ADDKF – SAWI/SGP Project

ADDRESSING THE SEASONAL WATER SCARCITY THROUGH INTEGRATED APPROACH OF ISOTOPE TECHNIQUE, REMOTE SENSING AND GIS APPLICATION.

Abstract

This project will be an attempt of combining the information on hydrology, hydrogeology and ecology aspects supported by the state-of-the-art tools & technique (Isotope, Tracer technique, Remote Sensing and GIS/GPS).Through this project attempt will be made to understand the dominant processes that regulate the hydrology in a watershed in the complex terrain like Himalaya. Advancement in hydrological data processing and analysis of large time series database through the existing methods of flow duration curve, hydrograph separation and recession analyses will be demonstrated. Emphasis will be given on the study of low-flow as well high-flow hydrology of small catchment and on the predictability aspects on lean period water availability, essential for wise water resource planning in the western Himalayan region where climate is governed by monsoon pattern of rainfall (i.e., about two-thirds of the annual rainfall of 150 – 250 cm occurs during mid-June to mid-September). A framework for watershed based spring source area protection will be introduced starting with delineation of source area, vulnerability assessment, resource assessment, implementation of tools to protect water quality and public awareness & education. Contributing area of the catchment will be delineated through isotope technique. Long term time series data collected from small catchment will not only assist in much-needed sound water resource planning but also serve as a backbone for assessment of anticipated impact of climatic change in Himalayan region. The region presents a unique situation of low-flow during the summer months and gives rise to water scarcity to the local inhabitants. Thus poses a great management challenge.

Topic area: **Management of water for enhancing water/food security**

Problem Statement

The High Mountain Basins of Indian Himalayan Region though act as water tower for millions of people downstream but in recent times inhabitants of these mountain basins are facing the problems of water scarcity. Access to adequate amount of fresh water for meeting the basic water needs has become a cause of concern for every citizen especially during the summer season.

Much of the problems can be attributed to firstly lack of proper management in storage and supply of the water, secondly lack of proper resource assessment and quantification, limited understanding of the groundwater aquifer in these hardrock catchment that acts as a reliable source of fresh water and most importantly the successful demonstration of effectiveness of groundwater recharge measure to augment the lean-flow in springs and streams supported by pre and post implementation long term hydrological data. Limited understanding of the processes that governs the functioning of the catchment as whole at different spatial scale ranging from hillslope transects to larger mesoscale (typically 10^2 km^2 area) river basin is also required to be addressed with sound long-term inter-disciplinary research.

As the concern over water demand for drinking and other purposes is increasing in the western Himalayan region, understanding of the intricate relationship between ecological factors (like vegetation type and its density), land use and land cover change, hydrological factors (like mean residence time and saturated hydraulic conductivity) and geometric factors like shape, size of hillslope and channel network topology) which governs the hydrological response of any catchment has become the prerequisite for any water resource management plan.

Presently huge funds and government efforts are put in to augment water from distant sources to the villages and urban centers, without properly assessing the potential spring and stream resources that is available in its proximity. An interdisciplinary approach with hydrological, hydrogeological and ecological understanding supported by state-of-the-art tools and techniques like isotope, remote sensing and geographic information system(GIS) therefore needs to be demonstrated, to re-enforce people’s and policy maker’s belief in conservation of these springs for sustainable supply of water to the local people.

Policy Context

Major water supply in majority of the hill towns of the western Himalayan region from river water pumping schemes and rural population is dependent on springs, seepages or streams, but very little attention is paid to the management and conservation of these life-supporting perennial sources. The measures taken up to protect water sources are short term in nature and often lack proper scientific investigation to address the increasingly relevant issue of long term water resource sustainability.

Since the catchment area is degrading in rural watershed due to lack of protection and management and urban area is ever expanding, it will be crucial to know the hydrological processes operated at a catchment scale & protect the source area for the life sustaining springs. It is also envisaged that there is a bigger risk associated with water security due to inevitable impact of climate change causing vast change in evaporation and precipitation, making the hydrological cycle more unpredictable.

In the western Himalayan region (Uttarakhand state in India) water is a state subject and provisioning of drinking and irrigation water tapped from local streams and rivers is conveyed through pipe lines and canals to the local habitations at a very minimal tax. However, due to highly seasonal rainfall pattern of the region most of these schemes become defunct; thus causing apathy of the local people. Therefore, the crucial issue is how to conserve the water sources for augmentation of sustainable yield of water year-round.

Project Goal and Objectives

The present study will attempt in finding out the approximate recharge zone and mean residence time for springs falling in the representative watershed in the study area (western Himalayan region) using environmental isotope technique. Artificial tracer technique will be used to find the zone of contribution and inter-linkages between aquifers systems in mountainous catchment. The remote sensing and GIS technique will be use in mapping the landuse/landcover & hydrogeology of the catchment area for the experimental watershed to address issues of conservation and mamangement. This project will also implement rainfall recharge and water conservation structure which will augment the groundwater recharge. The broad objectives of the project are:

Objectives

- To decipher the groundwater provenance, recharge and it's renewability for springs and streams falling in the study area using stable, radioactive isotope and artificial tracer technique.
- To analyze the relationship among rainfall, hydrogeology, landuse/landcover and topography with the hydrological response of the catchments.
- To assess the year round reliability of spring discharge to meet drinking and domestic water needs by recession analysis of spring flow.
- To implement groundwater recharge structure in the catchment area to enhance the productivity of the fracture hard rock aquifer.
- To bring out a set of good practices for water resource conservation and management for wider application in the region by policy makers.

Literature Review

Drying up or perennial springs becoming seasonal has been frequently highlighted in the western Himalayan region (Singh & Pande, 1989; Valdiya & Bartarya, 1991). Some of the noteworthy review publications on hydrological research in Himalayan Region (Bruiznzeel and Bremmer, 1989; Alford, 1992; Negi et al., 2002) strongly suggest need for intensive research on process based understanding, which can serve as guiding rule for effective soil and water conservation in the fragile mountain watersheds in the Himalayan mountains. Since the majority of the rural populations are dependent on springs and streams, the knowledge of low-flow hydrology will be critical for managing and improving the reliability of water supply. Excellent review of low-flow hydrology with insight into the existing methods, which includes flow duration curve, baseflow separation, characterization of streamflow recession etc. presented based on the summary of recent international low-flow research initiatives (Smakhtin, 2001). Taking into account the observed variability of recession rate in most catchments, a minimum of 10years of time series discharge data is necessary for reliable estimates of the recession parameters (Perzyna, 1990).Flow duration curve is one of the most effective method of arranging discharge availability with reference to the percentage of time for the period under investigation (Searcy, 1959).

The application of environmental isotopes have gained wide acceptance as one of the most informative method as far as understanding of the hydrological processes are concerned (Pearce et al., 1986; Sklash et al., 1986; Yurtsever et al., 1993). Stable isotopes are being used for recharge area identification (James et al., 2000; Leontiadis et al., 1999), investigating contribution of source waters and transit time (Pearce et al., 1986; Shanley et al., 2002; Rodgers et al., 2005; McGuire et al., 2007).Two recent publications on stable isotope in Himalayan mountains by Saravana Kumar et al. (2010) and Kumar et al., (2010) presents the findings from precipitation analysis and relationship with meteorological conditions. As oppose to environmental isotope which are more suitable over a much larger scale (spatial) and longer time span, artificial tracer technique can be applied to address issues at local scale vulnerability of spring capture zones, establishing inter-connections between different groundwater sources (like hand pump and springs) and defining the boundary of catchment (Kass,1998).

Project Approach and Methodology

1. ***Site-Identification and experimental set up:*** The project will be initiated by identification of experimental watershed, a preliminary water resource inventory by mapping of the springs/ seepages streams, and tube well/hand pumps in the map with the help of GPS. Next step will be selection and preparation of site for the year round measurement of spring flow data, stream discharge data, collection of rainfall and pan

evaporation data etc, .One Automated Weather Station (AWS) will be installed in the experimental watershed. The spring flow data and stream discharge will be measured three to five times at a particular time in a day and the average value will be recorded. On events of rainfall, data will always be collected after the rainfall, so as to record the influence of rainfall on the spring flow and stream discharge. To accurately measure the discharge data from springs and stream, setting up of RBC flume and 90^{o} V-notch weir box with stilling well for installation of pressure sensor will be done at selected locations in the experimental watershed. This data will be used to plan for any water conservation structure during the implementation part of this project.

2. ***Environmental Isotope application:*** Applications of stable isotope of oxygen and hydrogen have been used quite extensively in geohydrological investigation. Out of the many potential applications of environmental isotopes in hydrological sciences, the present study will focus on the following key issues pertinent to the address the seasonal water scarcity in the context of Indian Himalayan Region (IHR) 1) Origin of water, 2) Recharge area identification 3) Transit Time (or mean residence time), 4) Processes based understanding of stream runoff generation and components in spring outflow. Sampling in the experimental watershed under investigation will be carried out for two years under two schemes. Firstly, long term sampling at regular intervals following a weekly or biweekly interval sample collection from streams, springs and other groundwater water sources. Secondly the event based intensive sampling of springs and streams ranging from 15minutes to several hours interval sampling for two to three rainfall events in summers as well as monsoon period. Apart from the above mentioned sampling for short and long term, the precipitation sampling will be carried out at six locations at six different elevations for establishment of local meteoric water line and to work out the altitude effect crucial for recharge area identification. Water samples from springs, groundwater (tube well) and streams will be collected on pre-monsoon and during monsoon for analysis of radioactive isotope of tritium to decipher the qualitatively groundwater mean residence time for each spring falling in the study area. Sampling will be done following the standard procedures (Clark and Fritz, 1997).Environmental isotope e.g. stable isotopes (^{18}O or deuterium) and tritium database will be used to for determining the hydrological parameters like mean transit time etc., using lumped-parameter model [Maloszewski & Zuber (1982,1993,1996)]

3. ***Groundwater Tracer Technique:*** It is normally recommended to have multi-tracer approach to better understand the linkages between the catchment characteristics and hydrological behavior. The present study in additional to environmental isotopes, dye tracer technique will be used. It will be very crucial to understand the exact area of zone of contribution (ZoC) for the particular spring or springs in the study area. This is because

in this highly folded and fractured hardrock aquifer system in Himalaya, the hydrological divide might not always coincide with the grounwater boundary for a particular spring. Moreover since the water-table measurement and hydraulic data for aquifer characteristics are rare in this type of topography, it is through the use of tracer technique one can have an understanding of the subsurface hydrological parameters. To decipher the aquifer geographic extent and hydraulic characteristics, a specialized, site-specific predictive technique based on qualitative and quantitative dye tracing will be followed using Field Fluorometer. This instrument can be set up for continuous-flow monitoring or discrete sample analyses. The dye tracer technique will be used to the establish point-to-point connections between the discrete recharge areas and discharge point such as springs/seepages. In addition of dye recovery data would provide critical management information, such as time of travel, flow velocity, peak concentration. The book on Tracing Technique in Geohydrology by Werner Kass summarizes all of the tracing techniques with practical examples and interpretation, will serve as an excellent guideline for execution of tracer experimental in Himalayan region. Tracer will be injected into a pit centrally located in the catchment area to observe the changes in travel time and establish the interconnections between the groundwater sources for each of the spring resource present in the study area. The experiments will be carried out in post-monsoon condition to observe the difference in travel-time and proper identification of recharge area. Analysis of the dye-recovery (time-concentration) curve provide insight into the flow characteristic of aquifer such as effective time of travel and apparent velocity of groundwater.

4. ***Geohydrological and landuse/landcover mapping of the experimental watershed area using field, remote sensing and GIS/GPS applications:*** Detailed geological mapping in the field will be carried out and additional structural data will be collected in addition to the available geological maps of regional scale. Satellite data will be used to prepare fracture /lineament maps for the study area. Similarly the landuse/landcover mapping will be done in 1:25,000 scales for experimental watershed and stereo-pair high resolution satellite data will be used to prepare the digital elevation model and small scale LU/LC mapping. The satellite data will be georeferenced using ground control point collected from DGPS.
5. ***Geochemistry of springs/streams in the experimental watershed:*** The water samples will be collected in pre and post monsoon period for geochemical analysis. Samples will be analyzed for major cations and anions like Na,K,Mg,Ca,SO_4,CL,CO3 &HCO_3 . pH, EC, TDS & water temperature will be monitored during the collection of samples for analysis.

6. ***Spring flow and stream discharge recession analysis:*** The hydrograph of a spring is the final outcome of various processes that govern the transformation of precipitation and other water inputs in the spring's catchment area into the flow at the point of discharge. A thorough analysis of the spring discharge provides useful information on aquifer characteristics such as the nature of its storage and transmissivity, and types & quantity of its ground water reserves. In many cases, the discharge hydrographs of a spring closely resembles hydrograph of a surface stream, particularly if the aquifer is unconfined and high transmissivity. Although the process that generate hydrographs of springs and surface streams are quite different, there is much that is analogous between them.
7. ***Recession analysis:*** Analysis of the falling hydrograph limb, which corresponds to a period without significant precipitation, is called the recession analysis. Knowing that the spring discharge is without disturbances caused by a rapid inflow of new water into the aquifer, the recession analysis provides good insight into the aquifer. By establishing an appropriate mathematical relationship between the spring discharge and time, it is possible to predict the discharge rate after a given period without precipitation, and to calculate the volume of discharge water. For this reasons, recession analysis has been a popular qualitative method in hydrogeological studies.
8. ***Recharge area identification through integration of two approach***

    i. Firstly, detailed geological mapping of the structural elements of the study area on the High resolution satellite data through fields work and GPS. Geological cross-section will be made to understand the probable flow direction of the subsurface groundwater.

    ii. Second approach is through the application of stable isotope technique where we will try to establish a relationship between the variability of stable isotope of oxygen and hydrogen with elevation, which is also known as altitude effect. It is expected that rise in elevation will cause a decrease in the $\delta^{18}O$ & $\delta^{2}H$ concentration in the rainfall. The rainfall will be sampled for the two consecutive monsoon period at four different elevations in the experimental watershed. The altitude effect in terms of depletion of $\delta^{18}O$ & $\delta^{2}H$ per 100m rise in altitude will be established to know the recharge area of springs/seeps or streams under investigation.

    iii. This will help us in understanding the ground water provenance (local or regional) of the watershed under consideration. The results will be integrated with the findings from tracer test also.

9. ***Implementation of Artificial recharge structures:*** Based on the result of isotope analysis, artificial tracer and interpretation of hydrogeological data gathered from field checks and satellite data ,trenches ,tanks and other artificial recharge structures like recharge pits, subsurface dyke etc., will be constructed at the recharge zones for few prospective springs in the microwatershed. The implementation will be carried out through participatory approach to augment the rainwater recharge in the catchment area to enhance the productivity of the fracture hardrock aquifer as well as optimum storage structures will be created to cope with the seasonal water scarcity.

Project Activities

The project activities will start with water resource inventory of selected study area, with identification of springs & streams and site preparation for long term monitoring.

The first year will be focused on extensive literature survey, collection of available databases, procurement and establishment of hydro-meteorological instruments, procurement of satellite data, orientation of research fellow & field assistant for carrying out the regular monitoring, collection of ground control point with DGPS for image registration and DEM generation using stereo-pair cartosat-1 data of 2.5mt resolution and generation of base map using high resolution satellite data.

The next two year(2^{nd} and 3^{rd} year) will be used of sampling of precipitation, springs, streams and other groundwater sources for building a sound stable isotope datasets, Hydrological analysis of time series data,Landuse/Landcover & hydrogeological mapping and detail GIS analysis.

In fourth and fifth year experiments using dye tracer technique will be carried out followed by implementation of artificial recharge structures.

Subsequent years will be used for technological demonstration to various line department engaged soil and water conservation.

A complete hydrological analysis will be carried out in pre and post implementation scenario. Database generated will also serve as a model input for predictability analysis in terms of water resource availability.

Expected Results of the Project

- Demarcation of zone of spring recharge & understanding of residence time for spring flows falling in the study area.

- Quantification of the dynamic spring flow volume, assessment of year round reliability of the spring water to meet the drinking and domestic needs.
- Understanding of the relationship of rainfall, catchment characteristics to spring discharge to recommend long term solutions.
- Introduction of framework for source area protection (SAP) in IHR.
- Publications: report and papers

Potential Policy Contribution

Linkages between project activities and policy implication.

1. In developed countries like United States and European Union, they have legislated through Safe Drinking Water Act and Water Framework Directives respectively to ensure the protection of source of drinking water.EU Directive 2006 requires a protection zoning system for groundwater sources for human consumption. Further, identification of landuse in the catchment and catchment from which the ground water body receives its recharge has become an integral part of planning process.

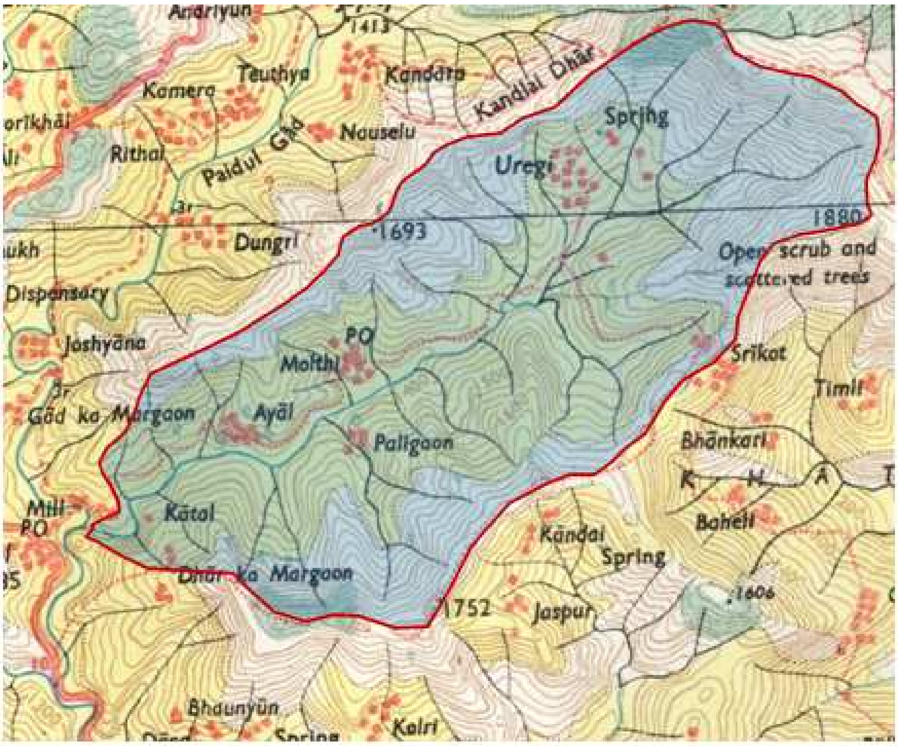
   --Through this project an attempt will be made in designing a spring protection system for conservation of spring and spring-fed-streams through landuse regulation for the catchment area***.(For long term water resource sustainability catchment centric approach is more appropriate option than source centric approach).***

2. Presently government agencies are either planning to bring in water from several kilometer distances to these villages and urban centers or spending huge money on groundwater augmentation schemes, without properly assessing the spring and stream resources that is available in its proximity.

--Through this project an attempt will be made to do a proper cost-benefit analysis between investment in optimum design storage structures depending on water availability in the natural spring & streams and investment in groundwater recharge structures*.* ***(Is spending on optimum storage structure, a more appropriate solution than investment in groundwater augmentation schemes to tackle the seasonal water scarcity?)***

Case I: India - Western Himalaya

The Study area:



The study area approximately having 16km^2 area, is located between latitudes 30^{o}03' N and 30^{o}06' N and longitudes 78^{o}45'E and 78^{o}50'E, having elevation ranging from 1300mts to maximum elevation of 1880mts. It is located at a distance of approximately 15kms from the Pauri district head quarter of Uttrakhand state. The experimental watershed is having three gram seba (Ayal, Molthi and Uregi) having six villages. The population of Uregi village is more than 1000 (approx. 300 household), where dweller are facing an acute drinking water scarcity during the lean period. The springs and stream act as source of water with no pipe water supply schemes. The major Landuse/Land cover classes for the watershed under the study area can be classified as forest area, terraced agriculture land and settlements. The higher elevations are covered by dense mixed forest and open scrubland, which is mostly degraded. Geologically the study area falls in Lesser Himalaya which ranges between 1500-to-2500m high, and is represented by Pauri Phyllite and Khirsu Quartzite members of the Maithana Formation in the Dudatoli Group (Kumar et. al., 1974). The study area is mainly dominated by Pauri Phyllite. The study area falls under humid temperate climatic condition; with average annual rainfall for the district is 1582.6mm (Indian Meteorological Department).