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Geohydrology and Watershed Management in Badiyargad Catchment, Garhwal Himalaya, Uttarakhand, India.

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Abstract: Water scarcity has emerged as a critical concern in the headwater regions of hilly terrains, particularly in Uttarakhand, where villages in the study area exemplify this growing crisis. Rapidly increasing pressure on land and water resources has severely altered both surface and subsurface hydrological regimes, thereby affecting regional development. Inadequate groundwater recharge, coupled with rising water demand, has led to a marked decline in the discharge of springs, wells, and streams, resulting in widespread water scarcity across most catchments.Groundwater plays a pivotal role in addressing this recurring water stress. In Uttarakhand's mountainous landscape, surface water primarily flows through deep valleys and is largely inaccessible for domestic use or irrigation. Consequently, nearly 90 percent of the rural population depends on natural springs to meet daily water requirements. This dependence explains the clustering of settlements around springs, with some springs shared by multiple villages. Although hand pumps have been installed in recent years to supplement drinking water supplies, they often become non-functional during the dry season due to the absence of a stable water table. In this context, geohydrological studies are essential for understanding groundwater occurrence and movement, assessing water quality, and formulating effective strategies for conservation, management, and recharge. The present study examines 21 springs and stream water samples from the Badiyargad watershed, analyzing their discharge patterns, catchment characteristics, and geochemical properties. The area is underlain by the Garhwal Group, comprising quartzite, metabasic rocks, slates, and carbonates. This paper highlights the geological control of springs, emphasizes water balance and hydrochemical studies, and proposes strategies for sustainable management and recharge of groundwater resources in the Badiyargad watershed.

Keywords: Groundwater springs • Water scarcity • Geohydrology • Badiyargad watershed • Uttarakhand Himalaya

Introduction

Geohydrological, geochemical and ecological research has been carried out in various ecosystem to understand the factors controlling the chemistry of natural water (Likens et.al 1977; Baron & Bricker 1990). Many of studies have been control the hydrogeochemistry of alpine and sub- alpine system of North America and Europe (Willam et.al 1993, Psenner 1989).

Watershed is natural unit of drainage system. It has its importance for development planning within the existing natural boundaries (Guleria 1987). A watershed or hydrological unit is a super local region considered to be appropriate for planning and management (Narian 1985, Subramanian et al 1987, Bhardwaj et al 1990). Working on these lines is important, especially in the hilly and mountainous terrain which have fragile and vulnerable ecological system. A watershed is a homogenous unit in terms of lithology, structure, geographic terrain, socio-economic conditions and eco-cultural settings. Land, soil, water, forest and living organism have optimum interaction in a watershed. The watershed problems and its management issues are likely to undergo rapid changes in the years to come. Further, there is a need to establish balance between dive's demands from diver's human groups, and scarcely available resources within the watershed. The watershed is considered to be an ideal management land segment for identifying prevalent problems, recharging capacities, managing the water resources and overall

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sustainability after fulfilling the requirement and managing the resources.

In the Himalayan region the problem of soil erosion and water scarcity is increasing day by day and a lot of attention is required for their conservation measures. The participatory approach in managing soil and water conservation on the basis of unit area and application of conservation measures such as rainwater harvesting; recharging water sources through pitting and contouring in the selected areas may be the useful techniques. Educating communities for restoration, water harvesting, and water conservation may be some of the important steps in this regards.

The Study Area

Badiyargad is a small ephemeral tributary stream of Alaknanda located in Tehri District, Uttarakhand between longitudes (E 78^0 47'4"-78^0 55'10"), latitude (N $30^0$15'40"-30^0 21'12") falling in SOI. Toposheet No.53J/15. The Badiyargad Catchment (Fig-1) has an area of about 75 sq.km^2. The catchment is well connected by all weather metalled road.

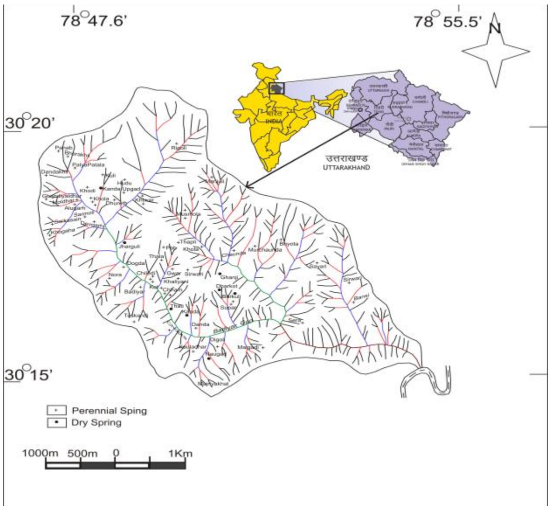

Fig-1 Springs of Badiyargad Catchment

The area consists of hill ranges, ridges, slope and valleys encompassing step like agricultural fields and high gradient streams, steep slopes, highly truncated spurs, interfluves, abrupt bend in the stream courses witnessing high intensity of mass wasting that indicate an immature topography prone to degradation.

The Badiyargad is a fifth order stream that flows from N to S upto Badiyar, taking a turn towards east upto Syari and then again flowing towards south joining Alaknanda near Khankra.

Geological Framework-: The study area constitutes metasediments of Garhwal group (Kumar and Agarwal 1974), which at places are intruded or intercalated by basic rocks in the form of sills/dykes and penecontemporaneous lava flows. Following lithology was observed in this area (Fig- 2).

Dhari Metavolcanics – It is probably the oldest basic flow and is generally exposed in the anticlinal cores such as at Rigoli, etc. The formation is characterized by basic flows and associated slates with minor quartzite lenses. The basic flows are generally dark-green, and show amygdaloidal structures.

Haryali Quarzites – A major portion of catchment is occupied by this formation. It is characterized by white to purple or maroon coloured quartzite which is thickly bedded, fine to coarse-grained, and some times gritty with occasional lenticular pebble beds. The current bedding and ripple marks are the main sedimentary features indicating right side up position of the quartzite beds. Quartz veins and slickensides were observed at many

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places. The quartzite shows colour banding (4-5 bands per cm.) of alternating dark and light colours as observed at south of Majriyakhal and Ghanji .

In the western part of the area, a number of lensoid bodies of dolomite –limestone/marble and slate occur in the basal part of quartzite.

Bhekunda Metavolcanics – It is predominantly vesicular and amygdaloidal basalt. The amygdales being of various shapes and sizes. The metavolcanics are green in colour and fine grained hard and compact rock in which individual minerals are indistinguishable. The fine grains generally constitute green pleochroic hornblende set in indistinguishable groundmass of feldspar exhibiting intersertal texture.

History of watershed management development

A watershed is a logical, natural planning unit for sustainable research and development particularly when environmental considerations are emphasized. Hydrologically, watershed could be defined as an area from which the runoff drains through a particular point in the drainage system.

In 1994, the Ministry of Rural Development (MORD) of the GOI produced a set of guidelines for implementing its watershed programmes, which aimed to tackle the concerns related to the realization of the full benefits of watershed work. The progressive policy was essentially people- centered and it incorporated good practice for NGO and government policy, such as awareness raising programs bottom- up planning, partnership with NGOs' and community participation.

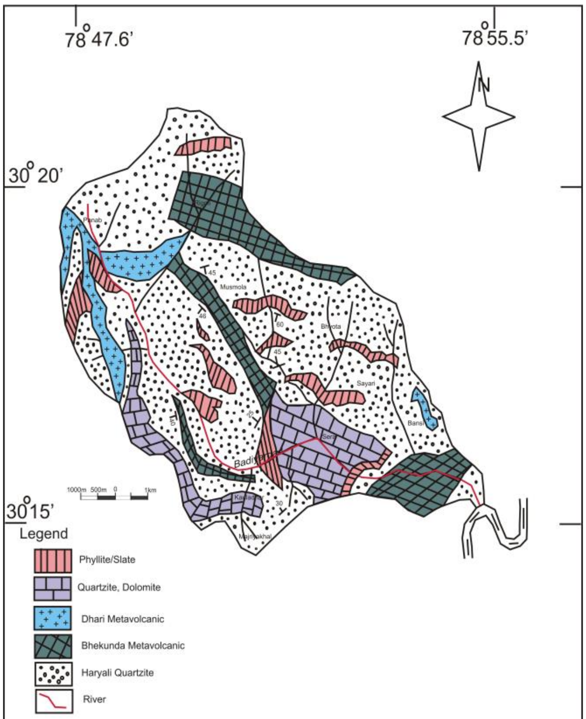

Fig.2-Geological Map Of Badiyargad Catchment

Aims of watershed management

The basic concept of watershed management is to incorporate every independent component or resources together as a result these are termed as interdependent component. Managing land water and vegetation in an integrated manner as natural resources on sustainable basis is the need of current management practices. Watershed management implies the proper use of all land and water resources of a watershed for optimum production with minimum hazard and degradation to natural resources.

Following aims were tentatively framed for sustainable development of a watershed.

1. To control surface runoff so as to cause minimum damage through soil erosion to the catchment area.
2. To control soil erosion and apply effective measures to reduce the sediment yield.
3. To reduce flood incidents in the downstream areas and to apply preventive measures in safeguarding human habitation, farms, forests, ponds, reservoirs, etc.
4. To enhance a storage of groundwater by a way of recharging through rainwater, and snow harvesting.
5. To suggest a rational use of land resources in the watershed with a purpose of developing forest and fodder resources.
6. To protect, conserve and improve the land for efficient and sustained productivity and
7. To develop and manage the water sources, springs and steams; thus regulating and making available supply to irrigation, drinking water, hydropower, pisciculture, etc.

Rainwater harvesting

Rain water harvesting is a scientific way to capture the rainwater during rains. The rainwater can be stored above ground or regulate the underground aquifers which can become as reserves later to use. These alike practices are mostly in use in the rural localities through natural process. But scientific structures in harvesting rainwater in the mountain areas where topography is steep and rugged, creation of skillful methods in harvesting rain is a need of the hour.

Traditional harvesting techniques

Rainwater harvesting is a widely accepted and practically reliable technique for watershed management in the Himalayan region. Under hill area development planning, there is an urgent need to promote scientifically designed water harvesting structures to meet diverse water demands ranging from drinking to irrigation. Traditionally, rainwater harvesting in the Himalaya focused on hydropower generation, irrigation canal development, and small-scale water-based industries such as water mills (gharats). At the village level, communities harvested rainwater directly from rooftops and stored it in tanks, collected runoff from open community lands in artificial wells, and captured monsoon flows from swollen streams in various types of storage structures. These indigenous practices effectively met local water needs in the past.

However, the present scenario has changed significantly. Declining discharge from natural sources such as springs and streams, coupled with increasing population and water demand, has rendered traditional systems inadequate. Ensuring year-round availability of water has become a major challenge. Himalayan rivers experience excessive flows during the monsoon but remain lean for most of the year, highlighting the need for efficient storage and recharge mechanisms. While traditional techniques are still suitable for headwater zones, they require scientific strengthening and integration with modern planning approaches.

Given the growing pressure on water resources, sustainable management of mountain water systems demands a comprehensive strategy. Key measures include preparing an inventory of existing water harvesting techniques and assessing them in terms of potential, cost, and benefits; understanding the influence of local culture, traditional knowledge, and policy frameworks on water harvesting practices; and training farmers through technical support and field-based exposure to enhance awareness of sustainable techniques. Additionally, developing robust databases on hydrology, meteorology, geomorphology, geology, and ecological impacts is essential for informed decision-making.

The study area receives high-intensity, torrential rainfall, much of which is lost as runoff, causing soil erosion and flooding. Erratic rainfall distribution further leads to inadequate soil moisture for crops and

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vegetables. Owing to rugged topography, canal irrigation is largely unfeasible, while springs and groundwater remain insufficient and economically inaccessible. In this context, farm-level rainwater harvesting emerges as a viable solution, enabling storage of natural rainfall in suitable structures for domestic and irrigation use, thereby helping to reduce regional water scarcity.

Traditional Techniques

Dammed Ponds: Ponds are constructed by constructing a dam of soil across a flowing stream of water. These ponds may be suitable for those areas where topography is rugged and slopes are steep. In these structures, the collection of water is raised up to an optimum height. "Talab" is constructed by digging out soil in a leveled land. These ponds are fed by the surface runoff. The areas having heavy soils are suitable for these ponds because of low flowing rate of water into these ponds.

Cemented or Stoned Ponds: In the hilly areas due to steep slopes, it is not easy to construct big ponds.As a result, in these areas rainwater is carried out through "khuls" (mud irrigation water channel) to stored in small ponds then it supplied for irrigation in agriculture fields. These ponds are made up of by cement and stones as in village Kanda.

Construction of "Bauris" (springs): The "Bauris" (springs) now a days are cemented storage structure which are used to collect water from natural sources and hence are rainfed. In this case, cemented storage structures are constructed across natural sources of water and automatically considerable quantity of water gets accumulated there in after then this storage water can be used for supply drinking water and irrigation too. Example such "Bauris" are used in village Khalyani and Chiladi (Plate No. 1) etc.

Hydrogeochmistry-

Method

Sample Collection – Sample of stream and springs (surface water) water was collected form 21 station of Badiyargad catchment during summer months (May-June) of 2006. These were stored in polythene bottles which washed double distilled water. Stream discharge was also measured the gauging site by using the float method.

Sample Analysis- Electrical conductivity (EC), pH, turbidity and total dissolved solids(TDS), were measured at the site using Digital Water Analysis Kit; . Total hardness (TH) total alkalinity, acidity, Cl-, No_3 , Fe^{++} , F, Cu^{++} and As measured in the chemical laboratory using standard method.

Observation- The physicochemical data of springs and stream water are presented in Table – 1 and are described below.

Quality of Surface water: Turbidity varies marginally between 2 N.T.U.(Khola) to 14 N.T.U.(Chham-ii) Majority of samples i.e.16 show a turbidity less than 5 when as rest of the samples exhibited the turbidity as 6, 8, 11, 12 and 14.

Sample No. 8 and 9 (Chham) are slightly acidic whereas water of all the other sites is neutral to alkaline. pH is a measure of the concentration of hydrogen ions in water.

Plate No. 1- Water harvesting shows the village Chiladi.

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Alkalinity varies between 40 mg/lit (Chham-iii, Chiladi-i and Khtwar-i) to 120 $mg.l^{-1}$ (Supar). Majority of the samples show alkalinity below 80mg/lit. Sera Gad and Khola show an alkalinity of 80 mg/lit. and Supar has higher alkalinity 120 $mg.l^{-1}$.

Total Hardness value in all 21 sample of spring and stream water are lower than the permissible limits and varies from low to moderate expect Sera which show 170 $mg.l^{-1}$

Nitrate as $N0_3$ is present in very low concentration which clearly indicates that springs and stream water are not affected by anthropogenic activities and nitrate pollution sources.

The concentration of chloride recorded varies from 9.99 $mg.l^{-1}$ (Chham-iv, Chiladi-ii and Upgad) to 24.99 $mg.l^{-1}$ (Sera Gad). The higher percent of chloride indicates the saline water. In natural fresh water, its concentration should remains quite low generally less than that of sulphate and bicarbonates.

Considerable concentration of iron is noticed around Chham (ii) in sample No. 9 which is 0.3 $mg.l^{-1}$ otherwise of iron is absent in other samples.

Concentration of fluoride, arsenic and copper in the springs and stream water of the catchment are almost zero during in the summer season.

Result and Discussion

Analytical results of springs and stream water sample of this Catchment indicate that it is excellent to satisfactory and suitable for irrigation and domestic purposes. Most of the parameters are within the maximum permissible limit of B.I.S. (10500-1991) for drinking water (Table 1).

The samples No. 6 (turbidity 12 N.T.U), No.9 (turbidity 14 N.T.U.) and No.19 (turbidity 11 N.T.U.) show very high concentration of turbidity. Turbidity in excess of 10 N.T.U. constitutes ground for rejection (plate no. 2 and 3).

Concentration of TDS is very low in all the springs and stream water samples. Total dissolved solid (TDS) is an important parameter for drinking water. The TDS concentration is a secondary drinking water standard and is regulated because of its aesthetic effect rather than a health hazard.

Conductivity is highly dependent upon temperature. It has got no health significance as such. Electrical Conductivity (EC) conductance was also taken in order to know the suitability of water for irrigation and domestic purposes (Wilcox 1955).

Table 1: Physical and Chemical Parameter for Stream and Springs Water.

S. No.	Name of Source	Turbidity NTU	TDS mg/l	EC µs	pH	Alkalinityity $mg.l^{-1}$	Acid $mg.l^{-1}$1	TH	No_3^-	Cl^-	F	Fe^{++}	Cu^{++}	As
								(-----------all in $mg.l^{-1}$						-----------------------------)
1	Sera Spring	4	68	300	7.7	80	-	170	Nil	14.99	Nil	Nil	Nil	Nil
2	Seragad	5	79	302	8.07	90	-	150	10	24.99	Nil	Nil	Nil	Nil
3	Badiyargad	5	76	229	7.7	60	-	120	30	9.99	Nil	Nil	Nil	Nil
4	Seragad & Badiyargad	-	-	-	-	-	-	-	-	-	-	-	-	-
5	Supar	5	94	300	7.24	120	-	130	Nil	19.99	Nil	Nil	Nil	Nil
6	Danda	12	87	249	7.56	60	-	140	Nil	19.99	Nil	Nil	Nil	Nil
7	Badiyar Spring	3	88	209	7.2	50	-	120	Nil	14.99	Nil	Nil	Nil	Nil
8	Chham (i)	4	77	197	6.62	-	50	140	Nil	14.99	Nil	Nil	Nil	Nil
9	Chham (ii)	14	98	290	5.64	-	70	140	Nil	19.99	0.3	Nil	Nil	Nil
10	Chham(iii)	3	75	247	7.68	40	-	120	110	14.99	Nil	Nil	Nil	Nil
11	Chham (iv)	8	64	196	7.97	50	-	140	Nil	9.99	Nil	Nil	Nil	Nil
12	Panabgad	3	85	267	7.58	70	-	160	Nil	14.99	Nil	Nil	Nil	Nil
13	Rigoligad	4	68	244	7.67	40	-	120	Nil	14.99	Nil	Nil	Nil	Nil
14	Panab &Rigoligad	5	87	297	7.66	60	-	130	Nil	14.99	Nil	Nil	Nil	Nil
15	Chiladi(i)	3	62	299	7.25	40	-	120	Nil	14.99	Nil	Nil	Nil	Nil
16	Chiladi (ii)	5	68	197	7.81	50	-	140	Nil	9.99	Nil	Nil	Nil	Nil
17	Chiladi(iii)	6	74	214	7.33	60	-	100	Nil	14.99	Nil	Nil	Nil	Nil
18	Khatwar (i)	3	78	212	7.64	40	-	130	Nil	14.99	Nil	Nil	Nil	Nil
19	Khatwar (ii)	14	95	193	7.65	70	-	120	Nil	14.99	Nil	Nil	Nil	Nil
20	Upgad	3	97	227	7.63	70	-	120	Nil	9.99	Nil	Nil	Nil	Nil
21	Khola	2	86	1 98	7.38	80	-	130	Nil	14.99	Nil	Nil	Nil	Nil

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Neutral to alkaline nature of water suggests suitability for domestic purposes, however springs No. 9(ii) (plate no. 2) is acidic with pH 5.64 which may cause, skin and dental hazards in case of regular use. Most chemical and biological reactions occur at a narrow range of pH. Determination of pH is one of the important objectives in treatment of the wastes.

Most of the springs and stream water samples with total alkalinity less than 100 mg/lit. Are desirable for domestic uses, however spring No. 5 with total alkalinity 120 mg/lit. Is not safe for domestic purposes.

All the water samples have hardness above than permissible limit. Hardness has no known adverse effect on health; however, some evidence has been given to indicate its role in heart disease (Peter 1974). The hard water is also not suitable for domestic use in washing, cleaning and laundering.

Nitrate concentration was found above than permissible limit in sample No. 2, 3 and 10. Excessive nitrate concentration causes infection particularly one is susceptible to asphyxiation by methemoglobinemia. In this disease the skin becomes blue due to decreased efficiency of hemoglobin to combine with oxygen.

Chloride concentration is very low in all the springs and stream water samples. The concentration is very important in classifying irrigation water. The presence of excess chloride is aesthetically unacceptable but it does not have any ill – effect on health.

Plate 2 

Plate 3 

Plate No.-2. Low range of pH and high range of Turbidity exhibited by this spring at Chham (ii).

Plate No. - 3. High Turbidity shows by this spring at Khtwar (ii).

Although iron has got little concern as a health hazard but is still considered as a nuisance in excessive quantities. Iron in excess of 0.3 mg/lit causes staining of clothes and utensils.

Conclusions

Watershed management has undergone dramatic change to include greater stakeholder's participitation for management of natural resources in a sustainable way. It is increasingly recognized that community participation was central to watershed development. More participatory approaches have achieved greater success in enhancing livehoods in an equitable fashion (Kerr and Pangare 2002).

It has been noted that participatory watershed management project have been conserving soil and water resources. Evidence from the three case studies and other general impact studies suggest that watershed development brought several positive tends including diversification of the rural economy, development of new institutions, increasing cropping intensity. Increasing cropping intensity, improved fodder production, increased availability of drinking water with rising ground water table, capacity development of the community etc. based on the evidence found, it has been suggested that watershed management could be a viable

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strategy of rural development for achieving sustainable rural livelihoods.

Hydrochemistry analysis of springs water of this catchment suggest all the concentration in it are well within the permissible limits (10500-1991) and thus is suitable for domestic purposes.

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