ASSESSMENT OF SPRING POTENTIAL FOR SUSTAINABLE AGRICULTURE: A CASE STUDY IN LESSER HIMALAYAS

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Collection

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HIGHLIGHTS

- Spring flows are the primary source of water for rural Himalayan communities.
- An attempt was made to understand the potential of spring discharge as an alternative irrigation source.
- Improved management of resources is vital to account for agricultural water use.
- Managing water resources is a collective endeavor for achieving water security.

ABSTRACT. *With increasing population and restricted water and land resources, there is a growing concern for better planning of the available water and land resources. In the mountainous regions or mountains, there is limited land with uncertain water availability as the rainfall patterns pose a major threat to the livelihood of the people. Therefore, it becomes necessary to quantify and manage the available water resources in a sustainable way. People in the Himalayas are mainly dependent on the springs for drinking water, but not much attention has been dedicated to the development and conservation of these springs. A spring in the Tehri-Garhwal district of Uttarakhand state of India, has been continuously monitored to quantify the available water for domestic use and agriculture. In this study, an attempt is made to understand the potential of a spring for agricultural water use by evaluating the crop water requirement and potential improved strategies to increase the water productivity. Analysis proves that crop evapotranspiration is higher (946-1062 mm) for crops with extended duration (165-180 days) as compared to evapotranspiration (92.91 mm) of short duration (60 days) crops. The total water requirement for major crops in the area is 6411.35 mm and the monitored spring has the potential to supplement this water requirement. Adopting the system of rice intensification to increase the rice yield (by 49%), increases the water productivity. The sensitivity analysis of benefit to cost suggests that, an increase in the crop yield by 30% can increase the revenue in the study area by Rs.3687197, which is 217% more than the input costs. Therefore, it is essential to optimize the available water and area for irrigation to achieve the global water security for increasing population. Further, utilizing springs as potential irrigation sources will support rural community in meeting domestic water requirement and achieving environmental sustainability. Findings of this study will help in planning and implementing management strategies that are resilient in the face of future changes and improve the economic condition of farmers.*

Keywords. *Crop evapotranspiration, Himalaya, Optimization, Sensitivity analysis, Spring.*

With more than 1.2 billion people, India is the second most populated nation on the earth (Census of India, 2011). There are increasing issues of water scarcity and absence of access to fresh water to many people living in the rural areas because of the burgeoning population, change in living standards, urbanization, industrialization, climate change, etc. The availability of water in India has decreased by 53% and is expected that by 2025 it will further decrease to 72% (Engelman and Lekoy, 1993) from the available limit of 2500 m^3 per person. Water demand for agriculture continues to dominate and is projected that the water required for agriculture by 2050 will increase by 11% to fulfill the biomass production (Postel, 2003). The problem of water crises has consequently received much consideration from a large number of researchers around the globe (Hanasaki et al., 2013; Schewe et al., 2014; Zhang et al., 2015). In sub-tropical and mountainous regions, where rainfall is intense leads to scarcity of water because of the high altitude and sloping nature of the region, the major rainfall gets converted to surface runoff/quick subsurface flows. Also ~70% of total annual rainfall occurs during monsoon season (3-4 months), i.e., July-September, thus is essential to conserve the natural rainfall. Security of water and food

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specially in mountainous regions for rural people unquestionably needs to guarantee of their basic needs such as domestic water supply, water for agriculture, water for livestock rearing, and other business exercises. Thus, one of the major challenges lies in the proficient management of available water with decentralized responsibilities and local authority to transmit the excess water to water scarce areas (James, 2003).

Most of the total world's population still live in rural areas and rely on agribusiness. In India, about 45% live in rural areas and about 250 crore people rely on agriculture for their source of income and livelihood. Agriculture is the key user of water in India but in the hilly regions the irrigation efficiency is not adequate. Water resource development for sustainable agricultural planning plays a vibrant role for promising food security and socio-economic progress (Singh, 2014). Food security depends upon agricultural production which further depends on the presence of sufficient amount of water for a particular duration and at a particular location. To fulfill the food requirements of the increasing population, expansion of agricultural production and sustainable management techniques are required (Tilman et al., 2002; Singh et al., 2006; Rockstrom et al., 2009). Availability of water at any location is also governed by spatial and temporal climatic conditions (Hammer et al., 2001). The comparative vulnerability because of shortage of water varies between districts and plain and hills within similar locations (Wheeler and Braun, 2013). In many locations, agricultural water resource accessibilities have suffered from the absence of the right amount of rainfall and its irregular temporal variation (Fereres et al., 2011; Garg and Dadhich, 2014; IPCC, 2014). Uncertain variables such as soil moisture, rainfall, temperature, and market demand hamper the development of agricultural water resource system which is often difficult to estimate, project which is not even controllable (Regulwar and Gurav, 2011; Zhang et al., 2011). Varela-Ortega et al. (2011) suggested that climate variability would unfavorably affect the recharge of the soil surface and agriculture productivity. Variability in the rainfall intensity moreover disturbs the overall crop and land productivity of poor and low land holdings whose dependency is on rainfed agriculture (Fauchereau et al., 2003; IPCC 2007). Climate change will also increase water demand for agricultural and crop evapotranspiration requirements (Lehmann et al., 2013) and affect crop yield and productivity (Barnett et al., 2007; Sarker et al., 2012; Palazzoli et al., 2015). Reduction in crop yield for different crops because of climatic and other variables such as shortage of rainfall, waterlogging, soil issues (Grassini et al., 2007; Askri et al., 2010). Remote sensing and GIS has also been applied to compute the total production from the irrigated area, and crop mapping at a different location with respect to time (Atzberger, 2013; Kouadio et al., 2014; Pandey et al., 2015). Therefore, for the management of agricultural area and to develop some plans and decision making policies require an understanding of agricultural water requirement and availability of water resources (Singh et al., 2007). Furthermore, the water requirement of a particular type of crop is normally varied and dependent upon the rate of evapotranspiration. The amount of evapotranspiration is mainly influenced by temperature which affects the availability of water and crops yield, predominantly, in mountainous regions.

Evapotranspiration (ET) is defined as the quantity of water which is lost to the atmosphere by the combined process of evaporation and transpiration. Estimation of ET plays an important role for valuation of crop water requirement (Vicente-Serrano et al., 2014; Lian and Huang, 2015) and also is one of the major factors in hydrological processes (He et al., 2015). The estimation of ET from meteorological parameters require an evaluation of a large number of variables and is often difficult to obtain (Stephens and Stewart, 1963; Christiansen, 1966; Burman, 1976). In the absence of the meteorological parameters, the pan-evaporation method can be used for the estimation of ET (Singh, 1989) which has been applied by (Chattopadhyay and Hulme, 1997; Tebakari et al., 2005). Management strategies for crop planning with increasing crop productivity and water resources varies with different ET values (Gao et al., 2006; Brauman et al., 2012), therefore it is essential to accurately estimate the ET values. To estimate ET, FAO-56 suggested an approach based on the Penman-Monteith (PM) equation (Allen et al., 1998) which is physically-based and does not need any correction hence, is used globally (Yoder et al., 2005; Pereira et al., 2015). Now a day, artificial neural network (ANN) is also gaining attention in the estimation of ET (Sudheer et al., 2002; Lee et al., 2010).

In the Himalayan areas, agriculture is utmost important for rural occupation. The use of water for a small land holder for agriculture and domestic need warns the people to optimize the use of land and water for sustainable development as well as food security (Seckler et al., 1998; Hellegers et al., 2013). Further, the decreasing trend of rainfall over the previous years has threatened the agriculture productivity in this region (Khandelwal et al., 2015; Mishra and Gupta, 2015). The situation of water scarcity will further intensify if the current trend of decreasing rainfall continues, therefore well utilization of the available water becomes a paramount issue. Optimization of the agricultural area and enhancement of water availability are considered as one of the vital parameters to resolve the scarcity and uneven use of water (Moradi-Jalal et al., 2007). Georgiou and Papamichail (2008) established a non-linear programming (NLP) optimization method to decide the reservoir release policies and optimal cropping pattern in Havrias River in Northern Greece. A stochastic dynamic programming has been developed for the optimization of water use with single and multiple cropping systems (Bras and Cordova, 1981; Vedula and Nagesh, 1996; Ghahraman and Sepaskhah, 2002). Genetic algorithm (GA) has been applied for the optimum planning of irrigation over Ram Sagar project and optimum irrigation area to regulate agriculture yield (Wardlaw and Sharif, 1999; Raju and Nagesh, 2004; Nagesh et al., 2006). Management decisions based on computer optimization and simulation have a substantial role in the performance of agriculture (Kuo et al., 2001). Besides the non-traditional optimization, other optimization techniques (GA, EA, and NLP) in agriculture planning have been applied in different areas (Matanga and Marino, 1979; Paudyal and Gupta, 1990; Singh et al., 1999). Mujumdar and Ramesh (1998) formulated reservoir operation model for irrigation of multiple crops using linear programming. Evolutionary algorithms (EA) have developed new tools for optimization in different areas and it has been applied in irrigation planning and reservoir operation (Teegavarapu and Simonovic, 2002; Janga and Nagesh, 2006). Although the aforementioned GA, EA, and NLP are applied for many optimization problems, linear optimization performs better for the linear constraints as well as easy identifiable of optimum solution and thus is therefore proposed for this study to allocate optimum area and water for multiple crops.

Rainfall in a mountainous region marginally satisfies crop water requirements, resulting in low yields of essential crops (Moeletsi and Walker, 2012, 2013). Review of literature indicates that there is a large scope to enhance the water and land efficiency so that surplus water during monsoon (July-September) can be stored and later released for irrigation. Water through the springs that emerge through hill slopes is recharged by rainfall that accumulates in aquifers during the monsoon and could be used as an alternative source for agriculture practice. For sustainable irrigation systems, the main issue is to decide the right crop based on the availability of water. Change in the cropping pattern which is independent of water availability is leading to heavy reliance on spring water for micro watershed development. Construction of storage tanks, trenching, and other interventions in the catchment to enhance food and water security (Wada et al., 2014) can facilitate optimal water allocation across space, time, and economic activities, resulting in higher crop yield. It becomes a major challenge to maintain the stability of the rate of increasing crop yield and decreasing of the available water resource. Optimization of land resources, water allocation, and crop planning in a scientific way thus reduce such challenges and provide food security under limited resources (Kang and Park, 2014).

To ensure food security in the Aglar watershed located in the Lesser Himalayas for increasing population and escalating urbanization, increasing water availability and productivity from agriculture will be imperative while addressing the issue of sustainability. Like other mountainous catchment, water resources in this region are highly scarce which effects agriculture that plays an important role in supporting the local economy and guaranteeing food security. In Aglar where sub surface flow meets the ground in the form of spring has some potential for irrigation but is often not considered for any agricultural practices rather than domestic use (Kumar and Sen, 2018). Thus the objective of this study is to (i) calculate the water requirement for different crops grown in the area, (ii) optimize available water potential (spring volume) to provide an alternative solution for sustainable development, and (iii) develop strategies for future food security by adopting system rice intensification.

STUDY AREA AND DATA

The Aglar watershed is a mountainous watershed of 30,500 hectares located within 30.49 to 30.52° N and 78.14 to 78.16° E in Tehri Garhwal district of Uttarakhand, India (fig. 1a). It is located behind the Mussoorie ridge which is known as the “Hill Queen” in the Lesser Himalayas. The watershed characterized by undulating topography that ranges in elevation from 450 to 3022 m approximately above the mean sea level and drains into the River Yamuna near the Yamuna Bridge (fig. 1b).

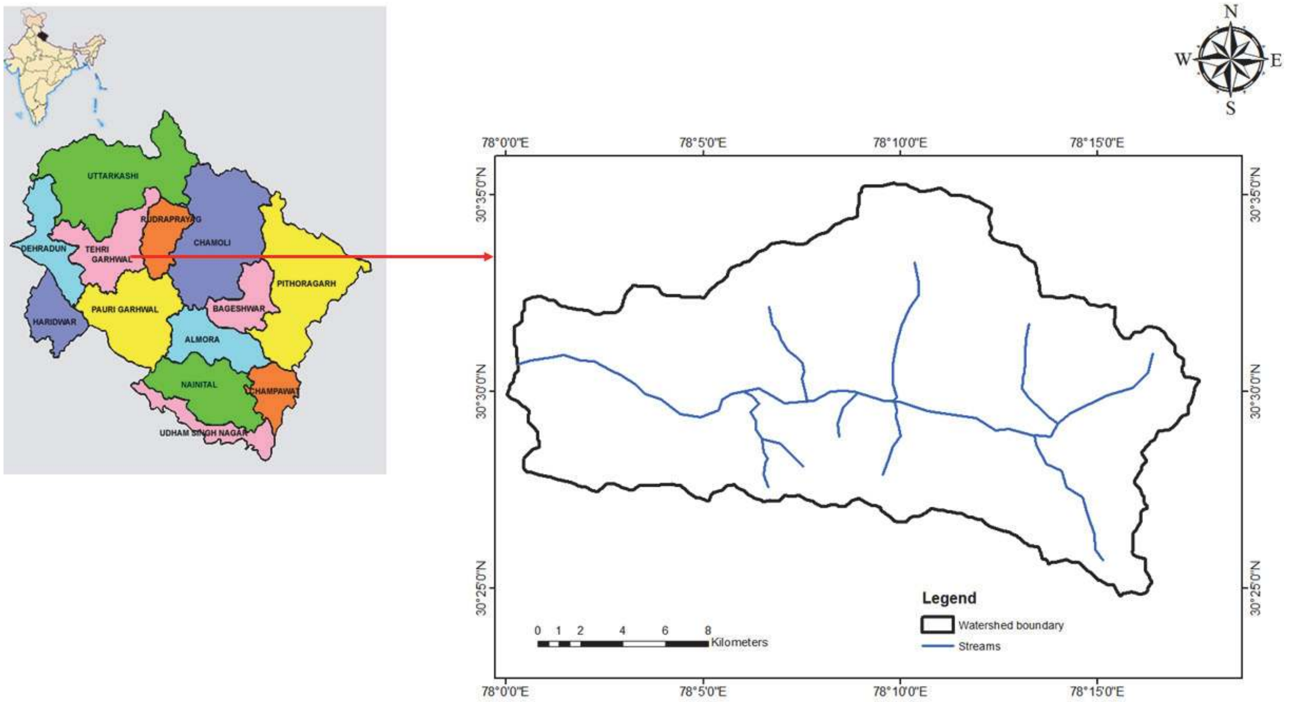

Figure 1(a). Location of study area.

Figure 1(b). Confluence of Aglar and Yamuna River near Yamuna Bridge.

This watershed is mainly covered by a forest of oak, pine, and deodar or deodar mixed. Patches of highland grass lands are found at a higher altitude. Shrubs and grasses mostly cover the lower slopes. Land use/land cover of this watershed is mainly forest (41.4%) with the remaining areas of pasture (16.1%), agriculture (19.3%), bare (13.9%), built up (4.1%), and water bodies (5.1%). A large part of the area is hilly with steep gradients (fig. 1c) and loose soils that lead to erosion of soil during the high intensity precipitation, particularly during the monsoon seasons. In terms of climate, the area varies between subtropical to temperate humid climates with an average annual temperature approximately between 6°C to 19.8°C. The majority of precipitation occurs as rainfall between July and September. Geology of the watershed consists mainly of shale, quartzite, slate, limestone, and phyllite.

For the present study, a small agriculture area has been selected which is located near Thatyur whose socio-demographic characteristics is summarized in table 1. Growth in population of the study area is high (28.61%) as compared to an average (2.35%) growth of the districts which thus increases the pressure for utilizing the natural resources in an optimal way.

Data: Continuous mean daily spring discharge data from February 2014 to April 2016 was measured from Mathamali location (fig. 1a). The daily spring volume varies between 8.31 to 71.41 m^3 with a mean of 22.55 m^3. The spring volume fluctuates regularly with a standard deviation of 11.25 m^3. The rainfall data was monitored from a tipping bucket rain gauge, which is located about

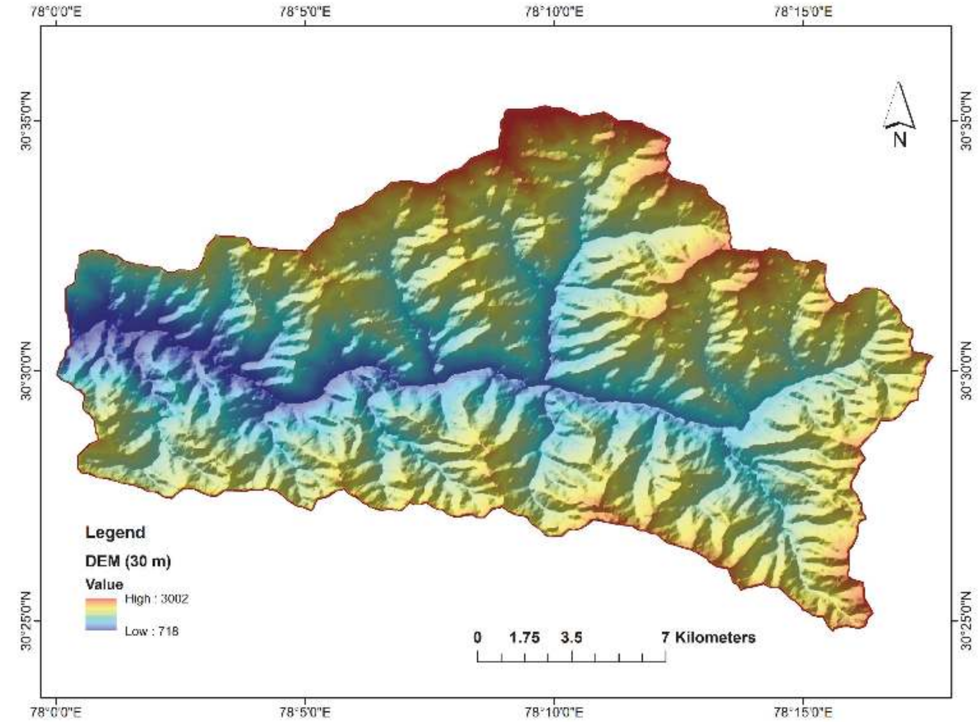

Figure 1(c). DEM of Aglar watershed (study area).

Table 1. Socio-demographic profile of Thatyur and Tehri-Garhwal regions.

Sr. No.	Particulars	Thatyur 2001	Thatyur 2011	Thatyur Percentage Change (%)	Tehri-Garhwal 2001	Tehri-Garhwal 2011	Tehri-Garhwal Percentage Change (%)
1	Area (ha)	22.92		-	364200		-
2	No. of Household	98	128	30.61			
3	Total Population	388	499	28.61	604747	618931	2.35
4	*Male Population*	209	264	26.32	295168	297986	0.95
5	*Female Population*	179	235	31.28	309579	320945	3.67
6	Total Population of Child (0-6 Yr)	67	77	14.93	98524	84657	-14.07
7	*Male Population of Child (0-6 Yr)*	36	43	19.44	51116	44634	-12.68
8	*Female Population of Child (0-6 Yr)*	31	34	9.68	47408	40023	-15.58
9	Total Schedule Caste	194	179	-7.73		102130	
10	*Male Schedule Caste*	109	92	-15.60		50371	
11	*Female Schedule Caste*	85	87	2.35		51759	
12	Total Schedule Tribe	0	0	0		875	
13	Total Literate	270	397	47.04	337816	407994	20.77
14	*Male Literate*	162	223	37.65	208251	227406	9.20
15	*Female Literate*	108	174	61.11	129565	180588	39.38

200 m from the location of the spring. The seasonal rainfall is most common in July-September and December-January which influence the behavior of the spring. The maximum rainfall measured in a day was 71.41mm with a mean rainfall of 2.76 mm. Kumar and Sen (2017) describe the behavior of Mathamali spring with rainfall for different seasons. The spread of discharge and rainfall is measured by measuring the sample variance.

The meteorological parameters such as temperature, humidity, wind speed, and solar radiation that are essential for the calculation of evaporation were also observed at a daily time scale. The statistics of the observed daily meteorological variables are summarized in table 2 and an average monthly minimum and maximum temperature, humidity, wind speed, sunshine hours, solar radiation, and calculated ET_0 is summarized in table 3. The solar radiation along with the percentage of humidity is one of the important features of climate, which influences ET_0 and found major variations at a monthly scale. The rainfall during the dry period (April-June, September-October) is usually less than the ET_0 throughout the month whereas during the wet period only the months of June to August expect rainfall that is more than ET_0.

Table 2. Statistics of the meteorological and spring flow based on daily observed data.

	Min.	Max.	Mean	Standard Deviation	Sample Variance
Temperature (°C)	6.71	28.42	18.96	6.14	37.65
Humidity (%)	23.87	97.89	70.49	15.7	246.79
Wind speed (K.M./h)	0	23.65	12.3	7.34	53.81
Solar rad (W/m^2)	7.3	307.35	156.73	66.7	4457.5
Rainfall (mm)	0	91.29	2.76	9.85	97.05
Spring volume (m^3)	8.31	71.41	22.55	11.25	126.61

METHODOLOGY

EVAPOTRANSPIRATION (ET_0) AND CROP WATER REQUIREMENT (ET_C) ESTIMATION

Evapotranspiration (ET_0): Loss of water from the soil surface and vegetative cover from two different processes are called evapotranspiration (ET). A large number of climatic (temperature, wind velocity, solar radiation, humidity) and other factors such as crop type, crop height, soil salinity, etc. affect the ET. The ET of any crop with reference to grass having specific characteristics is called reference crop evapotranspiration (ET_0). The Penman-Monteith equation is being applied to calculate ET_0 using equation 1.

$$ET_0 = \frac{0.408 \times \Delta \times \left(R_n - G\right) + \gamma \times \left(\frac{900}{T+273}\right) \times u_2 \times \left(e_s - e_a\right)}{\Delta + \gamma \times \left(1 + 0.34 u_2\right)} \qquad (1)$$

where

ET_0 = reference evapotranspiration (mm/d);

R_n = net radiation at the crop surface (MJ/m^2/d);

G = soil heat flux density (MJ/m^2/d);

T = mean daily air temperature at 2 m height (°C);

Table 3. Monthly average meteorological data for the Aglar watershed (2015).

Month	Temperature (°C) Max	Temperature (°C) Min	Humidity (%)	Wind Speed (km/d)	Sun shine (h/d)	Solar Rad. (MJ/m^2/d)	ET_0 (mm/d)	Rainfall (mm/d)
Jan	9.4	8.7	66	68	10.8	16.3	1.57	0.9
Feb	14.2	11.4	62	119	11	19	2.27	2.7
Mar	18.8	18	57	209	12.8	25.9	4.65	5.4
Apr	22.4	21.6	45	197	13.1	28	5.64	3.0
May	24.6	23.9	54	313	13.7	30.1	6.7	0.6
Jun	26	25.4	72	471	14.3	31.3	6.7	3.9
Jul	24.4	24.4	90	534	14.1	30.9	4.97	9.4
Aug	23.8	23.3	90	522	13.2	28.5	4.44	5.2
Sep	22.6	22.1	81	429	12.2	24.9	4.4	0
Oct	18.7	18	73	308	11.7	20.9	3.48	0
Nov	14.6	13.9	70	200	10.9	17	2.32	0
Dec	10	9.4	72	118	10.5	15.1	1.44	0.7

u_2 = wind speed at 2 m height (m/s);
e_s = saturation vapor pressure (kPa);
e_a = actual vapor pressure (kPa);
e_s-e_a = saturation vapor pressure deficit (kPa);
Δ = slope of saturation vapor pressure curve at temperature T (kPa/°C);
γ = psychrometric constant (kPa/°C).

Equation 1 requires daily records of air temperature, solar radiation, humidity and wind speed. Other required parameters for equation 1 can be derived using empirical equations.

Crop water requirement (ETc): Water requirement for the crop under certain specific conditions and to achieve full production is called crop evapotranspiration or crop water requirement (ETc).

$$ETc = ET_0 \times Kc \tag{2}$$

where

ETc = crop evapotranspiration (mm/d);
ET_0 = reference evapotranspiration (mm/d);
Kc = crop coefficient Kc varies with the crop growth, crop type and limited extent of climatic conditions. The value of Kc and growth stages for different crops in the study area is summarized in tables 4 and 5.

WATER BALANCE

The monthly water balance was calculated on the basis of daily monitored rainfall, temperature, ET, and spring flow at the catchment. At the spring catchment level, the water balance is being simply measured by its simplest form, by the equation: I - O = ΔS, where I = input of water to the catchment (rainfall); O = output from the catchment (spring flow); and ΔS = change in storage within the spring catchment. Not all rain that falls over the catchment reaches the streams and a significant fraction of total rainfall is intercepted by forest on the upper catchment and litter and evaporates back to the atmosphere. Storage of water can occur in soil and in vegetation. Storage in vegetation is small in total volume (compared to that stored elsewhere) but can have a significant impact, in the short-term, on crop water use. The average monthly water crop requirement is discussed in the later section. Table 3 shows the variation of the input (rainfall) and the monthly variation of this with the outflow (spring volume) is discussed in the later section in term of water availability.

OPTIMIZATION

Table 4. Growth stages of crops at Mathamali.

	Crop Growth Stages (days)				
Crop Type	Initial	Development	Mid-Season	Late Season	Total
Potato	30	25	45	30	130
Onion	15	25	70	40	150
Garlic	40	25	95	20	180
Rice	25	25	50	25	125
Beans	15	20	30	15	80
Tomato	35	45	70	30	180
Cabbage	40	60	50	15	165
Capsicum	40	60	50	15	165
Peas	15	25	35	15	90
Radish	10	10	15	5	40

Table 5. Crop coefficient and maximum average height for different crops at Mathamali.

	Crop coefficients and mean maximum height			
Crop Type	Kc (initial)	Kc (mid)	Kc (end)	Maximum crop height (cm)
Potato	0.5	1.15	0.75	60
Onion	0.7	1.05	0.75	40
Garlic	0.7	1	0.7	30
Rice	1.05	1.2	0.75	100
Beans	0.5	1.05	0.9	40
Tomato	0.6	1.15	0.8	60
Cabbage	0.7	1.05	0.95	40
Capsicum	0.7	1.05	0.95	55
Peas	0.7	0.9	0.85	30
Radish	0.5	1.15	1.1	50

Planning and management of available natural water resources and agriculture land are the key drivers of sustainable economic development in hills. A linear programming based optimization model is used for optimal crop planning and spring water distribution. The model maximizes net crops yield subjected to water availability constraints. The model is farmed on the basis of data availability of different crop type and observed data of available water on small micro agriculture land of 20,000 m^2. Linear programing is widely used for maximizing or minimizing a linear objective function subject to a given set of linear constraints. In this study, the main objective is to maximize the total crop yield in small micro agriculture watershed by optimal allocation of the area for different crop type using the spring and rainfall volume.
Mathematical representation of model

Objective function:

1. Maximization of crop yield;

$$\text{Max CY} = \sum_{i=1}^{m}\sum_{j=1}^{n} p_j \times A_{i,j} \tag{3}$$

2. Maximization of total crop area;

$$\text{Max A} = \sum_{i=1}^{m}\sum_{j=1}^{n} A_{i,j} \tag{4}$$

3. Minimization of irrigation water;

$$\text{Min Vol} = \sum_{i=1}^{m}\sum_{j=1}^{n} CWR_{i,j} \times A_{i,j} \tag{5}$$

Subjected to the following constraints:

Land availability:

$$\sum_{i=1}^{m}\sum_{j=1}^{n} A_{i,j} \leq 20{,}000 \text{ m}^2 \tag{6}$$

Monthly water availability:

$$\sum_{i=1}^{m}\sum_{j=1}^{n} W_{i,j} \leq \text{Monthly available volume} \tag{7}$$

Non-negativity constraints: All variables should be positive where

CY = crop yield;
n = type of crop;
m = month;
p_j = productivity per unit area;
A_j = area of jth crop;
CWR_j = crop water requirement for jth crop.

The decisive option would involve selection of optimum area and available water resource.

COST BENEFITS ANALYSIS

The main focus of this analysis is to calculate the cost involved to irrigate the particular crop and net benefits gained. Cost associated to the irrigation may include the land preparation cost, seed purchase, labors cost during the cultivation, transportation, cost of packing, etc. The ratio of the total input cost and the rate at which it sells gives the cost benefits. Ultimately, cost benefits analysis aims to help inform decisions about whether to proceed with the same crop or not, and to choose which crop option to implement, where there are several options. It is one of several tools that can be used to help inform decision-making where the land and water are the constraints.

SYSTEM OF RICE INTENSIFICATION (SRI)

The System of Rice Intensification (SRI) is a set of principles and thoughts which can increase the productivity by decreasing the rice water and fertilizer requirements. In SRI first principle is to use 8-15 day old seedlings with two or three leaves to preserve the crop inherent growth potential for rooting. The second principle is to transplant single seedling per hill as compared to the conventional planting of three to six seedlings in a clump with the minimum time interval between the time taken out from the nursery and plantation at a depth of 1-2 cm. Planting is to be done at a grid of 25×25 cm or 30×30 cm or more depending upon the fertility of the soil. This will reduce the plant density, have enough space for roots and canopy to grow and have more access to sunlight and nutrients. Supply water to the field up to 2.5 cm depth after the water ponded earlier disappear and hairline cracks are formed on top of the soil surface. It is preferred to apply less quantity of water in the field during the evening to allow water sink into the field and soil saturation to occur. The saturated soil should be aerobic to enhance the soil organic matter content. This practice will provide sufficient water to meet the need of the crop but not in excess to avoid root suffocation. After 10-12 days of the transplanting, control the weeds by inter cultivation with the weeder at regular interval of 12-13 days until the canopy closes, passing between the rows and making perpendicular passes across the field. This helps in soil aeration and improves the rice crop growth by benefiting both roots and aerobic soil organisms. Use of cattle manure, bio fertilizers, and vermi-compost is suggested instead of chemical fertilizers to improve soil structure to improve the performance of the rice crop. SRI offers a great scope not only to overcome the water scarcity but also to increase rice production and to enhance the livelihood of rice farmers at the same time.

RESULTS AND DISCUSSION

It is impossible to accomplish the sustainable development of an area without quantifying the availability of water resources and other natural resources. As projected, the water demand for India will increase to 22.5% and 32.3% and the food demand will increase to 44% and 87% by 2025 and 2050, respectively (Amarasinghe et al., 2007). The population of Tehri-Garhwal district has also increased from 604747 to 618931 (2.35%) in the past decade that leads to the decline in per capita water availability (Chandramouli and Registrar, 2011). The climate variability further threatens the water to decline and cause food insecurity in this region. To accurately measure the accessibility of spring water for irrigation we require quantification of rainfall, spring flow, and its variation together with evapotranspiration at the micro-watershed level.

WATER AVAILABILITY

The Aglar watershed is categorized as a humid sub-tropical climatic zone with medium to large slope in this region which offers less potential for major development. Rainfall data analysis of three years (2013-2016) over Aglar watershed revealed that the total annual rainfall is 2870.08 mm with an average rainfall of 956.69 mm/year. This region is mainly categorized into non-monsoon and monsoon period, the non-monsoon period occurs between the month of March-June and October-December, and the monsoon period from July-September. During the monsoon, the rainfall depth in July is the highest with an average rainfall of 330.8 mm followed by August and February with an average rainfall of 188 and 120.4 mm, respectively. The discharge of Mathamali spring analysis revealed that the average annual availability of spring water in this watershed is 7149.5 m^3. The volume of spring water varies with the season as shown in figure 2 and reached maximum volume (1063.8 m^3) in the month of October and minimum volume (293.2 m^3) in February.

The total monthly average domestic water requirement for 46 households with an average family size of five in study area region is 310 m^3. The surplus spring discharge available during the monsoon season and the amount of rain water is not being utilized by a local resident. The total volume of spring and rainfall (21119.4 m^3) which goes directly to the river has some potential to irrigate the small land holdings.

CROP WATER REQUIREMENT

The economy of the Aglar region is mainly dependent on agriculture which is the main user of water. Several people of this region, depend on predominantly on crops user cultivate themselves in their small marginal land. However, the absence of required rainfall, lack of conservation of natural resources such as soil and water hinders the economic growth. The estimation of evapotranspiration is a major issue in the estimation of crop water requirement as well as an understanding of hydrology (Von Zabeltitz, 2011). Monthly crop water requirement for different crops grown in the area in different month is given in table 6.

The FAO Penman-Monteith (PM) has been used in this study to calculate ETo which is widely and commonly

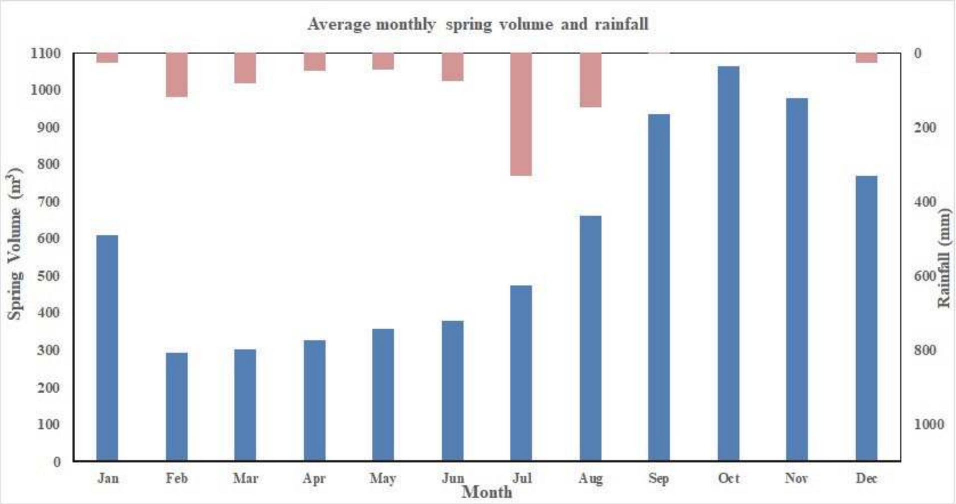

Figure 2. Average monthly spring volume variation.

used. The coefficients of determination (r^2) of estimated monthly average ETo and the monthly average of past 102 years (Portal, 2010) is 0.90 (fig. 3). Calculated ETo in the study area in 2015-2016 varies in between 1.04 to 9.14 mm/day with average of 4.75 mm/day. The ETo increases steadily from 1.04 mm/day in the month of January to the highest of 9.14 mm/day in the month of June, afterward it decreases gradually to 2.6 mm/ day in December. The maximum value of calculated ETo in the month of June can be explained by the hot and dry summer as compared to the other months (Hu et al., 2017). The variation in monthly average ETo directs that planting time can affect crop water requirement.

In the study area, 10 major crops are grown, i.e., potato, onion, garlic, rice, beans, tomato, cabbage, capsicum, radish, and peas. The total calculated monthly crop water requirement of each crop for the study area is given in table 6. The total water requirement for all of the crops in the study area is 6411.35 mm with a maximum crop water of 1091mm required in the month of May. Tomato requires the maximum amount of water (1062.42 mm) followed by cabbage and capsicum (946.76 mm each). The minimum water required (92.91 mm) is for radish. The two major crops of the region are potato and rice which require 707.5 and 733.72 mm of water. The calculated crop water requirement proved that the crop evapotranspiration is more (946-1062 mm) for crops with extended duration (165-180 days) as compared to (92.91mm) for short duration (60 days) crops. Also, the crop water requirement is more (1091 and 996.7 mm) in the month of May and June because of higher temperature (24.6-26 °C) and sun shine hours (13.7-14.3 h) than in the winter which is similar to the FAO-56 (Allen, 2000). This demonstrates that it is crucial to apply scientific water management in light of the need for the crop yield so that higher crop productivity and water efficiency can be achieved with the optimum amount of crop and water (Vishal et al., 2013). It is important to make a systematical strategy for the release of water from available water resource (spring) to meet the crop water requirement so that people have an adequate amount of water when needed.

OPTIMIZATION OF AREA

Optimum use of water and land can help in sustainable development (Janga and Nagesh, 2008). In Aglar, it is most prominent to use the spring flow for irrigation of a small agriculture area of at least 20,000 m². Major crops grown in this area are potato, onion, garlic, rice, beans, tomato, cabbage, capsicum, radish, and peas. Initially (trial 1), the optimum crop yield from the area of 20,000 m² is 521quintal with a uniform distribution of an area of 20,000 m² each to potato, radish, and pea. The benefit to cost (B/C) ratio is one of the methods used to understand the efficiency of agricultural practices and suggest the possibility to create further benefits from the same resources by altering the approach. The B/C ratio is very

Table 6. Monthly water requirement of crops (mm).

Sr. No	Crop Type/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	Potato		39.4	136.9	215.6	248.2	67.8							707.9
2	Onion	41.2	58.5	113.6	95.8								55.6	364.7
3	Garlic	49.75	78.01	155.8	185.4	71.47						31.2	38.64	610.22
4	Rice							185.0	195.8	199.8	153.0			733.72
5	Beans					148.4	241.6	108.5						498.54
6	Tomato		46.81	113.4	198.9	270.9	266.2	166.2						1062.42
7	Cabbage				131.2	175.9	210.6	183.2	176.1	69.75				946.77
8	Capsicum				131.2	175.9	210.6	183.2	176.1	69.75				946.77
9	Radish											73.48	19.43	92.91
10	Peas								103.2	186.4	157.8			447.4
	Total	90.95	222.7	519.7	958	1091	996.7	826.2	651.2	525.7	310.8	104.7	113.7	6411.35

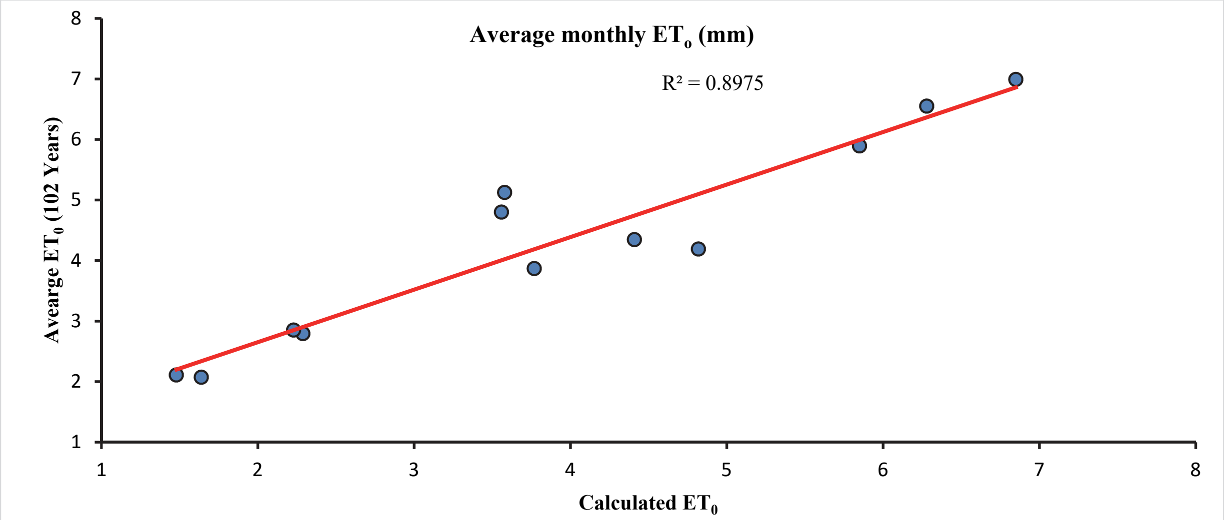

Figure 3. Comparison of calculated ET$_0$ at Aglar with mean of 100 year ET$_0$ of district.

Table 7. Cost-benefit and water productivity during different trials.

	Cost (Rs.)		B/C	Water Productivity	
Trial No.	Generated	Applied	Ratio	Conventional	SRI
1	556330	336140	1.56	2.09	2.09
2	487425	198795	2.45	1.78	1.86
3	572336	222594	2.57	1.68	1.73
4	414407	168202	2.46	1.26	1.29
5	433472	161141	2.69	1.03	1.07
6	414207	169750	2.44	1.48	1.52
7	437943	172328	2.54	1.45	1.48

low (1.56) for the above optimal allocation of the area. The optimized allocated area is also not in accordance with the survey and the questionnaire prepared with the local community (Appendix 1). There was no area allocated in optimization for rice which is the main local crop. After limiting the minimum 5000 m^2 (trial 2) of the area for their major crops (i.e., potato and rice) the total yield reduces to 410 quintals with improved B/C ratio of 2.45 (57%). To increase the B/C ratio by 64% and to improve the economy by further changing the crop type and optimum area will lead to the increase in the net productivity of 483.1 quintals (trial 3).

If excess spring volume during the monsoon is stored by constructing a tank of 5000 m^3 and utilizing it for irrigation during the required period will further increase the net benefit. After utilizing the surplus water with the area and monthly water availability constraints (trial 4) the net yield reduces by 35.1% with B/C ratio of 2.46. By changing the mindset to increase the net benefit by not growing onion and allocate the area to another crop (trial 5) will result in further decrease in the net productivity and B/C ratio of 2.69. Loss of net productivity in (trial 4 and 5) allows reducing change of crop type and crop area from which we are not gaining more profit (trial 6). Trial 6 provides the net profit of Rs. 244457 with the B/C ratio of 2.44 and have enough water to irrigate cabbage for some area.

After considering the available area (trial 7) during the growing period and water requirement the optimum area for this trial is presented in table 7. The net crop yield is 335.84 quintal with B/C ratio of 2.54 (trial 7). The crop yield from the field can be further increased by applying the water through drip irrigation rather than flood irrigation (Singh et al., 2009).

WATER PRODUCTIVITY

The increasing scarcity of water in the hills and lack of understanding of water management towards agriculture have raised questions regarding the total yield from a field and the net benefit. The major factors on which benefits depend are weather conditions, market conditions, governance and socioeconomic drivers, management of crops, and availability of natural resources (fig. 4).

Forecasting of weather has a great potential towards decision making process in relation to agricultural practices (Hammer, 2000; Roncoli et al., 2009, 2011). Accurate forecasting of ET and rainfall and timely forecasting helps to harvest the crop and prevent losses accordingly. Timely forecasting means that the forecast should be so long as with sufficient time to take the necessary decision and action regarding the type of crop grown and its water requirement. The forecast will have no meaning if the choice of crop and management strategies cannot be implemented in the agriculture field before the forecast event. Gain in total agriculture productivity by following timely forecast can be evaluated using the agricultural productivity index (API) equation 8.

$$\text{API} = \left(\frac{P}{P_n} / \frac{A}{A_n} \right) \times 100 \tag{8}$$

where P and P_n are the productions of particular crop per unit area (A) and the total production in the whole region having an area (A_n).

There is deficiency in government policies in dealing with climate change and changing water scenarios. Increase or decrease in available water because of climate change or other anthropogenic changes will lead to proper assessment of these changes and planning at the regional level to reduce the risk and vulnerability. The inequality of supply of water among the different users and stakeholders effect the convergence of laws and legislations and need some

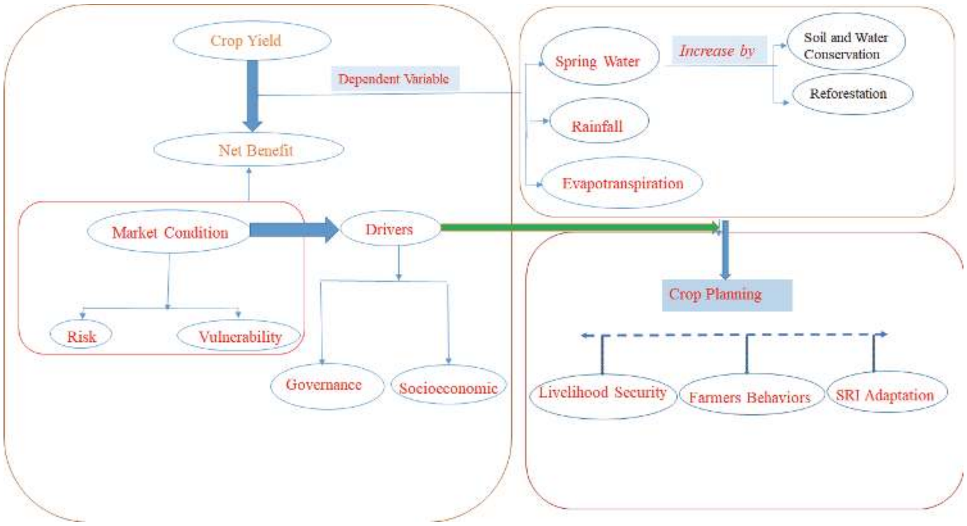

Figure 4. Flowchart showing major factors responsible for crop yield.

transparent regulations and monitoring. Socioeconomic is another important driver for market condition and net benefits from the total yield. The gain in total yield and increase of water productivity by adopting SRI techniques has been summarized in table 7. Overall, it has been found that, SRI produces 49% higher yield with 14% less water and thus increase the water productivity (Thakur et al., 2014). Increase in the total yield by adopting SRI from different countries has also been presented by Kassam et al. (2011) and concluded that stress should be given to water productivity than on water use efficiency. Economic analysis of SRI with the conventional method has been done by Durga and Kumar (2013). In SRI, all tiller has more time for growth and development resulting ability to form panicles is much higher than the conventional method. All of the factors discussed above improve agricultural productivity/production.

IMPLICATIONS ON GLOBAL WATER SECURITY

One of long-term visions of national and international organizations is to ensure water security for the growing population around the world by implementing integrated water resources management strategies at local levels. Water security promotes environmental protection and social justice by addressing the conflicts and disputes that arise over shared water resources. Especially in the mountainous regions like Himalayan terrain, water resources, and marginal lands with moderate to steep slope are some of the major constraints for socio-economic and sustainable development. The mountainous area community development is mainly associated with the enhancement of agricultural yield and its allied actions. Therefore, quantifying the water availability from springs and evaluation of reference crop evapotranspiration for major crops helps in assessing the potential of springs as an alternative irrigation source as compared to the dependence on rainfall. Optimal use of spring water can help in coping up with the water security issues in this region, which in turn can support sustainable agriculture and thereby accomplish economic security at the regional level.

SENSITIVITY ANALYSIS

With the current crops grown in the hilly area, the net profitability measured in terms of B/C ratio depends on the market selling price and the total yield from the field. Table 8 indicates that increase in yield is likely to be more sensitive than the decrease in the market selling price. The reduction of market selling price by 5% results in a decrease of 5.7% in B/C ratio whereas with an increase of 5% in the total yield results in an increase of B/C ratio by 4.9%. Further reduction of market selling price and increment in the crop yield by 10% results in the decrease and the increase of B/C ratio by 13.9% and 9.84%, respectively.

This implies that a change of crop yield can have a significant impact on the B/C ratio. To gain the net profitability of farmer a major increase in market price is required. The increase in the yield by 30% can increase the revenue of farmers by Rs. 3687197 which is 217% more than their input costs. A sensitivity analysis suggests enhancing the total yield from the irrigated area in comparison to the market price which is influenced by many governmental and non-governmental policies. This forces to conserve the natural resources such as rainfall and spring volume and utilize it for agriculture to improve the farmer's economy.

CONCLUSION

Quantifying the water availability from springs and evaluation of reference crop evapotranspiration at regional scale helps to assess the importance of springs as an option

Table 8. Sensitivity analysis of benefit-cost (B/C) ratio in Thatyur.

Description	Decrease in Market Price						Increase in Yield					
Percentage change (%)	5	10	15	20	25	30	5	10	15	20	25	30
B/C ratio	2.3	2.1	2.07	1.95	1.83	1.7	2.56	2.68	2.8	2.93	3.05	3.17

for agriculture other than rainfall in the Lesser Himalaya region. In this study, Thatyur region of Aglar watershed is selected as a case study. The crop water requirements of ten major crops that are grown were evaluated. The present study also focuses on optimization of natural resources (land and water) and on sensitivity analysis of B/C ratio. The analysis of water accountability shows that the rainfall in July is high with an average rainfall of 330.8 mm followed by August and February with an average rainfall of 188 and 120.4 mm, respectively. Spring discharge analysis revealed that the average annual availability of spring water in this watershed is 7149.5 m^3 and springs serve as an option to use the water for agriculture in an optimized way. Understanding of rainfall and spring variability are very important to develop any artificial structure for storage which can be used later for irrigation. The crop evapotranspiration is more for crops with extended duration in comparison to shorter duration.

Excess spring water during monsoon can be stored by constructing a tank of 5000 m^3 and utilizing it for irrigation during the required period will increase the net benefit from agriculture. The estimated net crop yield is 33584 ton with B/C ratio of 2.54 by utilizing the stored water. Crop yields can be further increased by applying water through drip irrigation. There is a scope to increase water productivity by adopting SRI techniques. It has been found that, SRI produces 49% higher yield with 14% less water. Sensitivity analysis divulges that the increase in the total yield by 30% can increase the revenue of farmers by 217%. Judicious use of these available natural resources requires long term planning and accurate database, and assessment of risks and benefits of agriculture.

The findings of this study offer an approach for a sustainable development of agriculture in the mountainous districts. The progress of agriculture by utilizing the available natural resources can also lead to the evolution of tourism and industries which is another way for the development of the mountainous regions. To alter the poor economic condition and overcome water security issues in the study region, it is thus important to adopt the approaches suggested in this study.

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APPENDIX I

Questionnaire

1. General Information of sampled village/MWS

Village Name:	Climate: Dry/ Wet/……….
Source of domestic and irrigation:	Location (Lat. & Long.)
Annual Average Rainfall: mm	Average Temperature: ……………..°C
Major Crops:	

2. Land Distribution

Sl. No.	Land Category	Total area (ha)
1	Personal	
2	Common Property	
3	Others	

3. Demographic Details:

Sl. No.	Caste	Population			Total Households (nos.)			
		Male	Female	Total	Landless	Marginal (<1.0ha)	Small (1.0 – 2.0 ha)	Large (>2.0 ha)
1	SC							
2	ST							
3	OBC							
4	Others							

4. Major Crops

Sl. No.	Crops	Kharif			Rabi			Summer		
		Area (ha)	Production (‘000 kg)	Productivity (kg/ha)	Area (ha)	Production (‘000 kg)	Productivity (kg/ha)	Area (ha)	Production (‘000 kg)	Productivity (kg/ha)
Rainfed/ Irrigated										
	Cereals									
	Pulses									
	Vegetables									
	Cash Crops									

5. Hydrological Details

Sl. No.	Particulars/ Indicators	::	Benchmark
a)	Rainfall (Intensity, no. of rainy days)	::	
b)	Stream Flow (cum/sec)	::	
c)	Ground Water Level (metre)	::	
d)	**Status of spring water**	::	
e)	Drinking Water availability	::	

6. Agriculture:

Sl. No.	Particulars/ Indicators	Benchmark	Sl. No.	Particulars/ Indicators	Benchmark
1	Forest land as % of total agri. Land		8	**Improvement in productivity (Agriculture)**	
2	Total cropped area in Agriculture			(i) Cereals	
3	Demonstration of new technology			(ii) Pulses	
4	No. of farmers undergone training			(iii) Oil seeds	
5	**Cropping intensity**			(iv) Cash Crop	
6	**Increase in area (Agriculture)**			(v) Fodder	
	(i) Cereals				
	(ii) Pulses/Vegetables				
	(iii) Fodder				
	(iv) Cash Crop				
	(v) Pasture Land				
7	**Improvement in productivity (Agriculture)**				
	(i) Cereals				
	(ii) Pulses/Vegetables				
	(iii) Fodder				
	(iv) Cash Crop				
	(v) Pasture Land				

7. Economic, Financial, Process, and Group participation

Sl. No.	Particulars/ Indicators	Benchmark	Sl. No.	Particulars/ Indicators	Benchmark
	Economic Indicators			**Financial Indicators**	
1	Total Income		1	Finance/credit linkages (SHGs etc.) (nos.)	
2	No. of families recorded positive change in income (Rs.)		2	Watershed development Fund - Utilization	
3	Distress migration		3	Maintenance mechanism	
	Process Monitoring			**Formation of Institutions**	
1	Status of area and stream treatment		1	No. of SHGs etc.	
2	No. of social audits		2	Awareness of participation in Watershed Committee (%)	
3	Gram Sabha participation in planning & management of watershed		3	Involvement of beneficiaries (%)	