Hydrogeology based approach for sustainability of springs for drinking water security in the Himalayan state of Uttarakhand, India.

Dr. R.C.Jain
Central Ground Water Board, Dehradun-248001, Uttarakhand State, India.
Email:ratan.jain@gmail.com

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ABSTRACT

Springs form the only reliable and sustainable source of fresh water in the Himalayan region. Spring water has been used by the mountain inhabitants since ancient times, and for a variety of purposes. Spring water has been used as drinking water, for domestic use, in agriculture, for religious purposes, in running flour mills and even for generating electricity. Springs are of crucial importance in rural Uttarakhand as almost 80% of rural household are dependent on springs for drinking water. Increasing population, upcoming technology, changes in rainfall patterns and poor legal policy framework for managing groundwater resources call for developing a scientific and community based approach to managing the springs in the Himalayas. This is especially important because of the complex hydrogeology of the Himalayas and the changing context of water use in the region, especially with the overarching impact of Climate Change. Each and every spring is unique and has its own characteristics. It is the mountain aquifer which stores and transmits water to the spring. The discharge and water quality of a spring over a period on time is completely dependent on the nature of aquifer the spring hosts. Thus, in understanding a spring, it is important that we first gain comprehensive knowledge about the aquifer supported by spring discharge, water quality and rainfall data. The science of hydrogeology can lead us to a better understanding of aquifers, thus providing ways and means for its proper sustainable management of springs. In the mountain areas like the Himalayas, high relief and the complex geological structure plays a vital role in formation of these mountain aquifers. 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. The extent and location of these areas are completely governed by local geology and the rock structure. This paper portrays a hydrogeology based scientific approach towards study of springs in Uttarakhand State in order to augment spring discharge. Based on the assessment of spring conditions in the state a strategy for maintaining their sustainability is outlined. An attempt has also been made to develop context sensitive protection plan of springs in the State based on sound hydro-geological principles.

1. INTRODUCTION

The Uttarakhand state is blessed with a large number of springs which have been quenching the thirst of communities of the hilly terrain for centuries. Increasing population ,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 Himalayan terrain in general to which Uttarakhand can not be an exception. This paradigm ought to include development of a science based, community-involved approach to managing the springs. Unless the argument for an overarching groundwater management gains momentum in the hilly terrain of 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 paper, while focusing on springs from Uttarakhand State, lays stress on how hydrogeology is important in understanding springs and how it can significantly contribute in the planning, implementation and monitoring processes of programmes that specifically target spring restoration and management, not just in Uttarakhand but across the entire Himalayan region.

2. HYDROGEOLOGICAL SET UP

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The Uttarakhand state can broadly be divided into two hydrogeological units, namely the Gangetic Alluvial Plain and Himalayan Mountain Belt (Fig. 1).

2.1 Gangetic Alluvial Plain – The Gangetic Alluvial Plain is a vast expanse of alluvium of Tertiary and Quaternary age. Alluvium is a generalized term for unconsolidated sediments consisting of a mixture of sand, silt clay, boulder and pebble. This formation occurs as a continuous belt along the southern boundary of the State starting from the base of the hills and extends into U.P. The area is very promising from hydrogeological point of view having substantial ground water resources. This unit can be sub-divided into three distinct subunits from south to north, viz. Axial Belt, Tarai and Bhabhar.

2.1.1 Axial Belt **–** This unit, also called as Alluvial Plain is demarcated by the termination of alluvial fans that grade further down slope into vast alluvial plains. This zone is composed of a mixture of gravel, sand, silt and clay deposited in alternating layers. Both unconfined and confined aquifers are present in this zone. The area, in general has good groundwater resource potential but intensive development of ground water at places has resulted in decline in water levels.

2.1.2 Tarai **–** This is a generalized term for a sedimentary unit consisting of a mixture of gravel, sand and clay (sometimes also referred to as Tarai Formation). The boundary between Tarai and Babar is demarcated by presence of springs forming a linear pattern, thus delineating a "spring line". Due to the highly porous and permeable nature of the constituent sedimentary material, many potential aquifers having ground water of good chemical quality exist in the area. Two types of aquifers can be found in this zone, namely (a) Unconfined Aquifers down to depths of 30 meters below ground level (bgl) , and (b) Free flowing Confined Aquifer that occur at depths greater than 30 meters bgl whose hydraulic head can be as high as 10 meters above ground surface. The discharge of tube wells tapping free flowing aquifers is as high as 5000 lpm. This formation occurs in almost the entire Udham Singh Nagar and part of Haridwar district.

2.1.3 Bhabhar **–** A specific feature of the Bhabhar is the complete absence of surface flow, as the river from the hills disappear underground to reappear above the surface at some distance further south. This submontane strip is mainly composed of the detritus washed down from the Siwalik range. A mixture of clastic material having different size fractions (e.g. boulder, pebble, granules, sand silt and clay) constitutes this unit which is also referred to as Bhabhar Formation. This zone consists of the coarsest sediments of the three sub-divisions. Bhabhar zone is also a promising hydrogeological entity with deep water table (>100 m bgl). Parched water bodies having limited ground water potential are frequently encountered in this zone. This formation occurs in the southern part of Pauri and Nainital districts and northern part of Haridwar district.

2.2 Himalayan Mountain Belt – This is a part of the Alpine-Himalayan Mountain chain and constitutes a major part of the total geographical area of state. This zone is also known as Extra-Peninsular Region. The belt trends NW-SE with roughly parallel mountain ranges spanning across the state. This region can be further subdivided into five tectonic units from south to north. These units are: Outer Himalayas, Lesser Himalaya, Central Himalayas, Tethyan Himalayas and Indus Suture zone. However, the Indus Suture zone does not fall within the geographical area of the state.

2.2.1 Outer Himalaya (Siwalik Mountain Ranges) **–** The Siwalik belt in a long chain of narrow and low hills (750-1200 meters), running almost parallel to the main Himalayas. In the north they are separated from the Lesser Himalaya, by the main boundary thrust. This unit is composed dominantly of sandstone, ferruginous shale and clay and is younger in age as compared to the other units of the belt. The general elevation of the zone is less than 1000 m above Mean Sea Level. The areas where the rocks are highly fractured /jointed hold good ground water potential. In the Siwalik, valleys have also developed as a result of tectonic activities.

One such valley, the Dun valley is very important from the hydrogeological point of view. Dun Valley was formed as an intermontane valley within the Siwalik group of rocks in a foreland propagating thrust system. The Middle and Upper Siwaliks are exposed in the area, and the Dun gravel, which is a post Siwalik formation, was deposited with the evolution of the valley. The Dun gravel is thickly bedded coarse clastic fan deposit of late Pleistocene and Holocene age. Central Ground Water Board has successfully constructed deep tube wells, with discharge ranging from 250 to 3197 lpm in the Dun valley, Dehradun district. The water levels in these aquifers range between 20 m bgl in the southern part of the valley to about 100 m bgl in the northern parts.

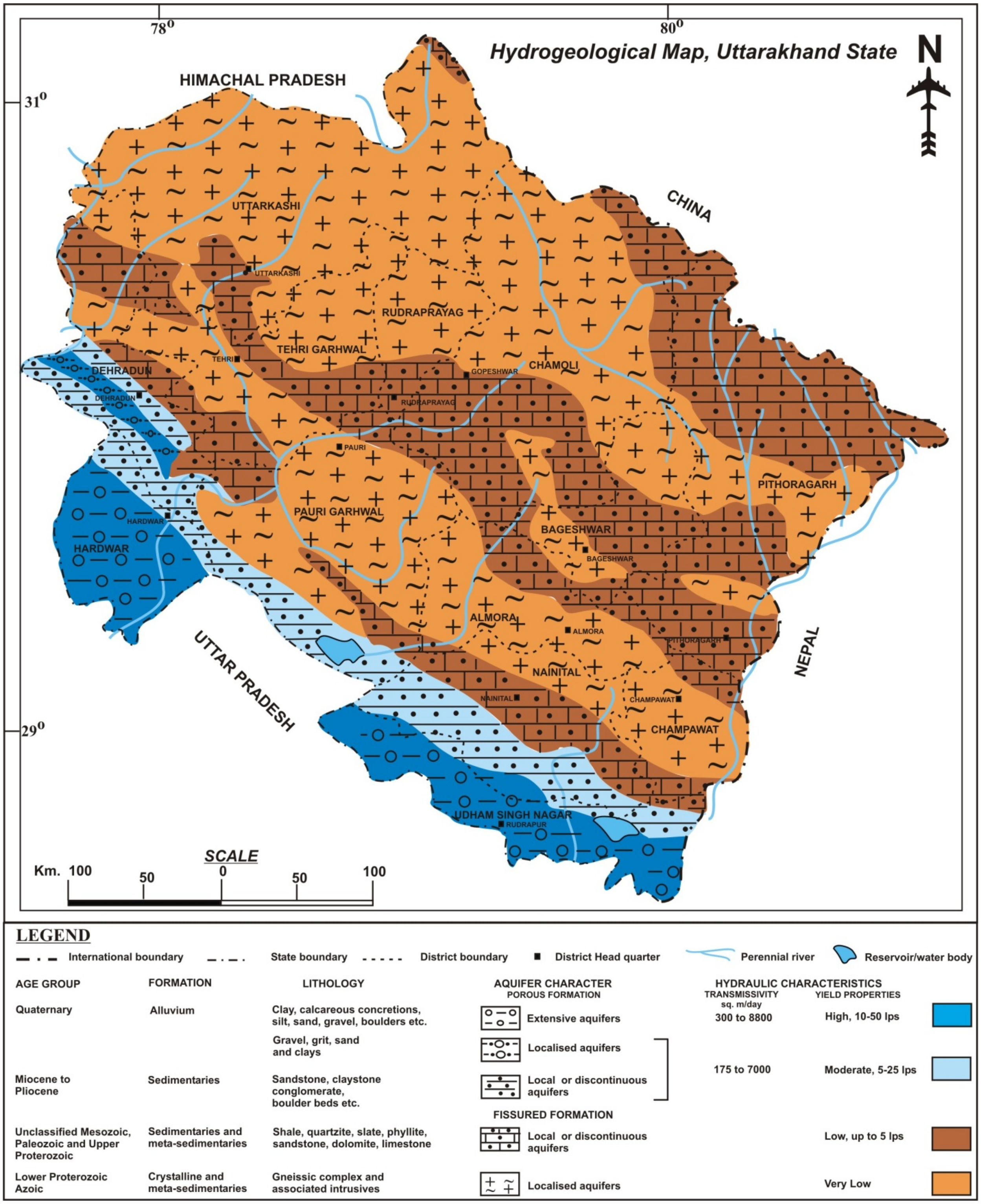

Figure 1 . Hydogeological Map of Uttarakhand state.

2.2.2 Lesser Himalaya - This zone is represented by mountains bounded by Main boundary Thrust (MBT) in the south and Main Central Thrust (MCT) in the north having an elevation ranging between 1000 and 3000 m above mean sea level. This unit is dominantly composed of meta-sedimentary rocks and minor plutonic intrusive (granitoids). Springs are the most important source of ground water in the zone. In these formations ground water occurrence is restricted to the weathered residuum and the highly fractured/jointed areas. Several hand pumps have been installed successfully in this zone. At a few places, especially in the river valleys, tubewells having 100 lpm to moderate discharges have also been successfully constructed.

2.2.3 Central Himalaya **–** The Central Himalayan zone lies to the north of the Main Central Thrust (MCT) with elevation ranging from 5000 to 8000 m above mean sea level. Both cold and hot water (thermal) springs are present in this zone. So far a total of 25 thermal springs have been investigated with temperature ranging from 32°C to 70°C and discharge varying between 60 to 600 lpm. Due to highly inaccessible, snow covered areas in the zone and a very steep hydraulic gradient, the possibility of ground water development is negligible.

2.2.4 Tethyan Himalaya **–** Situated to the north of the Central Himalayan zone, this zone is predominantly made up of highly fossiliferous sedimentary rocks ranging in age from pre-Cambrian to Jurassic. Due to the porous and permeable nature of the litho units, this zone is, in general, suitable for ground water development.

4. SPRING HYDROGEOLOGY

When groundwater, from water bearing rocks, is released on the surface, it is referred to as spring or seep. This water may be released as a concentrated discharge, as 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 as in Bhabhar and Tarai Zones, large aquifers exist, on the other hand, the undulating landscape and high relief means 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 in the hilly terrain. 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; hence, 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 aquifers, and therefore, in the behaviour of springs, which discharge from such aquifers (Aureli, A., 2010). 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, topographic undulations, differential hydraulic conductivities of the litho-units, weathered mantle, caverns, sink holes etc. These features are in abundance in Himalayas and for the same reason springs are of utmost importance in Himalayan context and Uttarakhand both, since >80 % of Uttarakhand State falls in Himalayan terrain.

The source of both perennial and ephemeral springs is the meteoric water. It is observed that the ephemeral springs are more sensitive to variation in rainfall as compared to the perennial ones.Water from springs sufficed the village needs in the past. In recent times, both the quantity i.e.,discharge and quality of water issuing from the springs is reported to be undergoing depletion and deterioration respectively.

5. TYPES OF SPRINGS IN UTTARAKHAND

The following five main types of springs are very common in the state:

4.1 Depression Springs: Depression springs are formed when the water table intersects the ground surface. The change in topography creates a corresponding undulation in the water table configuration. A local flow system, is thus, created in a local discharge zone and a spring forms. Such springs are common from outer Himalayas to Higher Himalayas. A number of such springs are formed along the road cuttings like Dehradun to Uttarkashi, Rishikesh to Badrinath, Rudraprayag to Kedarnath and Haldwani to Munsyari.

4.2 Contact Springs: Where permeable rock units overlie the rocks of much lower permeability, a contact spring may result. Such springs are common where phyllites, shales and slates are in contact with the comparatively more permeable fractured or jointed rocks. The areas where contact metamorphism has taken place may form good contact springs. Since the rocks occurring close to the intrusive body are impermeable and away from it have a higher permeability, a contact spring may result. Rocks within Intra Thrust zone are highly re-crystallized and impermeable. The contrasting properties of the Intra Thrust zone with that of the surrounding result in the formation of contact springs with high discharge. Springs so formed are common in the areas which have undergone regional metamorphism. Re-crystallization is prominent in the areas from where major thrusts like the Main Central Thrust (MCT) and their sympathetic thrusts pass.

4.3 Fault Springs: Faulting may create a geologic control favoring spring formation. A fractured rock unit that is impermeable may be emplaced adjacent to an aquifer. This can form a regional boundary to groundwater movement and force water in the aquifer to discharge as a fault spring. Springs are also associated with major thrusts. Sometimes the thrust extends deep into the intrusive bodies or major plutons, in such case a thermal spring is formed. The Vaikrita Thrust, which demarcates the sudden change in metamorphic grade and passes through Gauri Kund, is one such thrust. It helps connecting the hot sub surface water to emerge as spring at Gauri Kund. The hot sub surface water is due to the prominent granite body between Gauri Kund and Sonprayag.

4.4 Sinkhole/Cavernous Springs: Springs may be formed where a cavern is connected to a shaft that rises to the surface. The water in the sinkhole springs is under artesian pressure. Caverns in the limestone terrain pave the path of spring formation. The caverns are large conduits of water and virtually the subterranean flow occurs in this type of springs. Cavern related springs are common in Karol Limestone. Sahastradhara spring in District Dehradun is of this type.

4.5 Joint Springs or Fracture Springs: Such springs owe their genesis to the existence of jointed or permeable fault zones in low permeability rocks. Water movement in such rocks is through fractures, and springs can form where these fractures intersect the land surface at low elevations. Himalayas have undergone tectonic disturbance repeatedly which caused the rock formations to get jointed and fractured, hence such springs are abundant.

6. STATUS OF SPRINGS OF UTTARAKHAND STATE

More than 80 percent of the rural population in the mountainous terrain of Uttarakhand and many thousands of animals depends on water from springs. But the springs (locally called naula) are adversely affected as a result of changes in the environment. Among the many concerns two are of particular importance: (i) continuous extinction of springs , and (ii) reduction in their water discharge.

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 Uttarakhand represents a typical hydrogeological framework 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 spring catchment development.

7. STRATEGY FOR SUSTAINABILITY OF SPRINGS

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

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

ii. Reliable predictive modelling 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:

i. Resource protection
ii. Preventing contamination of the aquifer
iii. Land use management and control, especially in the recharge area

Changing climate has affected discharge of numerous springs all over Uttarakhand. Efficient development of spring catchments and a proper strategy for spring water management need to be adopted as a means to tackle spring depletion in these regions. This warrants that spring catchments should be treated for conservation and various protective measures employed for their rejuvenation.

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 (Kulkarni and Thakkar, 2012). 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. It may sometimes happen that the spring may be located in the revenue limits of one village (discharge) but its aquifer (and the recharge area for the aquifer) lies in the revenue limits of another village.

Measures intended for augmenting spring discharge should be practiced only in the natural recharge areas of the spring, 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 for regulated grazing, sanitation practices, afforestation etc., as part of the conservation and management process (Postel,S.L.et al, 2005).

Different type of remedial measures, which may be implemented in recharge areas for rejuvenation of springs, can be classified into three broad types, namely (i) Engineering Measures, (ii) Vegetative Measures, and (iii) Social Measures.

6.1 Engineering Measures*:*

6.1.1 Barbed Wire / Stone Wall: The construction of barbed wire/ stone wall ,as the site permits, in the recharge area is a very effective measure. It protects the recharge area from livestock foraging, bio-mass extraction and other human activities.

6.1.2 *Gully Plugs:* The recharge process starts from where the first rill of water begins and it pays dividends to construct gully plugs in the nallahs of first order itself. The plugging should be done on the permeable formation only. The method is very cost effective.

6.1.3 Gabion Structures: Gabion structures may be constructed on the nallahs preferably of first and second order where the width of the nallah is up to 10 m. The structures are constructed by putting the locally available stones in the wire mesh. Gabions are cost effective. They help in conserving the soil and promoting water infiltration and vegetation growth.

6.1.4 Brushwood Check Dam: Brushwood check dams are the obstacles put in the way of the descending water. These structures are constructed on permeable formations. The check dams may be of two types; (i) Single row post brushdam, and (ii) Double row post brushdam. Brushwood check dams are feasible where vegetative material for construction is available. The check dams can only be used in small gully heads not deeper than 1 m.

6.1.5 Contour Trenching: The recharge areas of springs are generally in the higher reaches of the catchments where the slopes are steep. Contour trenching is the most suitable engineering structure where the ground slope is more than 30%. Plantation should be done in the trenches. The area between in the trenches should be used for horticulture purpose. The trenches help infiltrating a large volume of water, so the springs lying on down slope side of the trenches get recharged.

6.2 Vegetative Measures: Vegetative measures such as plantation of low water demanding and shallow rooted grass/ shrubs/trees, mulching barrens spots with weeds/ leaf litter may speed up recharge process in the recharge areas of the springs. Vegetative measures are eco-friendly and environmentally sound. Among the vegetative measures seedlings of Alnus nepalensis, Prunus cerasoides and Quercus leucotrichophora are cost effective and suitable for Himalayan terrain.

6.3 Social Measures: The recharge area should be protected by putting ban on grazing, fuel wood and fodder cutting and taking measures to protect forest from fires.

8. WAY FORWARD

The lack of knowledge of the concept of aquifer as the basic unit of groundwater development and management has resulted in the unsatisfactory accomplishment of conservation and augmentation of groundwater resources in general and spring rejuvenation in particular. 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. Hence, the science of Hydrogeology should form the basis for any work related to watershed, springshed or any other intervention which is related to groundwater and aquifers.

There is an urgent need to adopt a participatory community based approach, based on scientific observations to cope up with the increasing demand and the changing climate. Hydrogeology enables a scientific understanding of springs. Even a rapidly but strategically conducted hydrogeological study enables appropriate demarcation of recharge areas for springs. The typical geological framework of springs, their complex distribution patterns and related hydrological factors imply that the size and location of recharge areas be kept flexible during spring management programmes and appropriate hydrogeological inputs considered in the design and execution of works for augmentation of recharge of springs.

In fact, a paradigm shift from the classical ridge to valley needs a serious consideration in policies dealing with spring water management in the Himalayan region. This is essential, in view of the emerging knowledge from various scientific studies that a spring catchment is determined by the hydrogeology of the area of recharge of spring, rather than a purely hydrological approach of using a surface water catchment to determine the spring catchment area and size.

Moreover, sensitization of the local community in relation to the governing role of hydrogeology in identification of recharge areas, protection of recharge areas, importance of spring water data collection etc. is vital on account of the complex relationship between natural boundaries namely watersheds, aquifers , land-cover and administrative units namely reserved forest, common lands, panchayat boundaries etc.

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