage characteristics and time of depletion of the springs irrespective of rainfall pattern.
d. To suggest a strategy for management and augmentation of spring discharge for making theses springs as sustainable drinking water source for the livelihood of the local people.

CHAPTER - 2
REVIEW AND LITERATURE

A spring is a concentrated discharge of groundwater appearing at the ground surface as a current of flowing water. It is a form of unconfined aquifer in which water table intersects the land surface, and the ground water comes out to the surface in the form of spring or seepage. Springs are the main and dependable source of drinking water in mountainous part of countries such as India, Turkey, Spain and Greece etc. But according to the available literature no detailed and systematic study has been done in the area of springs. The review of literature in this chapter is being contains (i) Geometry of spring (ii) classification of springs (iii) existing spring flow model, and (iv) studies on spring behaviour.

2.1 Geometry of Spring

Springs are the reflection of ground water resources of a catchment. Spring emerging point is called threshold point and it is also a constant drowdown point till the spring is active. A poor transmissive aquifer produces a few small springs while thick transmissive aquifer is the origin of large springs. Spring is only a water hole into the earth from a point of overview but actual hydrology of springs is not such as easy. The spring flow domain has been hydrologically decomposed into two domains i) recharge zone; ii) transition zone (Fig. 2.1).

The spring's threshold point lies at the end of the transition zone. In the recharge zone the flow has been assumed to be in vertical direction and in the transition zone, the flow has been assumed to satisfy Dupuit-Forchhemier assumptions.

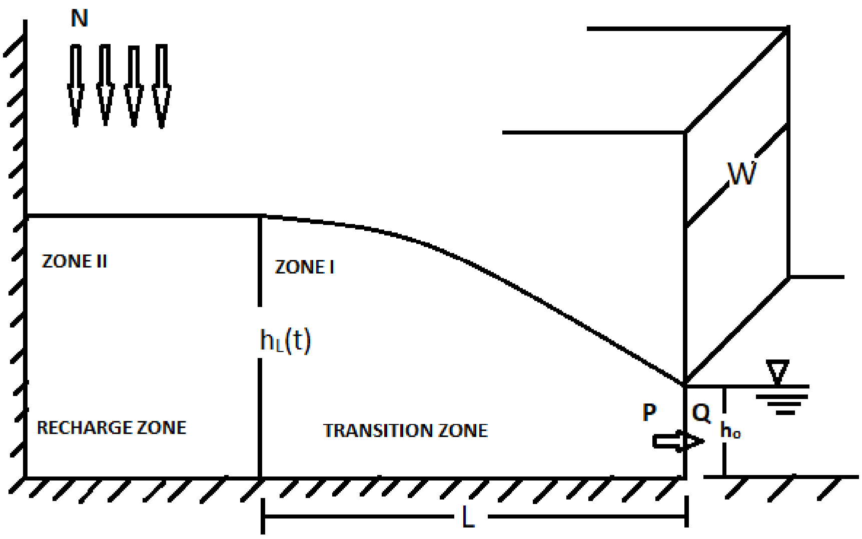

Fig. 2.1: Geometry of a spring

2.2 Classification of Springs

Springs occur in many forms and have been classified on the basis of genesis, rock structure, discharge, temperature and variability.

2.2.1 Classification on the basis of spring flow

Bryan (1919) divided all the springs in two categories:

a) **Gravitational springs-** Springs those resulting from gravitational forces.

b) **Non-gravitational springs-** Springs those resulting from non-gravitational forces. These include volcanic springs, associated with volcanic rocks, and fissure springs, resulting from fractures extending to the great depths in the earth crust. Such springs are usually thermal.

2.2.2 Classification on the basis of geo-hydrological conditions

a) **Depression springs-** These springs discharge where the ground surface intersects the water table. Such springs are generally found in middle and high Himalayan belt.

b) **Contact springs-** These springs are created by a permeable water bearing formation overlying a less permeable formation that intersects the ground surface.

c) **Artesian springs-** Water release from this type of springs is due to under pressure.

d) **Impervious rock springs-** Originated from the fracture of impervious rocks.

2.2.3 Classification on the basis of types of lithologies

It has been observed that lithologies, due to their characteristics and hydraulic parameters (porosity, permeability, storage coefficient) have influence on the recharge behaviour of spring. San Perez (1996) classified the flow of spring according to lithology in nine groups:

a) Alluvial sediments; sand and gravels
b) Conglomerates
c) Sandstones
d) Calcarenites, fractured limestones, karstic limestones, dolomites, marbles, tuff
e) Marls, limery marls, silts, clays
f) Quartzites
g) Slates, schists
h) Plutonic rocks, gneisses, dykes
i) Other rocks: gypsum, volcanic rocks

2.2.4 Classification on the basis of average discharge

Meinzer (1923) classified the springs according to their mean discharge and this classification has been in use for many years in the United States (Table 2.1).

Table 2.1: Classification of springs on the basis of spring discharge (after Meinzer, 1923)

Magnitude	Average spring discharge
First	>10 m^3/s
Second	1-10 m^3/s
Their	0.1-1 m^3/s
Fourth	10-100 l/s
Fifth	1-10 l/s
Sixth	0.1-1 l/s
Seventh	10-100 ml/s
Eighth	< 10 ml/s

2.2.5 Classification on the basis of season

a) **Intermittent springs-** Intermittent discharge, only during a part of year, when sufficient groundwater recharge to maintain the flow.

b) **Perennial springs-** Perennial springs drain extensive permeable aquifers and discharge throughout the year.

2.3 Existing Spring Flow Models

Though the first reported work on spring flow is almost a century old, the efforts on mathematical modeling of spring flow is somewhat limited. Some conceptual linear mathematical models have been developed during last one decade or so to estimate spring flow and to assess the dynamic storage inside a spring flow domain (Bear, 1979; Mandel and Shiftan, 1981). These models assume that during the recession period, the spring flow is linearly proportional to the dynamic storage inside the spring flow domain. The models are similar to each other and can accept only a lumped recharge in the beginning. The models simulate an unsteady state flow as a succession of steady state flow. In the first model, i.e., in Bear's model, the recession portion of a spring hydrograph could be simulated for a one-time recharge in the beginning. He interpreted the recession constant in terms of hydraulic diffusivity and the geometry of the aquifer. In the second model developed by Mandel and Shiftan (1981), the flow domain is conceptualized as a tank having an outlet at the lower portion and the recharge takes place at the open surface of the tank. The model, as such, is known as Unicell model. These two models are essentially for geological formation which has primary porosity. These three models are described herein.

2.3.1 Bear's Model

Bear (1979) suggested a simple tank model to analyze unsteady flow of a spring (Fig. 2.2). Assuming that at any time during recession period, the discharge Q = α_1 h, where α_1 is a constant, and h is the potential difference causing flow, the decline in dynamic storage from the spring flow domain during the recession period is

$$\mathbf{Q\,(t)\,dt = \alpha_1 hdt = -\,\phi\,Adh} \qquad (2.1)$$

Where, ϕ is storage coefficient, and A is the plan area of the flow domain. Rearranging Eq. (2.1) as

$$\frac{\alpha_1 dt}{-A\phi} = \frac{dh}{h} \qquad (2.2)$$

Integrating and applying the initial conditions, i.e., at t = t_0, h = h_0 and Q = Q_0 = $\alpha_1 h_0$, the solution of Eq. (2.2) is:

$$\mathbf{(t - t_1) = (\phi\,A/\alpha_1)\ In\ (h_o/h) = (\phi\,A/\alpha_1)\ In\ (Q_o - Q)}$$

Or

$$\mathbf{Q\,(t) = Q_o\ exp\left\{ -\ \frac{\alpha_1}{\phi\,A}(t - t_o)\right\}} \qquad (2.3)$$

The variation of Q(t) with t will plot as a straight line on a semilogarithm paper (Q on logarithmic scale).

Bear suggesting another simple model of a spring draining an unconfined aquifer (Fig. 2.1) with a view to giving an interpretation of α_1.

The unconfined flow in Zone I has been approximated to follow Dupuit's conditions and flow rate at any time has been expressed as

$$\mathbf{Q = WK\,(\frac{h_L^2 - h_o^2}{2}) = \frac{WK\,(h_L + h_o)}{2} * \frac{(h_L - h_o)}{L} = \frac{WT\,(h_L - h_o)}{L}} \qquad (2.4)$$

Where,
Q = rate of flow from spring,
K = permeability of the aquifer,
T = average transmissivity of the aquifer,
(h_L – h_0) = difference of head,
L = length of transition zone, and
W = width of the spring's threshold

As the spring discharge is linearly proportional to the head available, therefore, α_1 = (WT/L) and we have

$$\mathbf{Q\,(t) = Q_o \; exp\left[-\left\{\frac{WT}{AL\,\phi}\right\}(t - t_o)\right]} \qquad (2.5)$$

Thus, the depletion time to be equal to $\frac{AL\phi}{WT}$ If the aquifer contributing to the spring flow is made up of several separate sub regions, then each sub region will have its own characteristic depletion time, t_o.

The coefficient, t_o, or any other coefficient in one form or other appearing in the expression like Eq. (2.5) describing a spring recession curve, is related to the aquifer's geometry, transmissivity, and storativity. Therefore, as an inverse problem, it is possible to investigate about these aquifer properties by the analysis of the hydrograph of a spring discharge. It is assumed in the above mentioned analysis that pumpage or recharge does not take place during the recession period of the spring flow.

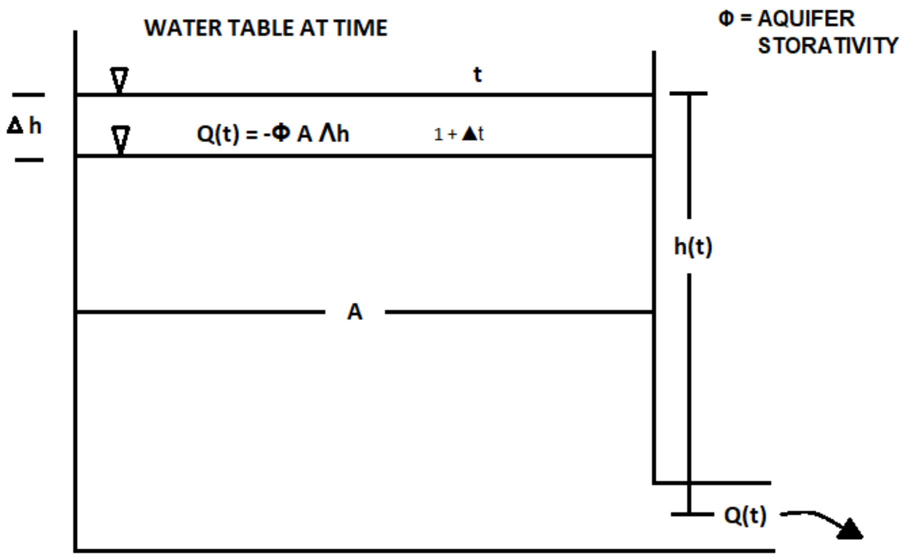

Fig. 2.2: Bear's spring flow model(Bear, 1979)

2.3.2 Unicell model

The Unicell model (Mandel and Shiftan, 1981) interprets the time series of spring discharge data and predicts spring discharge. It is assumed that the spring is perennial and has a well-defined outlet, and the flow of the spring is fed from a thick aquifer. The flow domain of the spring is conceptualized as a tank, with vertical walls filled with porous material. The tank has a spout at the bottom (Fig. 2.3).

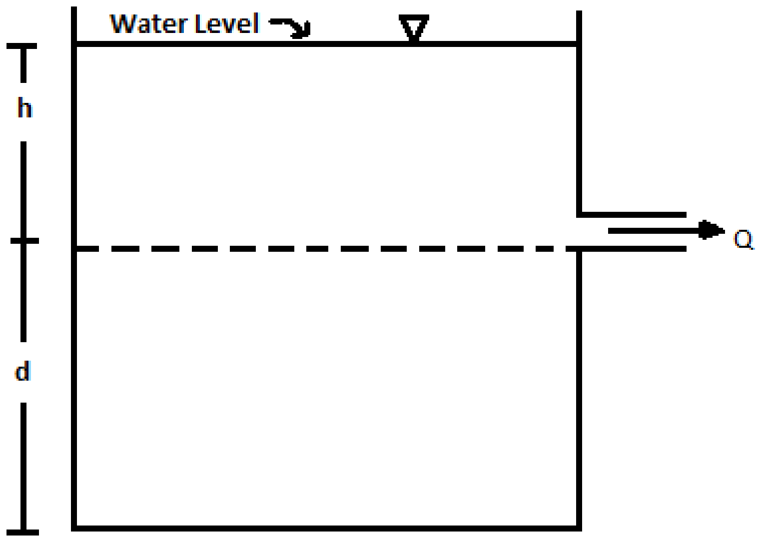

Fig. 2.3: Unicell model of spring flow (Mandel and Shiftan, 1981)

Equation (2.5) contains several aquifer parameters which are difficult to calculate in field conditions. To keep this point in view, Mandal and Shiftan (1981) derived following relationship for the estimation of discharge:

$$\mathbf{Q} = \mathbf{Q_o e^{\frac{-t}{t_o}}} \tag{2.6}$$

This equation is similar to the Equation (2.5), where t_0 is the depletion time.

Comparing Equation (2.6) with Equation (2.5)

$$t_0 = \frac{A\phi L_1}{WT} \tag{2.7}$$

And

$$\mathbf{Q_o Q(o) = \frac{WTN}{L_1\phi} = \frac{WATN}{AL_1\phi} = \frac{WRT}{AL_1\phi}} \tag{2.8}$$

Where, R = AN = Total recharge

The water present in the dynamic storage of spring at time t can be expressed as:

$$\mathbf{V(t) = \int_t^\infty Q(t)\,dt = \int_t^\infty \frac{WTN}{L_1\phi} e^{\frac{-WTt}{AL_1\phi}}\,dt}$$

$$\mathbf{= AN\left[e^{\frac{-WTt}{AL_1\phi}}\right]}$$

$$= R\left[e^{\frac{-WTt}{AL_1\phi}} \right] \tag{2.9}$$

This storage of ground water at time t can also be expressed as the product of depletion time and outflow rate at that time. Therefore, it is equal to $Q(t).t_0$.

Using Equation (2.8) and Equation (2.7), the following relationship for dynamic storage can be obtained

$$Q(t).t_0 = \left[\frac{WTN}{L_1\phi} e^{\frac{-WTt}{AL_1\phi}} \right] \left[\frac{AL_1\phi}{WT} \right]$$

$$= AN\, e^{\frac{-WTt}{AL_1\phi}} \tag{2.10}$$

From the above it is clear that depletion time is an important model parameter which consists of hydrogeological properties and the geometry of the aquifer.

Spring from the View of Depletion Time

The depletion time is reflection of recession characteristics and depends on the geology and geomorphology of the basin. For a spring whose recharge area is small or the aquifer from which it emerges has high permeability and low porosity, the t_0 value will be small. If the volume of water that is stored in the flow domain of the spring is large, or its drainage is slower, the t_0 value will be large. Karanjae and Altug (1980) studied a number of springs in Turkey and suggested some values of depletion time according to type of porosity (Table 2.2).

Table 2.2: Spring flow in the form of depletion time (t_0) values (after Karanjae and Altug, 1980)

Sl. No.	Type of porosity	Depletion time (month)
1.	Flow is primarily through inter bedding joints and tissues (3rd group of openings)	33
2.	Flow is primarily in larger fractures, faults etc. (2nd group of openings)	3.3
3.	Massive karstified limestone terrains with primary drainage through large flow channels, inter connected solutional features and other privileged ways (1st group of openings)	0.33

Englung and Meyer (1980) have found in their study that springs originated from strongly fractured rocks, e.g. limestone, have depletion time in the rage of 0.7-13 months while sandstones with minor fracturing give values around 13-33 months.

2.3.3 Bhar model

An expression for spring discharge due to an instantaneous recharge in the recharge zone has been derived by Bhar (1989) and the expression is given by

$$Q(t) = \frac{WTN}{L_1\varphi}\left(e^{\frac{-WTt}{AL_1\varphi}}\right) \qquad (2.11)$$

Where, T = Transmissivity of the aquifer in the vicinity of the aquifer; ϕ = Aquifer storativity; L_1 = Length of the transition zone;N = Instantaneous recharge quantity per unit area of aquifer; = Area of recharge zone;W = Width of the spring's opening andt = Time since the instantaneous recharge commenced. The physical process of releasing water from storage in the ground is a phenomenon which can be described by the law of bacteria decay or an expontial law. This process can also be simulated by a linear reservoir whose outflow is directly proportional to storage and can be derived by following equation (Chow, 1964):

$$Q_t = Q_0\ Kr^t \qquad (2.12)$$

Where, Q_t is the flow at any time t after Q_0 and K_r is a recession constant which is less than unity.

2.4 Spring Behaviour

The available literature related to spring behaviour is reported in this section.

Romani and Singhal (1970) studied the thermal springs of Kulu district of Himachal Pradesh and found from the geological and geochemical evidences that the main source of heat is from magnetic activity manifested on the surface by the tertiary granite, quartz veins and widespread hydrothermal mineralization.

Valdiya and Bartarya (1989) studied the effect of deforestation on diminishing discharge of mountain springs in a part of Kumaun Himalaya. They concluded that the discharge of Gaula River has diminished 29.2 per cent between 1951-60 and 1961-70 and 38.5 per cent between 1971 and 1981 due to deforestation. They also noticed the deficiency in rainfall amounting to 9.5 to 76 per cent between 1958 and 1986 in many parts of the study catchment.

Ryon and Meinan (1995) examined the short term variation in water quality at a Karst springs in Kentucky. Runoff from two different sub catchments was tagged with tracer dye and timing of the passage of the resultant dye cloud through big spring and was compared for water quality variations. Distinct lag time between the arrival of direct runoff at big spring and the bacteria and suspended sediment waveforms were shown through the concurrent quantitative tracer tests to be related to the areal distribution of land cover type within the basin.

Angelini and Drugoni (1997) examined the Bagnara spring (Central Italy) fed by a fractured, carbonate and in some areas karstic aquifer. Information was derived from geological mapping and daily flows over a period of 20 consecutive years. There are no data on the hydrological parameters nor on the aquifer hydraulic head, which is known only at the elevation of the spring.

The hydraulic conductivity and the specific yield equivalents were estimated by calibrating the model on the master depletion curve and taking into consideration the topographic elevation of the system's surface. The size of the protection area around the spring was investigated on the basis of the isochrones constructed from the results of the model.

Bhar and Mishra (1997) developed a one dimensional spring flow model for time variant recharge by using the Bear model and Duhumel's approach. The model was tested to compute recharge for Kirkgoz springs, a first magnitude Karst spring in the Mediterranean region of Turkey. By applying convolution technique, the monthly recharge to a spring flow domain and the depletion time (a model parameter) for a spring were estimated using the Newton-Raphson method.

Perez (1997) proposed a method for the estimation of basin-wide recharge rates using spring flow, precipitation and temperature data in Karstic aquifers by the analysis of hydrograph recession and multiple regression. Recharge (R) can be estimated from precipitation (P) and air temperature by the formula $R = aP – bT + c$. The component a, b and c were derived from time series data of four aquifers in the Mediterranean zone. Given the appropriate correlation coefficients, the procedure is advantageous because of its simplicity.

Desmarais and Rajstaezer (2001) studied of discharge, temperature, conductivity major ion chemistry, and δ^{13} C variations in a karst spring has revealed a relative single conceptual model of the hydrology controlling the spring's response to precipitation event. The spring's discharge response to precipitation events is very well behaved and repeatable over time. The recession of the spring qualitatively appears to be very diffusional in nature. The chemistry of the spring indicates a patchy connection to the groundwater system.

Hunt (2000) identified the recharge area for a spring complex in Southern Wisconsin using a variety of complementary techniques. A Telescopic Mesh Refinement (TMR) model was constructed from an existing regional scale ground water flow model. A probability distribution of particle captured by the spring, or a 'probabilistic capture zone' was calculated from the realistic Monte Carlo results.

Perez (2001) classified the number of springs in nine lithological groups according to their contribution of flow. These methods have been applied to Spain, a representative region with varied geology, climate and topography; 71.2 per cent of spring flow is supplied by limestones, 19.17 per cent by alluvial sediment and marls, 6.7 per cent conglomerates and sandstones and 3 per cent by slates, plutonic rocks, quartzites and other groups. Springs with discharge rates exceeding 2000 l/s exist only in limestone. The majority of springs with low flow occur in marls.

Rawat *et al.* (2001) identified 73 spring and 27 seepage in Khandagod catchment of Garhwal district. 45 springs were located in Pauri phyllite and rest 28 in Khrisu quartizite formation. 40 representative perennial springs were selected for detailed study and it was observed that their occurrence is mainly controlled by bed rock geology and structures. 18 spring were located along the fractured lineament, 11 in colluvial deposit, 7 along the joints in colluvian, 3 along bedding contacts and 1 along basic intrusive.

Corraton and Perrochet (2002) derived a one dimensional analytical porosity weighted solution of the dual porosity model and relate exchange and storage coefficients of the volumetric density of the high permeability medium. It is shown that porosity weighted storage and exchange coefficients are needed when handling highly heterogeneous system such as Karstic aquifers using equivalent dual porosity model. The presented 1D dual porosity analytical model is used to reproduces the hydraulic responses of reference 3D karst aquifers, modeled by a discrete single continuum approach.

Amit H (2002) developed the recession flow curves having two exponential term with exponential coefficient for nine springs of northern Israel. These coefficients are approximately constant for each spring, reflecting the hydraulic conductivity of different media through which the ground water flows to the spring. The highest coefficient represents the fast flow probably through cracks, or quickflow, whereas the lower one reflects the slow flow through the porous media or baseflow. The comparison of recession curves from different springs and different year's leads to the conclusion that the main factor that affect the recession curve exponential coefficient are the aquifer lithology and the geometry of water conduits therein.

Kristijan Posavec*et al.* (2006) have developed a visual basic program for an Excel spreadsheet was written to construct a master recession curve (MRC), and applied for to two examples. The first example shows the MRC of an observation well located in an unconfined alluvial aquifer, while the second shows creation of the MRC of a karst spring. The program uses five different linear/nonlinear regression models to adjust individual recession segments to their proper positions in the MRC. The program can also be used to analyze the recession segments of other time series, such as daily stream discharge or stage.

Jeelani *et al* (2011) were analyzed the water samples collected from precipitation, glacier melt, snow melt, glacial lake, streams and krast spring from south–east of Kashmir valley. The time series data on solute chemistry suggest that the hydro-chemical processes controlling the chemistry of the spring waters is more complex than the surface water. This is attributed to more time available for the infiltrating water to interact with the diverse host lithology. Total dissolved solids (TDS), in general, increases with decrease in altitude. However, high TDS of some streams at higher altitudes and low TDS of some springs at lower altitudes indicated contribution of high TDS waters from glacial lakes and low TDS waters from streams, respectively.

Kumar, *et al.* (2012) conducted a study of environmental isotopes (^{2}H, ^{18}O, ^{3}H) along with hydro geochemistry and geomorphology was undertaken to identify the recharge zones of the drying springs. From the stable isotope data of rainwater, altitude effect was estimated (–0.6‰ for δ^{18} O per 100 m elevation) and recharge zones of the drying springs were identified (+700 to +1150 m msl). Based on the recharge elevations identified from the isotopic study and from the interpretation of the geomorphological setting of the valley and taking into consideration the availability of space, it has been decided that contour-bunding, or building of check dams or levees structures with gabion are suitable methods of rainwater harvesting for augmenting recharge of the drying springs.

Vashisht and Bam (2013) were developed the master recession curves (MRC) for Ranichauri springs located in the mid-Himalayan region of Uttarakhand state for forecasting the discharge rate during the recession period of any year. They have found that the fitting of recession curve by two exponential components yields good results. They concluded that the maximum value of exponential components represents the major contribution to drainage from the spring's catchment's portion with highest permeability, whereas the minimum values represents the major contribution to spring discharge from the portion with lowest permeability. Analysis show that the permeability of the porous medium is responsible for the discharge rate and its capacity is responsible for perennial and seasonal behavior of the springs. The efficiency of formulated master discharge function for Ranichauri spring has been evaluated using the historical spring discharge data and found excellent as Nash-Sutcliffe efficiency was found 0.965.

Vashisht and Sharma (2013) studied the behaviour of a perennial spring with rainfall variation is analyzed from eight years 'data recorded daily. It is concluded that the time required for the water from the remotest part of the feeding catchment of the spring to reach the outlet (time of concentration) is equal to 57 days.

CHAPTER - 3

MORPHOLOGICAL ANALYSIS OF BAANGANGA WATERSHED

3.1 Introduction

A watershed is a physically complex system. It consists of a number of Unit Source Areas (having uniform properties), and Partial and Variable Source Areas each exhibiting a different response. The juxtaposition of different source areas of contrasting topography, rock types, and land use and soil characteristics result in areal variations in watershed response and processes. Every hydrologic design is therefore different because the physical properties may vary with site.

Morphological properties of a watershed are useful (i) to understand hydrological behavior of small ungauged catchments (ii) for prioritization of a micro-watershed for watershed development and (iii) for selecting site for artificial recharge and groundwater targeting. Computation of morphological parameters in GIS environment has proved to be less tedious, fast and accurate and made best spatial representation of topographic situations as illustrated by various studies (Singh, 1998; Kumar et al., 2001; Singh et al., 2003).

3.2 Definitions

3.2.1 Linear parameters

Watershed area (A): The watershed area reflects volume of water that can be generated from the rainfall. It is a necessary input in various hydrologic models.

Watershed perimeter (L_p): It is the length of the watershed boundary.

Watershed length (L_b): It is the distance between watershed outlet and farthest point in the watershed.

3.2.2 Shape parameters

Form factor (R_f): Form factor is the ratio of the watershed area (A) to the square of the maximum length of the watershed (L_b).

$$R_F = A / L_b^2$$

Elongation ratio (R_e): Elongation ratio is the ratio between the diameter of a circle with the same area as that of the watershed to the maximum length of watershed.

$$R_E = \frac{2}{L_b}\sqrt{\frac{A}{\pi}}$$

Circularity ratio: Circularity ratio is computed as:

$$R_C = \frac{2}{L_P}\sqrt{\pi * A}$$

3.2.3 Drainage parameters

Length of overland flow in a watershed is relatively very small than the length of channel flow. The travel time of runoff is an important input in many hydrologic design models. Thus the drainage pattern is indicative of the flow characteristics of storm runoff. A number of parameters have been developed to represent drainage pattern.

Stream order: Strahler (1964) suggested the method of stream ordering to analyze the drainage pattern of the area. The basic rules of stream ordering are:

(i) Streams that originate at a source are defined to be first order streams.

(ii) When two streams of order u join, a stream of order u+1 is created.

(iii) When two streams of different order join, the channel immediately downstream has the higher of order of the two joining streams.

(iv) The order of a watershed is the order of the highest stream.

Stream number (N_u): It is the number of stream segments of various orders.

Total stream length (L_u): It is the sum of all lengths of all the stream order.

Main stream length (L_{MS}): Main stream length is the length of the stream having maximum stream length. This is the length along the principal stream.

Bifurcation ratio (R_b): It is the ratio of the number of streams of given order u to the number of streams of next higher order u+1. It reflects the complexity and degree of dissection of a drainage watershed.

$$R_b = N_u / N_{u+1}$$

Length ratio (R_t): Horton (1945) proposed length ratio factor as the ratio of the average stream length (L_u) of order u, to average stream length (L_{u-1}) of the previous lower order u-1.

$$R_t = L_u / L_{u-1}$$

High R_t values are associated good permeable formation of the watershed while comparatively low R_t values are associated with impermeable formation of a watershed.

Drainage density (D_d): It is the ratio of total length of the streams of all the orders of a watershed to the area of the watershed.

$$D_d = \sum_{u=1}^{n} L_u / A$$

Higher drainage density in a watershed indicates quick disposal of runoff from the watershed. The comparatively low drainage density watersheds provide more opportunity time to infiltrate overland flow which subsequently may have better ground water storage condition under the same rainfall condition. High drainage density is associated with low permeability of underlying geological formation and vice versa.

Length of overland flow (L_g): Length of overland flow is equal to one half of the reciprocal of the drainage density.

$$L_g = \frac{1}{2D_d}$$

Drainage frequency (D_f): It is the ratio of the total number of streams in a watershed to the watershed area.

$$D_f = \sum_{u=1}^{n} N_u / A$$

Higher drainage frequency points to a larger surface runoff and steeper ground surface. It mainly depends upon the lithology of the watershed and texture of drainage network. Under the same slope condition, hard geological formations show higher drainage frequency value compared to soft geological formations in a watershed.

Constant of channel maintenance (C_m): Schumm (1956) introduced the factor, "constant of channel maintenance", as the inverse of the drainage density. It is the area required to maintain one linear kilometer of stream channel.

$$C_m = 1/D_d$$

Drainage texture (T): Drainage texture is defined as the ratio of number of streams of first order to the perimeter of the watershed.

$$T = N_1/P$$

3.2.4 Relief parameters

A number of parameters have been developed to reflect variations in watershed relief and to indicate erosion hazard.

Maximum watershed relief (H): It is the maximum vertical distance between the lowest and the highest points of a watershed. It is also known as total relief.

Relief ratio (R_h): Relief ratio is the total relief of the watershed (H) divided by the maximum length (L_b) of the watershed. High value of watershed slope shows rich drainage pattern which helps quick disposal of runoff. Low-sloped watersheds provide more time to infiltrate the generated runoff and subsequently build ground water storage.

$R_h = H/L_b$

Ruggedness number (R_N): Ruggedness number is defined as the product of the maximum watershed relief (H) and its drainage density (D_d). It provides an idea of overall roughness of a watershed.

$R_N = H * D_d$

Relative relief (R_r): Relative relief is the ratio of the maximum watershed relief (H) to the perimeter of the watershed (L_p).

$R_r = H/L_p$

3.3 Morphological Analysis Using GIS

In the present study Baanganga River catchment and its drainage network has been delineated from toposheets obtained from Survey of India (SOI). Two Toposheets of 1:25,000 scale have been geo-referenced in ArcGIS 10.2 followed by digitalization of drainage network. By following the Strahler (1964) method, stream ordering has been carried-out for the Baanganga watershed and it has found to be fourth order watershed (Table 3.1). The extracted drainage network (drainage area of 20.23 sq. km) is shown in Fig. 3.1. Various linear measurements such as area, perimeter, watershed length, drainage length and total relief are calculated from the attributes table of map layers such as boundary layer, drainage layer and digital elevation layer. With the help of these linear measurements, formula based morphological parameters are computed for Baanganga watershed. The different morphometric parameters calculated for Bannganga watershed have been presented in Table 3.2 and discussed.

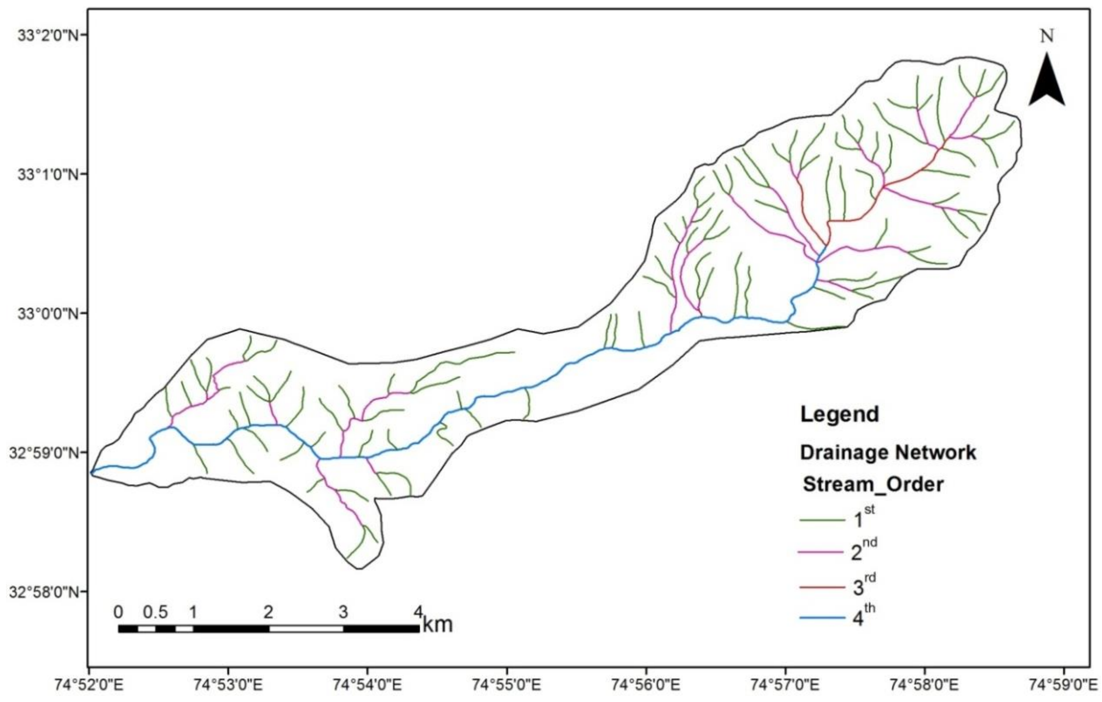

Fig. 3.1: Drainage network of Baanganga watershed

Table 3.1: Stream hierarchy and associated features of Baanganga watershed

Stream Order	Number of stream	Stream length	Mean stream length (km)	Bifurcation ratio (R_b)	Length ratio (R_l)
I	95	43.358	0.456	4.74	2.66
II	20	15.333	0.766		
III	3	3.321	1.107		
IV	1	10.580	10.580		

Table 3.2: Morphometric parameters of the Baanganga watershed

S. No.	Parameter	Value
1	Watershed area (km)	20.23
2	Perimeter (km)	28.76
3	Length of watershed (km)	13.84
4	Total length of stream (km)	72.59
5	Total number of streams	119
6	Bifurcation Ratio	4.74
7	Length ratio	2.66
7	Length of overland flow (m)	139
8	Drainage density (km/km^2)	3.59
9	Drainage texture (no./km)	4.14
10	Stream frequency (no./km^2)	5.89
11	Form factor	0.10
12	Circularity ratio	0.3037
13	Elongation ratio	0.36
14	Compactness coefficient	1.8
16	Maximum watershed relief (m)	2230
17	Relief ratio (km/km)	0.16
18	Relative relief (km/km)	0.077
19	Ruggedness number (R_N)	8.01

3.3.1 Linear aspects

Stream order (U_n): The drainage and stream order map of Baanganga watershed is shown in Fig. 3.1 The Baanganga watershed is a 4th order drainage basin. The total number of 119 streams are identified of which 95 are 1st order streams, 20 are 2nd order, 3 are 3rdorder and 1is 4th order. There is an inverse relationship between number of stream (N_s) and the order of the streams (U_n) in the watershed (Fig. 3.2). High value of r (0.99) indicates good correlation between these two parameters. The relationship is represented by the following regression equation:

$$N_u = --0.6757 \ln U_n + 2.6282$$

Where, N_u is the number of streams of the order U_n, n = 1, 2, 3 -------

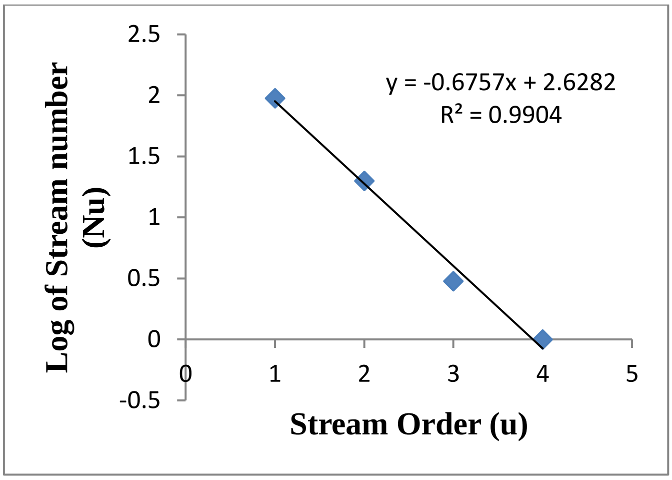

Fig. 3.2: Regression of logarithms of stream number versus stream order

Stream length (L_u): In the study watershed, total length of stream segments is maximum for first order and decreases as stream order increases, as shown in Fig. 3.3 and Table 3.1. Mean stream length of 1st order is minimum (0.456 km) and maximum (10.580 km) for 4th order. Streams of relatively smaller lengths indicate high slope and finer texture there by will generate more runoff. There is a good relationship between stream length and stream order in watersheds as indicates by high correlation coefficient (0.83). The overall relationship for Baanganga watershed is represented by the following equation:

$$L_u = 0.4255 \ln U_n – 0.9106$$

Where, L_u is the length of streams (km) of the order U_n, n = 1, 2, 3 -------

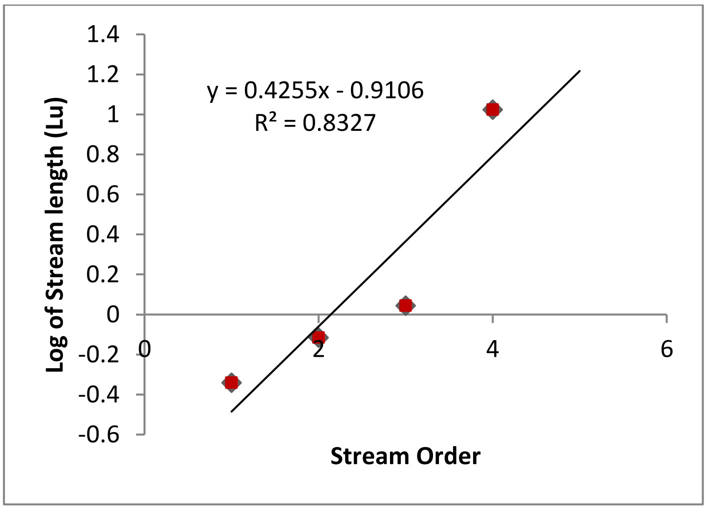

Fig. 3.3: Regression of logarithms of stream length versus stream order

Bifurcation ratio (R_b): The bifurcation ratio is found to be 4.74 of watershed which indicates that the geologic structures do not distort the drainage pattern. Higher values of Bifurcation ratio indicate strong structural control in drainage pattern while the lower values are indicative of not affected by structural disturbances (Dwivedi, 2011).

Length of Overland Flow (L_o): The computed value of the length of overland flow for Baanganga watershed is 139 m. The value is lower range of the overland flow It means that it has the potential to cause sheet erosion owing to the shorter overland flow distance and quicker runoff concentration. This factor relates inversely to the average slope of the channel and is quite synonymous with the length of sheet flow to a large degree. Smaller the value of overland flow the quicker surface runoff will enter the streams represents well developed drainage network with higher slope. In a relatively homogeneous area, therefore less rainfall is required to contribute a significant volume of surface runoff to stream discharge when the value of overland flow is small than when it is large.

3.3.2 Aerial aspects

Drainage density (D_d): The drainage density indicates the closeness of spacing of channels. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture. The drainage density of Baanganga watershed is 3.59 km/km^2, which is quite high indicating impermeable sub surface materials and mountainous relief resulting in high runoff and soil erosion (Strahler, 1964). However, magnitude of soil erosion would depend upon the development stages of the drainage lines in the watershed. In general there would be quick concentration of runoff resulting in high water yield.

Drainage texture (T): The drainage texture of Baanganga watershed is 4.14 no./km. Drainage texture provides information on the relative spacing of drainage lines. Drainage texture is affected by natural factors such as climate, rainfall, vegetation, rock and soil type, relief and stage of development of a watershed. Smith (1954) classified drainage texture, i.e. < 2 indicates very coarse, between 2 and 4 is coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture. Hence, the drainage texture of Baanganga watershed is moderate drainage texture. More is the texture more will be dissection and leads more erosion.

Stream frequency (F_s): Stream frequency or channel frequency is directly related to stream population per unit area of the watershed (Horton 1932). It indicates the close correlation with drainage density value of the micro-watershed. The stream frequency of the Baanganga watershed is 5.89 no./km^2. Higher value of stream frequency indicates that the topography of the watershed is not plain and less amount of rainfall would infiltrate into the soil, resulting in higher generation of runoff. The basins of the structural hills have higher stream frequency, drainage density while the basins of alluvial has minimum.

Form factor (R_f): The form factor is equal to unity when the basin shape is a square, and decreases according to the extent of elongation. Smaller value of the form factor indicates maximum elongation of the watershed. The value of form factor of Baanganga watershed is 0.38, which indicate that the watershed is elongated in shape. This type of watershed with sloping topography results in moderate to high runoff generation.

Circularity ratio (R_c): Circularity ratio is influenced by the length and frequency of streams, geological structures, land use/ land cover, climate, relief and slope of the watershed. The circularity ratio is a similar measure as elongation ratio, originally defined by Miller (1953), as the ratio of the area of the basin to the area of the circle having same circumference as the basin perimeter. The value of circularity ratio varies from 0 (in line) to 1 (in a circle). In the Baanganga watershed, the circulatory ratio value is 0.30, indicating that the watershed is significantly elongated in shape having high discharge of runoff. Such drainage systems are partially controlled by the structural disturbances causing problem of soil erosion in the uplands and siltation in downstream water harvesting structures to some extent.

Elongation ratio (R_e): According to Schumm (1956) elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. Strahler states that this ratio runs between 0.6 and 1.0 over a wide variety of climatic and geologic types. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (0.9~0.10), oval (0.8~0.9), less elongated (0.7~0.8), elongated (0.5~0.7), and more elongated (less than 0.5).The elongation ratio of Baanganga watershed is 0.36 which indicates that watershed is more elongated in shape resulting into generation of high quantities of runoff.

Compactness coefficient (C_c): Compactness coefficient is inversely proportional to the erosion risk assessment. Higher value signifies less vulnerability for risk factors, while lower value indicates great vulnerability and represents the need of implementation of conservation measures. The value of compactness coefficient for Baanganga watershed is 1.8.

3.3.3 Relief aspect

Relief aspects of drainage basin relate to the three dimensional features of the basin involving area, volume and altitude of vertical dimension of landforms wherein different morphometric methods are used to analyze terrain characteristics.

Total Relief (H): It is the maximum vertical distance between the lowest and highest point of the watershed. It is also known as maximum watershed relief. Watershed relief controls the gradient of drainage lines within the watershed and hence significantly influences the soil erosion of the watershed (Patton et al., 1988 and Ozdemir and Bird, 2009). Total relief was found to be 2230 meter for Baanganga watershed.

Relief Ratio (R_h): The relief ratio defined as the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line (Schumm, 1956). The advantage of relief ratio over the total watershed relief as it removes the size effect by dividing the total relief by the basin length. Relief ratio of Baanganga watershed was found to be 0.16 km/km which indicates that watershed is moderate to steep topography.

Relative Relief (R_r): It is the ratio of the maximum watershed relief to the perimeter of the watershed. The relative relief represents actual variation of altitude in a unit area with respect to its local base level. It enumerates that the steeper the slope the higher is the surface above its base. The value of the relative reliefs for Baanganga watershed was found to be 0.077 km/km.

Slope of watershed: Slope of the watershed is vital for making land capability assessment and in the estimation of runoff and soil loss. The slope map of the Baanganga watershed has been shown in Fig.3.4. The slope in the watershed is classified into five slope classes (<20%, 20-40%, 40-80%, 80-100%, and >100).

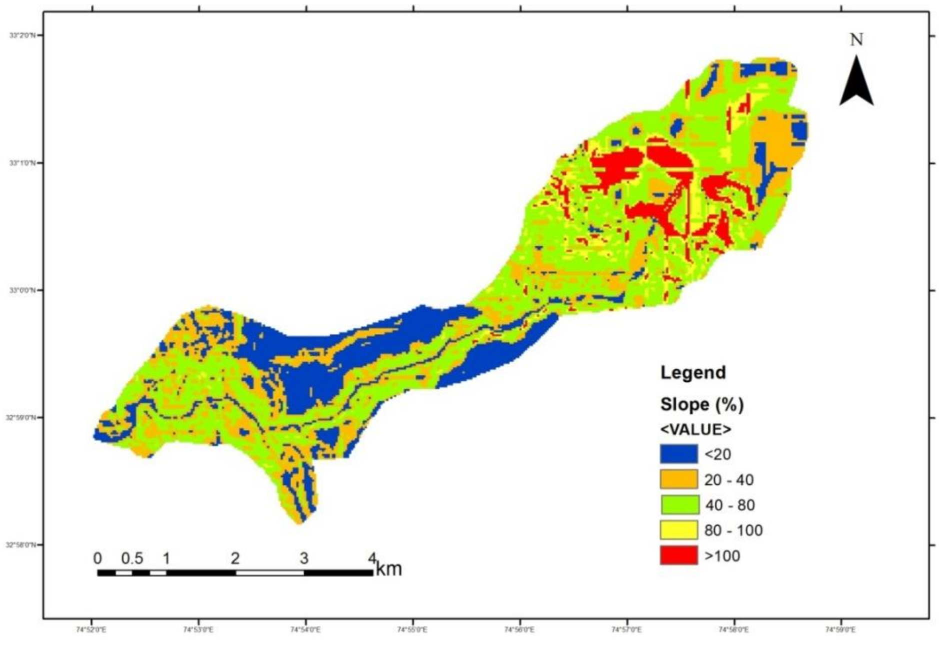

Fig. 3.4: Slope zone map of the study area.

3.4 Landuse of Baanganga Watershed

The land use map of the Baanganga watershed was prepared with the help of toposheets, satellite and google images and depicted in Fig. 3.5. Forest, Scrub, Rocky area and Agricultural land were identified as major land use system categories in the watershed and their areas are depicted in Table 3.3.

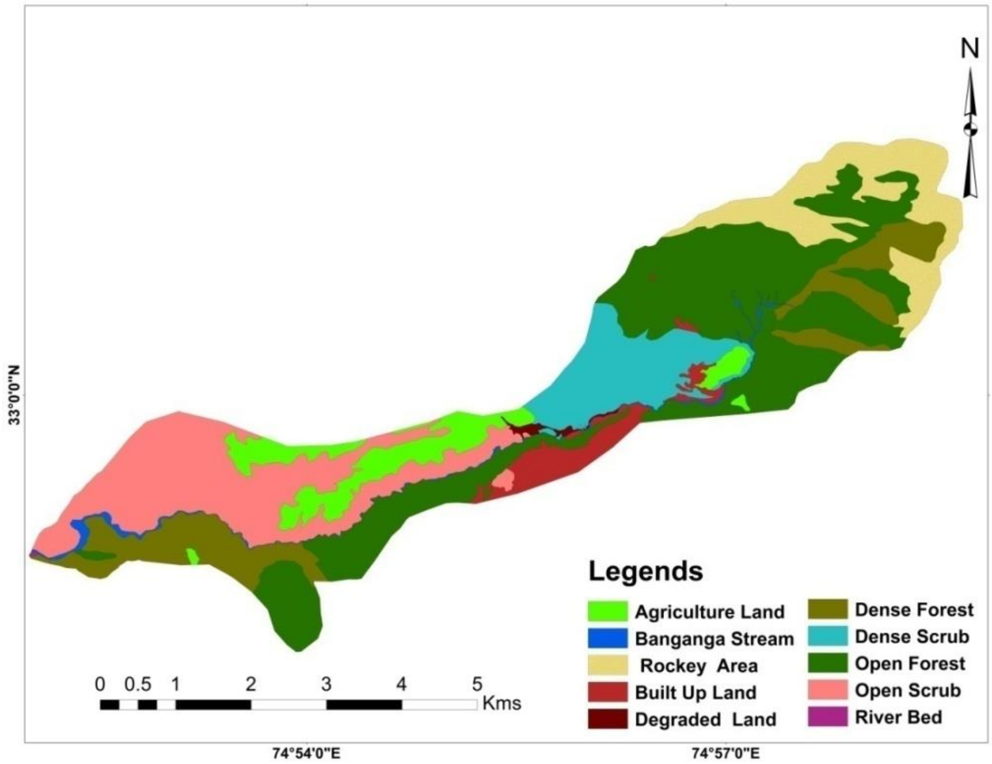

Fig. 3.5: Landuse map of the Baanganga watershed.

Table 3.3: Landuse of the Baan Ganga watershed.

Features	Area (ha)	% area
Agriculture Land	154.11	8.38
Rocky Area	221.48	12.05
Built Up Land	82.06	4.46
Degraded Land	7.72	0.41
Dense Forest	77.15	4.19
Dense Scrub	187.13	10.18
Open Forest	708.97	38.58
Open Scrub	398.18	21.67
River Bed	5.00	0.27

3.5 Soil of Baanganga Watershed

Soil map of the study area was prepared by digitizing the soil map obtained from NBSS&LUP, Nagpur. Four different soil unit has been identified in the watershed. Coarse loamy to fine loamy soil have been identified in the watershed. The upper part of the watershed which very steep in the slope is comprises coarse loamy soil, while the lower part of the watershed which having gentle or moderate slop is associated with fine loamy soil. The detail characteristics of the soils are given in Table 3.4.

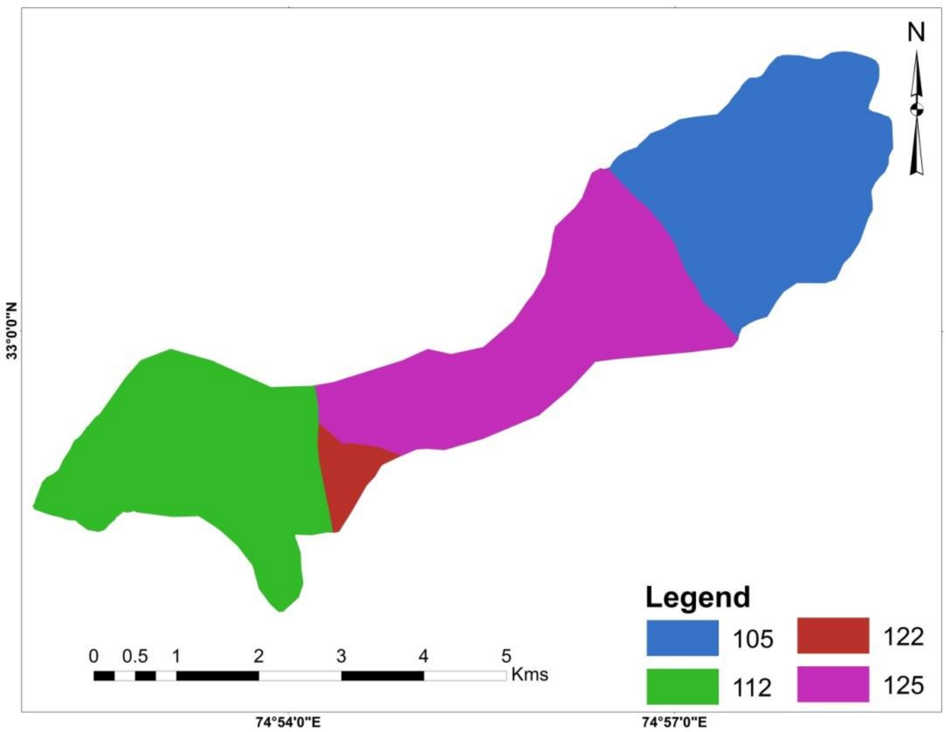

Fig. 3.6: Soil Map of Baanganaga watershed.

Table 3.4: Characteristics of soils of Baanganaga watershed.

Soil Unit	Soil Characteristics
105	Medium deep, excessively drained, coarse-loamy soils on steep slopes with loamy surface, severe erosion and moderate stoniness; associated with; Deep, well drained, fine-loamy, calcareous soils with loamy surface and moderate erosion.
112	Medium deep, somewhat excessively drained, fine-loamy soils on moderately steep slopes with loamy surface and moderate erosion, associated with: Medium deep, excessively drained, coarse-loamy soils with loamy surface and severe erosion.
122	Medium deep, well drained, coarse loamy soils on gentle slopes with loamy surface and moderate erosion; associated with: Medium deep, well drained, fine-loamy soils with loamy surface and moderate erosion.
125	Medium deep, well drained, coarse-loamy soils on gentle slopes with loamy surface and moderate erosion; associated with: Deep, well drained, coarse-loamy soils with loamy surface and moderate erosion.

CHAPTER - 4
HYDRO-METEOROLOGICAL DATA COLLECTION AND ANALYSIS

Baanganga, a small tributary of Chenab River, the legendary river associated with the miracles and legends of Mata. It is considered sacred and as is normal *Hindu* tradition, devotees like to bath in it before preceding the journey of the holy shrine *Mata Vaishno devi.*This River is originated from the Trikuta hills and passes from the side of Katra town (main base camp for *Mata Vaishno Devi* journey). Baanganga travels 8 km up to Katra town and comprises 13 sq. km catchment area. After travelling 12 km in south-west direction it meets with *Phare khad* and finally merged in almighty Chenab River after travelling 3 km in west direction. Since, there is no glacier presented in the Baanganga catchment, hence springs are the only available sources to fulfill the water demand of the livelihood of the surrounding people and also to maintain the flow of the river Baanganga.

Collection of data is foremost and first important step for any research study. As per review and literature collected, no hydro-meteorological study on Baanganga watershed has been reported so far. Therefore, no hydro-meteorological data are available for Baanganaga watershed. In the present study, two kind of data are needed (i) Spring related data, and (ii) rainfall data

4.1 Springs in Baan Ganga Watershed

Total fourteen springs have been identified from the toposheet of Survey of India (1:25,000) and the subsequent field visit in the Baan Ganga watershed. Out of 14 springs, 4 springs (SP1, SP2, SP3, SP10a&b) are located just outside of the Baanganga watershed boundary but consider in the study with this consideration that their recharge area may fall in the study watershed. Furthermore, theses springs are having societal importance and hence research on theses springs may be contributed towards the welfare of local people. However, SP6 (small dripping of water from the rocks nearby Bhawan) is considered only for validation of the isotopic samples. Fig 4.1 and Table 4.1are shown the locations and information about the different springs identified in the Baanganga watershed.

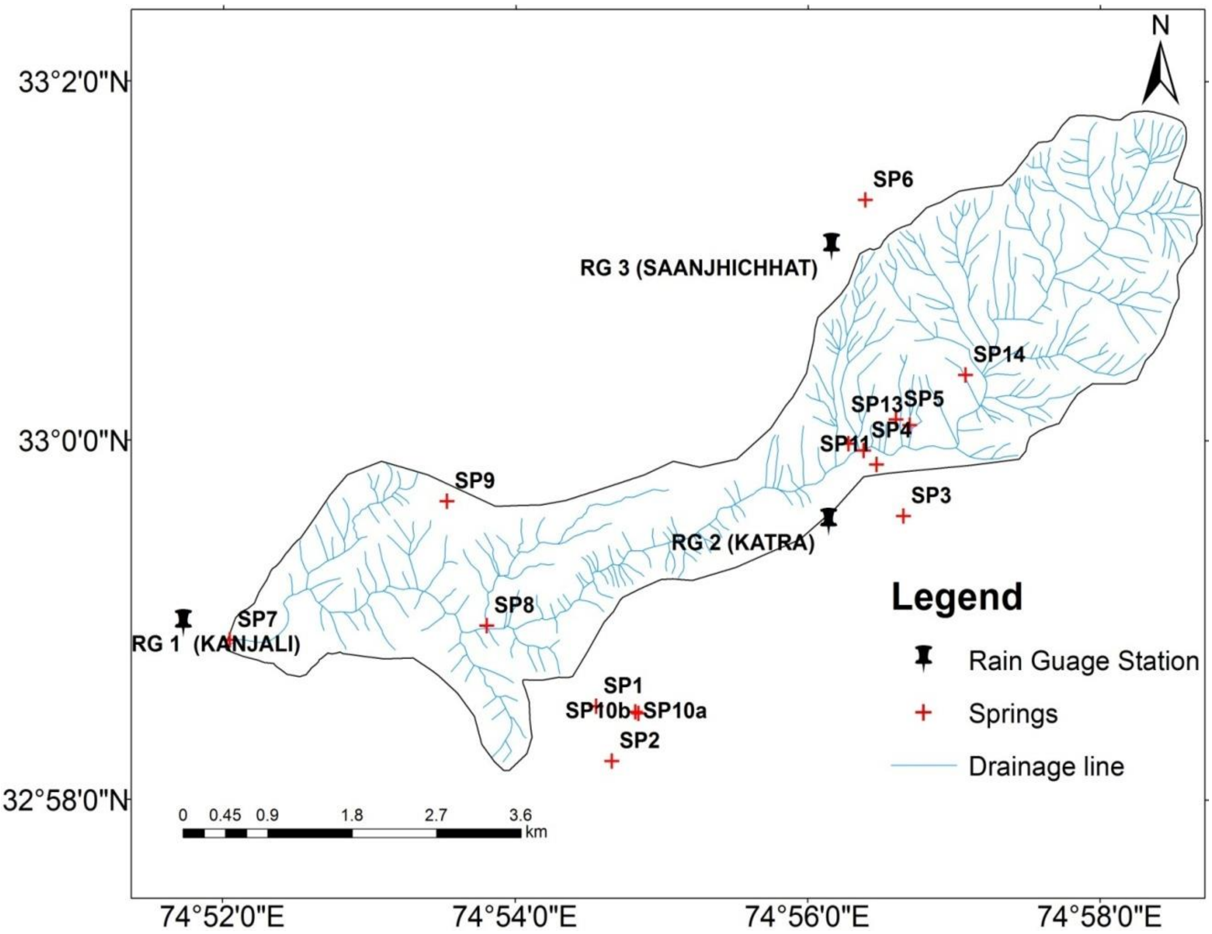

Fig. 4.1: Map showing the locations of springs identified in Baanganga watershed.

Table 4.1: Details of the springs located in the Baanganga watershed

Spring Code	**Location**	**Discharge (lpm)**	**Photograph**
SP1	32⁰ 58' 31.25"N, 74⁰ 54' 33.28"E Altitude: 731 m Village Kotli Bajialya, 300 meter above Highway 1C near residential colony of Shri Mata Vaishno Devi Shrine Board)	36.9	

SP2	32^0 58' 12.85"N, 74^0 54' 9.78"E Altitude: 682 m Village- Nawain, Below 500 m highway 1C, two openings)	7.9	
SP3	32^0 59' 34.83"N 74^0 56'39.44" E Altitude: 881 m (Near *Bhumika Devi* Temple	16.2	
SP4	32^0 59' 56.71"N 74^0 56' 23.06" E Altitude: 868 m (Near Biogas plant)	151.9	
SP5	33^0 00' 7.09"N 74^0 56' 36.32"E Altitude: 1006 m Near Pannas, nearly 500 m above Baanganga cross bridge)	60.6	
SP6	33^0 01' 20.45"N 74^0 56' 23.53" E Altitude: 1760 m (Near Bhawan)		Photography prohabited

SP7	32^0 58' 53.27"N 74^0 52' 3.05"E Altitude: 40 6m (Kanjali, Baanganaga outlet)	< 1	
SP8	32^0 58' 58.08"N 74^0 53' 48.39"E Altitude 572 m (Below Sarun village)	136.7	
SP9	32^0 59' 39.78"N 74^0 53' 31.89"E Altitude: 693 m (Below Batan village)	Baowli	
SP10a	32^0 58' 29.54"N 74^0 54' 49.39"E Altitude: 747 m (3 km before Katra on Jammu-Katra highway near Kalika mandir)	11.6	

SP10b	32^{0} 58' 29.02"N 74^{0} 54' 50.73"E Altitude: 743 m (3 km before Katra below Jammu-Katra highway (1C) near *Shani mandir)*	82.9	
SP11	32^{0} 59' 52.09"N 74^{0} 56' 28.37"E Altitude: 896 (At Langar)	13	
SP12	32^{0} 59' 58.95"N 74^{0} 56' 16.87"E Altitude: 876 (200-300 meter downstream of SP4)	30.3	
SP13	33^{0} 0' 5.21"N 74^{0} 56' 42.0"E Altitude: 988 m (200 meter below Charanpaduika temple)	132.2	

SP14	33^{0} 0' 21.97"N 74^{0} 57' 04.3"E Altitude: 1113 m (Near Purana Daroor)	44.6	

4.1.1 Measurement of spring flow

05 perennial springs (SP1, SP2, SP3, SP4 & SP5) have been monitored for their spring flow on daily basis. A bucket and stop watch were used to take the measurement of spring flow discharge (Fig. 4.2). Discharge variation with rainfall of SP1 and SP2 springs are depicted in Fig. 4.3& Fig. 4.4, respectively. It can be shown from Fig. 4.3 & Fig. 4.4 that SP2 is more stable than SP1 owing to less variability of flow during the period. Minimum, maximum and discharge variability of studied springs are given in Table 4.2. It has been seen that except SP2, all springs having discharge variability grater than 100%.

Fig. 4.2: Spring Flow measurement of springs in the Baanganga watershed.

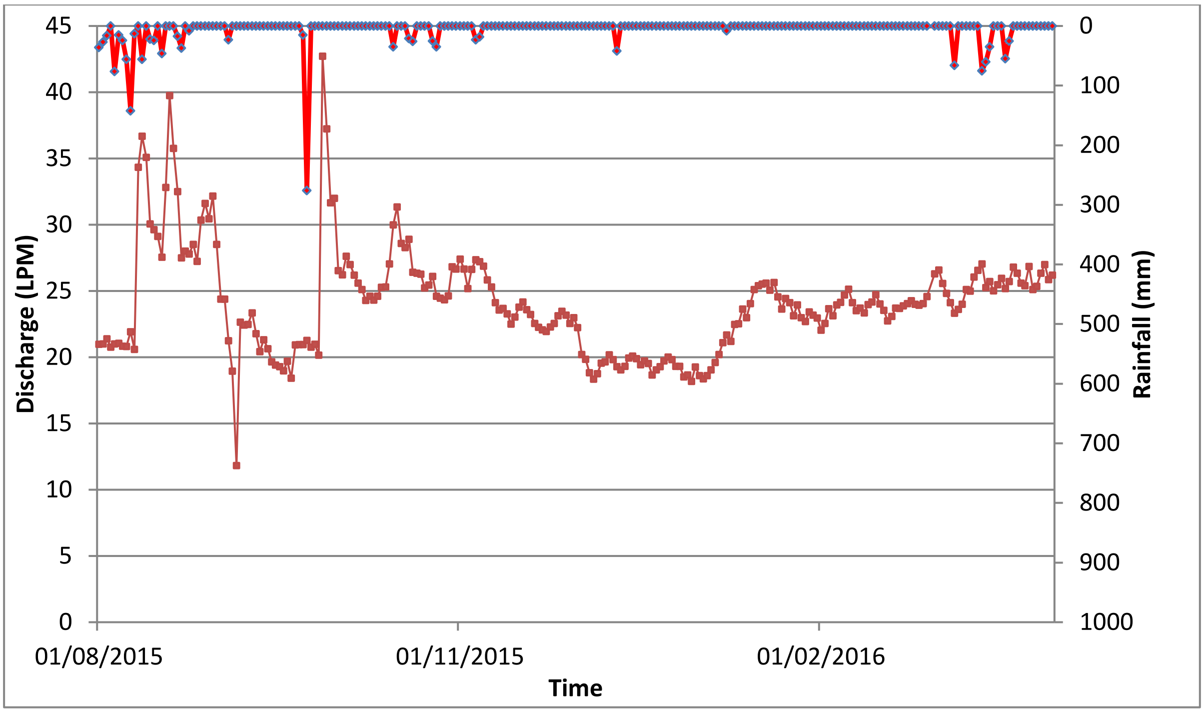

Fig. 4.3: Discharge variation of SP1 spring with rainfall from August, 2015 to March, 2016.

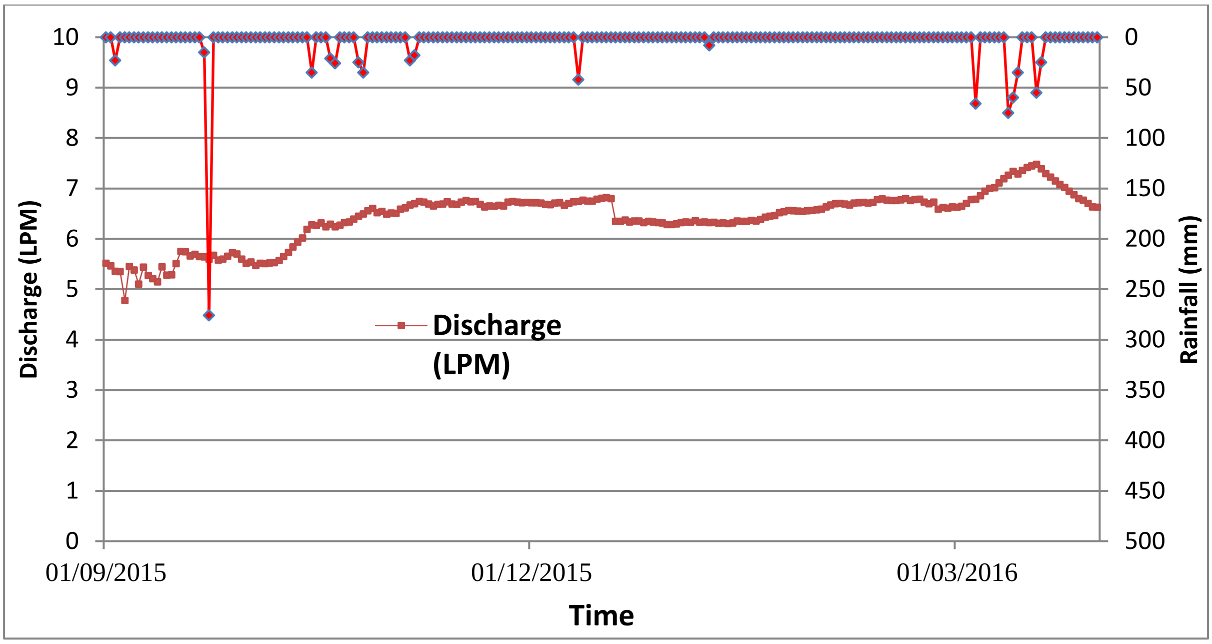

Fig. 4.4: Discharge variation of SP2 spring with rainfall from August, 2015 to March, 2016.

4.1.2 Development of Depletion Curve

Depletion curves for Bhumika Devi Spring and Nawai Spring have been developed using mean monthly spring flow data (2015 to 2017) and it was found to be 6.96 months and 6.52 months, respectively (Fig. 4.5). It has been found that both springs are reliable as they can outlast the most extreme dry spell of 5.2 months for western Himalaya during 1951-2007.

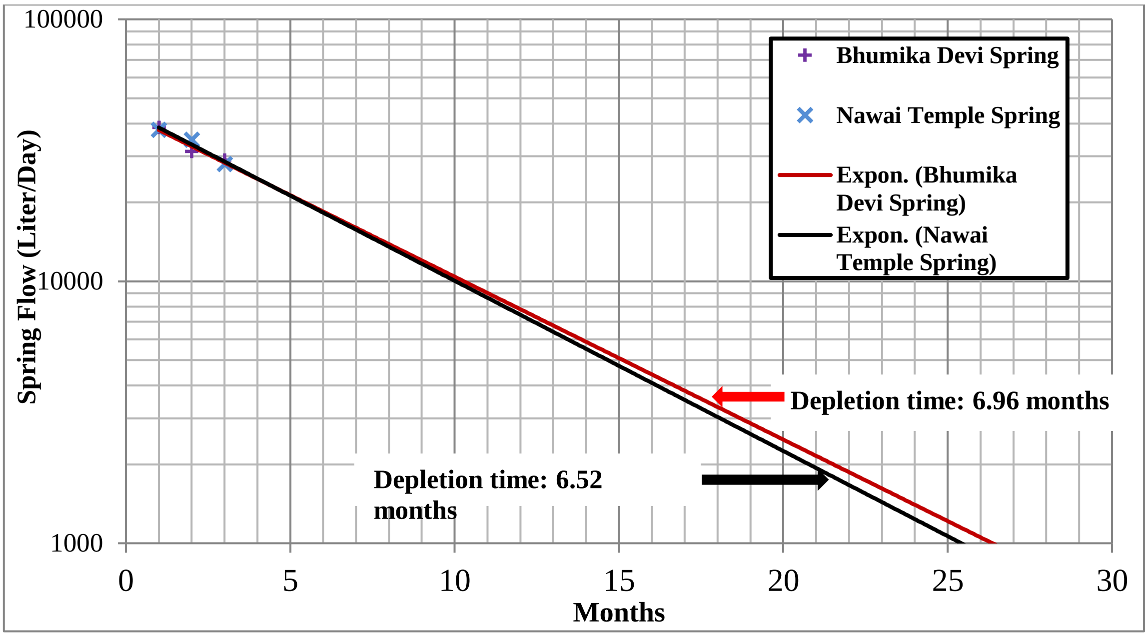

Fig. 4.5: Estimation of depletion time for Bhumika Devi Spring and Nawai Temple spring

Table 4.2: Characteristics of selected springs of Baanganaga watershed.

Spring Id	Location	Altitude (meter)	pH	EC	Discharge		Variability (%)
					Max	Min	
SP1	32^0 58' 31.25"N, 74^0 54' 33.28"E	731	7.5	820	59.87	4.62	209
SP2	32^0 58' 12.85"N, 74^0 54' 9.78"E	682	7.4	810	8.24	4.78	53
SP3	32^0 59' 34.83"N, 74^0 56' 39.44" E	881	7.8	410	17.3	5.7	107
SP4	32^0 59' 56.71"N, 74^0 56' 23.06" E	868	7.6	550	151.9	43.7	280
SP5	33^0 00' 7.09"N, 74^0 56' 36.32"E	1006	8	510	60.6	25.42	220

4.1.3 Estimation of minimum storage requirement to sustained local water security

Spring flow and local demand vary throughout the year. During monsoon, supply is more than demand; however, during summer demand is more than supply. The computation of minimum storage required to fulfill the variable demands of the users have been estimated by doing simple arithmetic calculations for studied springs. Assuming that the storage reservoir is full at the beginning of the dry periods (when inflow rate is less than the demand rate), the maximum amount of water drawn from storage is the cumulative difference between the supply and demand volumes from the beginning of the dry season.

Flow volumes of all springs and water demand of dependent humans have been calculated on a monthly basis. For calculation of daily water demand of humans, 55 liters per capita per day (lpcd) has been taken under the norm of National Rural Drinking Water Programme (NRDWP) by the Govt. of India. However, for spring SP2, it has been taken only 20 liters per capita per day (lpcd) as SP2 spring is used only for drinking.

To make the studied springs dependable sources for local people, minimum storage is required to store the surplus water to meet the excess demand during lean season. In this regard, minimum storage requirement has been calculated by the method discussed earlier and linear calculation in tabular form has been depicted in Table 3 & Table 4 for SP2 and SP3 springs, respectively. In the present study the storages requirement for spring near Nawai village (SP2) and Bhoomika devi (SP3) were estimated to be 1843 m^3 and 2877 m^3, respectively. Accordingly, a storage tank of 1843 m^3 and 2877 m^3capacity for SP2 and SP3 springs, respectively will be desirable so that these storage tanks may fulfilled the water demand from January to July. The storage tanks will start refilling again in August and will completely fill about in December. This increase the potential of *Nawai* spring to sustain water demand from 530 people to 655 people, while increase potential of *Bhoomika Devi* spring from 550 people to 970 people. This indicates that minimum storage requirement is more beneficial when spring flow is more variable as *Nawai* spring and *Bhoomika Devi* spring having discharge variability 53% and 107%, respectively (Table 4.2).

Table 4.3: Estimation of minimum storage requirements for *Nawai* spring (SP2).

Month (1)	Monthly Flow Volume (liters) (2)	Dependent Population (3)	Monthly Demand Volume (liter) (4)	Excess water 5=(2-4)	Cumulative excess demand (6)	Cumulative Excess harvested Water (7)
JAN	983.6	655	1081	-97.2	97.2	
FEB	1028.6	655	1081	-52.2	149.3	
MAR	1102.2	655	1081	21.4	127.9	
APR	1042.5	655	1081	-38.2	166.1	
MAY	984.9	655	1081	-95.8	261.9	
JUN	879.8	655	1081	-200.9	462.8	
JUL	964.9	655	1081	-115.8	578.6	
AUG	1869.0	655	1081	788.2	**1843.8**	788.2
SEP	1554.8	655	1081	474.1		1262.3
OCT	1474.9	655	1081	394.2		1656.4
NOV	1296.0	655	1081	215.3		1871.7
DEC	1185.5	655	1081	104.8		**1976.5**

Table 4.4: Estimation of minimum storage requirements for *Bhoomika Devi* spring (SP3).

Month (1)	Monthly Flow Volume (liters) (2)	Dependent Population (3)	Monthly Demand Volume (liter) (4)	Excess water 5=(2-4)	Cumulative excess demand (6)	Cumulative Excess harvested Water (7)
JAN	540.3	970	582.0	-41.7	41.7	
FEB	492.7	970	582.0	-89.3	131.0	
MAR	466.9	970	582.0	-115.1	246.1	
APR	478.0	970	582.0	-104.0	350.1	
MAY	397.6	970	582.0	-184.4	534.5	
JUN	335.6	970	582.0	-246.4	780.8	
JUL	569.3	970	582.0	-12.7	793.6	
AUG	1432.8	970	582.0	850.8	**2877.8**	850.8
SEP	1402.2	970	582.0	820.2		1671.0
OCT	1158.6	970	582.0	576.6		2247.6
NOV	939.7	970	582.0	357.7		2605.3
DEC	870.0	970	582.0	288.0		**2893.4**

4.1.4 Sampling of spring water

pH and EC of the spring waters have been measured in-situ condition during the field visit (Fig 4.6). It was found that all spring water are slightly in alkaline nature and EC ranging from 410 to 820 µS/cm (Table 4.2) However, for isotopic analysis daily water samplehas been filled in a air tight reagent bottle for ^{2}H and ^{18}O analysis. It should be kept in mind that filled sample must be air bubble free. However, for water quality analysis 1 liter sample on a particular day of the month has been filled.

Fig. 4.6: Collection of spring water sample for isotopic and water quality analysis

4.1.5 Water quality testing and analysis

Pre-monsoon and post monsoon water quality data for year 2017 have been collected and tested in the water quality lab of environmental Hydrology division (EHD) of NIH and presented in Table 4.3 & 4.4. It has been observed from Table 4.5 & 4.6 that water quality parameters for all spring waters are within the desirable limit of drinking water as per Indian Standard for Drinking Water (IS 10500-2012). However, springs located at downstream of Katra town (SW1, SW2, SW10, SW15 and SW16) are very close to desirable limit and need to be monitored continuously. However, the water quality parameters of springs located in the upstream side of Katra town (SW3, SW4 and SW5) are quite below the desirable limit. High values of water quality parameters like EC, TDS, Hardness, Ca, Mg and HCO3 for springs SW1, SW2, SW10 and SW15 (Table 4.5&4.6) indicate that theses spring are originated from one spring system, however relatively low values of springs SW3, SW4 and SW5 indicate that these springs are originated from the other spring system. Water quality parameters of local Nallahs water i.e. NW1 and NW2 indicate that the sources of these Nallah are same as the source of springs SW3, SW4 and SW5. Relatively high values of NO_3 for springs SW1, SW4 and SW5 indicate that the source of these springs might be in agricultural land or settlement.

The ratio of calcium and magnesium ions for all springs indicated (1-6) that the genesis of these springs is from dolostone which contain dolomite and limestone and hence these springs are the best example of karst spring. However, the concentration of Ca is not much higher which indicates that low residential time of water in the conduit or sinkhole. All springs and *nallahs* having hardness greater than 180 mg/l which indicate that all springs water is very hard, however all are within the acceptable range (<500 mg/l).

Microorganisms (viruses, bacteria, protozoa and larger organism) are easily transported into karst aquifers, because of the absence of filtering from the soil. The most widespread of these are fecal coliform and fecal streptococci bacteria. The presence of these organisms is the most common indicators of pollution from sewage or animal waste. Every day huge number of ponies is used for transportation of pilgrims of *Maa vaishno devi*, hence spring water contamination from ponies feces cannot be ignored and it is recommended to regular examination of the biological parameters of waters in the springs emerging from such catchment.

Table 4.5: Pre-monsoon water quality parameters of springs (SW), nallahs (NW), and rain (RW) water of study area.

Sample code	pH	EC µS/cm	TDS mg/L	Alk mg/L	Hard mg/L	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	HCO3 mg/L	Cl mg/L	SO4 mg/L	NO3 mg/L
SW 1	8.3	709	454	299	350	11	1.36	70	43	364	10	9.5	21
SW 2	7.9	680	435	361	392	0.11	0.33	88	42	441	5.8	8.7	6.2
SW 3	8.3	348	223	185	208	1.20	0.95	42	25	225	1.0	4.9	3.9
SW 4	8.3	493	316	238	265	6.37	4.22	55	31	290	8.7	12	12
SW 5	8.4	434	278	206	257	3.06	1.73	49	33	251	5.5	24	11
SW 6	8.8	299	191	169	169	0.61	0.32	35	20	206	0.6	2.5	3.0
NW 1	8.3	419	268	225	204	1.91	1.08	36	27	275	1.7	4.9	4.3
NW 2	8.5	383	245	163	192	3.60	1.27	35	25	199	4.8	11	10
RW 2	6.8	54	34	11	22	0.54	0.48	7	1.3	14	0.8	3.8	4.3
RW 3	6.8	130	83	22	44	1.29	1.08	16	0.9	27	1.9	6.6	14

SW: Spring water; NW: Nallah water; RW: Rain water

Table 4.6: Post-monsoon water quality parameters of springs (SW), nallah (NW) and rain (RW) water of study area.

Sample code	pH	EC µS/cm	TDS mg/L	Alk mg/L	Hard mg/L	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	HCO3 mg/L	Cl mg/L	SO4 mg/L	NO3 mg/L
SW1	7.7	765	490	371	412	6.2	1.8	89.4	46.0	452	7.71	6.69	12.45
SW2	8.2	771	493	345	373	5.6	1.9	80.3	42.0	421	5.09	6.07	ND
SW3	8.4	368	236	172	195	1.6	2.1	42.5	21.7	210	1.81	5.31	7.27
SW4	8.4	515	330	230	249	4.1	3.4	51.8	29.0	281	5.61	9.99	11.30
SW5	8.3	459	294	213	228	2.1	1.9	45.1	28.1	259	2.98	9.76	6.97
SW10	8.2	740	474	371	364	3.7	1.1	81.2	39.2	453	3.59	9.07	7.15
SW15	7.8	871	557	408	418	15.6	1.2	103.1	39.0	498	15.11	8.08	5.75
SW16	8.0	748	479	361	409	7.4	0.8	92.5	43.3	440	8.67	9.03	11.93
NW1	8.2	429	275	214	217	2.05	1.40	45.3	25.2	261	2.17	4.85	3.08
NW2	8.4	348	223	163	182	2.03	1.02	36.5	22.2	199	2.71	5.66	6.59
RW1	6.8	46	30	14	19	2.09	1.75	6.2	0.77	17	2.79	3.17	6.41
RW3	6.4	26	17	6	9	1.86	1.32	2.91	0.40	8	2.33	2.18	4.39

SW: Spring water; NW: Nallah water; RW: Rain water

4.2 Establishment of Raingauge Stations

Keeping in view of shape and size of the Baan Ganaga watershed and the locations of the selected springs, three numbers of raingauges were installed at different altitudes in the catchment. The main objective of establishing the raingauges at three different altitudes were to capture the altitudinal effect in the isotopic composition of the rain water. Raingauge RG1 was installed near the outlet of the Baanganga watershed at an altitude of 388 meter amsl (Fig.

4.7a). RG2 was installed in the premises of Forest office at Katra at an altitude of 870 meter amsl (Fig. 4.7b) and RG3 at 1801 meter amsl (Fig. 4.7c) at Saanjihichhat. For RG2, the permission of District Forest Officer (DFO), Reasi, however for RG3, the permission of Deputy Chief Execuitive Officer (CEO), Shri Mata Vaishno Devi Shrine Board (SMVDSB) had been taken for the safety purpose. Ordinary raingauges (ORG) were used to take the rainfall reading and filling of rainwater sample for isotopic analysis because rain water filled in ORG is less susceptible to evaporation due to its shape and design.

(a) (b) (c)

Fig. 4.7: Installation of Raingauage at (a) Kanjali (RG1), (b) Katra and (b) Saanjhichhat

4.2.1 Measurement of rainfall

Every day morning 8:30 AM rainfall is measured with the help of the measuring cylinder supplied with the raingaugs. Monthly rainfall data for two years at three raingauge stations R1 (Kanjali), R2 (Katra), and R3 (Saanjhichhat) are given in Fig 4.8. Average annual rainfall at R1, R2 and R3 have been recorded 2126 mm, 2282 mm and 2696 mm, respectively. The areal distance between R2 and R3 is about 1.5 km, but R3 received 18% more rainfall than R2. It clearly indicates that catchment has high variability in rainfall. Hence, it may prefer to be established separate raingauge in the spring-shed of each spring for detailed study of an individual spring.

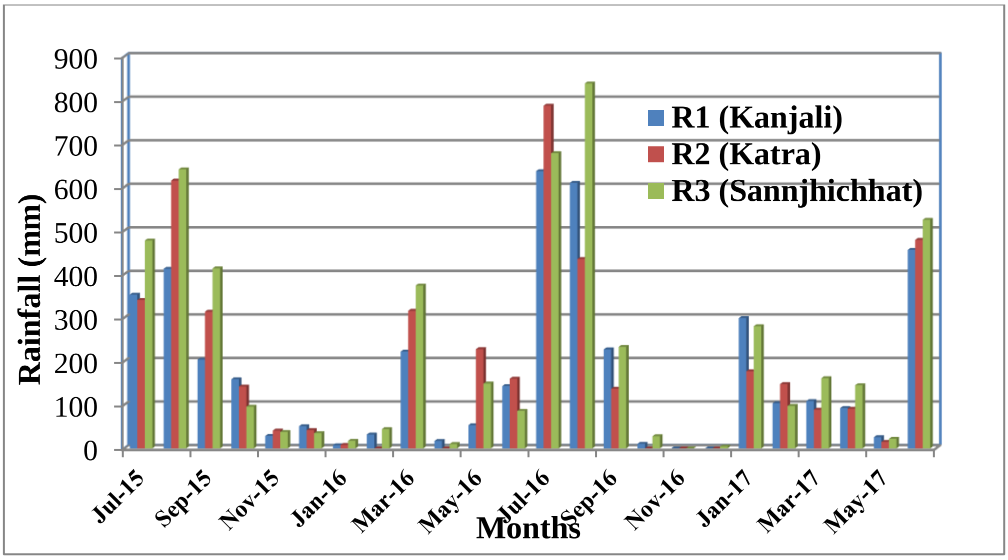

Fig. 4.8: Monthly rainfall occurred at three raingauge stations of Baan Ganga watershed during July 2015 to June 2017.

4.2.2 Sampling of rain water

In monsoon season, when rainfall occurs a 15 ml sample in a reagent bottle is filled air tightly for ^{1}H and ^{18}O analysis (Fig. 4.9). Remaining rainwater is collected in a 10 liter plastic cane. At the end of the month a representative sample of 15 ml is filled from the composite rain water for ^{18}O & D analysis.

Fig. 4.9: Collection of rain water sample for isotopic and water quality analysis

CHAPTER - 5

ISOTOPIC ANALYSIS OF RAIN AND SPRING WATERS OF BAAN GANGA WATERSHED

5.1 Introduction

There are a number of conventional methods available to study the hydrological processes linked with the various types of water resources (Todd, 1959), but these methods cannot always address all aspects of the system, particularly in case of springs. Environmental and artificial radioactive isotopes have proved to be effective tools for solving many critical hydrological problems and in many cases, provide information that could not be obtained by any other means (Clarke and Fritz, 1997; Kendall and McDonnell, 1998; Rao, 1984). However, the use of environmental isotopic techniques in conjunction with conventional hydrogeological and geochemical information can be employed to understand the recharge source/s of a spring and to locate its recharge area/s for taking effective measures for its longer time sustainability. Environmental isotopes (stable and radioactive) have a distinct advantage over artificial tracers as they facilitate the study of various hydrological processes on a much larger temporal and spatial scale through their natural variation in a system as the use of artificial tracers is generally effective for site specific and local applications (Tirumalesh et. al., 2007; Rangarajan and Athavale, 2000; Kulkarni, 1992). Mostly, environmental stable isotopes of oxygen (O-18), hydrogen (H-2 or D) and radioactive isotopes of hydrogen (H-3) and Carbon (C-14) serve the purpose in case of springs investigations.

Environmental isotope techniques help in understanding the source and mechanism of recharge (Sukhija et. al. 1996, Shivanna et al., 2004, Nair et al., 1979) groundwater circulation and its renewability (Rao and Kulkarni, 1997, Navada et al., 1993) recharge areas and transit times of the aquifer (Sukhija et al., 1998, Aggarwal et al., 2006) hydraulic interrelationships (Navada and Rao, 1991, Jain et al., 1987) and source and mechanism of groundwater contamination (Shivanna et al., 2000, Tirumalesh et al., 2007, Shivanna et al., 1993). Stable isotope compositions are generally reported as δ values in parts per thousand (‰). The δ values are given by

$$\delta D\ or\ (\delta^{18}O)‰ = \frac{(R_{sample} - R_{standared})}{R_{standared}} x100 \qquad (5.1)$$

Where, R represents the ratio of heavier to lighter isotope ($^2H/^1H$ or $^{18}O/^{16}O$). $R_{sample}$and $R_{standard}$ are the isotope ratios in the sample and the standard, respectively. δD and $\delta^{18}O$ value sare reported relative to Vienna Standard Mean Ocean Water (VSMOW). The sample is termed as depleted if the δ values are lower, and as enriched if the δ values are higher withrespect to a reference.

Stable isotopic composition of water (δ D and $\delta^{18}O$) is modified by processes like evaporation and condensation, and hence the recharge water in a particular environment will have a characteristic isotopic signature. This signature serves as a natural tracer for water movement. Globally, δ D and δ 18O of precipitation show good correlation given by (Craig, 1961):

$$\delta D = 8 \text{ X } \delta^{18}O + 10 \qquad (5.2)$$

This equation is called Global Meteoric Water Line (GMWL). Variation in local climatic conditions and source of the moisture affect the isotopic composition of precipitation, and therefore the local meteoric water line (LMWL) needs to be constructed for each location under study (Fritz et al., 1987).

5.2 Methodology

Daily discharge rates of springs are measured and water samples are collected from the springs. Precipitation samples are collected for entire monsoon season at 3 altitudes (RG1 at 384 m, RG2 at 870 m and RG3 at 1801 m)and the samples are analyzed for environmental isotopes such as ^{2}H and ^{18}O. Stable isotopes (^{2}H or D and ^{18}O) are analyzed using an isotope ratio mass spectrometer. For δ D analysis, 400 µl of the water sample is equilibrated with H2 along with Pt catalyst at 40°C for 3 hrs and the gas is introduced into the mass spectrometer. The $\delta^{18}O$ of the sample is measured by equilibrating 400 µl of water with CO2 gas at 40°C for 7 hrs and the equilibrated gas is introduced into the mass spectrometer. The measured values are reported as delta (δ) values (Coplen, 1996). The precision of measurement for $\delta\ ^{2}H$ is ± 1‰ and that for δ^{18} O is ± 0.1‰.

After analyzing the results, the relationship between δD and $\delta^{18}O$ for spring, and precipitation is plotted to identify the recharge source/s whether it is precipitation, some other water source lake or snow-glacier melt water depending upon the isotopic signatures. Altitudinal effect and spatial distribution/variation of isotopic signatures of spring water are mainly utilized to find out the zones or altitude of recharge. The hydrogeological and hydro chemical data are used to further understand the recharge zones and taking necessary steps to increase the sustainability of spring water supply.

5.3 Development of LMWL of Baan Ganga Watershed

The local meteoric water line (LMWL) was developed for Baanganga river catchment as shown in Fig. 5.1 using the monthly weighted average isotopic values of precipitation. The equation for LMWL is given by:

$$\delta D = 8.187 \times \delta 18O + 13.03 \quad (R^2=0.98, n=106) \qquad (5.3)$$

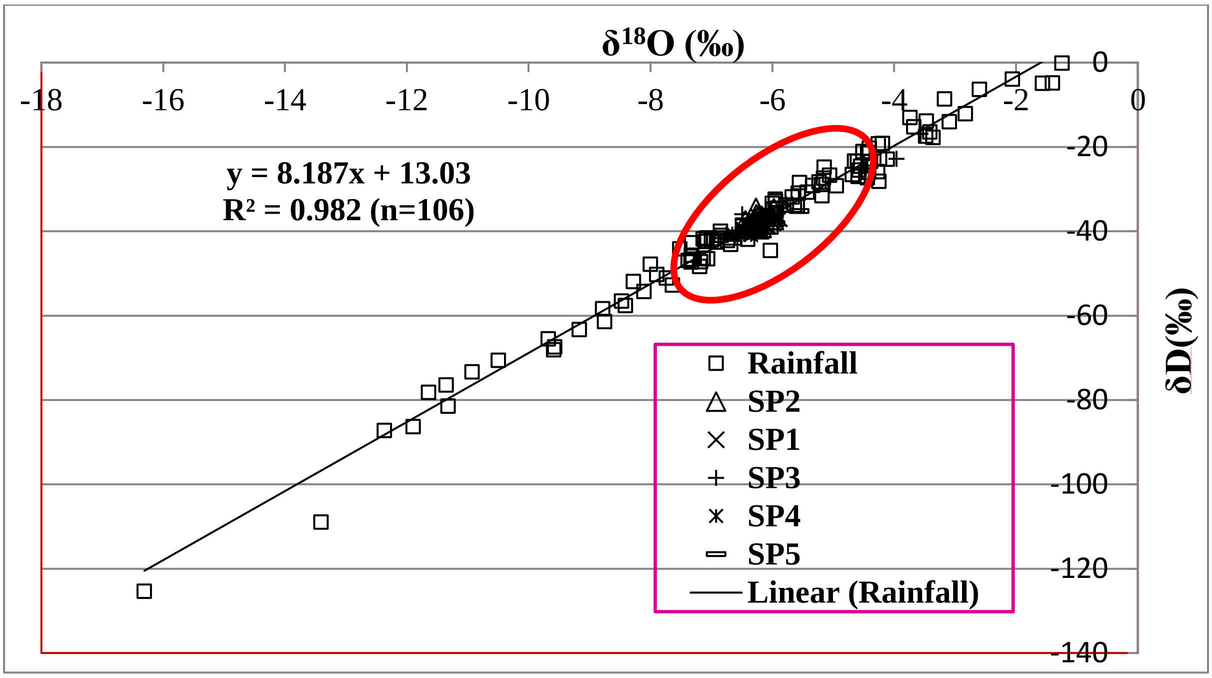

Fig. 5.1: Plot of isotopic values of different springs along with LMWL

Isotopic values of the springs fall on the LMWL indicating no evaporation effect. It indicates that the source of spring water is solely the precipitation occurred in the area. Altitudes of recharge areas were estimated directly applying the altitude effect. The isotopic values of δ^2H and $\delta^{18}O$ of rain water were plotted against their altitude which gives the altitude effect in rain and depicted in Fig. 5.2. A mean $\delta^{18}O$ altitude effect of –0.1‰ per 100 m and mean δ^2H altitude effect of –0.8‰ per 100 m were found. With the help of altitude effect altitude of recharge area for springs SP1, SP2, SP3, SP4 and SP5, were estimated and depicted in Table 5.1.It is evident from the Table 5.1 that all springs have localized recharge

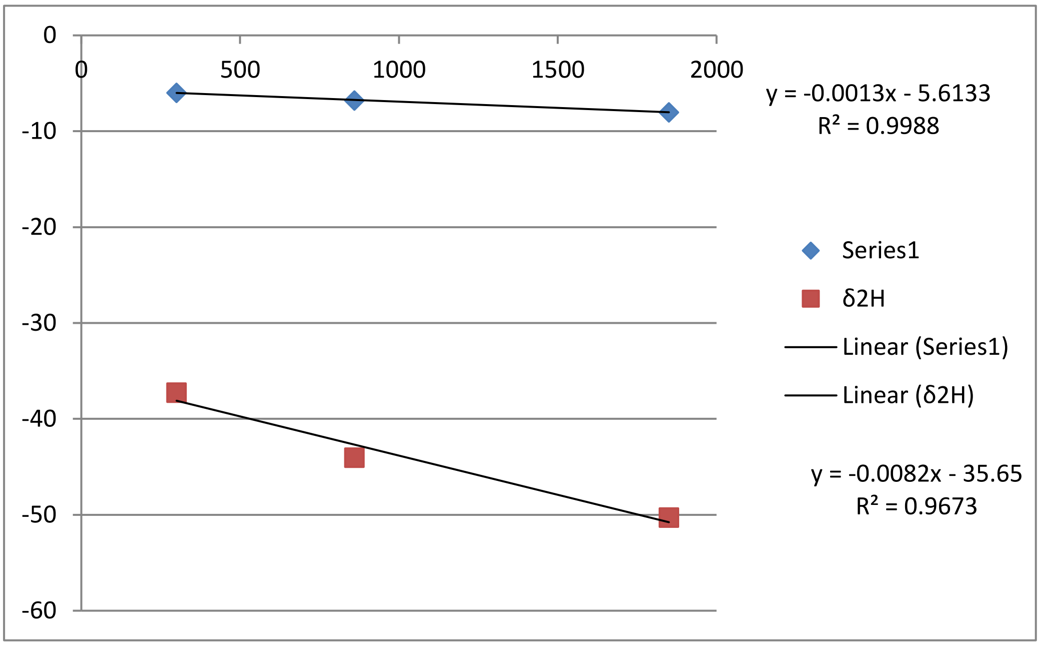

Fig. 5.2: Plots of δ^{2}H and δ^{18}O of rain against their altitude for showing the altitude effect in rain.

Table 5.1: Estimated altitudes of recharge areas of different spring of Baanganga catchment using isotopic altitudinal effect.

Spring Id	Spring Location	Spring discharge point elevation (m, amsl)	Recharge area elevation (m, amsl)
SP1	Kotli Bajialya	731	868
SP2	Nawain Temple	682	767
SP3	Bhumika Devi Temple	881	1076
SP4	Bio Gas Plant	868	876
SP5	Pannas	1006	1113

CHAPTER - 6

GEOLOGICAL INVESTIGATION OF BAANGANGA SPRINGS FOR IDENTIFICATION OF RECHARGE AREA

6.1 INTRODUCTION

Rock formations saturated with groundwater, which feed the springs are termed as 'aquifers'. In areas where the topography of land is quite flat, large aquifers may exist, depending upon the regional geology. On the other hand, the undulating landscape and high relief mean that mountain aquifers are relatively smaller in size, both in extent and thicknes.The extent of the aquifers, their geometry, their hydrogeological properties, viz. storativity and transmissivity show great variation. High degree of deformation in the Himalaya resulting in intense folding, faulting and development of fracture zones contributes to the loss of aquifer continuity in the mountain belts. Under the prevailing conditions, a large number of springs form in the mountain ranges of the Himalaya. Understanding local aquifers is important because the local geology and topography play a vital role in formation of such (mountain) aquifers, and therefore, in the behaviour of springs, which discharge from such aquifers. The abrupt termination of the aquifer along the mountain slopes and exposures in valley portion causes the aquifer to discharge groundwater in the form of springs. Many springs owe their genesis to structural features such as fractures, faults and other weak planes.

Different rocks show different properties that are characteristic of the process of formation of the rock. The two most important properties of rocks with regard to groundwater are its texture and structure. Texture refers to the manner in which individual mineral grains or sediments in a rock are arranged in relation to each other. The hydrogeological property of different rocks is controlled by the texture of the rock. If the mineral or sediment grains in a rock are closely packed the porosity (and permeability) of the rock reduces considerably (Fig. 6.1). Igneous rocks are formed from cooling molten rock material; the minerals usually have 'tight' boundaries resulting in low porosity and permeability. Many metamorphic rocks are also formed by heating of parent rocks and result in recrystallization of minerals, with tight boundaries. Thus, porosity and permeability of these rocks is also quite limited. Sedimentary rocks and metamorphic rocks formed only under the effect of pressure show variation in porosity and permeability depending on their grain size, shape, mineral content and arrangement of grains. Rock texture is thus an important factor controlling the storage and transmission capacities of an aquifer or water bearing formation. Rock formations are often disturbed or deformed from their original state of formation. This deformation is the result of tectonic forces or crustal stresses. The deformation of the rock bodies produces different structures such as inclination or dips of sediment beds (layers), folds, faults and fractures.

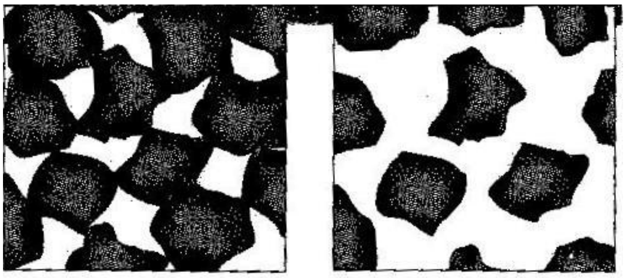

Fig.6.1: Graphical representation of arrangement of sediment grain for understanding porosity and permeability.

Identifying and understanding a geological structure is an essential element of any hydrogeological study (study of groundwater) as such structures determine the direction of movement and accumulation of groundwater. Geological mapping helps understand the lithology (rock types) and structure (features that reflect the genesis and geometry of deformation of rocks, particularly important in the Himalayan region). Fig.6.2 illustrates the meaning of strike and dip of beds, clearly illustrating that in this case, the slope of the ground and the dip (of rock strata) are in opposite directions, a factor that must be considered while studying groundwater. Often, one assumes that the flow of surface water (depending upon the slope) and groundwater is always along the same direction thus, topography and geology (texture, structure and attitude / inclination) together decide the properties of an aquifer, especially in the Himalayan region. Sometimes, the flow of groundwater is controlled by complex geological structures rather than the geometry of the land surface alone. Slope and geology together influence spring discharge and spring water quality. The amount of water discharged by the spring varies with time and depends on both recharge to the aquifer, the storage of groundwater and the transmission properties of the aquifer, all of which govern spring discharges. Hence, a periodic monitoring of spring discharge provides useful clues in understanding various aspects of spring hydrology, including recharge.

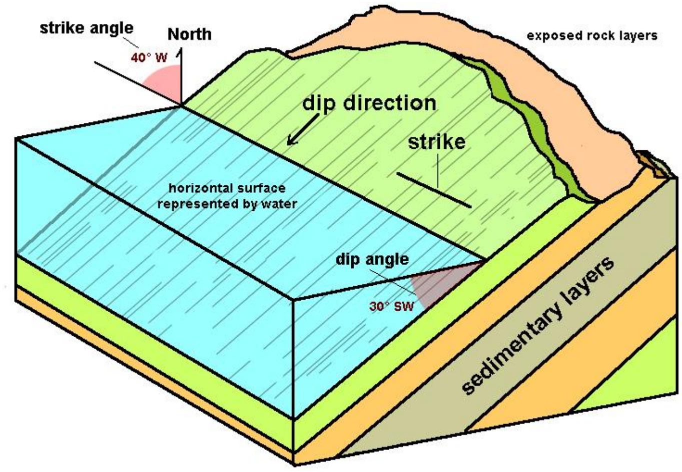

Fig.6.2: A conceptual diagram depicting strike and dip of strata.

In order to investigate and understand the structural evolution and tectonics of any area or region it is essential to observe and understand the rock deformation and explain how and why the rocks evolved to their present state. Field observations are of paramount importance to achieve this objective, together with experimental studies and modelling. In the past, the Riasi Inlier has been mapped and investigated by Raha (1976 & 1984); Chadha (1979); Karunakaran & Rao (1979), Thappa (1993) and Hakhoo (2016).

6.2. GEOLOGY OF THE AREA

In the Katra area of the Jammu region (Jammu and Kashmir, India), four different rock units crop out within the Sub-Himalayan foothill fold-thrust-belt (FTB), and form southeastern part of the Riasi Allochthon (RA) (Craig et al., 2018) (Figs 6.3 and 6.4). In the order of succession, the Neoproterozoic Sirban Limestone Formation (SLFm), comprising thickly bedded, compact and jointed dolostones and limestones, interbedded with thin shale and chert beds, represents the oldest sequence in the region. The SLFm is tectonically juxtaposed in a back-thrusted contact against the Cenozoic sedimentary successions of the Late Palaeocene to Middle Eocene Subathu Formation (SFm) (coal, carbonaceous shale, nummulitic limestone), and the Miocene Murree Formation (sandstone and mudstone) in the northern part of the RA, and against the Plio-Pliestocene Siwalik Group (mudstone, sandstone and conglomerate) in the south. The southern contact is the Riasi Thrust (defined by fault breccia and gouge), a subsidiary of the Himalayan Main Boundary Thrust (MBT) (Hakhoo et al., 2011; Hakhoo, 2013) (Fig.6.4). The structural investigations, primarily in the context of fracture analysis were undertaken along this contact (within the Riasi Thrust Zone-RTZ), where the SLFm and the Siwalik Group have been subjected to multiple deformation episodes in association with the activity of the RT (Hakhoo et al., 2011; Hakhoo, 2013; Hakhoo et al., 2016a and 2016b). The SLFm has experienced very strong first major regional folding episode forming a reclinedrecumbent fold nappe, and causing the upheaval of the SLFm. The axial plane of this regionally disposed nappe acted as a thrust plane, and the subsequent folding of the hanging wall, followed by the corresponding imbrication associated folding caused anticlinal stacking of the thrust sheets, and the genesis of the FTB. The continued compressional (thrust) tectonics is expressed by the younger cross folds, associated cleavage planes and multiple fracture sets within the hanging and foot-wall zone of the Main Riasi Thrust (MRT) (Hakhoo, 2013; Hakhoo et al., 2016a and 2016b).

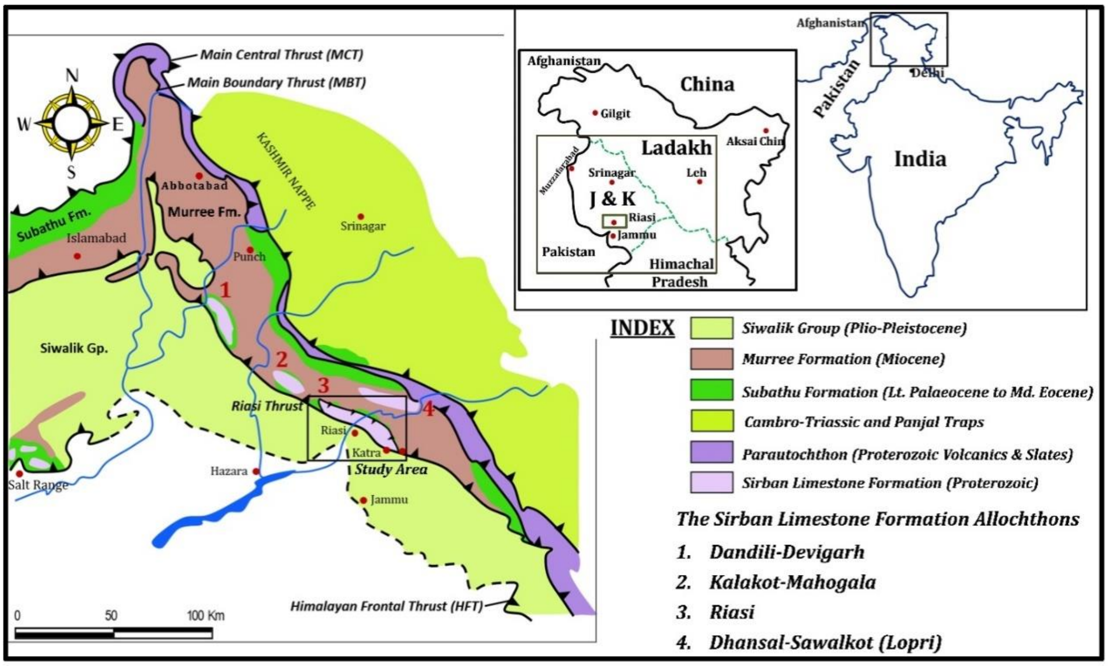

Fig. 6.3: Main geological features of the region

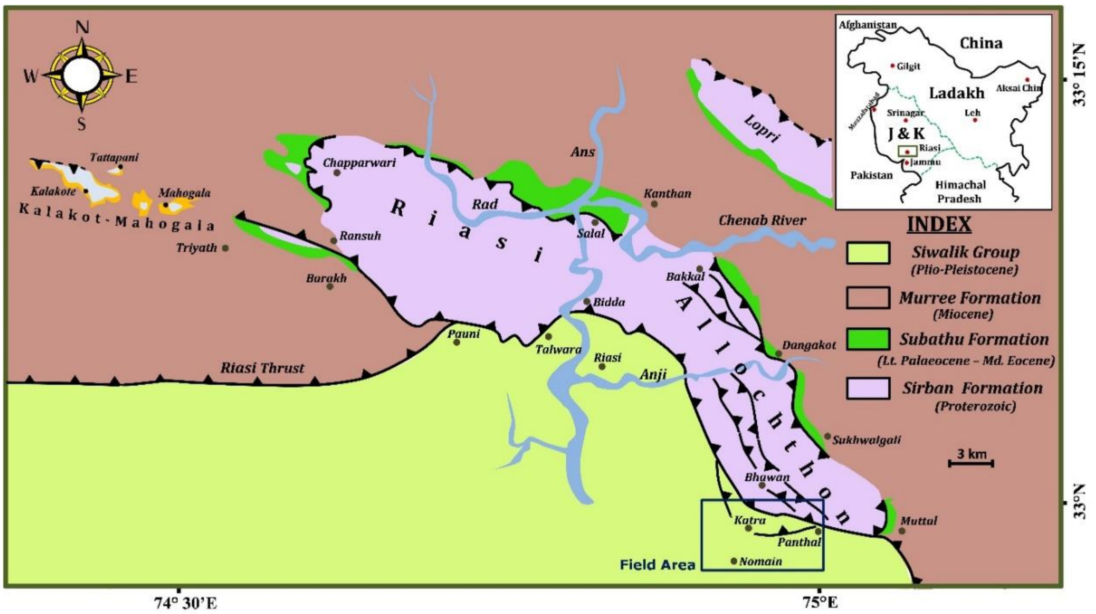

Fig. 6.4: Geological map of the Riasi Inlier depicting general geology, sections traversed during reconnaissance survey and key out-crop localities.

6.3 FIELD INVESTIGATIONS AND FRACTURE ANALYSIS

Detailed field mapping was undertaken in and around Katra to identify the fracture systems and the potential recharge areas of the *Bhoomika Devi*, *Baanganga* and *Nomain* springs systems and seepage zones (Fig.6.5 and 6.6). The *Bhoomika Devi* spring is located in the proximity of the MRT, and the spring system is located within the Riasi Thrust Zone (RTZ). The lithology consists of the SLFm carbonates in thrusted contact with the Siwalik Group sandstones (Fig. 6.5, 6.6 and 6.7). The rocks are intensely fractured, and the carbonates are extensively karstified. The proximity of the thrust and the thrust splays has gouged the rocks, as also observed in the foot-wall zone of the RT comprising the tectono-sedimentary breccia/olistostrome. The bedding planes (primary foliation), cleavage and the fractures parallel the behaviour of the RT plane, which is curvilinear and undulatory (Hakhoo, 2013) (Fig. 6.7). The fractures are oriented in every direction, six fracture sets (F_1-F_6) were identified, and two fracture sets (F_1 and F_6) (steep, sub-vertical to vertical and dipping towards SE and SW) are very prominent and present throughout the study area (Fig. 6.8). Two recharge areas are identified, and the stream in the proximity of the fractured (and karstified) rocks has the potential to recharge the shallow aquifers traversed by the SE and SW dipping fractures that form a continuity (fairway) for the movement of water into the fractured aquifers. The fractures are very mobile and dynamic, and respond to the direction and intensity of the movement along the active RT, as evidenced by the fracture age relationships (Fig. 6.7, 6.8 and 6.9). The intense deformation and gouging of the fractures has rendered the sealing of the older fracture sets and at the same time has opened new fractures.

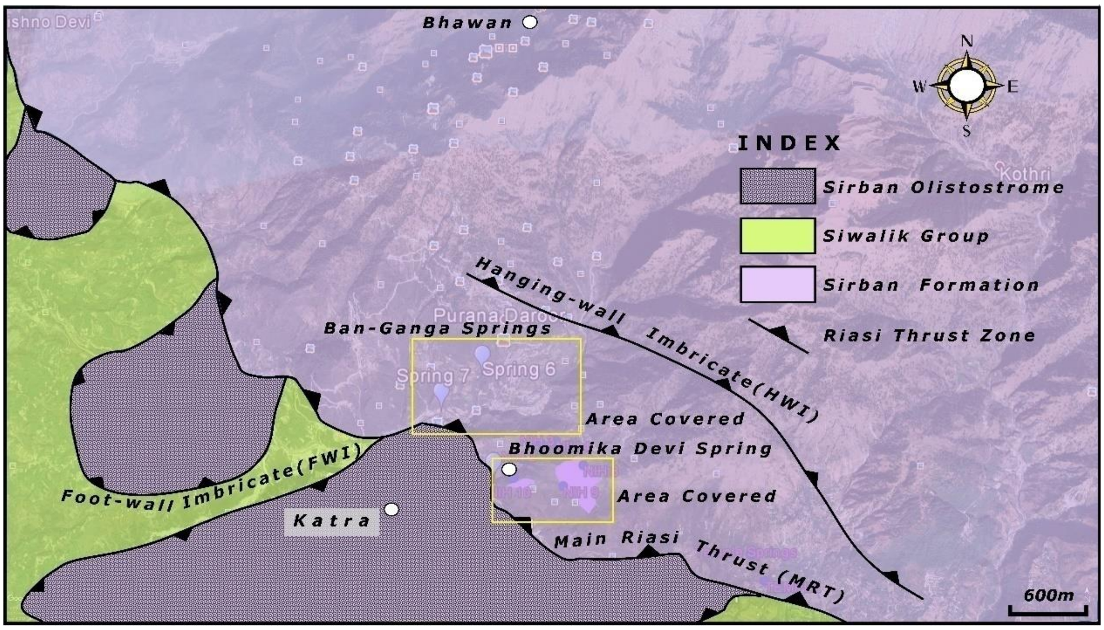

Fig. 6.5: Location of Baanganga and Bhoomika Devi spring with respect to main geological features prevailing in the area.

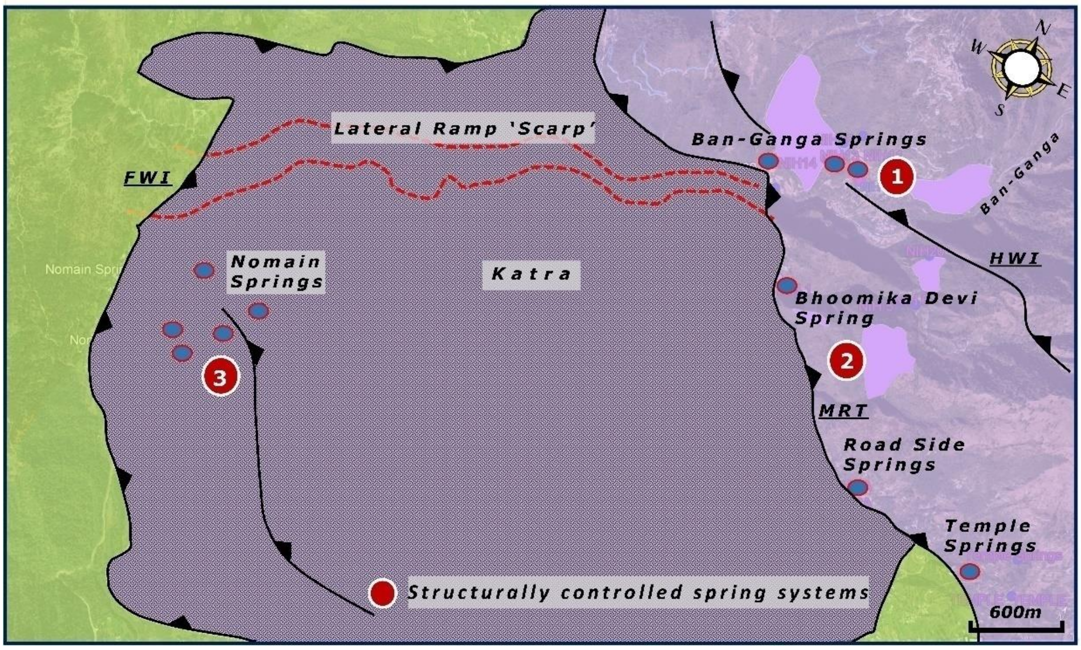

Fig. 6.6: Location of Nomain springs with respect to main geological features prevailing in the area.

Fig. 6.7: Field photograph for showing different geological features like breccia, fault and fractures in the study area.

The *Baanganga* springs are located in the proximity of the MRT (~600m NW of the *Bhoomika Devi* Spring), and the spring system is located within the RTZ. The lithology consists of the SLFm in thrusted contact with Quaternary (tectono-sedimentary) breccia accumulations, and the Siwalik Group sandstones (Figs. 6.5, 6.6 and 6.10). The area is structurally very complex with multiple deformation episodes governed by the MRT, the most prominent structural feature in the area. We report the existence of 3 spring systems in the area that are localized within the RTZ, these springs occur prominently along the (1) hanging-wall imbricate zone, (2) MRT, and the (3) foot-wall imbricate zone (Fig. 6.10).

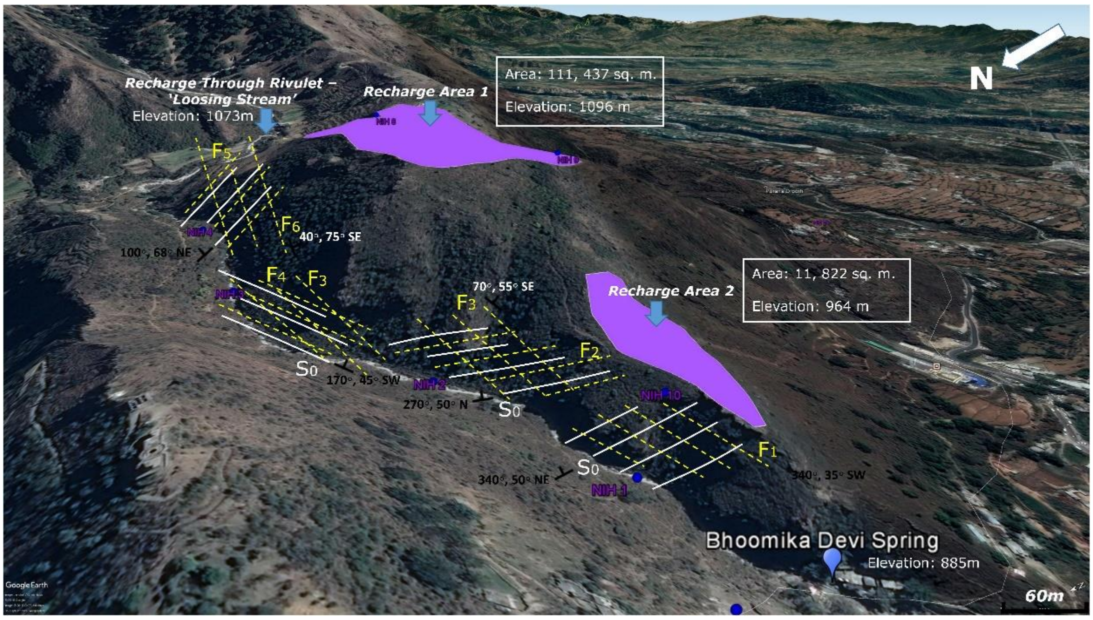

Fig. 6.8: Fractures mapping in the proximity of *Bhoomika Devi* spring

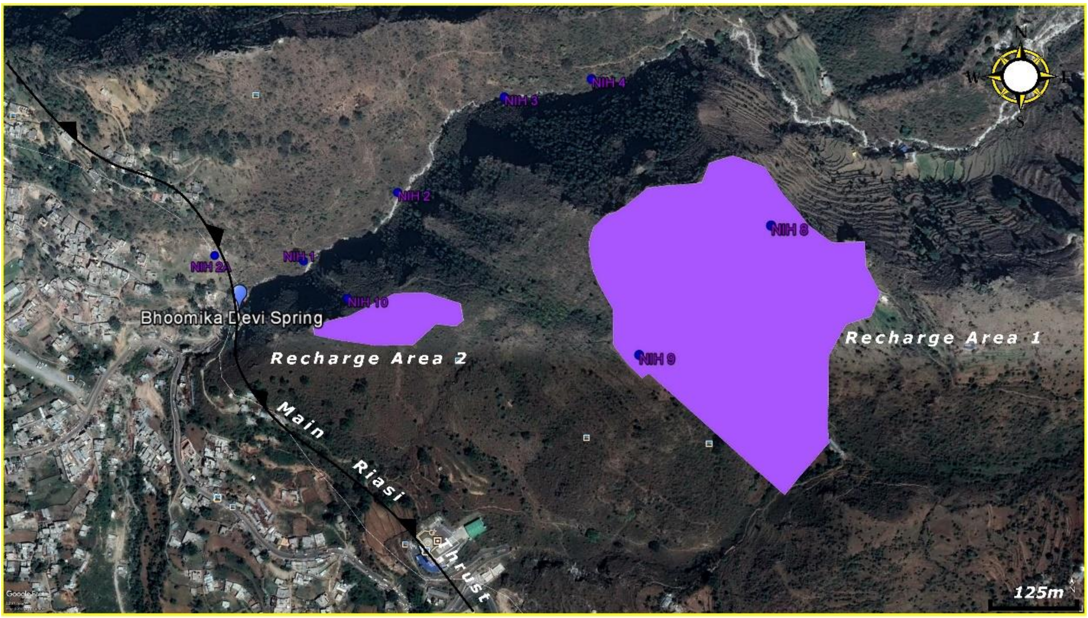

Fig. 6.9: Identification of recharge area of *Bhoomika Devi* spring

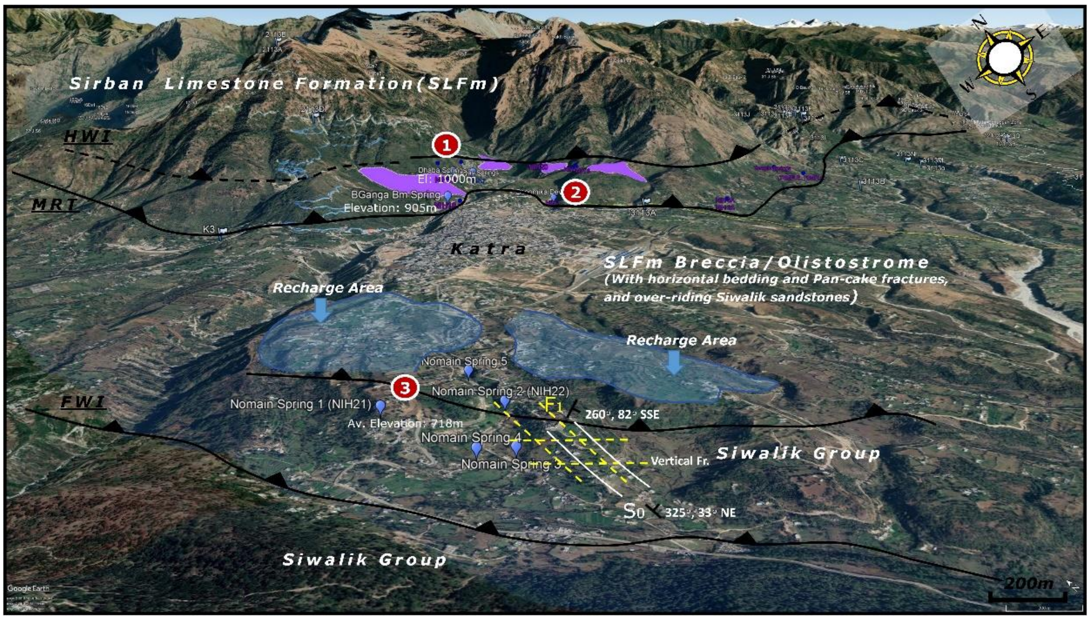

Fig. 6.10: Identification of recharge area of springs in Nomain area.

In the hanging-wall imbricate zone the rocks are intensely fractured, brecciated and the carbonates are extensively karstified, and fracture, breccia and cavern porosity is abundantly observed (Fig. 6.11). The bedding planes (primary foliation-S_0), cleavage and the fractures parallel the behaviour of the RT plane, which is curvilinear and undulatory (Hakhoo, 2013; and this study). The fractures (F_1-F_5) are oriented in different directions, and three fracture sets (steep, sub-vertical to vertical and dipping towards SE, NE and NW) are very prominent and present throughout the study area. Three recharge areas carved by terracing (step-farming) are identified between the hanging-wall imbricate zone and the MRT, the rock fractures act as dominant conduits for the flow of water under the influence of gravity towards the springs and seepages (Figs. 10 and 11). The *Baanganga* stream in the proximity of the fractured (and karstified) rocks has the potential to recharge the shallow aquifers traversed by the SE, NE and NW dipping 'steep' fractures that from a continuity (fairway) for the movement of water into the fractured aquifers. The *Baanganga* spring is located at the base of section where the SLFm comes in thrusted contact with Quaternary (tectono-sedimentary) breccia that has horizontal 'bedding' planes and 'pan-cake' fractures depicting extensive contractional deformation associated with the proximal MRT (Fig. 6.11). The proximity of the thrust and the thrust splays has gouged the rocks, also observed in the foot-wall zone of the RT comprising the tectono-sedimentary breccia/olistostrome towards *Bhoomika Devi* spring.

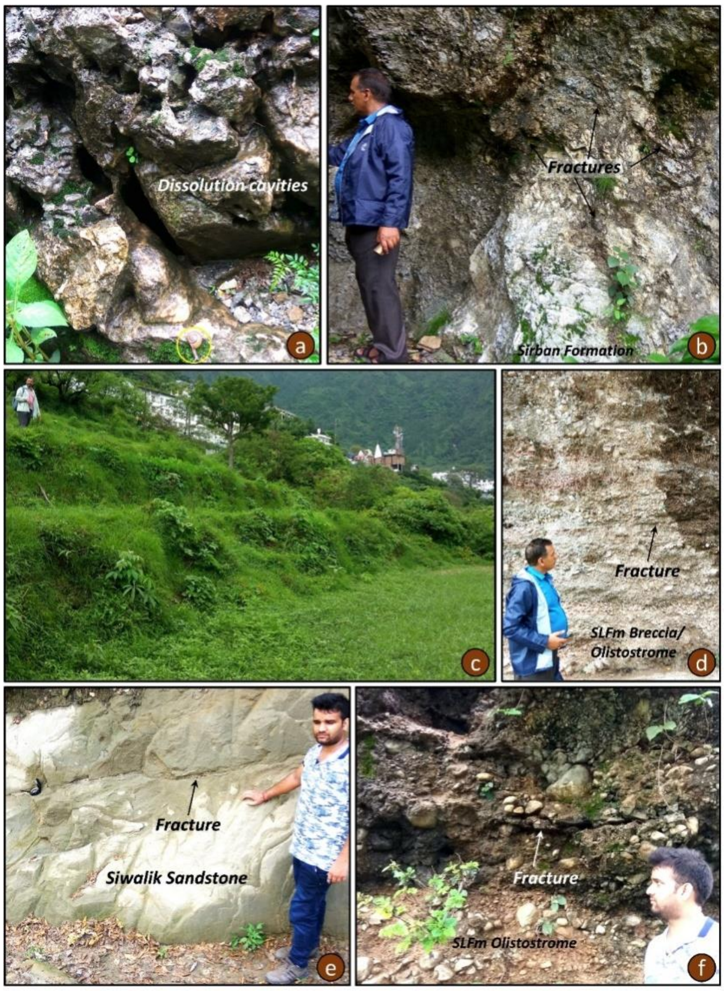

Fig. 6.11: Field photograph of geological features in hanging-wall imbricate zone of Bannganga springs.

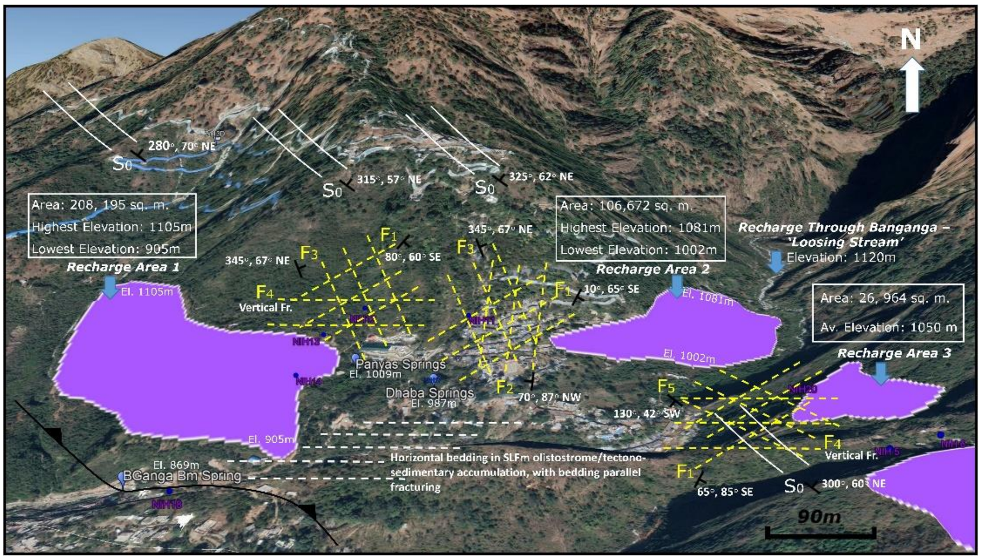

Fig. 6.12: Fractures mapping in the proximity of *Baanganga* spring.

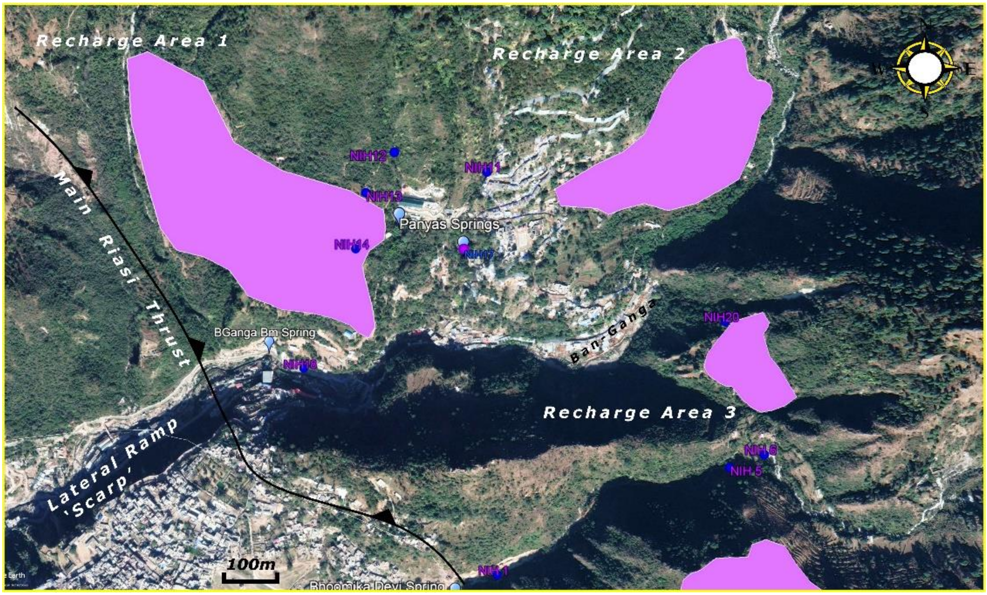

Fig. 6.13: Identification of recharge areas of the Baanganga springs.

The quaternary accumulation overrides the Siwalik Group sandstones in and around this place, and the same relationship is observed further south in the *Nomain* area where the third spring system occurs (Fig. 6.13). Two recharge areas have been identified here, and the same are feeding the spring system that is dominated by the deformation happening along zone of juxtaposition defined by the foot-wall imbrication. Two prominent fractures (vertical, and dipping SSE) are seen here in the Siwalik Group sandstones dipping NE, these fractures are very mobile and dynamic, and respond to the direction and intensity of the movement governed by the active RT (Fig. 6.11). We have observed that the structurally controlled spring systems in this area are being directly supplied (and the aquifers are recharged) by the controlled water flow in the catchment areas (where terracing is prominent, and vegetation is thick), this increases the time of water retention, reduces runoff and aids in percolation of water along the rock slopes thereby causing voluminous spring recharge.

CHAPTER - 7
SUMMARY AND CONCLUSION

Spring water, a prime natural resource in mountainous region is fastly detoriating due to its improper utilization, assessment and management. The protection and proper management of this natural resource is essential to maintain its quality and quantity especially for the period when its availability in less.

Baanganga River is considered sacred by the local populace and the lakhs of pilgrims that visit the *Mata Vaishno Devi* Shrine near Katra. As is the normal Hindu tradition, devotees like to take a holy dip in it before proceeding to the shrine of Mata Vaishno Devi. However, these pilgrims find that the discharge of Baanganga has significantly reduced. Except for rainy season, there is hardly any water flowing in the River. Apart from disappointing the pilgrims, the local population also faces acute shortage of water. Since Baanganga is a spring-fed river, an internal study on "Hydrological Investigation of Natural Water Springs of Baanganga Watershed in Jammu & Kashmir State" was taken-up. Along with the objectives, the main purpose of the study was to suggest a strategy for development and management of springs based on hydro-geo-chemical and isotopic approaches. The following conclusions were drawn from the study:

- Baanganga watershed (up to the confluence of *Phare Khad*) having total drainage area 20.23 sq. km, length of 13.09 km and perimeter of 28.76 km is a fourth order watershed comprising a total of 119 streams. The watershed has moderate to steep topography, with a significant area having more than 100% slopes. Morphological parameters studied based on linear, areal and relief aspects clearly indicate that the watershed can produce moderate to high runoff and hence is susceptible to severe erosion.
- Nine major landuse classes, viz. agriculture land, rocky area, built-up land, degraded land, dense forest, dense scrub, open forest, open scrub and river bed have been identified in the Baanganga watershed. Open forest (38.58%) is the major class in the watershed; however significant part (12.05%) of the watershed is rocky.
- Four soil classes varying from coarse loamy to fine loamy, medium deep, well drained to extensively drained with moderate erosion to severe erosion were found in the watershed.
- Fourteen springs (SP1 to SP14) ranging from low discharge (≈1 LPM) to high discharge (≈152 LPM) has been identified inside and near the boundary of Baanganga watershed.

Most of the springs are oriented near the Reasi fault and characterized as fracture or fault springs.

- Daily rainfall data have been recorded at three locations viz. Kanjali, Katra and Saanchichhat. Annual average rainfall at Kanjali, Katra and Saanchichhat were found to be 2126 mm, 2282 mm and 2696 mm, respectively, indicating the catchment has high variability in rainfall. The areal distance between Katra and Saanchichhat is about 1.5 km, but Saanjhichhat received 18% more rainfall than Katara, clearly indicating orographic effect in precipitation that favours the upper part of the catchment. The annual weighted rainfall of Baanganga watershed was found to be 2407 mm, which is more than twice the country average. 77% of annual rainfall occurred during the monsoon season while 23% rainfall occurred during winter due to western disturbances.
- All spring waters are alkaline in nature (pH>7.0) and have electrical conductivity (EC) ranging from 300 µS/cm to 700 µS/cm. Thus all spring water samples were within the desirable limit of drinking water as per Indian Standard for Drinking Water (IS 10500-2012). However, the springs located downstream of Katra town (SW1, SW2, SW10, SW15 and SW16) needs to be regularly monitored as their water quality parameters are near the upper limit set as desirable.
- Water quality parameters of local Nallahs' i.e. NW1 and NW2, which are close to that of upstream springs indicate that the sources of these Nallahs are same as the source of upstream springs i.e. SW3, SW4 and SW5. Relatively high values of NO_3^- for springs SW1, SW4 and SW5 indicate that these springs might be derive waters sourced from agricultural land or settlements.
- The ratio of calcium and magnesium ions for all springs indicated that the genesis of these spring waters is dolostone terrain, which contain dolomite and limestone. However, the moderate concentration of Ca^{2+} indicates low residence time of water in the conduit or sinkhole. All samples from springs and *nallahs* have hardness greater than 180 mg/l (very hard water), yet within the acceptable range (<500 mg/l).
- In this study we did not study the microorganisms; however, these microorganisms (viruses, bacteria, protozoa and larger organism) are easily transported into karst aquifers, because of the absence of filtering through the soil. The most widespread of these are fecal coliforms and fecal streptococci bacteria. The presence of these organisms is the most common indicator of pollution from sewage or animal waste. Every day large numbers of ponies are used for transportation of pilgrims of *Maa Vaishno devi;* hence spring water contamination from ponies faeces cannot be ignored

and it is recommended that regular examination of the biological parameters of waters be carried out in the springs emerging in this catchment.

- All springs (except the springs near Shrine Board residential colony, Nawai village and Nawai temple) have discharge variability greater than 100%. It has been found that the discharge of springs emerging from Plio-Pleistocene Siwalik Group (sandstones and conglomerates) are less variable, while that of springs emerging from Neoproterozoic Sirban Limestone Formation (dolostones, limestones, shales, breccia and chert) are highly variable. This probably is due to the karst nature of springs emerging from Sirban limestone formation where water drains through well- developed conduit and sinkhole system. In such spring systems, it has been observed that discharge also significantly vary from year to year even without much changes in rainfall trend and volume. This probably is due to development of some new conduits as well as closing of some old conduits, which directly alter the discharge of spring.
- Depletion curves for *Nomain* Spring and *Bhumika Devi* Spring have been estimated and it was found to be 6.96 months and 6.52 months, respectively. It has been found that at present both springs are reliable as they could outlast the most extreme dry spell of 5.2 months for Western Himalaya during 1951-2007. The reliable depletion time obtained for *Bhumika Devi* Spring even though it is karst spring indicates good porosity of aquifer material and that the conduits in the aquifer system of the spring is presently in development phase, giving a sufficiently long time for draining the water upto spring emergence point.
- Potential of a spring to fulfil the water demand of local populace can be increased by storing the surplus water of spring during the peak season in a suitable capacity tank to fulfil the excess water demand of the populace during the lean season of spring flow. In the present study the storage requirement for springs near *Nomain* village and *Bhoomika devi* were estimated to be 1843 m^3 and 2877 m^3, respectively. This increases the potential of *Nomain*village spring to sustain water demand from 530 people to 655 people, while increasing the potential of Bhoomika devi spring from 550 people to 970 people. This indicates that storage requirment is more beneficial when spring flow is more variable.
- Local meteoric water line (LMWL) for Baanganga watershed (Y=8.187X+13.03, R^2=0.98) has been developed based on stable isotopic analysis of rain water samples from three different altitudes. It resembles the global meteoric water line (GMWL) i.e. Y=8X+10. It has been observed that the isotopic signatures of all springs fall on

LMWL, indicating rainfall is the only source of water that recharge the aquifers feeding the springs. Isotopic values of the springs falling on the LMWL indicate no evaporation effect; hence the altitude of recharge area can be estimated directly by employing the altitude effect. A mean $\delta^{18}O$ altitude effect of –0.1‰ per 100 m and mean $\delta^{2}H$ altitude effect of –0.8‰ per 100 m were calculated. With the help of altitude effect, altitude of recharge area for springs SP1, SP2, SP3, SP4 and SP5 have been estimated.

- We report the existence of 3 spring systems in the area that are localized within the RT zone, these springs occur prominently along the (1) hanging-wall imbricate zone, (2) MRT, and the (3) foot-wall imbricate zone. In the hanging-wall imbricate zone the rocks are intensely fractured, brecciated and the carbonates are extensively karstified, and fractured; breccia and cavern porosity is also abundantly observed. The bedding planes (primary foliation), cleavage and the fractures parallel the behaviour of the RT plane, which is curvilinear and undulatory. The fractures are oriented in every direction, and three fracture sets (steep, sub-vertical to vertical and dipping towards SE, NE and NW) are very prominent and present throughout the study area. Three recharge areas carved by terracing (step-farming) are identified between the hanging-wall imbricate zone and the MRT, the rock fractures acting as dominant conduits for the flow of water to the spring outlets under the influence of gravity.
- The Baanganga stream in the proximity of the fractured (and karstified) rocks has the potential to recharge the shallow aquifers traversed by the SE, NE and NW dipping 'steep' fractures that form a continuity (fairway) for the movement of water into the fractured aquifers. The Baanganga spring is located at the base of a section where the SLFm comes in thrusted contact with quaternary olistostrome that has horizontal 'bedding' planes and 'pan-cake' fractures depicting extensive contractional deformation associated with the proximal MRT. The proximity of the thrust and the thrust splays has gouged the rocks, as also observed in the foot-wall zone of the RT comprising the olistostrome towards Bhoomika Devi spring.
- The quaternary accumulation overrides the Siwalik Group in and around this place, and the same relationship is observed further south in the *Nomain* area where the third spring system occurs. Two recharge areas have been identified here, and the same are feeding the spring system that is dominated by the deformation happening along zone of juxtaposition defined by the foot-wall imbrications. Two prominent fractures (vertical, and dipping SSE) are seen here in the Siwalik Sandstone dipping NE; these

fractures are very mobile and dynamic and respond to the direction and intensity of the movement governed by the active Riasi Thrust.

- We have observed that the structurally controlled spring systems in this area are being directly supplied (and the aquifers are recharged) by the controlled water flow in the catchment areas (where terracing is prominent, and vegetation is thick), this increases the time of water retention, reduces runoff and aids in percolation of water along the rock slopes thereby causing voluminous spring recharge.
- The fractures are very mobile and dynamic, and respond to the direction and intensity of movement along the active Riasi Thrust. The intense deformation and gauging of the fractures has rendered the sealing of the older fracture sets and at the same time has opened new fractures. Therefore, it is pertinent to carry out an overall fracture analysis of the entire region to identify the possible zones that could seal/open in the near future.

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