GROUNDWATER RESOURCES AND SPRING HYDROGEOLOGY IN SOUTH SIKKIM, WITH SPECIAL REFERENCE TO CLIMATE CHANGE

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ABSTRACT

'Mountain springs', a lifeline of Himalayan habitants, are affected by climate change in myriad ways. Reduction in spring discharge is being experienced as a common phenomenon across the Himalayan region. Common belief attributes reduced rainfall, its uneven spread and reduced infiltration as the main factors for the reduction in dry period spring discharge. However, the finer impacts on these springs are governed by aquifers, where groundwater is stored and discharged to these springs under differing geological conditions. Without a proper understanding of aquifers, any study of groundwater remains incomplete. Study of springs, with a strong hydrogeological context is especially relevant to the conservation, protection and land-treatment measures in order to adapt to various fluxes imposed by the overarching climate change phenomenon. Springs in the Himalayan state of Sikkim represent a typology of 'mountain aquifers', with a large degree of variability and complexity, attributed by the geology, terrain and hydrological factors. Conservation and recharge measures depend largely upon the relationship between slope and the underlying geology. Measures to augment water supply from such springs, on which rural habitations depend, can benefit largely from hydrogeological approaches within the planning, implementation and monitoring of programmes such as watershed and "springshed" development.

Pipes carrying water to the villages from Kuapani springs in South Sikkim

Mountain springs are the primary source of drinking water for the rural households of the Himalayan range

Groundwater resources form the backbone of India's water supply. Some 85% of all rural water supplies in India are derived from groundwater (The World Bank 2010). While, wells are the mechanisms used to supply groundwater to large parts of rural India, '*springs'* form the main source of water supply to rural (and often to urban) habitations in the Himalayan region. The Himalaya stretches for 2500 km all along the northern border of India and forms part of India's seven international boundaries. Nearly 40 million people reside in the Indian Himalayan Region (IHR) (Census 2001). The Himalaya is also divided from west to east, into three distinct regions, the Western, the Central and the Eastern Himalaya; the Nepal Himalaya occupies the central segment with the Western Himalaya and Eastern Himalaya bordering it on the respective sides (Thakur and Rawat 1992). Sikkim Himalaya can therefore be considered to be in the transition between the Central and Eastern Himalaya. A large proportion of the population in the Himalayan region depends on natural spring water for fulfilling their domestic and livelihood needs such as drinking water, sanitation and irrigation. The large dependence of a majority of the population on spring water implies that with changing climatic conditions and rainfall pattern, a large number of villages, hamlets and settlements face drinking water shortages. In fact, half of the perennial springs have already dried up or have become seasonal and nearly 8000 villages are currently facing acute water shortage even for their drinking purposes (Rana and Gupta 2009). Spring depletion in the Himalayan region has been specifically described in various works. The specific impacts of urban pressures on springs and rivers has been discussed in some detail by Valdiya and Bartariya (1989) and Kumar (2006), while discussing hydrological aspects of the Gaula river and Almora township area respectively.

'*Springs'* are points on the surface of the earth through which groundwater emerges and flows. They represent exfiltration of groundwater onto the surface. Springs in the Himalayan region contribute to base flows of streams and rivers. However, most significantly, spring water has been used by the mountain people since ancient times, to meet most of their basic needs. Increasing population (demand), upcoming technology, changes in rainfall patterns and a poor legal policy framework for managing groundwater resources call for a specific paradigm on spring water management in the Himalaya. This paradigm ought to include development of a science based, community-involved approach to managing the springs in the Himalayas. Unless the argument for an overarching groundwater management gains momentum in the Himalayan region, spring-water management may remain a small argument within the overall *hydrology – climate change* paradigm, without capturing the essence and substance of groundwater management, an approach that needs to gain strength in the overall water management strategy for this region. This article, while focusing on springs from South District of Sikkim, lays stress on how hydrogeology is important in understanding springs and on how it can significantly contribute in the planning, implementation and monitoring processes of programmes that specifically target spring restoration and management, not just in Sikkim but across the entire Himalayan region.

SPRING HYDROGEOLOGY WITH SPECIAL REFERENCE TO SOUTH DISTRICT

The geology of the Himalayan region has been a matter of great academic and research interest for a long time. A variety of rocks are found in Sikkim, with ubiquity in their great degree of structural deformation. The complex geology and structure prevalent in the State, is clearly captured through the Geological Map of Sikkim (GSI 2007). The map clearly shows that the northern and eastern parts of the State are dominated by high grade gneisses, while the southern part exhibits softer sedimentary rocks. The degree of rock deformation is quite variable, with rocks in the southern parts more deformed than those found in the Northern regions of the State. A variety of rock types are exposed in the region and include sandstone, shale, limestone, slate, quartzite, phyllite and deposits of unconsolidated sediment. Coal-bearing sandstone-shale sequence is also observed in the Gondwana Group of rocks from this region.

The Sikkim Himalaya is blessed with a large number of springs which have been quenching the thirst of mountain communities for centuries. When groundwater from water bearing rocks is released on the surface, it is referred to as springs or seeps. This water may be released as a concentrated discharge, in other words, a *point source* of groundwater discharge (released on to the surface) to form a spring. When there is no single source of discharge, but water is released from soil or rock, over a somewhat larger area, it is called *seep*. Rock formations saturated with groundwater, which feed the springs (and wells, if any) 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 thickness.

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 *springs* form in the mountain ranges of the Himalaya. Understanding local aquifers is important because the local geology, structure 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. Water from springs sufficed the village needs in the past. In recent times, both the quantity (discharge) and quality of water issuing from the springs is reported to be undergoing depletion and deterioration respectively.

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. 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

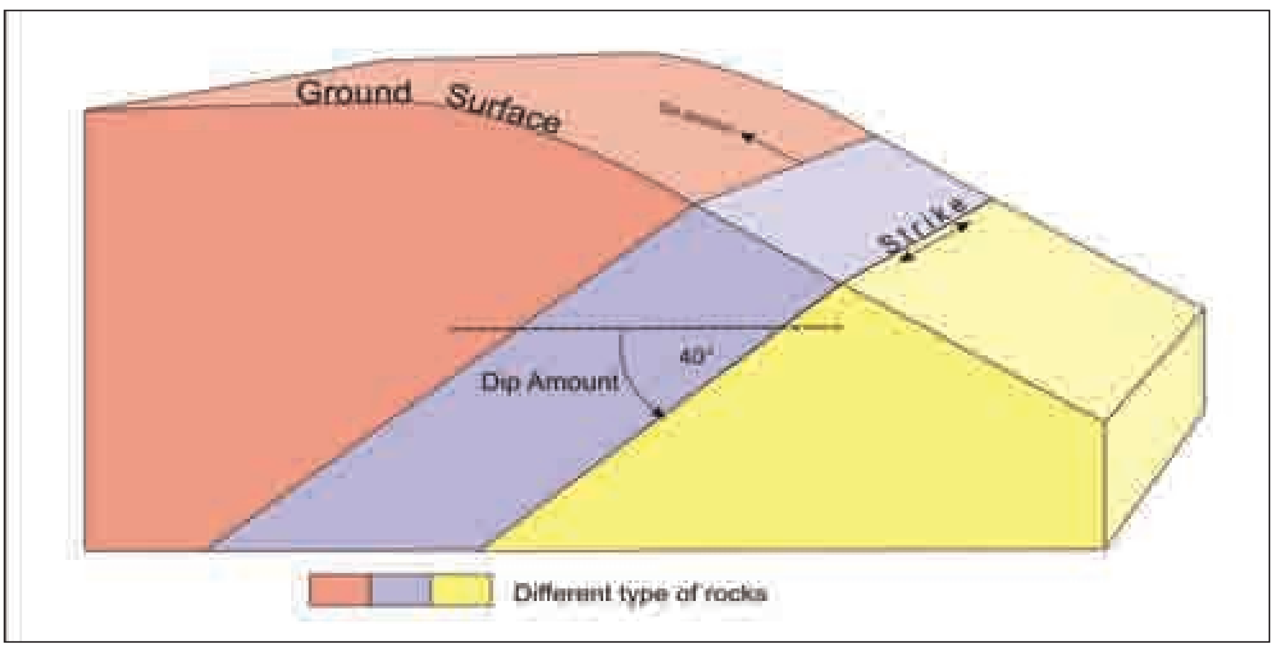


Fig 1: A conceptual diagram depicting strike and dip of strata (or even different rocks)

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. 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). Figure 1 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.

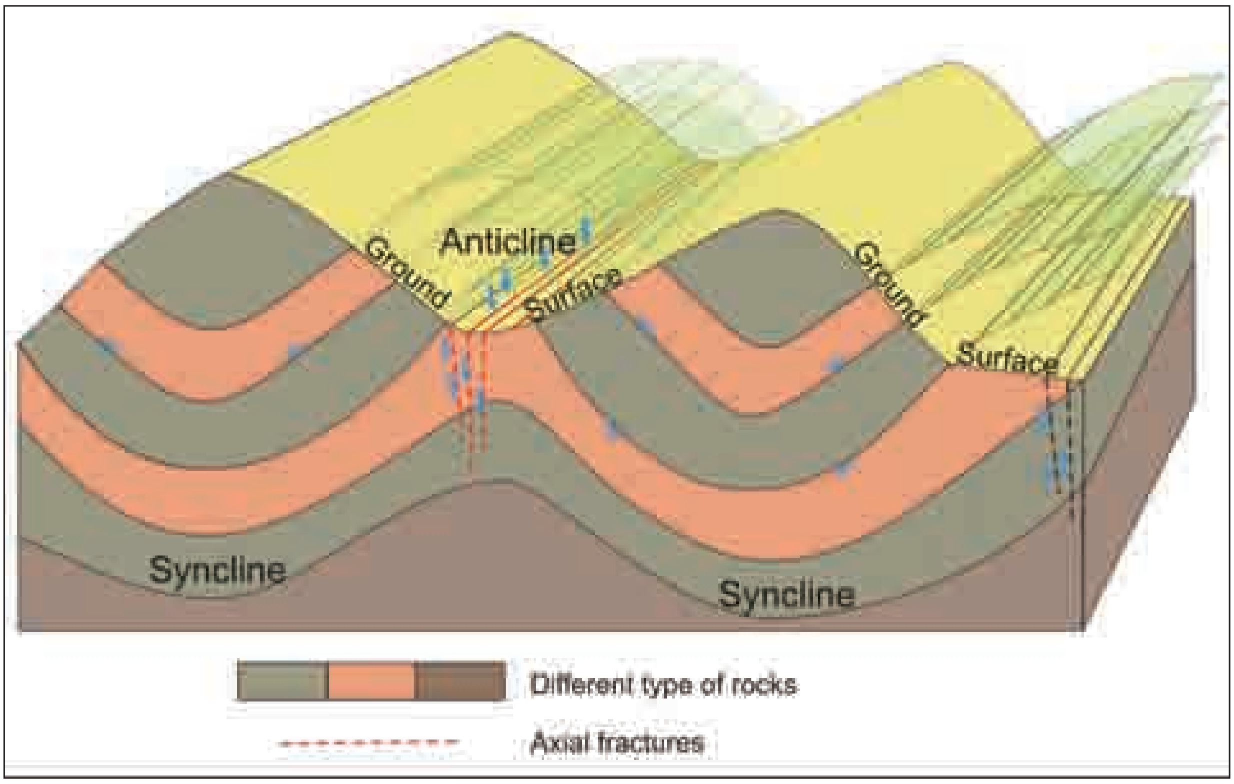


Fig 2: A conceptual diagram depicting structures and openings in rocks through which groundwater movement takes place in a folded sequence of sedimentary rocks

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 (as depicted in Figure 2). 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.

Springs, based on their characters can be classified into the following types (*adapted from* Freeze & Cherry (1979), Fetter (1980), Kresic and Stevanovic (2010)):

1. **Depression spring**: Formed when water table reaches the surface due to topographic undulations.
2. **Contact spring**: Formed at places where relatively permeable rocks overlie rocks of low permeability.
3. **Fracture spring**: Occur due to existence of jointed or permeable fracture zones in low permeability rocks.
4. **Karst spring**: Large quantities of water move through the cavities, channels, conduits and other openings developed in limestones.
5. **Fault spring**: Faulting may also give rise to conditions favorable for spring formation as groundwater (at depth) under hydrostatic pressure (such as in confined aquifers) can move up along such faults.

Each of the above type behaves differently, depending upon factors such as the characteristics of aquifers feeding the spring. A spring hydrograph (discharge versus time) is a simple way of understanding spring behaviour and also an indirect mechanism of understanding aquifers and aquifer systems feeding various springs. The volume of water discharged by a spring varies from as less as a trickle of less than a litre per minute (lpm) to hundreds and even thousands of litres per minute (lpm). The magnitude of change in spring discharge, from one season to another, reveals sizeable information about the change in storage in the aquifer feeding the spring, transmission and storage properties of such aquifers and is even indicative of the type of the aquifer. The discharge pattern of a spring is a useful way of ascertaining aquifer behaviour; Figure 3 and Table 1 are only a crude attempt to illustrate the relationship between spring-discharge behaviour and the characteristics of an aquifer feeding the four springs characterized by the four hydrographs. And although such a classification would need to be validated through detailed investigations, this generic pattern is based on observations made during the course of ACWADAM's projects on springs from different parts of India, particularly the Himalayan region.

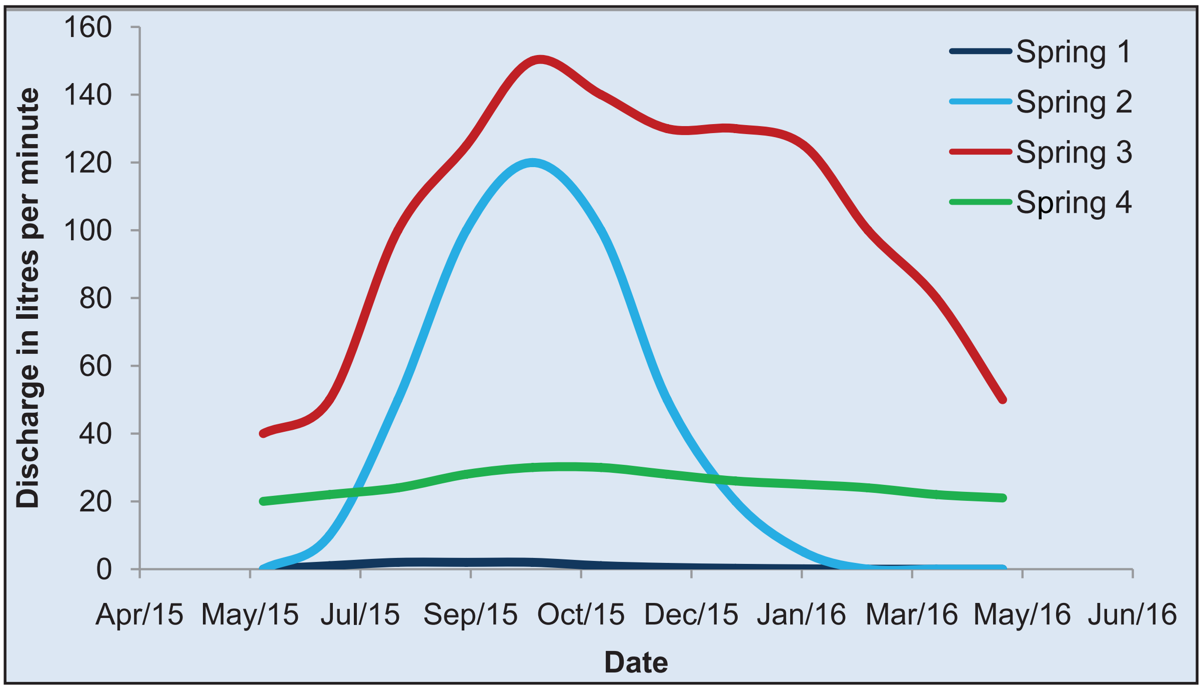


Fig 3: Typical spring discharge patterns (generalized on the basis of observations made in various parts of India, during studies by ACWADAM)

Table 1: Qualitative aquifer properties of model spring discharge type curves *(see Fig.3)*

Spring	Annual discharge trend	Probable nature of aquifer feeding spring	Aquifer Attributes
Spring 1	Low discharge, highly seasonal	Very local aquifer	Small storage, slow transmission
Spring 2	Widely ranging discharge, seasonal	Unconfined	Low storage, quick transmission
Spring 3	High and perennial discharge	Unconfined / Confined	Slow flow, moderate to large storage
Spring 4	Moderate, fairly constant perennial discharge	Unconfined / Confined	Large storage, rapid flow

COPING WITH CLIMATE CHANGE

The study of springs involves a synthesis of two branches of science - hydrology and hydrogeology (Brune 1975). Hydrology is primarily concerned with the study and understanding of surface water while Hydrogeology is the study of water in the subsurface including its chemical, physical and environmental characteristics. For the sustainable development and management of springs, it is essential to understand the hydrogeology and the surface water features in the area. Kresic (2010) has stated that any workable, realistic plan drawn for the management of springs must fulfill the following prerequisites:

a) Hydrogeologic and hydrologic characterization of the spring type, drainage (discharge) and recharge area, and recharge and discharge parameters, such as water quality and quantity.

b) Reliable predictive modeling of spring discharge and water quality, achieved by collecting discharge and quality data of springs.

Additionally, the importance of demand side management is also emphasized in literature. Demand management refers to initiatives that ensure the satisfaction of the current water requirement in times of limited resource availability, by augmenting the efficiency of water use. At a local scale, this implies the involvement of the community, educating various stakeholders about:

1. Resource protection
2. Preventing contamination of the aquifer
3. Land use management and control, especially in the recharge area

A changing climate and increasing demand for water have affected water resources the world over. Needless to say numerous springs all over the Himalayan region have shown a reduction in discharge as a compounded consequence of these two factors. Springs in the state of Sikkim are no exception. Efficient development of spring catchments and a proper strategy for spring water management are being adopted as a means to tackle spring depletion in these regions. Catchments are "treated" for conservation and various protective measures employed. Hydrogeological mapping of the springs often reveals that the recharge area and the area of protection of the springs show a very site-specific relationship, controlled primarily by the underlying geology. In some cases, it is found that the recharge areas for springs do not fall within a typical hydrological watershed, and do not necessarily respect administrative boundaries or type of land viz., private, common, agricultural, forest etc., many of which are "anthropogenic" divisions that are not always coherent with boundaries of natural resources such as groundwater. In such typical cases, the spring is located in one village (discharge) but its aquifer (and the recharge area for the aquifer) lies in another village.

Measures intended for augmenting spring discharge should be practiced only in the natural recharge areas of the spring, areas identified considering the local geology, including the structure of the rocks. A sound hydrogeological investigation of the spring, watershed and the underlying aquifer system can lead to proper identification of recharge areas and the area of protection (regulated grazing, sanitation practices, afforestation etc.), as part of the conservation and management process.

South Sikkim, the worst hit district by climate change, is also the most drought-prone area of the State. More than three-fourths of the local people in Sikkim believe that water sources are drying up, and 60.2% of them feel that there is less snow in the mountains now than in the past (Chaudhary et al. 2011). Keeping in mind the shortage of water in South District, a study was conducted on augmenting spring discharge through artificial recharge, with the intention of preparing plans, based on hydrogeological mapping. The study aimed at providing scientific inputs based on hydrogeological mapping and related studies, for the spring recharge programme (*aptly called Dhara Vikas*). This collaborative effort with the Rural Management and Development Department (RM&DD) also involved capacity building of Field Facilitators (FFs) in various fields of "springshed" development and management. The FFs participated in a 15 day training course on 'Groundwater' at ACWADAM in Pune. This included various classroom sessions on different topics such as hydrogeology, drainage analysis, water balance, water quality, sanitation, climate change etc. and its importance in groundwater management. Fieldwork in different areas involving activities designed to relate theory and practice, mainly in the form of 'simplified field hydrogeology' was also an integral part of the training programme.

Hydrogeological mapping of 15 springs (and 3 lakes) in South district of Sikkim was carried out by ACWADAM in close co-ordination with the Field Facilitators. Capacity building of FFs in understanding hydrogeology was a continuous process even during the field visits to different springs. The following sections illustrate

Fig 4: A google image of south district, Sikkim depicting location of springs under this study

summaries of four of these springs studied by ACWADAM through rapid hydrogeological investigations leading to the preparation and implementation of *springshed development plans*, often with significant data contributions by the FFs.

The hydrogeology of a few of the studied springs in South district is given below, through diagrams and profiles for each of the springs. The diagrams also depict the location of recharge areas for these springs. Each diagram is followed by a short narrative providing the description of each spring.

1. Jamuney Spring

Location: N27°07'17.4' E88°22'04.7''

Elevation: 631 m

Discharge: 4 litre per minute (January 2011)

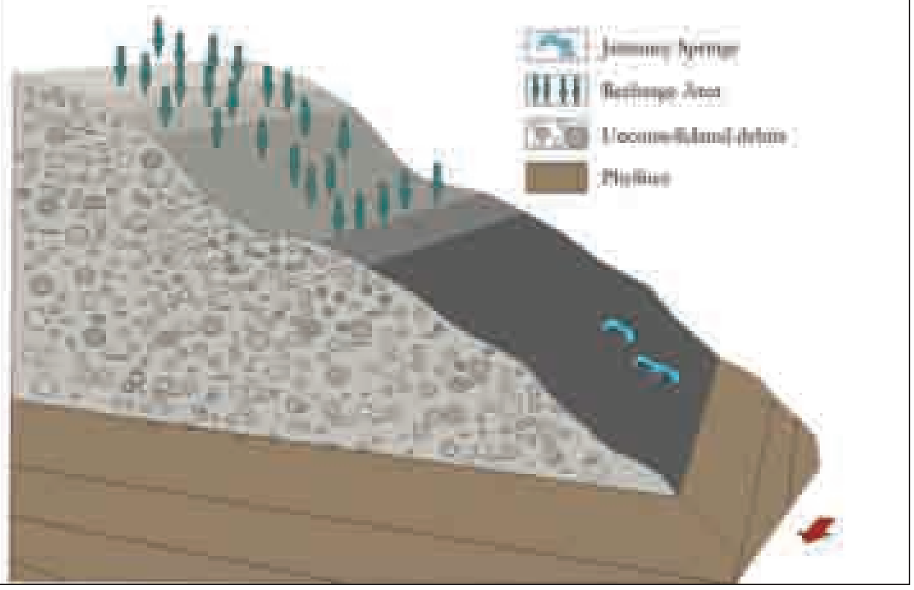
pH: 7.44

Salinity: 127 ppm

Temperature: 21°C

TDS: 227 mg/l

EC: 244 µs



Hydrogeology: The springshed is made up of phyllites at the base overlain by debris of coarse-grained unconsolidated material. The phyllites being less permeable form the base of the overlying unconsolidated sedimentary aquifer, feeding the Jamuney springs. The unconsolidated material is constituted of fragments of quartzite and phyllites with a wide ranging grain size – fine sand to pebbles. This debris acts as the main unconfined feeding Jamuney springs. The springs emerge at multiple points from the debris above the contact with the underlying phyllites and are classified as depression springs. The area on the western slope above the springs is interpreted as the recharge area for the springs.

Jamuney spring with a low discharge

The main spring at Jamuney

2. Kuapani Spring

Location:
N27°07’33.1’ E88°23’30.8’’

Elevation: 1140 m

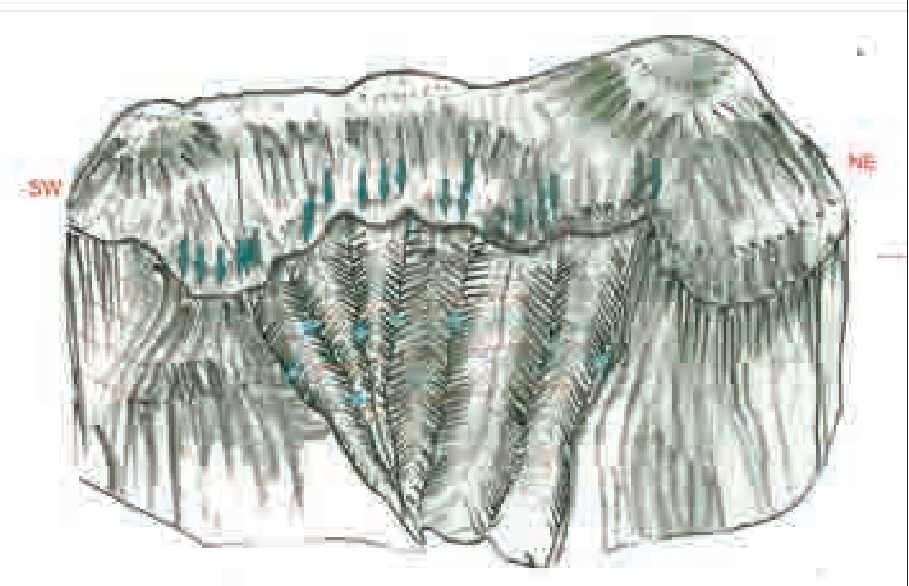
pH: 7.9

Salinity: 8.7 ppm

Temperature: 19.1° C

TDS: 14.5 mg/l

EC: 20.6 µs



Hydrogeology: The entire Paireni area, wherein Kuapani spring is located, is underlain by fractured quartzo-phyllitic rocks, with intercalations of carbonate horizons. The area supports a system of 9 springs, which are either the depression type (controlled by the relationship of the water table and the topography) or fracture-type. Unconsolidated debris, including large boulders, is observed in the lower order small streams. The regional dip of the rocks is towards southwest, but the fracture openings co-incident to the rock foliation direction, are inclined towards southeast, with a dip amount of 35°. These fractures play an important role in the movement and accumulation of groundwater for these springs.

Lapchey Dhara

3. Gati and Ghurpasaney Springs

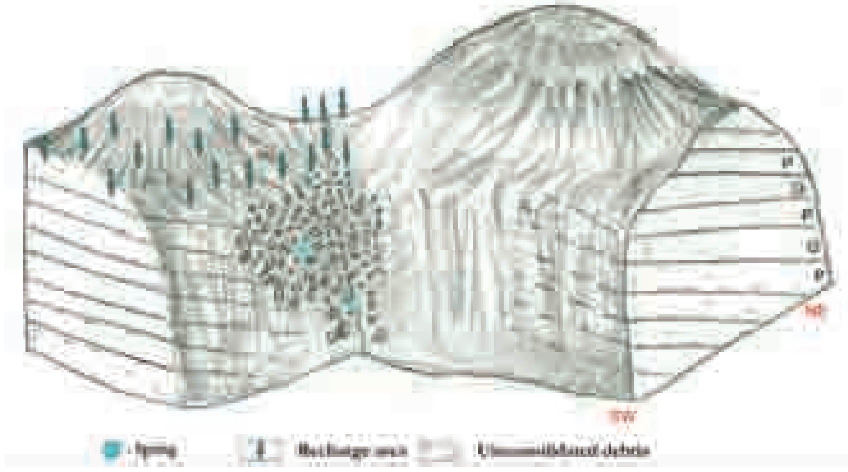
Location: N27°13’25.8’’ E88°23’49.3’’

Elevation: 2013 m (Gati Dhara)

Discharge: 21 - 150 lpm

Location: N27°13’23.1’’ E88°23’47.2’’

Elevation: 1135 m (Ghurpaseny Dhara)



Ghurpaseny dhara

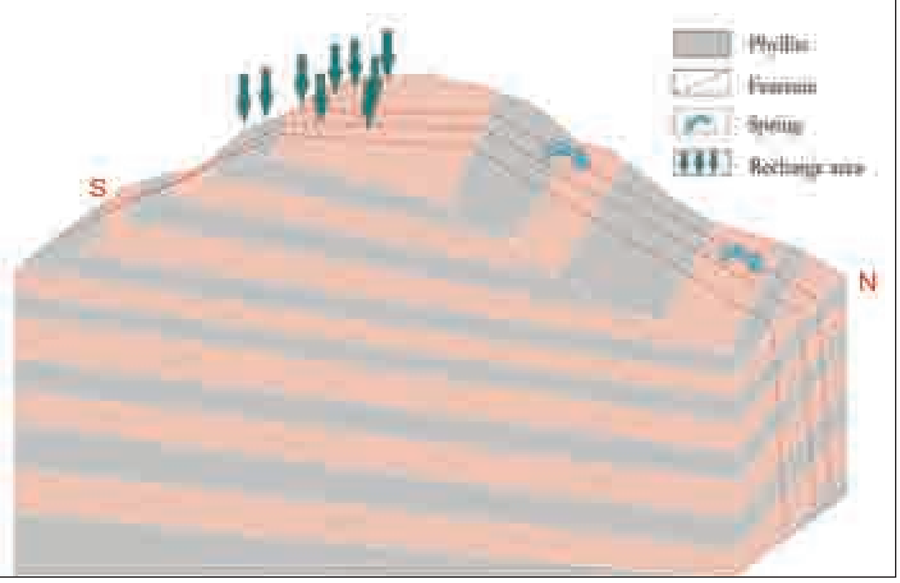
Hydrogeology: The springshed is made up of alternate layers of phyllites and quartzites. The phyllite layers dominate and are quite weathered. Unconsolidated debris is seen deposited in the small streams. Gati dhara emerges from the debris and is thus classified as a *depression spring,* while Ghurpaseny dhara emerges further downstream at the contact of the debris and the underlying phyllite and is classified as a *contact spring*. The phyllite sand quartzites dip ENE with an amount of 45-55°. The recharge area for the springs was identified in the upper reaches of the small streams in which the springs emerge and also towards SW, on the escarpment side of the ridge.

4. Bermelli springs

Location: N27°13’25.8’’ E88°23’49.3’’

Elevation: 2013 m (Gati Dhara)

Discharge: High discharge, piped to Namchi for water supply; spring contribution estimated to be in the range of 100 to 200 lpm



Hydrogeology: The springshed is made up of alternate layers of phyllites and quartzites. The phyllites dominate and are highly weathered at places. The rocks dip North East with an amount of 30° to 40°. Two set of fractures are observed, one along the dip of the rocks and the other vertical, trending NS. A series of springs is observed along the N-S trending fracture. The ridge top towards the south and a part of the escarpment slope (SW) forms the recharge area for the springs.

Wide open vertical fractures

One of the first (Bermelli) springs that form the 1st order stream

MANAGING SPRING WATER

Hydrogeological science should form the basis for any work related to watershed, springshed or any other intervention with connection to groundwater and aquifers. The ignorance of the concept of aquifers as the basic unit of groundwater development and management has resulted in the haphazard implementation of groundwater – related work, whether in the form of augmentation or managed usage. The seasonality and sustainability of spring water depend on aquifer properties, i.e. storativity and transmissivity. Every aquifer has its own range of these properties based on local hydrogeology. Artificial recharge to augment spring discharge has obvious limitations on the quantities of water that can be artificially infiltrated to obviate spring discharge depletion.

A two-fold approach that combines augmentation with management (and regulation) of increasing water-demand is suggested for managing Himalayan springs, particularly with the backdrop of a changing climate (Kulkarni and Thakker 2012). To cope up with the increasing demand and the changing climate, a participatory community based approach, based on scientific observations is needed. Hydrogeology enables a scientific understanding of springs. Even a rapidly but strategically conducted hydrogeological study enables appropriate demarcation of recharge areas for springs. The typology of springs, complex distribution patterns of springs and related hydrological factors imply that the size and location (distance from spring) of recharge areas be kept flexible during spring management programmes and appropriate hydrogeological inputs considered in the design and execution of recharge of springs.

In fact, a shift from the classical *ridge to valley* to a *valley to (the next contiguous) valley* approach is desired in policies dealing with spring water in the Himalayan region. This shift is a consequence of understanding created from the *Dhara Vikas* and other similar programmes in the Himalayan region, wherein the basic premise of a spring catchment is determined by the hydrogeology of the area or spring, rather than a purely hydrological approach of using a surface water catchment to determine the spring catchment area and size.

Sensitization of the local community regarding role of hydrogeology governing recharge areas, protection of recharge areas, importance of spring water data collection etc. is necessary; it becomes an imperative in any groundwater related work, with springshed management being no different. This is primarily on account of the complex relationship between natural boundaries (watersheds, aquifers) and land-cover or administrative units (reserved forest, common lands, panchayat boundaries etc.). The concept of spring water catchment works can be extended to supplement the process of rejuvenating dried-up lakes too, but that then is a case for a separate paper, after more rigorous work on Himalayan lakes.

ACKNOWLEDGEMENT

This study was jointly funded by GIZ (New Delhi), RM&DD (Government of Sikkim) and through some support from the Ford Foundation to ACWADAM. The authors are grateful to the support from all the three agencies. In addition, help and suggestions from colleagues, peers and senior trustees at ACWADAM is also acknowledged with gratitude. We would particularly like to mention the encouragement and support we received from Dr. Sandeep Tambe, Special Secretary, Government of Sikkim and his team including Mr. Ghanshyam Kharel, Mr. Bikash Subba and particularly from the FFs in this study. Last but not least, we would also like to thank three organizations – People's Science Institute & Himmotthan (both from Dehra Dun) and Chirag (Nainital district) - who drew our attention to the hydrogeology of spring water and to healthy collaborations on studies of a similar kind in other regions of the Himalaya.

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