ENVIRONMENTAL IMPLICATIONS OF NATURAL SPRINGS IN DUGA, EAST SIKKIM

Dissertation Submitted to Sikkim University in PartialFulfillment of the Requirement for the Award of the Degree of

MASTER OF PHILOSOPHY

Submitted by:

BASANTI RAI

Under Supervision of

Dr. Uttam Lal

Department of Geography

School of Human Sciences

Sikkim University

Gangtok- 737102

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DEPARTMENT OF GEOGRAPHY
SIKKIM UNIVERSITY
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DECLARATION

I, Basanti Rai, hereby declare that the subject matter of this dissertation entitled "**Environmental Implications of Natural Springs in Duga, East Sikkim**" is the record of work done by me, that the content of this did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and the dissertation has not been submitted by me to any other University/Institute.

This is being submitted in partial fulfillment of the requirements of the degree of **Master of Philosophy** in the Department of Geography, School of Human Sciences, Sikkim University. This work may be placed before the examiners for evaluation.

Basanti Rai 31/07/14
(Basanti Rai)
Roll No: 12MPGP 02
Registration No: 10SU2013

Forwarded by

31.07.2014
(Dr. Sohel Firdos)
Head of the Department

Head
Department of Geography
School of Human Sciences
SIKKIM UNIVERSITY
6th Mile, Tadong 737102, Gangtok- Sikkim

31/7/14
(Dr. Uttam Lal)
Supervisor

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BASANTH RAI

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LIST OF ACRONYMS AND ABBREVIATIONS

ACWADAM- Advanced Centre for Water Resource Development and Management

AWS- Automatic Weather Stations

BAC- Block Administrative Centre

CPR- Common Property Resource

DST- Department of Science and Technology

EC- Electrical Conductivity

FGD- Focus Group Discussion

GDP- Gross Domestic Product

GHC- Greater Himalayan Crystalline

GIS- Geographic Information System

GPS- Global Positioning System

GPU- Gram Panchayat Unit

GSI- Geological Survey of India

HHC- Higher Himalayan Crystalline

ICIMOD- International Centre for Integrated Mountain Development

IHR- Indian Himalayan Region

IRS- Indian Remote Sensing

ISRO- Indian Space Research Organization

LANDSAT- Land Satellite (aUnited States scientific satellite that studies and photographs the earth's surface by using remote-sensing techniques)

LISS- III- Linear Imaging Self-Scanning System

LULC- Land Use Land Cover

MBPCL- Madhya Bharat Power Corporation Ltd.

MBT- Main Boundary Thrust

MCT- Main Central Thrust

MGNREGA- Mahatma Gandhi National Rural Employment Guarantee Act

NGO- Non Governmental Organization

PHE- Physical Health Centre

RHEP- Rongnichu Hydroelectric Project

RM&DD- Rural Management and Development Department

SIMFED- State Co-operative Supply and Marketing Federation Ltd

STDS- South Tibetan Detachment System

TDS- Total Dissolved Solids

UNESCO- United Nation Educational Scientific and Cultural Organization

VDAP- Village Development Action Programme

WHO- World Health Organization

WUA- Water User Association

WWF- World Wide Fund

CHAPTER I

GENERAL INTRODUCTION

I.1 Introduction

Water is indispensable for sustaining life. It has been vital for socio- economic and environmental sustainability. The three quarters of the world is covered by water, but most of it is saline. Of all the water on the Earth, the saline water present in the earth is 92 percent, 2 percent is locked in ice and only 1 percent is potable water. As per ICIMOD report (2010), mountain areas cover 24 percent of the world's land surfaces and are home to 12 percent of the global human population with a further 14 percent living in their immediate vicinity. Most of the world's major rivers have their origin in the Mountains and more than half of the world's mountain areas play a vital role in supplying water to downstream region.

The Himalayas, largest mountain system of the world generally considered to have an abundance of water now are experiencing acute water problems[1]. It stretches for 2500 km all along the northern border of India and forms part of India's seven international boundaries. Nearly 40 million people reside in the Indian Himalayan Region (IHR). The Himalayas is divided from west to east, into three distinct regions, the Western, the Central and the Eastern Himalayas; the Nepal Himalayas occupies the central segment with the Western Himalayas and Eastern Himalayas bordering it on the respective sides[2]. Dependence of a majority of the population largely on spring water implies that with changing climatic conditions and rainfall pattern, a large number of settlements would face drinking water shortages. In fact, half of the perennial springs have already dried up or have become seasonal and nearly 8000 villages are currently facing acute water shortage even for their drinking purposes in Indian Himalayan region[3].

Springs are locally known as *Dharas*. These are the natural discharges of groundwater from underlying various *aquifers*[4]. Springs form the only reliable and sustainable source of fresh water in the Himalayan region. The mountain people have been using it as source

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[1] S. Tambe et al., "Reviving Drying Springs: Climate Change Adaptation Experiments from the Sikkim Himalaya," *BioOne (2012): 62.*

[2] K. Mahamuni and H. Kulkarni. "Groundwater resources and spring hydrogeology in South Sikkim, with special reference to Climate Change ," accessed March 12, 2013, url: http:// Sikkimsprings.org/dv/research/ACWADAM_report.

[3] S. Rana and V. Gupta. "Watershed Management in the Indian Himalayan Region: Challenges and Issues," *American Society of Civil Engineers*, (2009).

[4] Underground bed or layer yielding ground water for wells and springs.

of water for domestic as well as for agricultural purposes since time immemorial[5]. During recent years, a variety of changes have emerged in the land use structure in the Indian Himalayas. With population growth, there has been increased demand for food, fodder, grazing land, water and other natural resources and increasing socio-economic and political marginalization[6].

Sikkim is blessed with number of natural springs, which forms the primary source of water to both urban and rural population. The scattered springs in the state have been significant in meeting people's water requirements for drinking, household, agricultural and other purpose. However, of late, these sources are unable to meet their water requirements as such there are marked decline in spring discharge or some have dried out[7]. Various factors are responsible for diminishing discharge such as land use and land cover change, deforestation, developmental works and other anthropogenic factors. Besides, changes in climatic condition leading to variability in rainfall trend and pattern. The challenge lies both in rejuvenating or augmenting the discharge of these springs as well as steady discharge.

In comparison to rivers and glaciers, natural springs could garner lesser academic attention. It may be due to very nature of these being scattered resource, less population dependent on it and lack of related data. Sikkim has more than seven hundred springs classified as critical. The eight blocks, fifty three gram panchayat units and two ninety three gram panchayat wards are identified as drought prone area in the state by Rural Management and Development Department, Government of Sikkim. The lower parts of south and west district and some part of east district of Sikkim are under serious water shortage. Various institutions from within state and outside state collaborated to work on different aspects of springs. These institutions are DST, WWF- India, Peoples Science Institute (Dehradun), Arghyam (Bangalore), and ACWADAM (Pune). The Arghyam and

[5] G.C.S Joshi and V. Negi. "Geohydrology of Springs in a Mountain Watershed: The need for problem solving Research," *Current Science*, (1996):.
[6] P.K Rawat et al., "Climate Change accelerating hydrological hazards and risk in Himalaya: A case study through remote sensing and GIS modeling," *International Journal of Geomatics and Geosciences*, (2011).
[7] S. Tambe et al., "Reviving Drying Springs: Climate Change Adaptation Experiments from the Sikkim Himalaya," *BioOne (2012): 62.*

ACWADAM are institute for geohydrological studies. Eventually '*Dhara Vikas*'[8] programme has been introduced with regard to developing springs sanctuaries and to manage rural water.

In Sikkim water resource management is pursued largely through Watershed Management approach. A watershed being a geographical demarcation of surface features makes it comparatively easy to manage, monitor and develop surface water. But giving importance to both groundwater management and surface water management in current and future scenarios, it is likely that these two aspects of an overall water management strategy will progressively enhance the water potential to meet the growing water demand.

I.2 Statement of the problem

Mountain has often been regarded as world's water tower which provides essential freshwater to people in the mountain and downstream through snow-fed rivers. However, the people living there are primarily dependent on scattered water resources in forms of springs and streams. These sources are often reported being seasonal or permanently drying out Various studies on springs in Western Himalayas shows the probable factors for the marked decline of spring discharge and incidence of springs becoming seasonal are due to change in climatic condition as well as anthropogenic factor. The anthropogenic factor includes the developmental activities such as construction of road, bridges, buildings and other project work.

In Sikkim, 80 percent of rural population is primarily dependent on natural springs for domestic and agricultural purpose[9]. Most of the springs are rain fed and precipitation pattern of the region usually gets influenced by local orographic features. The lower part of South and West district of Sikkim receives comparatively less amount of rainfall due to its location in rain shadow zone of Darjeeling Hills. The scarcity of water in Sikkim is becoming a major concern for local people and a challenge for government. Some attempts have been made at policy making levels to improve the water security. Rural

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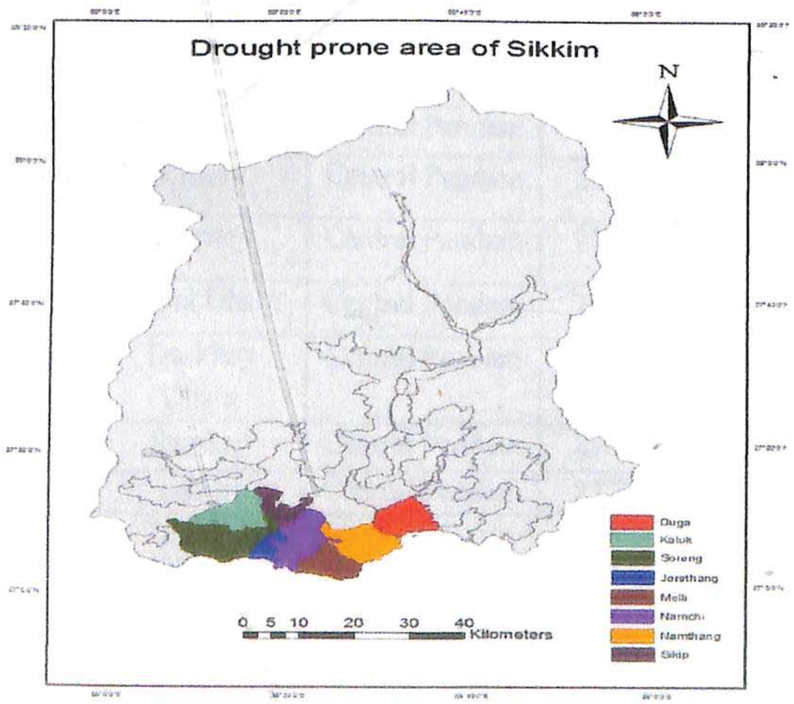
[8] The programme is being initiated by Rural Management and Development Department, Government of Sikkim to conserve and manage rural water resources.

[9] Ibid. p. 62.

Management and Development Department, Government of Sikkim under the programme '*Dhara Vikas*' for rural area water security have identified eight blocks of Sikkim as drought prone area viz. Duga, Namthang, Melli, Jorethang, Namchi, Sikkip, Soreng and Kaluk. Therefore, it is important to have systematic study on natural springs to emphasis on water security so as to make local community resilient with regard to changing environment.

The present study is an attempt to understand the characteristics of natural springs of drought prone area, the Duga block with regard to changing resource utilization and land use practices. The growing populations, changing land use pattern and changes in climatic condition have brought new challenges in the area. It has high impact on the scattered water resource. The unsustainable changes have resulted especially in marked decline in spring discharge; in some cases springs have become seasonal. Thus, scarcity of water has impacted on physical as well as socio- economic structure of the landscape leaving tremendous impact on micro environment. The study has also tried to understand the changes in land use practices and also attempt to document the water conservation and management practices.

Map I.1: Drought prone areas of Sikkim.



I.3 Study Area locations

The study has been carried out in the thirteen springs of Duga block in Eastern part of Sikkim Himalayas, which is located between 27.19 to 88.52 E and altitude ranges from 711 to 1830 meters as shown in Table I.1. The total geographical area of study area is 68 km^2.

Duga has been considered as among the driest part of Sikkim by RM&DD, Government of Sikkim under Dhara Vikas Programme. Entire population of this belt relies on natural springs for drinking, other domestic purpose as well as for agriculture.

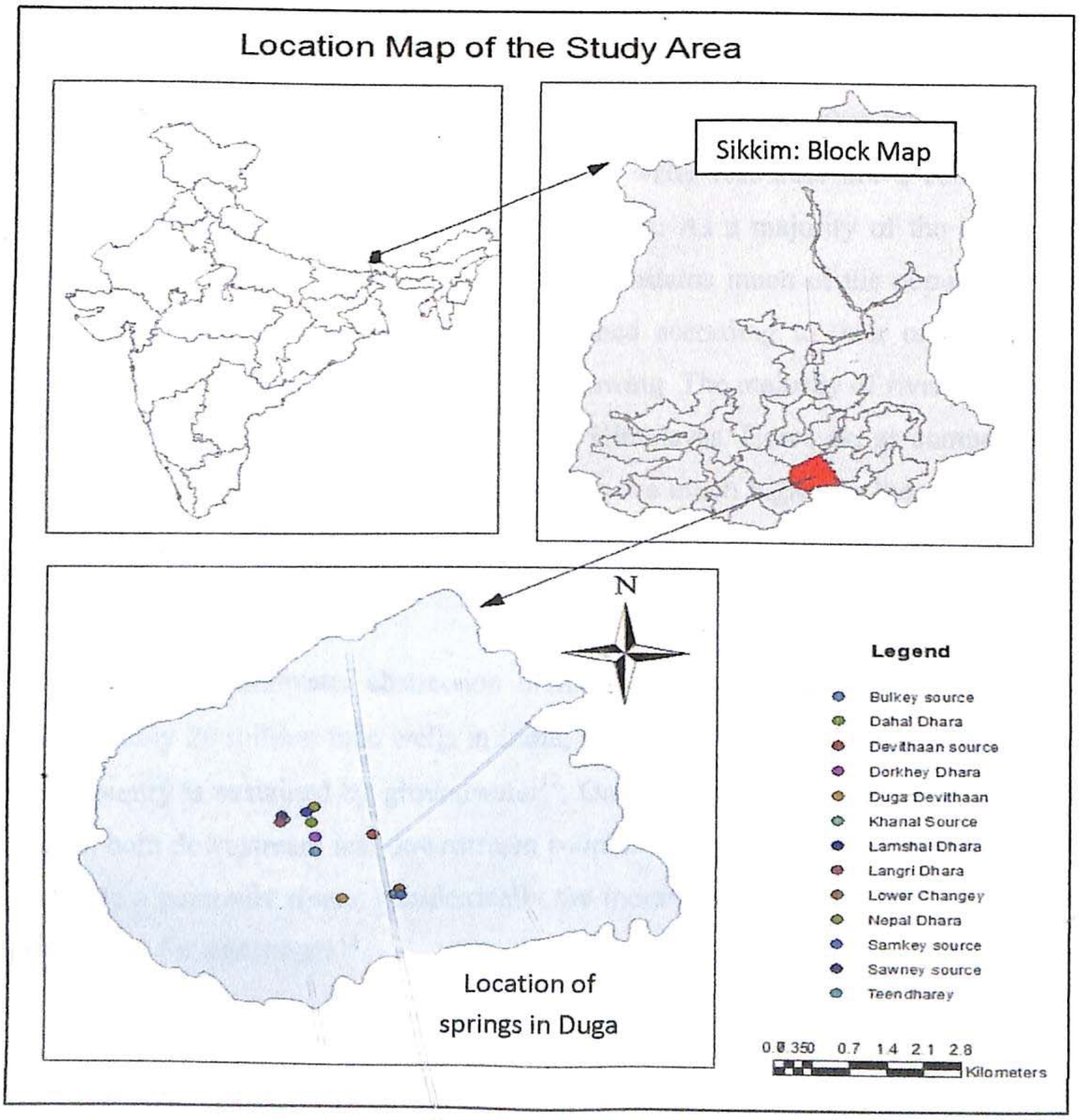
Table I.1: **Location of different springs in Study Area.**

Sl.no	Village/GPW Name	Spring Name	Gram Panchayat Unit	Location		
				Latitude (in ^{0}dec)	Longitude (in ^{0}dec)	Altitude (in mts)
1.	Karmithang	Lamshal	Central Pendam	27.215	88.530	1588
2.	Sajong	Devithaan	East Pendam	27.211	88.543	1453
3.	Bhurung	Dhalay	Central Pendam	27.213	88.531	1447
4.	Deorali	L. Changey	Central Pendam	27.199	88.545	806
5.	Deorali	Bhulkey	Central Pendam	27.198	88.547	811
6.	Duga	Duga Devithaan	Central Pendam	27.197	88.537	952
7.	Bhurung	Teendharay	Central Pendam	27.207	88:532	1128
8.	Karmithang	Khanal	Central Pendam	27.213	88.526	1509
9.	Karmithang	Sawney	Central Pendam	27.214	88.526	1389
10.	Karmithang	Nepal Dhara	Central Pendam	27.216	88.532	1514
11.	Bhurung	Dorkhey Dhara	Central Pendam	27.210	88.533	1275
12.	Deorali	Samkey	Central Pendam	27.197	88.548	702
13.	Karmithang	Langri	Central Pendam	27.215	88.530	1486

Source: Pilot survey, August, 2013.

Map I.2:

Study area map- Duga Block, East Sikkim.



I.4 Overview of Literature

Water is an inherent human need. The International body, United Nation Educational, Scientific and Cultural Organization (UNESCO) had also urged that water should be at the top of the agenda for the Earth Summit in Rio de Janeiro, in June 2012. According to the UN analysis on global water consumption rate, the three countries viz India, China and United States has been listed as the world's most thirstiest nations with its consumption rate of 13, 12 and 9 per cent respectively. This is followed by Russia and

Indonesia- 4 percent each, Nigeria and Brazil- 3 per cent each and remaining 52 percent of water consumes by rest of the world. Owing to population growth, the world's agricultural production is expected to increase approximately by 75 percent by 2050, which again puts pressure on water resources[10]. India and China, with their massive populace, are already facing several water related problems, and these problems are set to worsen considerably in upcoming days. India's water resources are a combination of groundwater resources and surface water resources. As a majority of the rivers in the country are not perennial, groundwater actually sustains much of the population during lean months. India's rivers are usually described according to their origin– either as Himalayan and Peninsular or, East and West flowing. The majority of rivers are rain-fed, with the exception of those originating in the Himalayas. However, as compared to the ground water resources, surface water resources are much higher in the country. Rivers constitute the most valuable and voluminous part of the different types of surface water resources[11].

The excessive groundwater abstraction in India has become unsustainable. There are approximately 20 million tube wells in India, and over fifty per cent of agricultural land in the country is sustained by groundwater[12]. Groundwater makes an essential source of water to both downstream and downstream people. Though, Himalayan range is a source of countless perennial rivers, paradoxically the mountain people are largely depends on spring water for sustenance[13].

I.4.a Springs characteristics

A spring is places where water issues from the ground and flows or where it lies in pools that are continually replenished from below[14]. Likewise, Larry W. Mays (2011) defines spring as a concentrated discharge of groundwater appearing at the ground surface as a current of flowing water. Therefore, springs are points on ground surface from where

[10] Natasha Gilbert,"Water under pressure: A UN analysis sets out global water management concerns ahead of Earth Summit," (2012).
[11] UNESCO Report, "water in a challenging world," (2009).
[12] Ibid. p. 256.
[13] S. Tambe et al., "Reviving Drying Springs: Climate Change Adaptation Experiments from the Sikkim Himalaya," *BioOne (2012): 62.*
[14] Kirk Bryan, "Classification of Springs," *The journal of Geology,* (1919): 523.

water gets discharged and replenished from underlying aquifers under some pressure. Aquifers are defined as a saturated geological formation which can yield sufficient quantities of water to wells and springs[15]. The mountain aquifer acts as water storages and transmits it to the spring. The quantitative (discharge) or qualitative (spring water quality) behavior of a spring over a period on time is completely dependent on the nature of aquifer the spring hosts. However, the seasonality and sustainability of spring water depend on aquifer properties, i.e. storability and transmissivity. These properties of an aquifer are again based on local *hydrogeology*[16].

Larry W. Mays (2011) has categorized aquifers into three types- Unconfined aquifers, confined aquifers and leaky aquifers, depending on the presence or absence of water table. The unconfined aquifers are one in which a water table varies in undulating form and in slope, depending on areas of recharge and discharge, pumpage from wells, and permeability. The confined aquifers, also known as artesian aquifers or pressure aquifers occur where groundwater is confined under pressure greater than atmospheric by overlying relatively impermeable strata. Similarly, the aquifers that are completely confined or unconfined occur less frequently than do leaky, or semi confined aquifers. Therefore, the leaky aquifer represents a combination of unconfined and confined aquifers.

In unconfined aquifers, there are some common characteristics to most recharge areas; likewise, most discharge areas have some common denomination as follows: (i) Recharge areas are usually in topographical high places; discharge areas are located in topographical lows, (ii) In the recharge areas, there is often a rather deep unsaturated zone between the water table and the land surface, (iii) Conversely, the water table is found either close to or at the land surface in discharge areas[17]. The incidence of unconfined aquifers are largely depends on recharge area characteristics such as soil structure and permeability, geology, slope and the vegetational cover on the surface area. In the recharge areas of such aquifers, there is often a deep unsaturated zone between the

[15] Ibid.p.27.

[16] Hydrogeology encompasses the interrelationships of geologic materials and processes with water (C.W Fetter, "Applied Hydrogeology" 4th Edition, Ch 1, pp 3).

[17] C.W Fetter, Applied Hydrogeology, (New Jersey: Prentice Hall, Inc., 2001).

water table and the land surface. The recharge of the unconfined aquifers can be from downward seepage through the unsaturated zone and can occur through lateral groundwater flow or upward seepage from underlying strata. Likewise in confined aquifers, recharge can occur either in a recharge area where the aquifers crops out, or by slow downward leakage through leaky confining layers. If a tightly cased well is placed through the confining layer, water from the aquifer may rise considerable distances above the top of the aquifer. This indicates that the water in the aquifer is under pressure.

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Kirk Bryan (1919) found that temperature, dissolved salts, contained gases, rate and amount of flow, form and position of the spring opening are all characteristics of springs, which, while in many cases related to genesis, vary among springs of the same origin. Nevertheless, various scholars have classified these springs on different basis for making it simpler in understanding springs dynamics. He pointed out two types of difficulties may arise. In the first place, the local structure in the vicinity of springs is difficult to determine, for the presence and passage of water facilitates weathering and destroys the evidence. The presence of luxuriant vegetation also tends to conceal the structure. The second difficulty arises through various combinations of structures which may combine to produce a spring. The structure which plays the predominating role should then determine the classification of the spring. He has classified the springs based on their characteristics into five types viz (i) Depression spring; formed when water table reaches the surface due to topographic undulations, (ii) Contact spring; formed at places where relatively permeable rocks overlie rocks of low permeability, (iii) Fracture spring; occur due to existence of jointed or permeable fracture zones in low permeability rocks, (iv)

[18] Ibid. p.538.

Karst spring; large quantities of water move through the cavities, channels, conduits and other openings developed in limestone, and (v) Fault spring; faulting may also give rise to conditions favorable for spring formation as groundwater (at depth) under hydrostatic pressure can move up along such faults.

Each of the above type behaves differently, depending upon factors such as the characteristics of aquifers feeding the spring. Spring water itself and specifically its chemical composition and physical properties reflect the processes going on in the relevant geological environment[19]. In the mountain areas like the Himalayas, high relief and the complex geological structure plays a vital role in formation of these mountain aquifers. Hydrogeological mapping of the springs often reveals that the recharge area and the area of protection of the springs show a very site-specific relationship, controlled primarily by the underlying geology [20] .Measures intended for augmenting spring discharge is practiced only in the natural recharge areas of the spring, where the identification of local geology, including the structure of the rocks are very important. As such the lineaments produced by joints, fractures and faults play a very significant role on the hydrogeological regime of a catchment[21].

Perenniality or seasonality of springs has a close relationship with precipitation trend and pattern[22]. Fluctuation in spring discharge is due to variations in the rate of recharge and the prevailing hydrologic and geologic conditions where the hydrologic and geologic conditions of a watershed do not vary frequently, however, the discharge variability of a spring can be credited to only one factor, i.e. rainfall. In the window period of rainfall, the rainwater is able to infiltrate the ground surface and recharge the ground water considerably[23]. Further L. Coulson et al (2010) found that discharge of the springs

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[19] J. Siwek and W. Chelmicki, "Geology and land-use related pattern of spring water quality: Case study from the catchment of the Malopolska Upland," *Geologica Acta* (2004).

[20] K. Mahamuni and H. Kulkarni. "Groundwater resources and spring hydrogeology in South Sikkim, with special reference to Climate Change ," accessed March 12, 2013, url: http:// Sikkimsprings.org/dv/research/ACWADAM_report.

[21] G.C.S Joshi and V. Negi. "Geohydrology of Springs in a Mountain Watershed: The need for problem solving Research," *Current Science*, (1996).

[22] G. Sharma and L.K Rai. "Climate Change and Sustainability of Agrodiversity in Traditional Farming of the Sikkim Himalaya," in *Climate Change in Sikkim; Pattern, Impacts and Innitiatives*, ed. S. Tambe (Gangtok, 2012).

[23] G.C.S Negi and V. Joshi, "Rainfall and Spring Discharge Pattern in two small Drainage Catchment in the Western Himalayan Mountain, India," (2004).

occurring in different types of rock formations in the eastern part of Sikkim varies from 0.25 to 1.8 liters per second though the discharge decreases generally from December-January to May and maximum discharge is recorded during post monsoon period i.e., September to November. This implies that the local precipitation pattern has dominant influence over spring discharge.

Changing land use and land cover is another issue in water management. The relationship between land use change and hydrology is complex, with linkages existing at a wide variety of spatial and temporal scales; however, land change unquestionably has a strong influence on global water yield. Land cover and use directly impact the amount of evaporation, groundwater infiltration and overland runoff that occurs during and after precipitation events. These factors control the water yields of surface streams and groundwater aquifers and thus the amount of water available for both ecosystem function and human use[24]. Studies indicate that deforestation, grazing and trampling by livestock, soil-erosion, forest fires, and development activities (roads, mining, construction, etc.) reduce water infiltration capacity of ground surface. The extensive land use changes in the Himalayas have not only disrupted the fragile ecological balance of the watersheds in the region through deforestation, erosion, landslides, hydrological disruptions, depletion of genetic resources, but have also threatened the livelihood security and community sustainability in mountains as well as in adjoining plains ecosystem (Rawat et al; 2011). The high rate of land use change accelerating several environmental problems such as high monsoon runoff, flash flood, soil erosion and denudation during monsoon season and drought during non-monsoon period as dry up of natural springs and decreasing trends of stream discharge. Increasing population and demand of land for agriculture has resulted in pressure in the watershed of the Lesser Himalayan region. Wang Genxu et al, (2005) found a great impact of land use change on regional hydrological process in the Heihe River Basin. The results indicate that with different intensities of land use changes, it has probable impacts on groundwater recharge and discharge regime.

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[24] J.L Frenierre. "Relationship between land changes and water resources vulnerability: A review of exixting literatures," accessed November 18, 2013, url: http://assets.openstudy.com/update/attachments/relationship between land change and water resources vulnerability.pdf.

I.4.b Water Management Practices

With a growing population, global climate change and changes in land use/ land cover occurring, water management is moving to the forefront of government policy. The challenge is to develop a mechanism which enables to manage depleting water resources and to make it use in a sustainable way. In the Himalayan region, the undulating topography with steep terrain itself is the biggest challenge which may hinder the resource management mechanism in a large extent. Mountain people have been managing their springs at best of their traditional knowledge.

Madhukar Upadhya (2009) has highlighted the various traditional water management techniques of different region. In Nagaland the Ruza or Zabo are built on the ridge tops and the middle terraces to collect runoff. The stored water is used for the animals, and then runs down to the paddy fields. The Aahal or Pokhari in Nepal is common meaning a place for wallowing buffalo, is the Nepali name for a type of shallow community pond built to collect runoff in the hills and mountains. The Johad in Rajasthan which consists of a small but long earthen bund (small check dam) built on the upper side of the land to hold back surface flow during rainfall and allow every drop of rainwater to soak into the soil and augment the groundwater. In Pakistan, people build Karez system which consists of a series of wells starting from the foothills along the hill slope and linked at the bottom by an underground channel that collects and brings groundwater to the bottom of the hill. The water can be taken out vertically or drawn at the mouth of the channel at the foot of the hill. The unique advantage of this system is that it helps access groundwater for irrigation using gravity and minimizes evaporation loss in channels that are usually tens of kilometers long. Likewise, the Hiti or Dnunga Dhara in Kathmandu Valley is a stone spout that channels water from springs or a shallow aquifer usually about ten meters below the surface of the ground. In addition, ponds were built close to it to augment the aquifer by storing rainwater.

However the increasing demand of water and interplay of climatic change factor has put tremendous pressure on existing water resources thereby indicating traditional techniques alone are not efficient in present water management system. Thus, it is important to amalgamate the both traditional and scientific techniques and has to implement it in a decentralized manner.

Valdiya (1997) has suggested the concept of spring sanctuary to treat the catchment area of natural spring with an aim to augment its discharge. It includes the three principle measures- engineering, vegetative and social measures. The engineering measures includes the detailed geological mapping to delineate recharge zone of a spring and initiation of recharge zone treatment with barbed wire/ stone wall fencing (to keep away livestock foraging, biomass extraction and other human interferences), digging trenches and pits (infiltration wells) along contours and permeable spots (bedding plane, joints etc.), gully ploughing, bonding of terraces and making them inward sloping, stone and mud built water retention structures etc. Likewise the vegetative measure includes the plantation of low water demanding and shallow rooted grass/ shrubs/ trees, mulching barren spots with weeds/ leaf litter etc. and finally the social measure includes the ban on grazing, fuel hood and fodder cutting, social fencing and preventing the recharge zone from wildfires.

Negi (1997) initiated an experimental research on nearly extinct spring of Dugar Gad watershed with spring sanctuary development concept. The study was carried out from June 1995 to June 1998 water year. The recharge area of spring was treated with engineering and vegetative measures. As a result, it was found 3.8 times increase in spring discharge with 595 liters/ day in June 1995 to 2170 liters/ day in June 1998, indicating the positive impact of spring sanctuary development. However, it has also pointed out that much of this increase in discharge was supported by greater rainfall during summer 1997 and 1998, as compared to 1995 water year. It is also important to estimate the loss of water due to evapotranspiration demand of the plantation and revived vegetation of the recharge zone, which. He assumes the possibility that evapotranspiration losses override the benefits acquired due to plantation and urges this aspect needs further research.

I.5 Research Questions

1. What are the factors leading to seasonal behavior of springs and their implications?
2. What measures have been undertaken for conservation and management of water resource?

In order to answer the above research questions, the study has been done with following objectives

I.6 Objectives

(i) To study the catchment area characteristics of natural springs and their relationship with spring discharge.

(ii) To examine the impacts of water shortage on socio-economic and physical landscape/environment of the area.

(iii) To assess the various initiatives taken to conserve and manage water resources.

I.7 Database and Methodology

The study has been conducted using both primary and secondary data. The primary data includes identification of different springs, collection of rock sample, identification of vegetation types, monitoring spring discharge and other qualitative data through Focus Group Discussions. The secondary data includes the geological maps issued by Geological survey of India, satellite imageries and climatic data acquired from ISRO.

The methodology employed in this study is based on both field investigations and laboratory work. The field investigation enabled to access the ground data whereas the laboratory work facilitated in analyzing the acquired data. Therefore, the whole methodology can broadly be divided into (a) methodology for data collection and (b) methodology for data analysis.

Table I.2: **(a) Methodology for Data Collection**

S.No.	Data Types	Methods
1.	Toposheet and geological map	Acquired from Geological Survey of India (GSI).
2.	Satellite imageries	LISS-III (1990) and LANDSAT (2013) imageries issued by ISRO are acquired from DST, Government of Sikkim.
3.	Spring catchment characteristics	The rock type, vegetation type, land use type, spring types have been identified based on primary field survey. Slope/ aspect will be measured with clinometer.
4.	Climatic Parameters	Rainfall data is acquired from ISRO through Automatic Weather Station (AWS), placed in Duga.
5.	Water Discharge	Springs discharge has been measured at bi-monthly intervals with the help of a measuring jar and a stop watch.
6.	Physical parameters of water	pH, temperature and Electrical conductivity of spring water has been measured at bi-monthly basis with the help of instrument -pocket tracer.
7.	Water Management	A village wise Focus Group Discussions is conducted in seven villages.

(b) Methodology for data analysis

The collected data is analyzed in the following manner:

- A correlation analysis has been done to understand the relationship between spring discharge and catchment area characteristics such as spring type, rock type and land use type etc.
- Descriptive analysis has been done to show the rainfall and spring discharge relationship.
- The land use land cover change detection has been done on GIS platform using satellite imageries such as Landsat and Liss-III issued by ISRO.
- A spring hydrograph (discharge vs time) is being drawn to analyze the qualitative aquifer characterization under ACWADAM framework.

I.8 Organization of materials

The second chapter introduces the geographical setting of the study area including climatic conditions such as rainfall and temperature, the vegetation types, soil, geology and sacred landscape. All these parameters have direct or indirect linkages with spring discharge and recharge regime.

The third chapter focuses on understanding spring dynamics including its discharge, its linkages with catchment area characteristics, rainfall etc. An attempt has also been made to analyze the qualitative nature of aquifer viz., its storability and transmissivity. This is done under ACWADAM framework with the help of spring hydrograph. It also includes the analysis of physical parameters of spring water including pH, temperature and electrical conductivity.

The chapter four has tried to comprehend the water conservation and management strategies in the area based on intensive field work and focus group discussions. It includes the various locally adopted water management practices as well as the government initiatives. Based on people's experiences and perception, causes and consequences of water shortage have also been highlighted in this chapter.

Finally, the summary of conclusions and suggestions has been included in the fifth chapter of the study.

I.9 Limitations of the study.

This study is largely based on intensive field work. Therefore, physical accessibility was the challenge many place of the area. The steep slope, scattered nature of springs and sometimes blockade of routes due to landslides during monsoon period made it difficult to reach the area. Thus, it amplified the expenditure of both time and money.

The springs taken for this study are somehow located in same fault zone. As a result, most of the springs are fracture springs and few are depression springs. This restricted in understanding the spring dynamics in terms of its types and their linkages with regard to the nature of spring discharge.

CHAPTER II

NATURAL SETTING OF DUGA

Sikkim is a small mountainous state in the Eastern Himalayan region with about 113 km north to south extent and 64 km from east to west; having a total geographical area of 7,096 sq. km. The state has elevations ranging from 240 to 8484 meters above mean sea level. The State of Sikkim is located in the southern mountain ranges of Eastern Himalayas between Northern Latitudes 27°05′and 28°08′ and Eastern Longitudes 88°10′ and 88° 5′. It is surrounded by vast stretch of the Tibetan plateau in the north; Bhutan in the east; Darjeeling district of West Bengal towards the south and Nepal in the west. This land is drained by the Tista River, which flows in the north-south direction. Sikkim was an independent kingdom ruled by the Namgyal dynasty till 1975 before its merger with India as the 22nd state. The administrative divisions in this least populous state of the country includes four districts (East, West, North and South), 9 sub divisions, 8 towns and 166 Gram Panchayat units.

Duga is located in Eastern part of Sikkim Himalayas in between $27^0 20'$ and $27^0 22'$N latitude and $88^0 55'$ and $88^0 53'$ E longitude. The elevation of study area ranges from 711 meters in Deorali to 1830 meters in Gadi. It is located in Teesta river basin.

II.1 Climatic conditions

The climate of the state has been roughly divided into the tropical, temperature and alpine zones. For most of the period in a year, the climate is cold and humid. The area experiences a heavy rainfall due to its proximity to the Bay of Bengal. The rainfall in north district is comparatively less than that of other districts. Pre-monsoon rain occurs in April- May and monsoon (south- west) operates normally from the month of May and continues up to early October.

II.1.a Temperature

The temperature in the lower altitudes fluctuates between 4° to 35°C and places with moderate height (around 1829 m) such as Gangtok temperature varies between 1°C and 25°C. In the high altitude area (above 3993 m), the temperature never rises above 15°C and slides down to the freezing point in winter[25]. The studies suggest that the rate of increase in mean minimum temperature has been highest during last two decades.

[25] Gelogical Survey of India Report, "Geology and Mineral Resources of Sikkim," (2012).

Duga exhibits temperate climate condition with temperature ranging between 4^0 to 30°C at lower altitude (of about 700 m) and at 1^0 to 25°C at moderate altitude with around 1750 m. The maximum temperature is observed during the month of July and minimum during the month of January. The weather of Sikkim can be divided into four seasons, namely winter (November- February); spring (March- April); Monsoon (May– mid September); and autumn (Mid-September- October).

II.1.b Precipitation

Most part of the state receives heavy rainfall throughout the year. It is only in the month of October-March that the State remains comparatively drier. The extreme northern parts, adjoining Tibet, however, receive very little rainfall. The mean annual rainfall is minimum at Thangu (82 mm) and maximum at Gangtok (3494 mm). An isohyatal analysis of these data reveals that there are two maximum rainfall areas (i) South-East quadrant including Mangan, Singhik, Dikchu, Gangtok, Rongli, etc. (ii) South-West corner including hilly terrain. In between these two regions, there is a low rainfall area around Namchi as shown in map II.1. There is an area in North-West Sikkim which receives less than 4.9 mm of rainfall. Rainfall is heavy and well distributed during the months from May to early October. July is the wettest month in most of the places. Places with an altitude of 6065 m and above are snowbound and places as low as 3002m come within the snowline in the winter[26].

The climate change studies in Sikkim found that monthly rainfall showed both increase and decrease with substantial increase in rainfall in the month of June from 1961- 1990[27]. Again, the comparison of rainfall figure of periods 1981- 1980 and 1957- 2005 suggests an increase in annual rainfall in the early decades of 21^{st} century. Rainfall over thirty year period has increased by 124 mm. However, during last two decades rainfall has decreased both in terms of number of rainy days (loss of 14.40 days) and total rainfall (355 mm).

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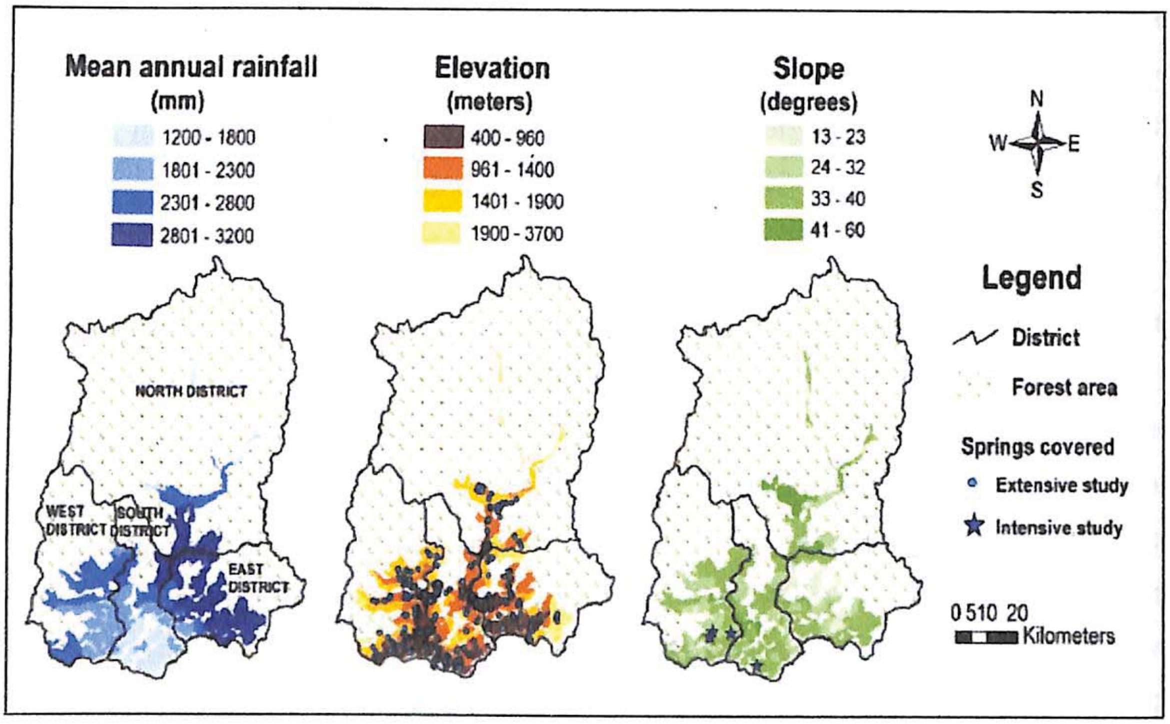
[26] Ibid.p.1.

[27] H. Rahman et al., "An analysis of past three decade weather phenomenon in the mid-Hills of Sikkim and strategies for mitigating possible impact of climate change on agriculture," in *Climate Change in Sikkim: Patterns, Impacts and Innitiatives*, ed. S.Tambe (2012), 19.

Map II.1: **Rainfall, Elevation and Slope Map of Sikkim**



Source: Tambe et al., 2012.

The local climatic condition and orographic features plays an important role in rainfall distribution. Duga receives highest mean rainfall in the month of August (1466±233) and diminishing trend starts from onset of September which goes on till February. The last three years rainfall data shows that the amount of rainfall has been diminished in the area.

Though the Eastern Himalayas as a whole receive abundant rainfall, but a large proportion of it is restricted to the monsoon season. Further study on climate data available from Gangtok indicates that winters are becoming increasingly warmer and drier with October to February being the exceptionally dry period.

II.2 Physiography and drainage

The State encompasses parts of Lesser Himalayas, Higher Himalayas, and the Trans Himalayas and hosts some of the highest mountain peaks of the Himalayas. The elevation ranges from 300 to 8586 m with increasing elevation from south to north. The exposures of Higher Himalayan rocks start at about 650 m and continue up to 8586 m at Mount Kangchenjunga. The outcrops of gneisses with granitic intrusions exhibit sharp, rugged, snow bound mountains with steep in accessible scarp faces. Extending in the form of an east-west trending ridge, it forms a barrier between the Trans-Himalayan zone and the Lesser Himalayas with Kanchenjunga as its western limit and Lama Angdang as the eastern limit and a series of high peaks, deep valleys, gorges and numerous glaciers in between. Langbo Chhu, Naku Chhu and Chhombo Chhu form main drainage flow through flat bottomed 'U' shaped valleys and finally meet with Tista River[28].

In Sikkim Himalayas, the first hill ranges starting from south are having summit between 1158 m to 732 m and runs east west. In the western part, the height increases very sharply to 2592 m within 20 km crow fly distance towards north. Siwaliks starts at 153 m and ends at 823 m. Daling continues up to 1220 m and then Darjeeling Gneiss starts. On the eastern side Siwalik ends at 732 m, Daling at 1376 m. At the central part of the area, i.e. in Tista Dome the height is in general between 1200 to 2500 m though the summit point is on 3233 m. As soon as the Daling rocks are crossed the height increases sharply from average 1800 m to 3000 m in the lower reaches, 3000 m to 4500 m in the middle reaches and 4500 m to 6700 m in the upper reaches of the dome. The rocks north of South Tibetan Detachment System (STDS) are in general occurring above 4200 m to 7300 m[29].

The middle part slowly decreases its height towards south and central part giving rise to an amphitheater type relief feature. The amphitheater follows the trend of MCT indicating that the Higher Himalayas is uplifted relative to the Lower Himalayas. The important Mountain peaks of Sikkim are: Mt. Kanchenjunga (8559.42 m), Mt. Kabru (7361.36 m), Mt. Talung (7356.8m), Mt. Siniolchu (6870.4 m), Mt. Simovo (6832.7 m), Mt. Pandim (6718.4 m), Mt. Rathong (6718.4 m), Mt. Paunhri (6688m), Mt. Kokthang (6129.2 m), Mt. Lamaongden (5887.26 m) and Mt. Masunyange (5867.2 m)[30].

II.3 Natural springs

Natural springs are the main source of water for both urban and rural population of Sikkim. The 80 percent of rural populations of Sikkim are primarily dependent on natural

[28] Gelogical Survey of India Report, "Geology and Mineral Resources of Sikkim," (2012). 2.
[29] Ibid. pp. 2.
[30] Ibid. pp. 3.

springs for meeting their water requirements for drinking, household, agricultural and other purposes. As far as spatial distribution of natural springs is concerned, seven hundred and four springs have been identified as shown in table II.1.

Table II.1 **Block wise distribution of natural springs in Sikkim.**

Sl.no	Block	No. of springs	Sl.no	Block	No. of springs
1	Yangang	6	14	Sikkip	21
2	Regu	6	15	Kaluk	22
3	Ranka	7	16	Gyalzing	23
4	Gangtok	8	17	Khamdong	24
5	Dentam	10	18	Duga	24
6	Kabi	10	19	Jorethang	27
7	Daramdin	11	20	Pakyong	31
8	Yuksom	11	21	Namchi	33
9	Chungthang	12	22	Namthang	43
10	Rakdong Tintek	14	23	Rhenock	50
11	Mangan	16	24	Ravongla	59
12	Passingdong	19	25	Melli	76
13	Temi Tarku	20	26	Soreng	121

Source: Dhara Vikas Report, 2012.

II.4 Vegetation

Land use analysis indicates that about 43 per cent of the state's total land area is under forest cover, and about 11 per cent under agriculture. Approximately 28 per cent of the area is under perpetual snow cover, and 14 per cent is under alpine pastures[31]. Alpine areas are famous for the occurrence of numerous medicinal plants. The distribution of the trees in the Himalayas greatly varies with regard to the different altitude. An elevation transect includes vegetation from tropical monsoon forest to alpine meadow and scrub, constituting an unusually extensive elevation and vegetational gradient. The most visible changes of community composition are directly related to the climatic conditions viz. rainfall, temperature, humidity and altitude. Vegetation of the Sikkim can be grouped under various forest types with respect to six altitudinal zones, viz, Tropical Semi- Evergreen Forest (300–900 m), Sub-Tropical Mixed Broad Leaved Hill Forest (900–1800 m), Himalayan

[31] Nandita Jain, "Community conservation in Sikkim Himalaya," accessed March 22, 2014. url: http://www.kalpavriksh.org/images/CCA/Director/M-20%20Sikkim.pdf.

Wet Temperate Forest (1800–2700 m), Sub-Alpine Forest (2700–3700 m), Moist Alpine Forest (3700–4000 m), Dry Alpine Forests (4000 m)[32].

Duga exhibits the Tropical semi-evergreen Forests with Sal as a dominant species along with a few deciduous components, is the climax type of vegetation in the foot hills of the district. These forests have been influenced by physiographic, edaphic and biotic factors of the region. As altitude increases from 900-1800m, the forests also gradually change from Tropical to Sub-tropical forests comprising tree species of Macaranga, Schima, Eugenia, Sapium, Castanopsis and these are generally mixed with shrubby species of Baliospermum, Clerodendrum and Emblica[33].

II.5 Soil type

Soil being the nutrient medium, is indispensable for vegetation. Soil moisture, mostly depending upon the soil thickness has an explicit impact on green cover. The entire state primarily consists of gneissose rocks and half schistose rocks. The soil developed from the gneissose group of rocks is brown clay, generally shallow and poor. They are typically coarse, often with ferric concentration, neutral to acidic with poor organic/ mineral nutrients. They tend to carry most of the evergreen and deciduous forests. The high intensity of rainfall in the state often causes extensive soil erosion and heavy loss of nutrients of land by leaching[34].

Soil type of Duga is primarily derived from parent rocks such as schist, gneiss and colluvial materials. The characteristic of soil varies from place to place due to topographical variations. The texture of the soil is loamy sand to silty clay loam. Soils are generally acidic in nature having the pH value of 5.0 to 6.0[35]. A brown red and yellow soil is found in a small area in lower part.

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[32] S.B.S Bhadauria, "Forest resources of Sikkim," accessed March 22, 2014. url: http://www.sikkimforest.gov.in/soer/Forest%20Resource%20Sikkim.pdf.
[33] Ibid.p.52-53.
[34] "Soils of Sikkim," accessed March 22, 2014. url: http://www.sikkimforest.gov.in/soer/Forest%20Resource%20Sikkim.pdf.
[34] Ibid.p.52-53.
[35] Groundwater Information Booklet of East Sikkim, accessed May 13, 2014. url: http://www.sikkimsprings.org/dv/Educational_reserach/EastSikkim.pdf.

II.6 Geology

The Himalayas are traditionally been divided into linear geotectonic belts supposedly with distinct geological characteristics. Like other parts of the Himalayas, in Sikkim-Darjeeling Himalayas, the Sub Himalayan domain comprises the molasses type deposits of the Siwaliks as shown in Table 2.2. It is followed northward successively by a thin strip of sandstone, carbonaceous shale and coal, stromatolitic dolomite and variegated slate of Buxa and Reyang Formation of Daling Group and a thick metasedimentary sequence of dominantly pelites with subordinate psammite and wacke of Gorubathan Formation of Daling Group, constituting the Lesser Himalayan Belt. Towards the north, Daling sequence is overlain by Higher Himalayan rocks of medium to high grade dominantly pelitic schist with minor interbanded quartzite, calc-silicate and metabasites which is commonly known as Chungthang / Paro Formation and small bodies of granites. This sequence in turn towards north overlies a migmatitic terrain known as Darjeeling Gneiss/ Kangchenjunga Gneiss and thought to be equivalent of what is variously described as Central Crystalline/ Greater Himalayan Crystalline /Higher Himalayan Crystalline (GHC/HHC). In the far north, a thick pile of fossiliferous Cambrian to Eocene sediments, belonging to the Tethyan Belt of Tethyan Sedimentary Sequence overlies the HHC[36].

However, in the central part of the Sikkim-Darjeeling Lesser Himalayas, a domal shaped culmination structure known as Tista/ Daling Dome has exposed a wide expanse of the Lesser Himalayan rocks. The Main Boundary Thrust, with the Mio-Pliocene synorogenic Siwalik Group in the footwall and the Permo-carboniferous Gondwana in the hanging wall, has not been affected by this culmination structure and has a roughly East-West trace. The Gondwana rocks as well as the Buxa and Rangit pebble slate are exposed in the Rangit window zone where these are surrounded by Daling Group of rocks. The Tethyan Belt is exposed on the hanging wall side of a series of north-dipping normal faults constituting the South Tibetan Detachment System (STDS), Higher Himalayan Crystallines being the footwall. Geological investigations in Sikkim and the adjoining Bengal Region began in the middle of nineteenth century. Hooker (1854) in his famous

[36] Gelogical Survey of India Report, "Geology and Mineral Resources of Sikkim," (2012). 11-12.

Himalayan Journal reported the geological observations from his extensive two years travel, found the regional domal picture of the gneisses[37]. The detail lithology and minerals of different formations of different groups of Sikkim has shown in map no. II.3.

Table II.2:
Generalized stratigraphic succession of Sikkim Himalayas

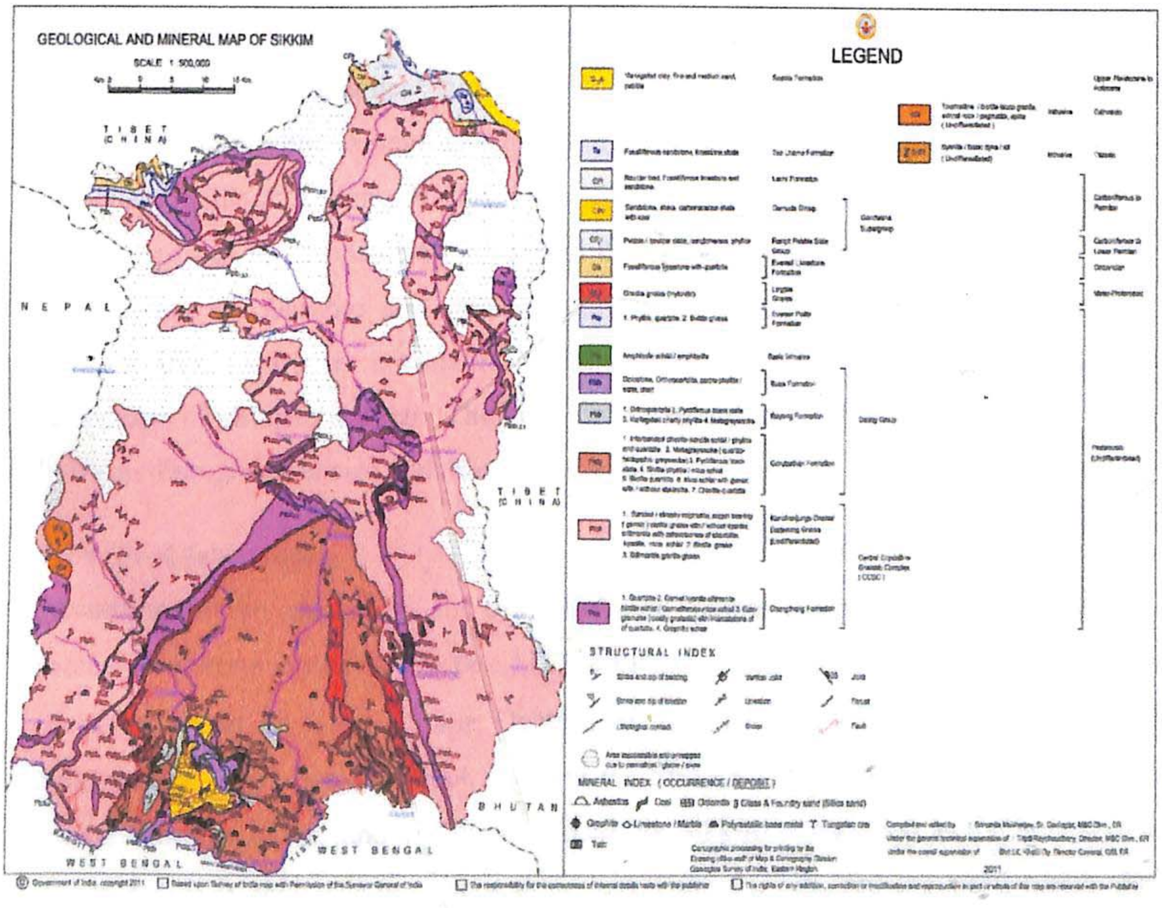
Sl. No	Lithology	Formation	Groupage
1	Variegated clay, fine and medium sand,	Sesela Formation	Upper Pleistocene pebble bed
2	Tourmaline / biotite leuco granite, schroll rock/ pegmatite, aplite (Undifferentiated)	Intrusive	
3	Syenite / basic dyke/sill (Undifferentiated)	Intrusive	
4	Fossiliferous sandstone, limestone, shale	Tso Lhamo formation	Formation Triassic
5	Boulder bed, Fossiliferous limestone and sandstone.	Lachi Formation	Carboniferous to permain.
6	Sandstone, shale, carbonaceous shale with coal Pebble/boulder slate, conglomerate, phyllite.	Damuda group Rangit pebble state Groups of Gondwana subgroups.	
7	Fossiliferous limestone with quartzite.	Everest Limestone Formation	Ordovician
8	Granite gneiss (mylonite).	Lingtse Granite Gneiss	Meso Proterozoic
9	Phyllite, quartztte, biotite gneiss.	Everest pelite formation	Meso Proterozoic
10	Amphibole schist / amphibolite.	Sill	
11	Dolostone, ortho-quartzite, purple phyllite / slate, chert.	Buxa Formation	Proterozoic Undifferentiated
12	Ortho-quartzite, pyritiferous black slate, variegated cherty phyllite, meta-greywacke.	Reyang Formation	
13	Interbanded chlorite-sericite schist /phyllite and quartzite, meta-greywacke, pyritiferous black slate, biotite phyllite / mica schist, biotite quartzite, mica schist with garnet, with / without staurolite, chlorite quartzite.	Gorubathan Formation of Daling Group	
14	Banded / streaky migmatite, augen bearing (garnet) biotite gneiss with/ without kyanite sillimanlte with palaeosomes of staurolite kyanite, mica schist, biotite gneiss, sillimanite granite gneiss.	Kanchenjunga Gneiss/ Darjeeling Gneiss (Undifferentiated) of Central, Crystalline Gneissic Complex (CCGC)	Proterozoic Undifferentiated
15	1. Quartzite, 2. Garnet kyanite sillimanite biotite schist / Garnetiferous mica schist 3. Calc-silicate, carbonaceous schist.	Chungthang Formation	

Source: Geological survey of India.

[37] Hooker (1954) cited in GSI Report (2012):p.6.

Duga watershed is characterized by granite gneiss i.e., lingtse gneiss in patches and interbanded chlorate- sericite schist/ phyllite and quartzite and blotetit quartzite of Gorubathan formation of Dailing Group. The Daling group also known as sensu lato of Darjeeling- Sikkim Himalayas is characterized by distinct tectono- stratigraphic position being placed below high grade gneiss rocks limited by the sheared belt of mylonite granite gneiss. The Gorubathan formation of rocks are exposed extensively in the southern part of Sikkim from east of Rhenock to west of Gyalzing and north of Dikchu to Rangpo in the south having a dome shaped outcrop loosely known as Tista dome.

Map II.2:
Geology and minerals of different formations of Sikkim.



Source: Geological Survey of India.

Table II.3:
Lithology and formation of Duga Block.

Group	Formation	Lithology
Dalling group	Gorubathan formation	1. Interbanded chlorite-sericite schist /phyllite and quartzite,
		2. Metagreywacke (Quartzo-feldspathic greywacke)
		3. Pyritiferous black slate
		4. Biotite phyllite / mica schist, biotite quartzite
		5. Biotite quartzite
		6. Mica schist with garnet, with / without staurolite,
		7. Chlorite quartzite.

Source: Geological survey of India

The formation consists of mappable, monotonous sequence of inter banded chlorite sericite schist / phyllite, quartzite, metagreywacke, pyritiferrous black slate/ carbon phyllite, basic metavolcanic. Chlorite phyllite is dark green to light green whereas the quartz chlorite phyllite is only light green in color. The geology of the study area shows fine quartz veins in Rongpo, Vasme, Duga and Pachekhani area. Quartzites are occurring as thin partings to mappable bands within the chlorite schist and quartz chlorite schist. Intercalation of quartzite and chlorite schist is observed in Rongpo, Duga, Pandem, Singtam area. Quartzites are mainly white to light green in color depending upon the percentage of chlorite in them. They are also observed as grey to buff at places. Mostly these are fine grains in size and massive in nature.

2.7 Sacred landscapes

According to Ramakrishnan, for the Sikkimese people the whole state of Sikkim is sacred. Sometime in the 7th century AD Lord Padma Sambhava, a great Indian saint was invited to Tibet by King Trisong Deutsen to establish and introduce Buddhism. It is believed that on his way to Tibet, he went via Sikkim and is said to have hidden many treasures or ters in the land of Sikkim. Therefore Sikkim is regarded as the holiest of all places and it is said that one merit done here equals a hundred thousand merits done elsewhere. The area below Mount Khangchendzonga in West Sikkim referred to as Demojong, as most sacred and the abode of Sikkim's deities. This entire region is also referred to as Yuksam[38]. These sacred landscape are spread all over the state, as shown in map no. II.4.

Sacred landscape grasps the variable forms including sacred grove, temples or shrines and sacred water bodies such as lakes, waterfalls and springs[39]. A sacred grove called Gadi or locally known as Budang Gadi is rested on the crest of Duga. It is approximately located at 27^0 13′ N and 88^0 31′ E at an elevation of 1874 Meters. Gadi has a historical significance. In fact, it is a fort built by the monarch of Sikkim, the then chogyal Chador Namgyal in the year 1717 AD to resists the invasion of Bhutanese army. During one of the invasion by Bhutanese army, the princess Pendi took shelter there and so the name of the village Pendam from her name. The fort is 1000 ft. long and 100 feet in height and spread over an area of 5 acres. The indigenous communities believe that this sacred mountain is the abode of deities who protect them from natural calamities[40].

The area is under Khasmal area of dense vegetation or grove type and top canopy consists of tree species like mauwa, kawla, angeri, kharaney, phusrey chap, lek kharaney, chilawney, arkanlo, phaledo etc. The ground cover consists of shurbs like ghuipis, chulari, algeri, dholeray phool etc and herbs like kibu, kuro. Harketa, manay, chipalay, das paisa jhar etc.

Other than Gadi sacred grove, natural springs are considered sacred by local community. The tree species or grove is worshipped near spring catchment area. Various pujas are performed and the area is well fenced to minimize human interferences. Springs such as Langri Dhara, Bhulkey Dhara, Duga Devithaan, Devithaan source etc. are considered sacred.

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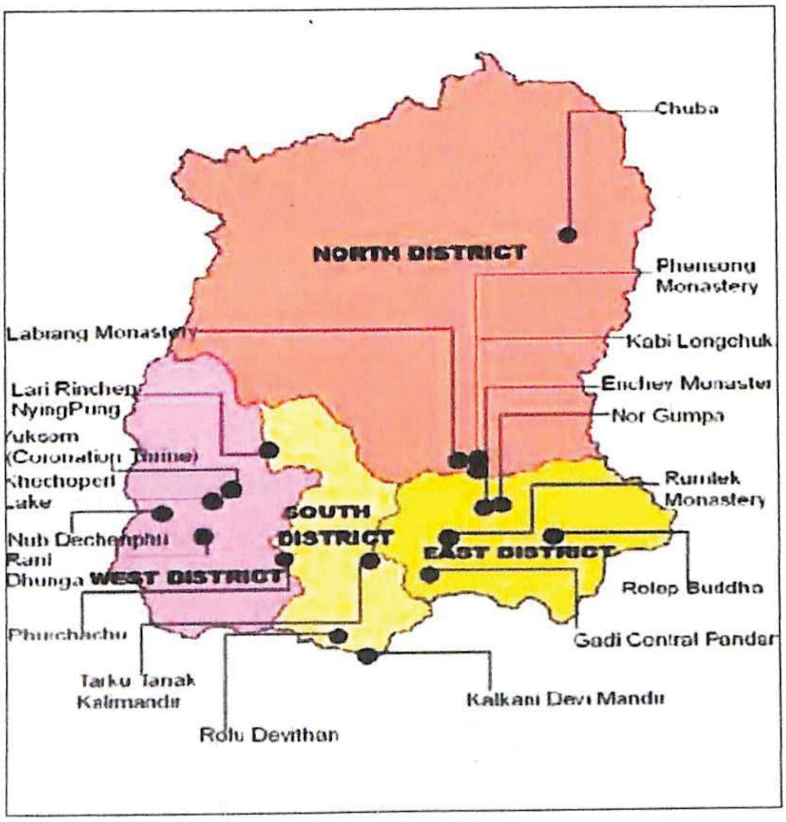
[38] Nandita Jain, "Community conservation in Sikkim Himalaya," accessed March 22, 2014. url: http://www.kalpavriksh.org/images/CCA/Director/M-20%20Sikkim.pdf.
[39] Vibha Arora, "The forest of symbols embodied in the Tholung sacred landscape of North Sikkim, India," *Conservation and society*, (2006): 55-83.
[40] Forest, Environment and Wildlife Management Department, Government of Sikkim, *Sacred Groves of Sikkim*, accessed April 15, 2014. url: http://www.sikkimforest.gov.in/Report%andpublication/SacredGrove/Edition%FEWMD.pdf.

Map II.3:

Sikkim: Spatial Distribution of Sacred groves.



Source: Forest, Environment and Wildlife Management Department, Government of Sikkim.

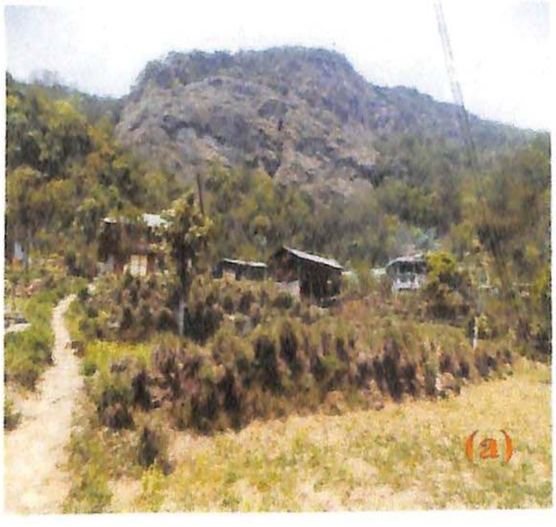


Plate II.1: In the crest of Karmithang village of Duga block, there rets the Gadi sacred grove with an elevation of 1874 meters (a), A view of Gadi fort (b), built by chogyal of Sikkim Chador Namgyal in around 1700 A.D.

CHAPTER III

NATURE AND DISCHARGE REGIME OF SPRINGS

In the geo- dynamically young Himalayan ecosystem, the fragile slopes are on account of being tectonically active and potentially erosive. Anthropogenic activities are continuously disturbing the natural system of the Himalayan environment, impacts of which can be seen in the hydrological behavior of streams and springs[41]. Springs occur where sloping ground and impermeable strata intersect with the ground water table. Such water sources are associated with unconfined aquifers where the water flows under gravity.

Kirk Bryan (1919) had identified the essential factors in the production of springs are the source of the water underlying aquifers and the rock structure which brings it to the surface. Temperature, dissolved salts, contained gases; rate and amount of flow, form and position of the springs opening are all characteristics of springs which in many cases related to genesis, vary among springs of the same origin. Thus he has categorized springs into two groups based on character of water- (a) springs due to deep seated water, (b) springs due to shallow seated water. In shallow water springs, the pore spaces of the upper crust of the earth are filled with water below a certain level called the water table. This zone of saturation generally has an indefinite extension downward, but in relatively few deep wells is much water encountered below 1500 feet. Further, springs due to this relatively shallow water may be divided into four large groups, according to the character of the rock in which they occur- (i) springs in porous rock, (ii) springs in porous rock underlying impervious rock, (iii) springs in porous rock between impervious rock and (iv) springs in impervious rock.

Likewise, F.W Fetter has categorized springs into four type- (i) Depression spring- Formed when water table reaches the surface due to topographic undulations, (ii) Contact spring-Formed at places where relatively permeable rocks overlie rocks of low permeability. (iii) Fracture spring- Occur due to existence of jointed or permeable fracture zones in low permeability rocks, (iv) Karst spring- Large quantities of water move through the cavities, channels, conduits and other openings developed in limestone, and (v) Fault spring- Faulting may also give rise to conditions favorable for spring

[41] G.C.S Negi and V. Joshi, "Rainfall and Spring Discharge Pattern in two small Drainage Catchment in the Western Himalayan Mountain, India," (2004).

formation as groundwater (at depth) under hydrostatic pressure (such as in confined aquifers) can move up along such faults.

Each type of above springs are largely influenced by rainfall trend/ pattern, the recharge area characteristics, vegetation cover, type of land use, slope/ aspect and the aquifer characteristics i.e., transmissivity and storability. Spring water discharge fluctuations owe primarily due to rainfall pattern in the recharge area or more precisely stated, to variation in the amount of rainwater that is able to infiltrate the ground and recharge the ground water. Therefore, recharge and discharge regime of springs depends largely on above factors. Thus, spring characterization is important in order to understand the spring dynamics.

High degree of deformation in the Himalaya resulting in intense folding, faulting and development of fracture zones contributes to the loss of aquifer continuity in the mountain belts. Different rocks show different properties that are characteristic of the process of formation of the rock. The two most important properties of rocks with regard to groundwater are its texture and structure. Texture refers to the manner in which individual mineral grains or sediments in a rock are arranged in relation to each other. The hydrogeological property of different rocks is controlled by the texture of the rock. If the mineral or sediment grains in a rock are closely packed the porosity (and permeability) of the rock reduces considerably. Igneous rocks are formed from cooling molten rock material; the minerals usually have 'tight' boundaries resulting in low porosity and permeability. Many metamorphic rocks are also formed by heating of parent rocks and result in recrystallization of minerals, with tight boundaries. Thus, porosity and permeability of these rocks is also quite limited. Sedimentary rocks and metamorphic rocks formed only under the effect of pressure show variation in porosity and permeability depending on their grain size, shape, mineral content and arrangement of grains. Rock texture is thus an important factor controlling the storage and transmission capacities of an aquifer or water bearing formation[42].

[42] K. Mahamuni and H. Kulkarni. "Groundwater resources and spring hydrogeology in South Sikkim, with special reference to Climate Change ," accessed March 12, 2013, url: http:// Sikkimsprings.org/dv/research/ACWADAM_report.

Rock formations are often disturbed or deformed from their original state of formation. This deformation is the result of tectonic forces or crustal stresses. The deformation of the rock bodies produces different structures such as inclination or dips of sediment beds or layers, folds, faults and fractures. Identifying and understanding a geological structure is an essential element of any hydrogeological study as such structures determine the direction of movement and accumulation of groundwater. Often, one assumes that the flow of surface water and groundwater is always along the same direction depending upon the slope. Thus, topography and geology including texture, structure, altitude and inclination together decide the properties of an aquifer, especially in the Himalayan region. Slope and geology together influence spring discharge and spring water quality[43].

In Sikkim there is not a single kilometer of 'flat land'. With an area of 7096 sq. km, measuring 113 km from north to south and 64 km from west to east, the state has elevations ranging from 240 to 8484 meters above mean sea level. The State of Sikkim is located in the southern mountain ranges of Eastern Himalayas between Northern Latitudes 27°05' and 28°08' and Eastern Longitudes 88°10' and 88° 55 [44]. Hydrogeologically, entire Sikkim is divided into two basic subdivisions (a) Non permafrost area; and (b) Permafrost area. In non-permafrost area groundwater occurs in largely disconnected localized bodies under favorable geological conditions, such as jointed, fractured zones, weathered zones etc. Due to higher slope most of the precipitation flows off as surface runoff through streams, rivers, and intermittent springs. Due to steep gradient groundwater comes out as seepages and springs, whenever the surface intersects ground water table. Direct infiltration of rainfall through joints, fractures, weathered zones of the rocks and through soil covers is principal mode of recharge of the springs. Relatively flat areas on tops of hills and ridges, saddle, spurs form the potential recharge areas. Steeper hill slopes dominantly form the areas of spring discharge. The movement of ground water in Sikkim is mainly controlled by the structural set up of the area and physiography[45].

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[43] Ibid.p.264-265.

[44] Ibid.p.265-268.

[45] Indranil Roy, "Understanding about springs of Sikkim," in *Workshop on Integrated Water Resource Management* (2009), 81-88.

The typical characteristics of springs of Sikkim may be summarized as follows. Mainly gravity springs are available as a result from water flowing under hydraulic pressure. In Sikkim basically two types of gravity springs are available viz. Depression Spring and Fracture Spring. The structurally weak plains, mainly joints, fractures and small scale faults are good avenues for movement of spring water. During monsoon season discharge of the spring is increased by two to six times. The peak discharge starts from onset of May to September and normally decreases from December to April. Spring water temperature varies from 110 C to 240 C and it is higher in lower altitudes. Quality of spring water is commonly potable for drinking purposes[46].

III.1 Natural springs of Duga

As shown in table 2.1 in chapter 2, Duga block as a whole has total number of 24 springs and out of those 13 springs have been taken for this study. These thirteen springs are scattered over five villages' viz. Duga, Bhurung, Sajong, Deorali and Karmithang as shown in map.no.3.1. It found that the average household dependency is 38 household per springs which means more than 5 hundred springs are dependent on 13 springs.

III.2 Springs catchment area characteristics

The steep topography of Duga with and elevation ranges from 711 meters to 1830 meters suggests gravity springs are mostly available. Two types of gravity springs have been identified viz. Fracture and Depression Spring which are continuously feeding by underlying unconfined aquifers. It is observed that catchment area characteristics of these springs varies considerably from one another with respect to area, slope, land use, vegetation, geology etc. as shown in Table III.1.

The rainwater during monsoon season quickly runs off down slope through natural drainage networks, without much retention in the recharge zones. Therefore, there is a need to understand the spring discharge behavior as influenced by different recharge/catchment area characteristics to develop strategies for long term water conservation in the area.

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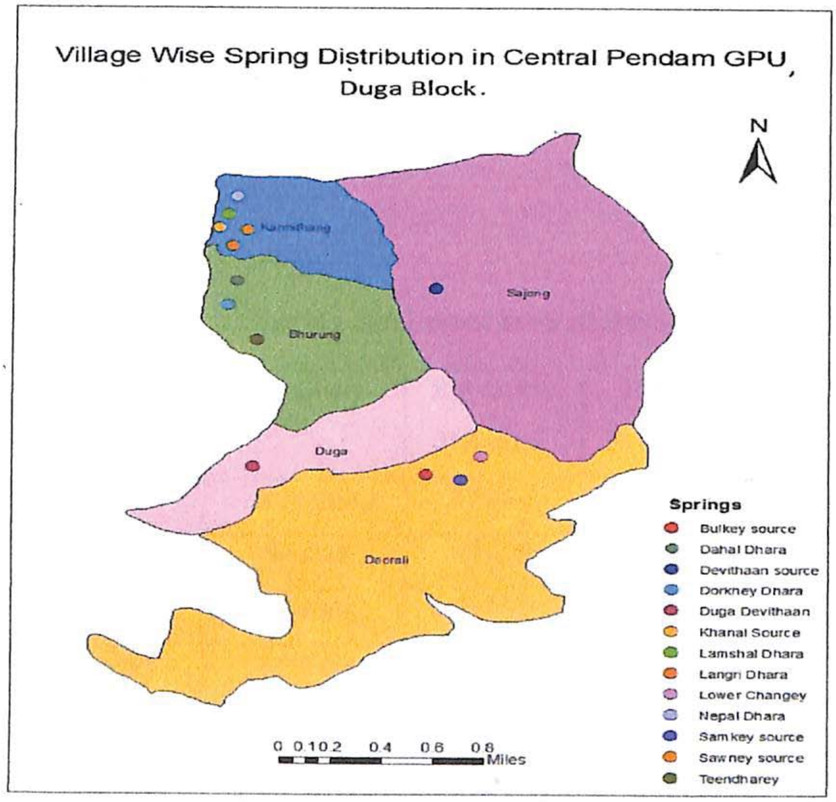
[46] Ibid.p.85.

Map III.1:



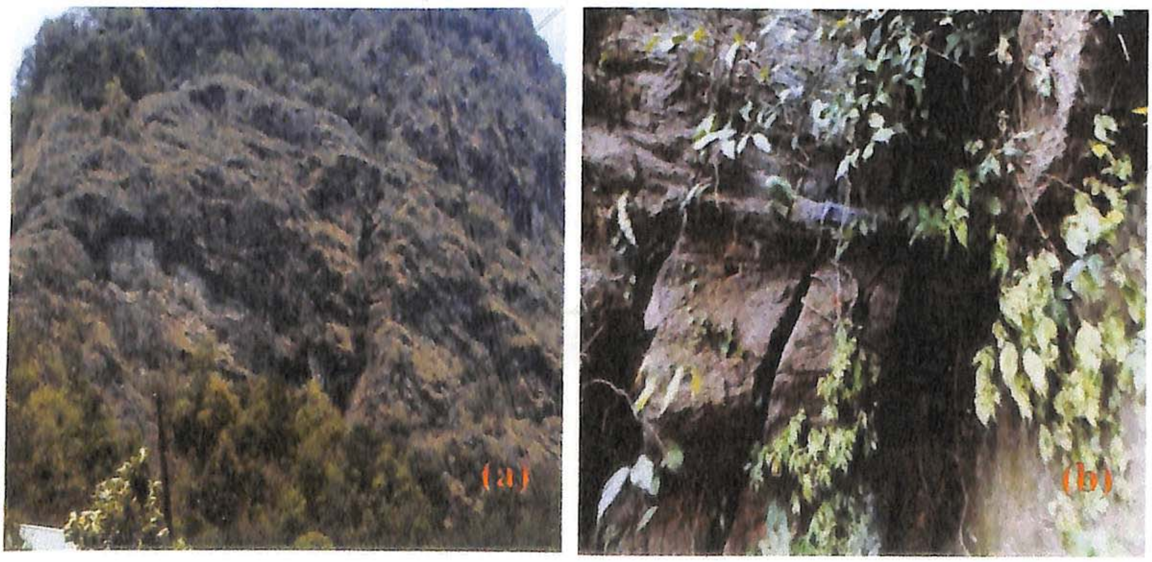


Plate III.1: A fractured lithology in the crest of Gadi (a), Outcrop of Gneiss in Devithaan source (b).

III.2.a Spring catchment area characteristics and spring discharge

It found that catchment area characteristics such as geology, spring type, vegetation, and land use type are the main controlling factor for recharge-discharge regime of springs. The degraded land with high biological interference and grazing lands has negative impacts on spring discharge[47].

Table III.1: **Spring catchment area characteristics.**

Sl. No.	Spring Name	Location	Elevation (in mts)	Rock type	Spring Type
1	Lamshal	Karmithang	1588.7	Gneiss	Fracture
2	Devithaan	Sajong	1453.8	Gneiss	Fracture
3	Dhalay	Bhurung	1447.7	Gneiss	Fracture
4	L. Changey	Deorali	806.5	Quartzite	Fracture
5	Bhulkey	Deorali	811	Quartzite	Fracture
6	Duga Devithaan	Duga	952	Quartzite	Depression
7	Teendharay	Bhurung	1128	Gneiss	Fracture
8	Khanal	Karmithang	1509.2	Schists	Fracture
9	Sawney	Karmithang	1389.6	Schists	Fracture
10	Nepal Dhara	Bhurung	1514	quartzite	Fracture
11	Dorkhey Dhara	Bhurung	1275	quartzite	Fracture
12	Samkey	Deorali	702.8	Schists	Fracture
13	Langri Dhara	Karmithang	1486	Quartzite, Schists	Fracture

Source: Field survey, May 2013.

47 G.C.S Negi and V. Joshi, "Rainfall and Spring Discharge Pattern in two small Drainage Catchment in the Western Himalayan Mountain, India," (2004).

Table III.2:

Spring catchment area characteristics- household dependency, land ownership, land use in the catchment area and observed vegetation types.

Sl. no	Spring Name	Land use in catchment	HHD*	Land Ownership
1	Lamshal	Agricultural field, thin vegetation cover.	27	private
2	Devithaan	Dense vegetation, agricultural field.	70	private
3	Dhalay	Dense vegetation, agricultural field.	25	private
4	L. Changey	Agricultural waste land and thin vegetation cover.	12	private
5	Bhulkey	Agricultural field, wasteland and thin vegetation cover.	13	private
6	Duga Devithaan	Dense vegetation, agricultural field.	12	private
7	Teendharay	Agricultural field, thin vegetation cover.	120	private
8	Khanal	Agricultural field, thin vegetation cover.	40	private
9	Sawney	Agricultural field, thin vegetation cover.	30	private
10	Nepal Dhara	Dense vegetation, agricultural field.	30	private
11	Dorkhey Dhara	Dense vegetation, agricultural field.	25	private
12	Samkey	Agricultural field, wasteland and thin vegetation cover.	40	private
13	Langri Dhara	Agricultural field, thin vegetation cover.	80	private

Source: Field survey, April 2013- March 2014.

*Household Dependency.

Table III.3:

Vegetation types in the Catchment Area.

Sl. No	Spring Name	Vegetation types (Common Name)	Botanical Name[48]
1	Lamshal	Bar, Kera, Baas, Dhokrey phul.	*Ficus Bengalensis,* Musa Sapiendis, Arundinasia recemosa, Datura surveolens.
2	Devithaan	Panisaj, Chelauney, Saaur, Firferay.	*Terminalia myriocarpa, Schima wallichii (M), Betula alnoides, Acer oblongum.*
3	Dhalay	Dhokrey phul, Sembal, Firfirey, Seris, Lupsey, Baas.	*Datura surveolens, Bombax ceiba, Acer oblongum, Albizzia procera, Spondias axillaris, Arundinasia recemosa.*
4	L. Changey	Sembal, Taki, Syal khosrey, Barar.	*Bombax ceiba, Bauhinia purpurea,* Grewia optiva, *Ficus bengalensis.*
5	Bhulkey	Seto seris, Barar, Khamari, Sembal.	*Albbiza procera, Ficus bengalensis, Gmelin arborea, Bombax ceiba,*
6	Duga Devithaan	Barar, Baas, Kaizal, Chelauney, Rudraksh, Panisaj.	*Ficus bengalensis, Arundinasia racemosa, Bischofia javanice, Elaeocarpus Ganitrus Roxb, Schima wallichii (M), Terminalia myriocarpa.*
7	Teendharay	Bar, Amliso	*Ficus Bengalensis,* Thysanolaena maxima,
8	Khanal	Bar, Kabra, Chelauney, Okher, Baas, Seris.	*Ficus Bengalensis,* Ficus, infectoria, Schima wallichii (M), Juglans regia, Arundinasia racemosa, Albizzia procera.
9	Sawney	Kabra, Panisaj, Chuletro, Utis, Sembal.	*Ficus, infectoria, Terminalia myriocarpa,* Brassiopsis hainl, *Alnus nepalensis, Bombax ceiba.*
10	Nepal Dhara	Baas, Dhokrey phul, Kera, Chuletro, Nevara, Paiyon.	*Arundinasia racemosa, Datura surveolens, Arundinasia racemosa,* Ficus rosenbergii, Brassiopsis hainl, *Prunus cerasoides.*
11	Dorkhey Dhara	Phaledo, Bar, Kabra, Barar, Kera, Chelauney.	*Erythrina stricta,* Ficus Bengalensis, *Ficus infectoria, Ficus bengalensis, Arundinasia racemosa, Schima wallichii (M),*
12	Samkey	Barar, Seris, Peepal, Sembal, Baas, Taki.	*Ficus bengalensis, Albizzia procera, Ficus religiosa, Bombax ceiba, Arundinasia racemosa, Bauhinia purpurea.*
13	Langri Dhara	Baas, Kera, Taki, Dhokrey phul, Chuletro.	*Arundinasia racemosa, Musa Sapiendis, Bauhinia purpurea, Datura surveolens,* Brassiopsis hainl.

Source: Field Survey, April 2013- March 2014.

[48] Umberto Quattrochhi, "CRC World Dictionary of Medicinal and Poisonous plants: Common names, Eponyms, Synonyms and Etymology," (CRC Press: May 2012).

As shown in Table III.4, a positive correlation (r= 0.156966) has been found between geology of the catchment area and spring discharge This means geology is the main controlling factor for influencing amount and pattern of spring discharge. Likewise, the land use type also has a positive relationship with spring discharge (r= 0.171235), which means the changes in land use type by a unit results increases or decrease in spring discharge. It implies that spring catchment area under agricultural land and forest cover found to be conducive for spring recharge- discharge process than the area under wasteland and high biological interference.

Table III.4:

Correlation matrix of spring type, rock type and land use type with spring discharge.

	Spring Discharge	Spring Type	Rock Type	Land use Type
Spring Discharge	1			
Spring Type	-0.13678	1		
Rock Type	0.156966	0.030429	1	
Land use Type	0.171235	0.365148	-0.35	1

However, a negative correlation (r= -0.13678) has been found between spring discharge and spring type. This may be because of data that there were mostly fracture spring in the study area except Duga Devithaan, which is a depression springs. The inclusion of more springs type may give good results.

The different vegetation types have different capacity to hold the water and also have varied evapotranspiration capacities. The oak forests are found to be conducive for spring recharge[49]. The large variety of vegetation type in spring catchment area could not allow drawing relationship with spring discharge or recharge, which requires further study to see the level of impacts.

Plate III.2: Agricultural land in the catchment area of Khanal Dhara (a); counter ploughing is conducive for water rain retention (b).

III.3 Qualitative analysis of aquifer properties under ACWADAM framework

The high degree of deformation in the Himalayas resulting in intense folding, faulting and development of fracture zones contributes to the loss of aquifer continuity in the mountain belts. Understanding local aquifers is important because a finer impact on these aquifers affects the spring discharge. The groundwater is stored and discharged to these springs under differing geological conditions. Many springs owe their genesis to structural features such as fractures, faults and other weak planes. Therefore, the extent of the aquifers, their geometry, their hydrogeological properties such as storability and transmissivity show great variation[50].

A spring hydrograph (discharge versus time) is a simple way of understanding spring behavior and also an indirect mechanism of understanding aquifers and aquifer systems

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[49] G.C.S Negi and V. Joshi, "Rainfall and Spring Discharge Pattern in two small Drainage Catchment in the Western Himalayan Mountain, India," (2004).

[50] K. Mahamuni and H. Kulkarni. "Groundwater resources and spring hydrogeology in South Sikkim, with special reference to Climate Change ," accessed March 12, 2013, url: http:// Sikkimsprings.org/dv/research/ACWADAM_report.

feeding various springs. The magnitude of change in spring discharge, from one season to another, reveals sizeable information about the change in storage in the aquifer feeding the spring, transmission and storage properties of such aquifers and is even indicative of the type of the aquifer. The discharge pattern of a spring is a useful way of ascertaining aquifer behavior [51]. A qualitative characterization of aquifer has been done by ACWADAM [52], Pune.

An attempt has been made to analyze the qualitative characteristics of aquifers that are feeding the various springs of the study area, Duga block. Within the frame work of ACWADAM, separate hydrograph of spring discharge (one year data from March 2013 to March 2014) has been drawn. The x-axis shows the time (month) and the y- axis shows the spring discharge (in L/Min) as shown in Fig. III.1. Their probable nature of aquifer has been described below in detail.

Figure III.1:
Spring hydrograph of the study area, Duga block.

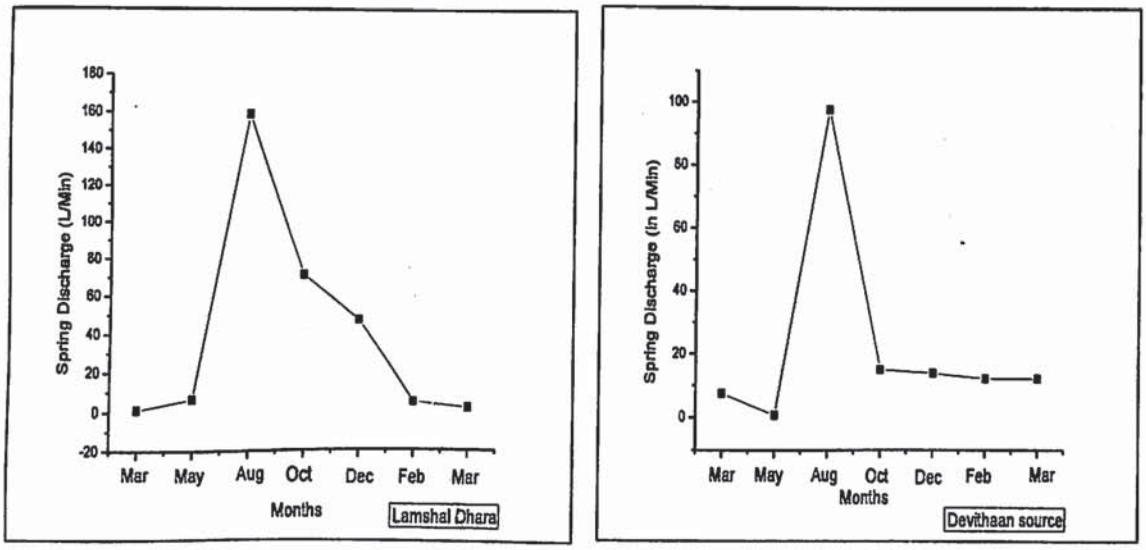

Figure III.1.a: Lamshal Dhara

Figure III.1.b: Devithaan source

[51] Ibid. pp. 266-267.
[52] Advanced Centre for Water Resource Development and Management, a Pune based non-profit organization for water Development.

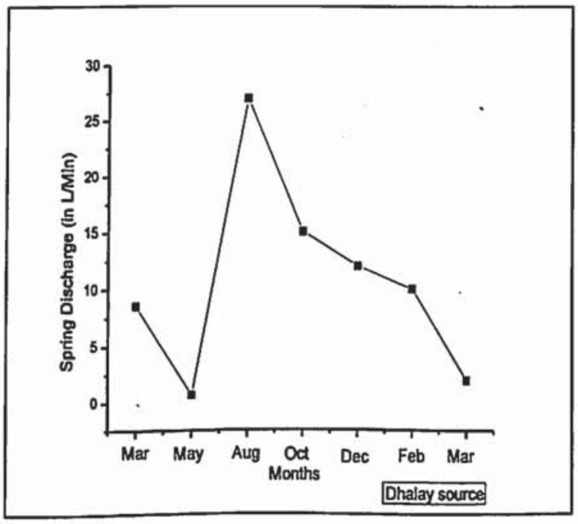

Figure III.1.c: Dhalay Source

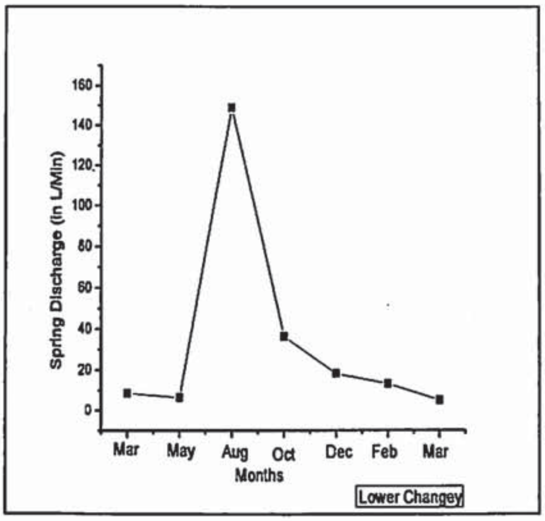

Figure III.1.d: Lower Changey

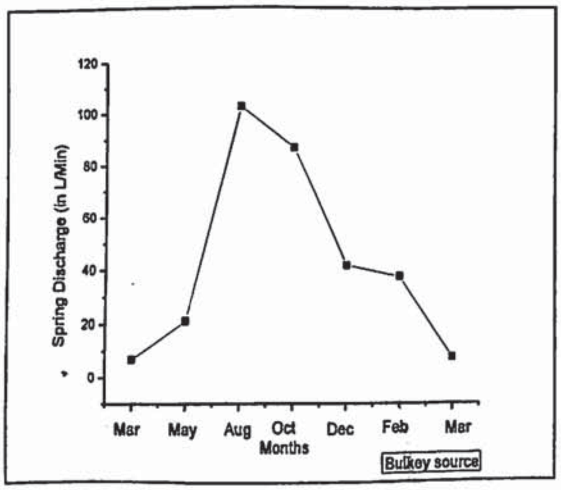

Figure III.1.e: Bhulkey source

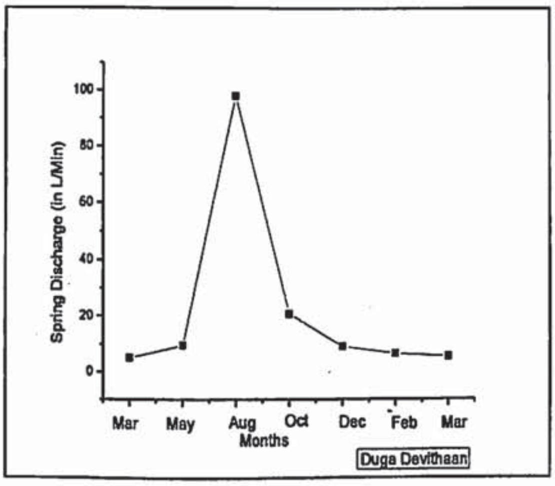

Figure III.1.f: Duga Devithaan source

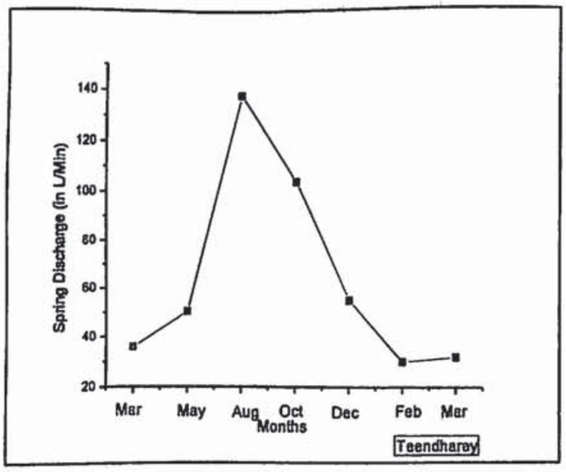

Figure III.1.g: Teendharey source

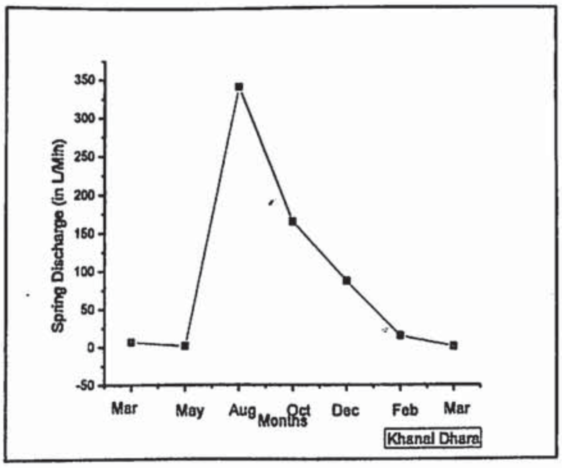

Figure III.1.h: Khanal Dhara

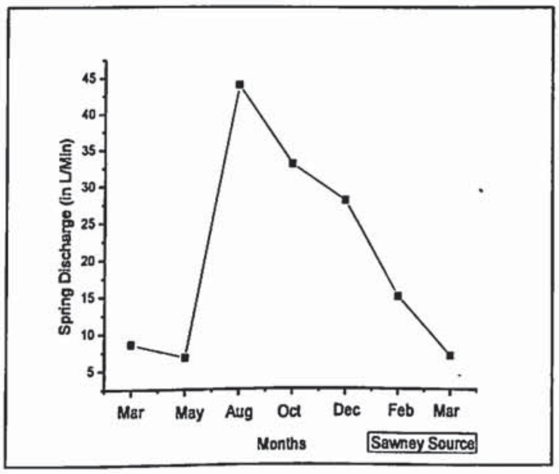

Figure III.1.i: Sawney source

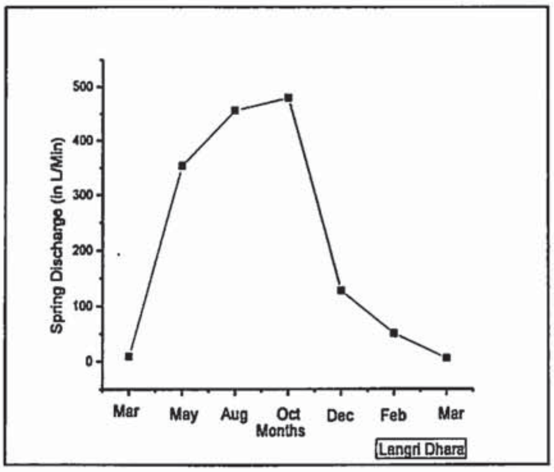

Figure III.1.j: Langri Dhara

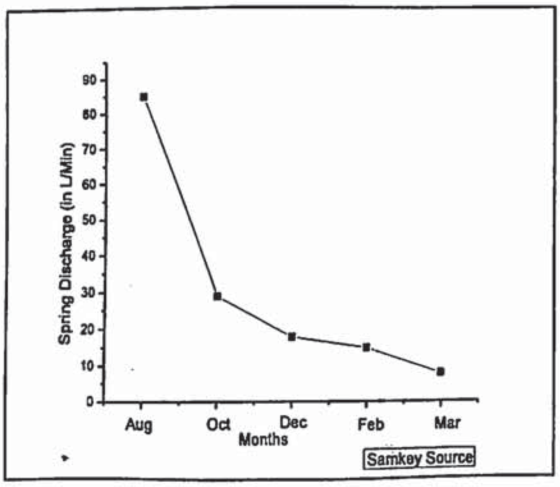

Figure III.1.k: Samkey source

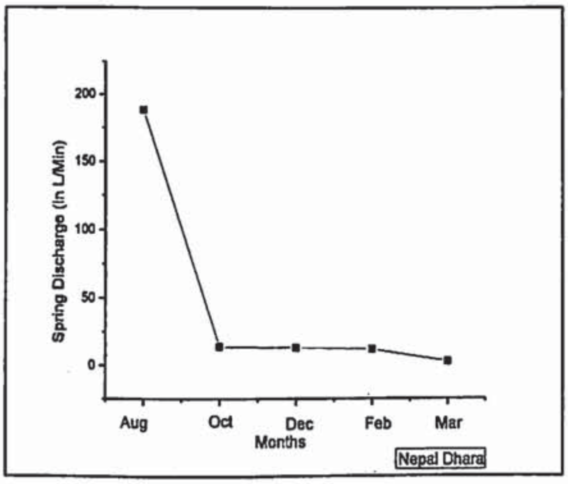

Figure III.1.l: Nepal Dhara

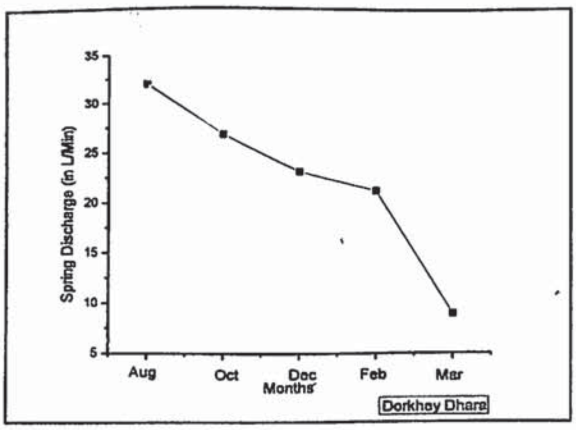

Figure III.1.m: Dorkhey Dhara.

[Spring hydrograph of the study area based on bi-monthly spring discharge data, Duga block].

Table III.5:

Aquifer properties and Spring discharge.

Sl.no	Spring Name	Annual Discharge trend	Probable nature of aquifer feeding spring	Aquifer Attributes
1	Lamshal Dhara	High and perennial discharge	Unconfined	Slow flow, moderate to large storage.
2	Devithaan	Widely ranging discharge, seasonal	Unconfined	Low storage, quick transmission
3	Dhalay Dhara	Low and perennial discharge	Unconfined	Slow flow, low Storage
4	L. Changey	Widely ranging discharge, seasonal	Unconfined	Low storage, quick transmission
5	Bhulkey Source	High and perennial discharge	Unconfined	Slow flow, moderate to large storage
6	Duga Devithaan	Widely ranging discharge, seasonal	Unconfined	Low storage, quick transmission
7	Teendharay	High and perennial discharge	Unconfined	Slow flow, moderate to large storage
8	Khanal Dhara	High and perennial discharge	Unconfined	Slow flow, moderate to large storage
9	Sawney Source	Low and perennial discharge	Unconfined	Slow flow, low Storage
10	Langri Dhara	High and perennial discharge	Unconfined	Slow flow, moderate to large storage
11	Samkey source	Widely ranging discharge, seasonal	Unconfined	Low storage, quick transmission
12	Dorkhey Dhara	Low and perennial discharge	Unconfined	Slow flow, low storage
13	Nepal Dhara	Widely ranging discharge, seasonal	Unconfined	Low storage, quick transmission

Source: field survey, January 2014.

The spring hydrograph (discharge vs time) reveals that discharge trend of the spring vary in large extent in terms of amount of water yield and spring behavior (seasonal/perennial and high /low). The behavior of spring further reveals probable aquifer attributes.

With the clear observation and analysis of various spring discharge trend, springs are classified into three categories. The springs such as Lamshal Dhara, Bhulkey source, Teendharey, Khanal Dhara and Langri source has high and perennial discharge and the probable nature of aquifer feeding these springs has moderate to large storage capacity as shown in Table 3.5. The transmissivity is slow.

Likewise, springs like Devithaan source, Lower Changey, Duga Devithaan, Samkey and Nepal Dhara has widely ranging discharge. The nature of trend is seasonal. As shown in graph, their discharge is high only during peak rainfall period leaving other month with relatively less discharge. Their aquifers may have low storage capacity and the transmissivity is quick.

The springs such as Dhalay Dhara, Sawney and Dorkhey source are the springs which have low discharge but flows throughout the year. The aquifer feeding these springs may have slow transmissivity and low storability.

III.4 Rainfall and Spring Discharge Analysis

Rainfall is the main source of water for the recharge of underlying aquifers. Spring water discharge fluctuations are primarily due to variation in rainfall in recharge area or more precisely stated to variation in the amount of rainwater that is able to infiltrate the ground and recharge the grown water[53]. Even though the area has adequate rainfall during the monsoon, the high surface runoff means that the water ends up at the valley bottom.

The local climatic condition and orographic features plays an important role in rainfall pattern as such Duga block lies in rain shadow zone of Darjeeling hills and receives relatively less rainfall than other parts of the state. The southwest monsoon, from the months of July to September, is responsible for 80% of the total annual rainfall in the state.

III.4.a Rainfall trend of Duga

The rainfall trend of the last three years of the study area shows that rainfall starts increasing from June to August and diminishing trend starts from onset of September as shown in Fig. III.2. The period from January to May is driest period. The highest mean rainfall has been recorded in August 2010 (1466±233) and the same month of 2011 (886±74).

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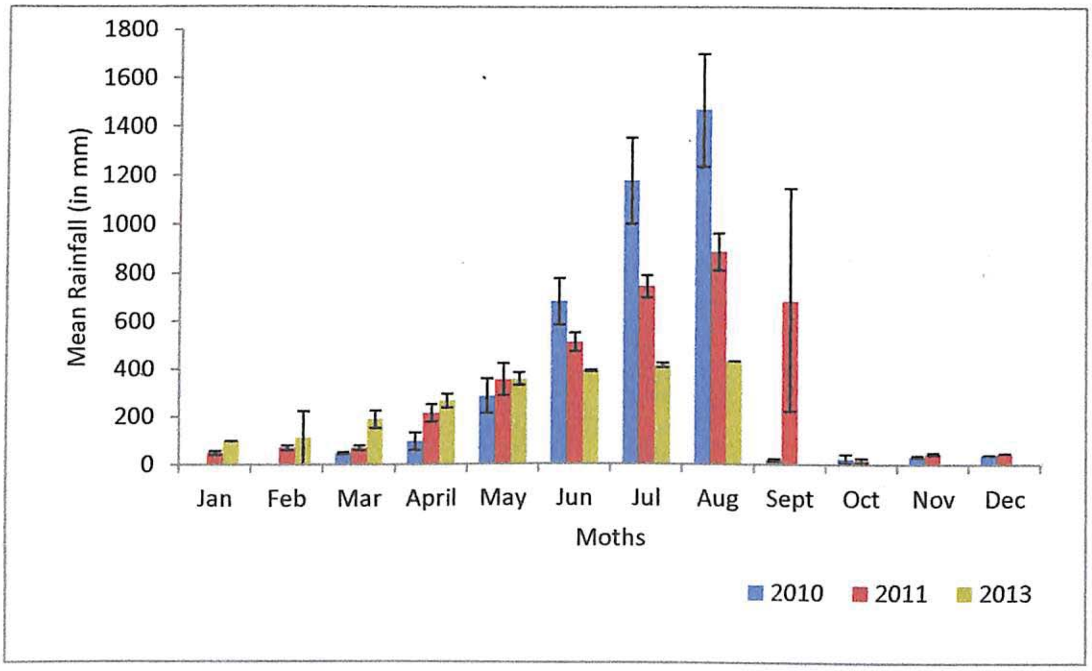
[53] G.C.S Negi and V. Joshi, "Rainfall and Spring Discharge Pattern in two small Drainage Catchment in the Western Himalayan Mountain, India," (2004).

Figure III.2: **Mean rainfall (in mm) of Duga (2010, 2011 and 2013).**



It is also shown that the amount of rainfall has been decreased from 2010 to 2013. High rainfall variability has seen in the area. An intense rainfall has been observed from the month of June to August, leaving other months with relatively less rainfall. This indicates the high surface run off and less water infiltration, which further indicates less water for recharging aquifers.

III.4.b Linkages between Rainfall and Spring Discharge

In order to understand the relationship between rainfall and discharge of various springs of the study area, mean rainfall of Duga has been potted in the graph along with spring discharge as shown in see Fig. III.3. Mean rainfall (in mm) is shown by bar diagram in left axis and spring discharge (in L/Min) is shown by line features in right axis. It is found that peak spring discharge is coincided with peak rainfall.

The spring discharge has increased drastically following the rainfall trend in the area. Springs like Devithaan source, Dhalay Dhara, Duga Devithaan source, Nepal Dhara, Lamshal Dhara and Dorkhey Dhara showed a high discharge exactly coinciding with high rainfall in month of August and drastic decrease in discharge as rainfall goes down.

Figure III.3:

Rainfall and Spring Discharge Relationship.

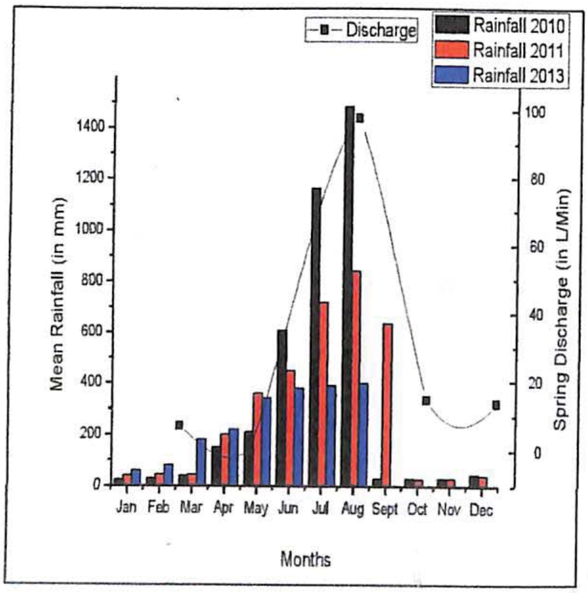


Figure III.3.a: Lamshal Dhara

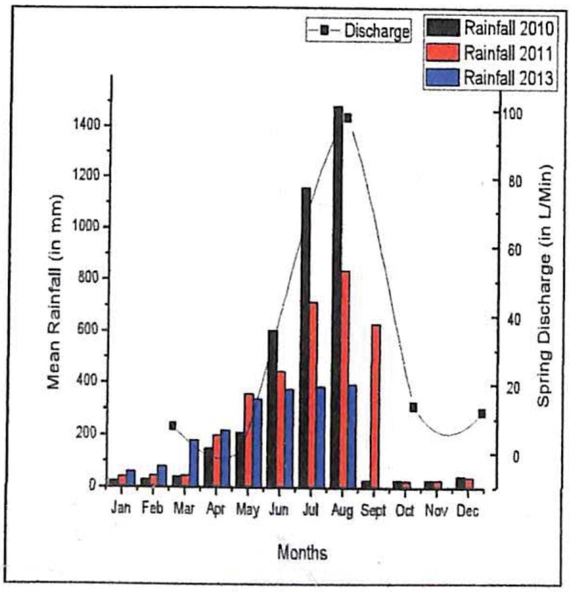


Figure III.3.b: Devithaan Source

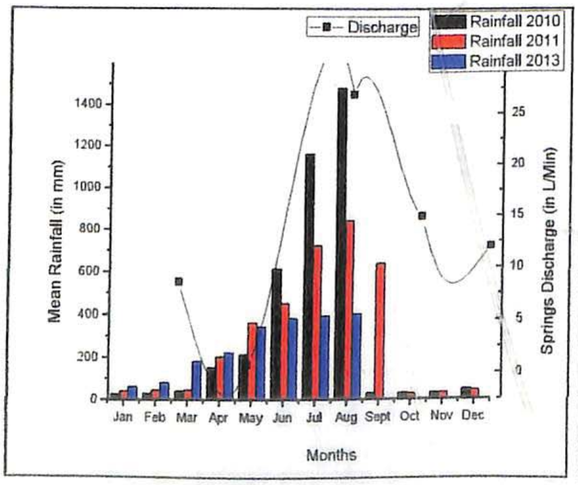


Figure III.3.c: Dhalay Source

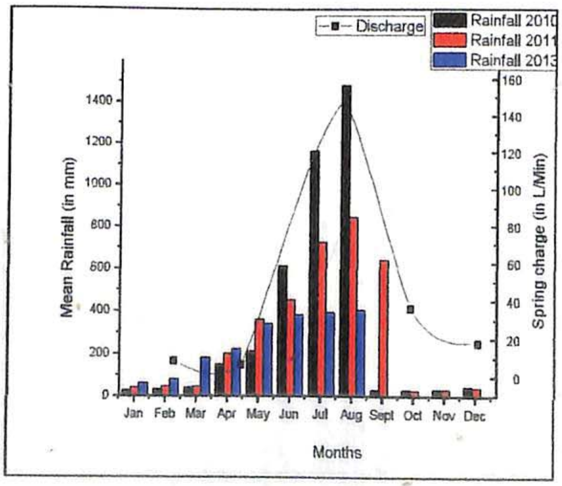


Figure III.3.d: Lower Changey Source

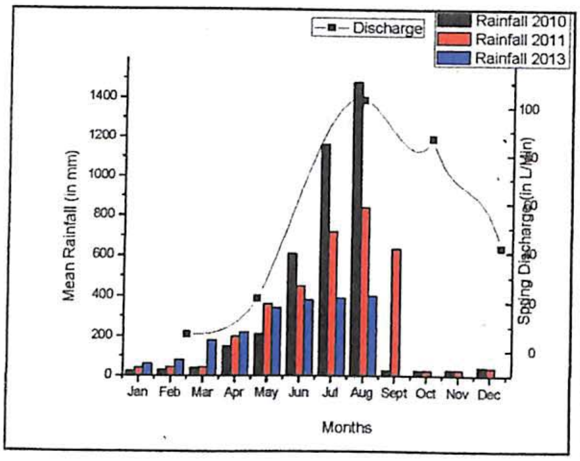


Figure III.3.e: Bhulkey Source

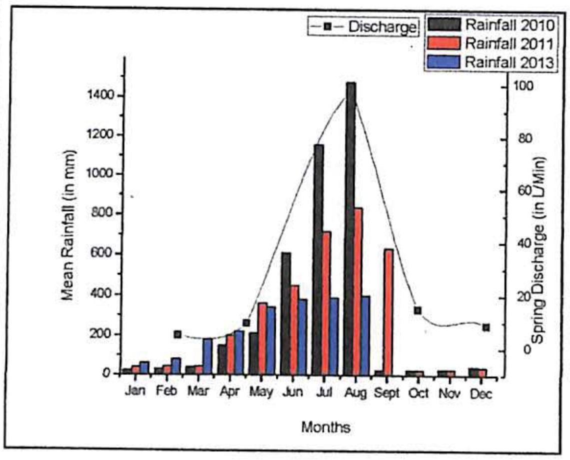


Figure III.3.f: Duga Devithaan

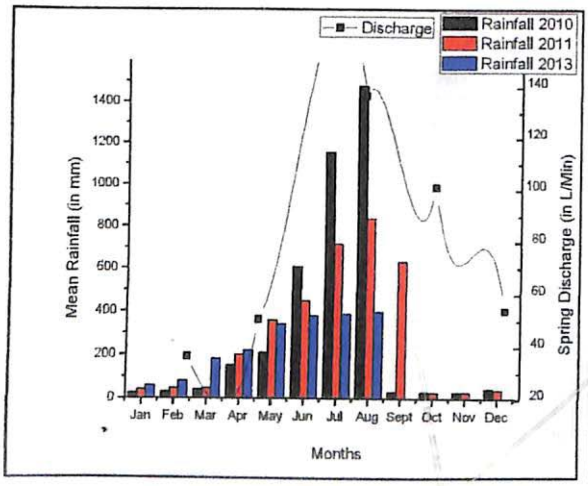


Figure III.3.g: Teendharey source

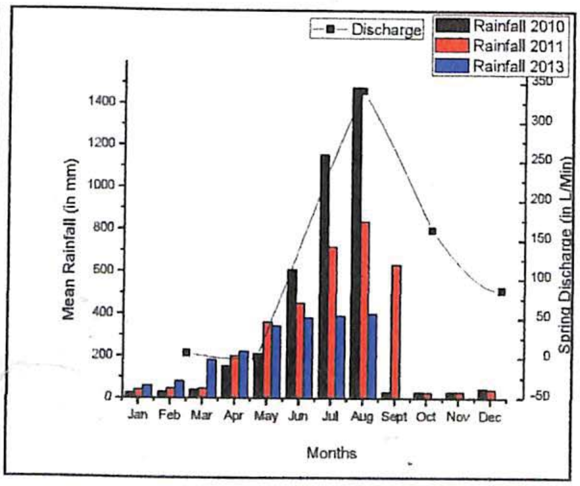


Figure III.3.h: Khanal Dhara

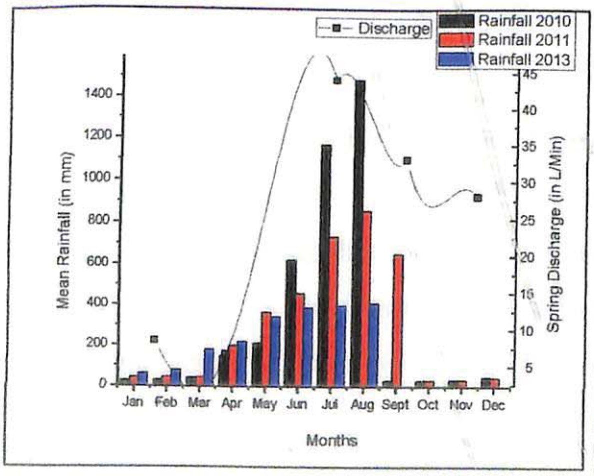


Figure III.3.i: Sawney Source

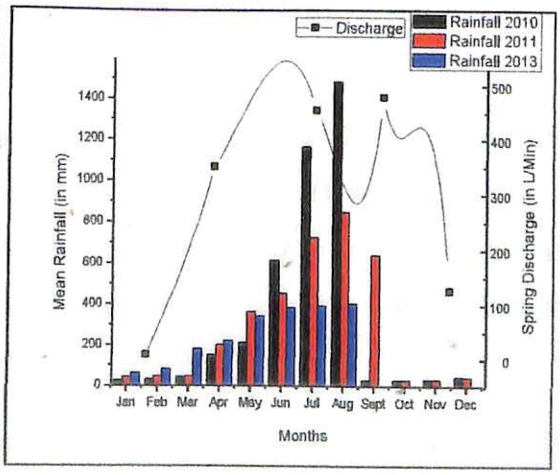


Figure III.3.j: Langri Dhara

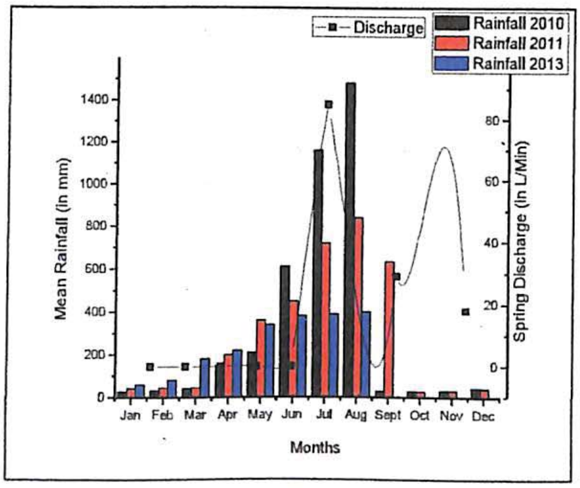


Figure III.3.k: Samkey Source

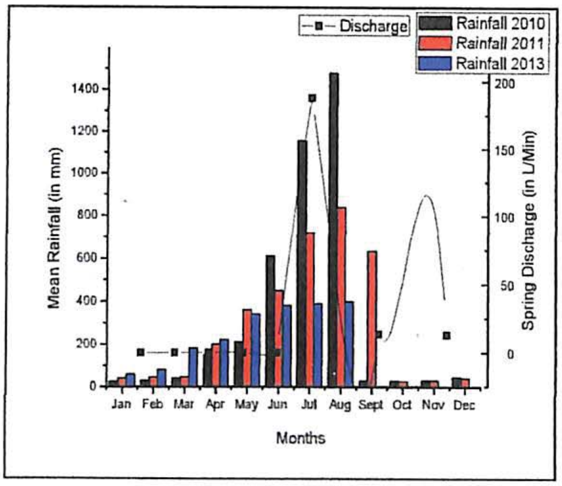


Figure III.3.l: Nepal Dhara

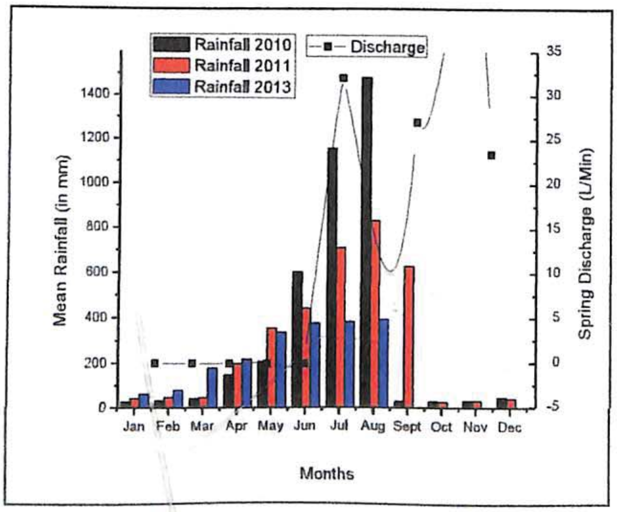


Figure III.3.m: Dorkhey Dhara

The mean rainfall of August 2013 was 400 mm and their discharge was 98, 27, 96, 188, 98 and 32 L/ Min respectively. In the following month (October), mean rainfall decreased to 26 mm and the spring discharge also decreased as Devithaan source with 13.8, Dhalay Dhara with 15, Duga Devithaan source with 15, Nepal Dhara with 13.5, Lamshal Dhara with 15 and Dorkhey Dhara with 27 L/Min.

Other springs like Lower Changey source, Sawney source and Samkey had slow decrease of discharge in post monsoon period with 36, 33 and 29 L/Min. Some springs such as Teendharay source, Khanal Dhara and Bhulkey Source had good discharge rate in post

monsoon period. In August (peak period), their discharge was 137, 340, 103 L/ Min respectively. It was decreased to 101, 163, 87 L/Min respectively in month of October.
It is also observed that Langri Dhara is the only spring which had high discharge in post monsoon period. In peak month (August), the discharge was recorded to be 456 L/Min and in post monsoon period (October), the discharge was increased to 480L/Min.

The lowest discharge of the springs recorded in the month of March- May. The discharge of Lamshal Dhara, Devithaan source and Dhalay Dhara was recorded less than 1 L/Min during same month. Likewise, the highest discharge was recorded in the month of August. It is observed that high spring discharge coincides with peak rainfall period. Other important observation is the pace of increase in spring discharge following the rainfall pattern is slower than pace of decrease. In other words, in case of post monsoon period the discharge of spring decreased drastically except one spring (Langri Dhara). However, it is observed that spring discharge did not increase immediately after onset of rainfall. This means, aquifers that are feeding natural springs needs considerable time for recharging it.

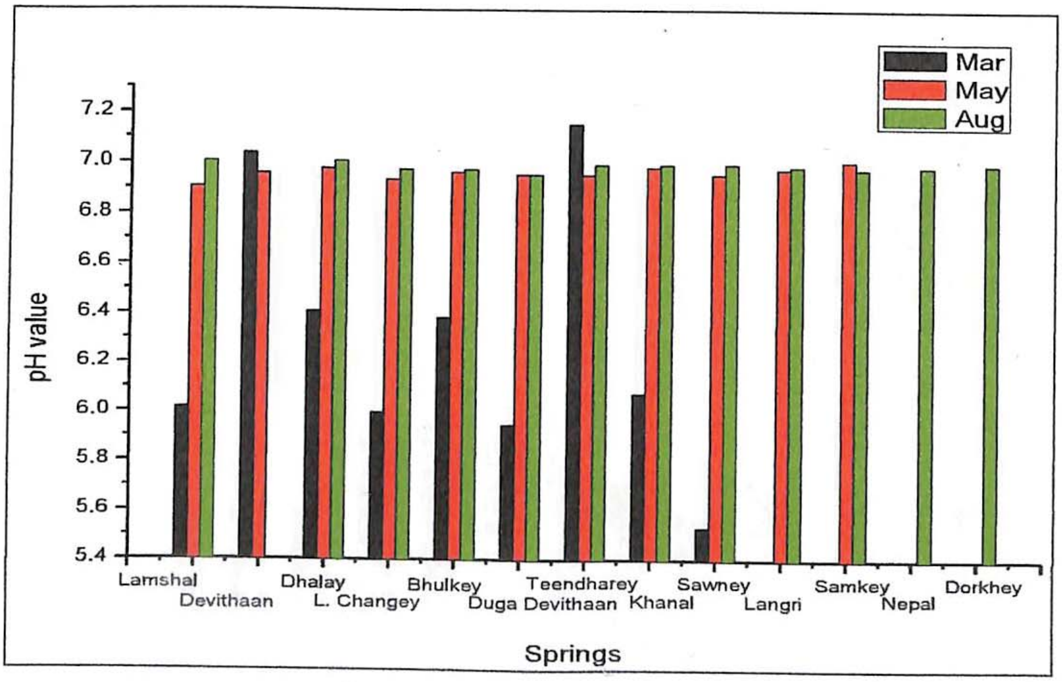
III.5 Physical parameters of water

The three physical parameters have been taken are pH, temperature and electrical conductivity (EC) in order to have better understanding of spring recharge- discharge regime and water suitability for potable use in general.

III.5.a pH of spring water

The seasonal variation of pH has been observed as such low pH during lean period (not less than 5.53) and high pH (not more than 7.15) during peak period as shown in Fig. III.4. It is shown that two springs such as Devithaan source and Teendharey source had pH value more than 7 during the month of March while others had less than 6.4. The water is acidic in nature during lean period and neutral in peak period. This implies that water at these locations is fresh may be due to the presence of dissolved carbon dioxide in rainwater or due to the absence of carbonate rocks and/or biological activities with which the water needs time to interact. The World Health Organization's permissible standard for water pH is 5.5 to 8.5. Thus, spring water is suitable for potable use.

Figure III.4:
pH of Spring Water (May to August 2013).



Source: Field Survey, March- August 2013.

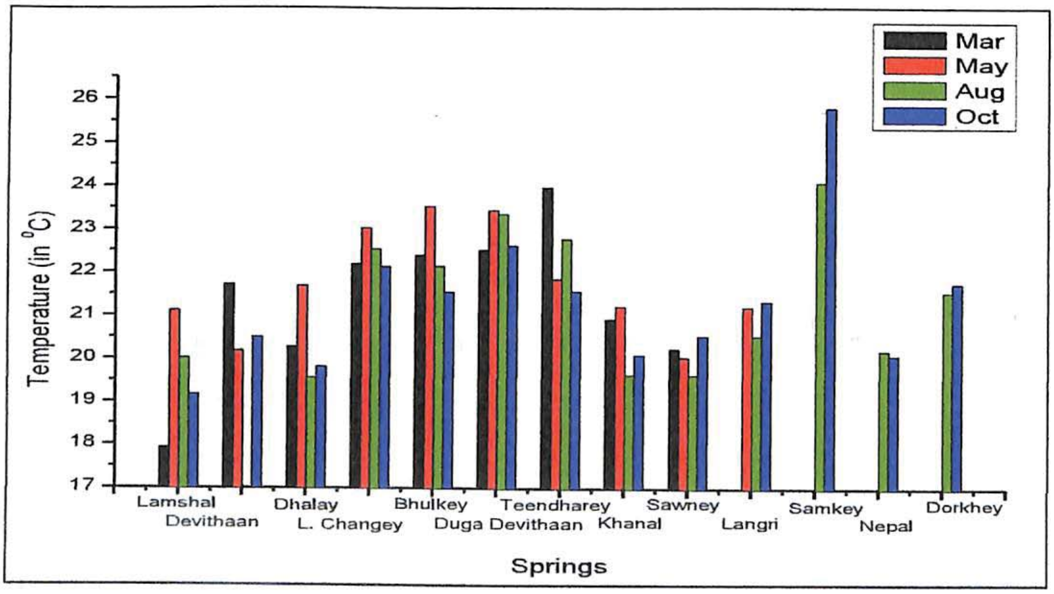
III.5.b Water Temperature (in ^{0}C)

Temperature of spring water shows a seasonal variation as shown in Fig. III.5. It is observed that in most of the springs, highest temperature is being recorded in the month of May and decreases from month of August. The high temperature during lean period further signifies that ground water table has reached the lower level and particular water is coming out from deep beneath the ground.

III.5.c Electrical Conductivity (in µS/cm)

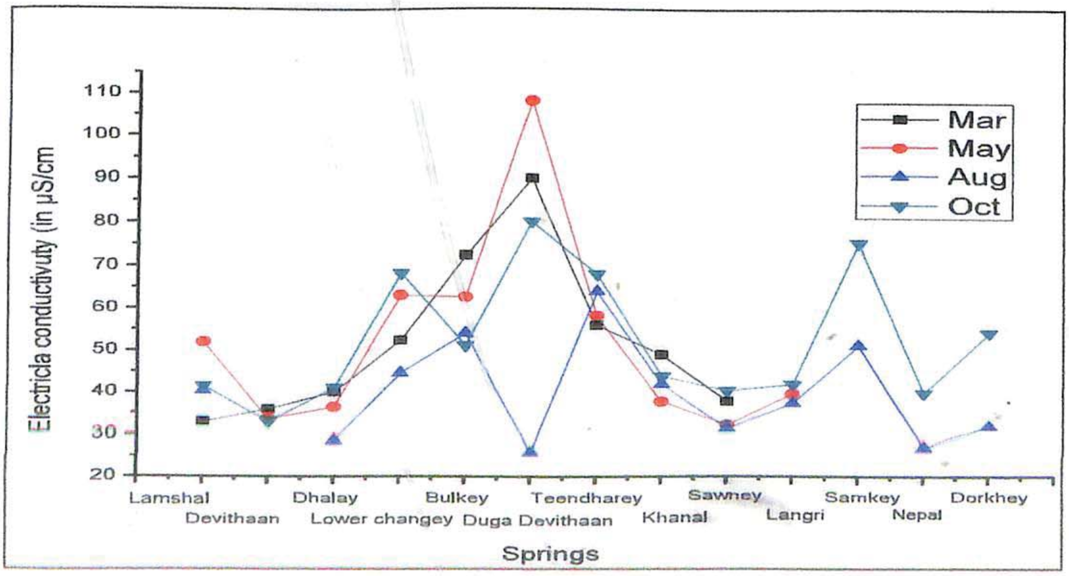
The bimonthly record of the electrical conductivity of the springs is shown in Fig: III.6. Electrical conductivity (EC) of all spring samples is less than 110 µS/cm indicating all the spring samples are extremely fresh. It is inferred that for most of the spring's electrical conductivity show a higher value during the lean period and a lesser value during the high discharge period. The electrical conductivity increases during the lean season as a result of flow of relatively older water out of the storage. Whereas the decrease in the conductivity can be inferred due to an increase in the flow of the low conductivity recharging water (precipitation) into the springs.

Figure III.5:
Temperature (in ^{0}C) of spring water of Duga Block.



Source: Field Survey, May- October 2013.

Figure III.6:
Electrical conductivity (in µS/cm) of various springs of Duga block.



Source: Field Survey, March- October 2013.

To conclude, Duga block with its steep and irregular topography presents variability in catchment area characteristics viz. geology, land use and rock type. Interplay of all these factors affects the water yield and nature of both perennial and seasonal springs. These catchment area characteristics have found to be positively correlated with spring discharge pattern. This further implies that catchment area characteristics are the controlling factor which has strong linkages with spring recharge and discharge process.

The probable natures of aquifers which are feeding these springs are unconfined, where the flow of water is under gravity. The qualitative analysis of spring hydrograph further reveals that most of the springs are having moderate to large storage capacity with slow transmission and few other have low storage capacity with quick transmission.

The descriptive statistics analysis of rainfall trend and the discharge pattern of the springs show high interdependence. The most of springs have followed the rainfall trend there by indicating rainfall as the main source of water for recharging the aquifers underlying below. The analysis of last three years rainfall data shows decreasing trend of rainfall amount in the area. This further indicates less amount of rainfall is able to percolate into the grounds and it may have probable impacts on discharge pattern. Over the last few years, the discharge from the spring as observed by the local community has shown a marked decline as well. This decrease of spring discharge has resulted in an acute shortage of drinking water and a shift in land use pattern is being observed which is further discussed in chapter IV in details.

The analysis of physical parameters of spring water such as pH, temperature and electrical conductivity further supports the interdependence of spring discharge and rainfall pattern. The seasonal variation in pH, Temperature and conductivity has been found. In general, water coming out from these springs found to be fresh and suitable for potable use. An extensive study is required to analyze the water suitability for potable and agricultural use by taking multiple parameters such as total dissolved solids (TDS), microbial analysis of water etc. This would enable to check water borne diseases and it will also ensure rural water quality.

CHAPTER IV

CONSERVATION AND MANAGEMENT OF NATURAL SPRINGS

The conservation and management of springs are utmost important in Sikkim. The interplay of climate change and anthropogenic factors has an immense impact on these scatted resources. The growing population, as Malthus said which tends to grow geometrically or exponentially, is the main reason that has put pressure on finite natural resources. Generally, earth's water is considered as conventional resources that can be recycled through time again. But the unwise or over exploitation may leads to depletion or desertification. In contemporary times, the water resource and therein involved geo-politics has become global burning subject. The wise and sustainable utilization of resources greatly depends on the principles and role of government and non-governmental institutions and resource users at community level.

Natural springs are always considered as common property resource in Sikkim though it lies in private lands. These vary resource is access to all. To make sense of this resource utilization system, we need to revisit Garrett Hardin's (1968) much quoted expression 'Tragedy of Commons'. According to him, in the absence of government regulation, each individual user of the commons tries to maximize his or her self- interest and ends up overexploiting the commons. To support this idea, the forest was a common property resource till 1977 in Sikkim. The open access to forest areas has had led to overexploitation of resources leading to over grazing, open felling of trees, depletion of pasture lands. That situation perfectly matches with Hardins (1968) influencing expression "picture a pasture open to all".

In the year 1977, State government regulated the land acquisition act, which empowered government to transform any wasteland, barren land, whose ownership is anonymous to be under government property. The defined boundaries of such public property as reserved forest, *Gaucharan* and *khasmal* helped to minimize human encroachment on forest area. This has boosted green forestry and pasture land. However, this vary idea has had impacted on community whose livelihood was solely based on forest resources. Maringanti et al., (2012) argued that state regulations on natural resource have not been improved the situation rather it is under threat. Likewise, Shiva's (1986) argument is, in the name recovery of the commons, the wasteland development programme is just a privatization policy of government which threatens to accentuate rural poverty and increase ecological instability.

Damodaran (1991) had argued that state appropriation of the common is an attempt transforming free riding commons to common property equity resource. He emphasized the principle which is desirable and feasible to manage commons as non-free rider equity resource without compromising the principles of 'open access". The need is to evolve and set up appropriate management structures of the communities concerned. While constitution of such management structures may not automatically ensure participation of the user community in the sustainable management of common resource, it will at least create necessary pre-condition for realizing the CPR[54] potential and threats.

Water resource management is an important parameter for the development of any nation as it directly relates to the development and growth of the economy[55]. The management encompasses the process of maintaining its sustainability and pristinely condition as well as harnessing its full potential for various uses. This leads to integrating various interest and groundwater user groups both in upstream and downstream of the springs and conflict resolution between them, which will provide stability in the operational area with societal implications. Traditional knowledge on artificial ground water recharge is well established in the western Himalayas with a history of water scarcity, while it is a relatively new concept for the traditionally water surplus eastern Himalayas.

IV.1 Status of natural springs

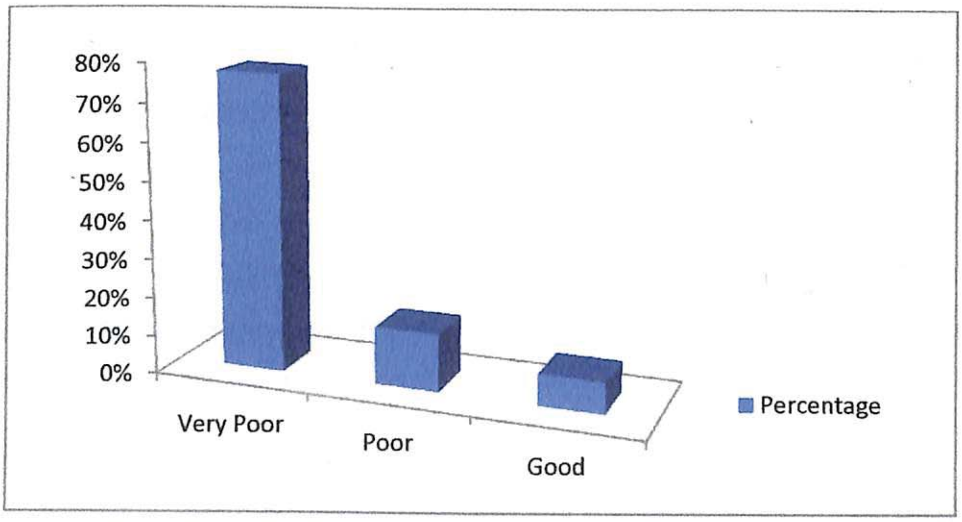
Springs and streams are primary sources of water for more than five thousand population living in Central Pendam Gram panchayat Unit of Duga Block. The shortage of water during dry period is acute. People have to walk few miles away from their houses to fetch water. A spring hydrograph has been plotted with spring discharge data of lean period (March- April) because discharge is very small in these months. As a result, status of 80 per cent of springs is very poor, 15 per cent are poor and only 8 percent is good with discharge rate of 1 to 7, 7 to 14 and 14 to 21 Liters per minute respectively as shown in Fig: IV.1. More than five hundred household are dependent on thirteen springs with an

[54] Common property resource.

[55] G.K Khadse, "Conservation, Development and Management of Water Resources," *International Journal of Water Resource and Arid Environments,* (2011):193-199.

average dependency of thirty- eight household per springs. Some springs yields less than 1 Liter water per minute during lean seasons. This means people have to rely on other sources like rainwater for drinking as well as for other household purposes, which may not be suitable for potable use.

Figure IV.1: Status of spring discharge during lean periods



[Analyzed using spring discharge data of lean period (March- April) with a class interval of 1 to 7 liters/ minute is **Very poor**, 7 to 14 is **Poor** and 14 to 21 is **Good**].

Plate IV.1: Spring discharge during peak period (a) and lean period (b), Khanal Dhara, Duga block.

IV.2 Conservation and management strategies

A people's participatory approach has been found in conservation and management of water resources in the area. The water user group (undefined) is active in community/ village level to deal with minor water problems. The major water problems such as construction of storage tanks, repairing of old tanks and pipelines are taken care by village panchayats through higher authorities. It includes sanctioning of financial support, water schemes and programmers, their monitoring and implementation.

The Non-governmental organization has a significant role in conservation and management of land and water resource in community level such as Self- helps groups, farmers group and other groups in the village locally known as 'Samaj'[56]. Various plantation works has been done in the area along the road sides and in forest area through the village NGOs. The vegetative measure is well developed in the area with regards to conservation of land and water resource.

IV.2.a Fencing and plantation

Springs are considered a community resource and not the property of the landowner. In this case it is the community's responsibility to protect the spring and usually members of water users are involved in protection activities. Fencing and plantation in the spring's source area have commonly adopted in the area. The sources of most of the springs are fenced with using bamboos and wood with an aim to reduce human interference in the water source.

Plantation is another important measure to conserve water resources in the area. Traditionally the plants like *Dhokrey phul*[57] and banana plant are considered important and are seen common in every springs. However, banana plant actually extracts a lot of water from the soil instead through evapotranspiration[58]. The state government has given effort in establishing plantations of fast growing indigenous tree species. These fast growing tree species will not only help in conserving soil, water and sequestering carbon

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[56] NGOs that establishes with an aim for social and economic assistance in the community level.
[57] Angel's trumpet plant or *Datura surveolens.*
[58] Laura Coulson, "Spring Development in Sikkim," accessed March 16, 2014. url: http://www.sikkimsprings.org/dv/research/Final_Coulson%20.pdf

but also provide assured additional economic returns to the farmer. *Pansaj*[59] and *Utis*[60] are the two fast-growing indigenous tree species preferred by the farmers in the area. The *Kaizal*[61] tree is believed by locals to attract water. The *Lampati*[62] tree and the foleta plant are also very good for water conservation.

IV.2.b *Devithaan* or sacred grooves

The folk communities always have an intention to learn from nature as well as tried to understand nature. This trial of understanding nature resulted into a folk intelligence with which they derived their culture. This eco- folk wisdom has enriched them in being closely associated with the rhythms of nature. Such religious ideology got materialized through the worship of these physical entities. Age- old environmental awareness amongst the society got materialized that resulted in the several religious community groups, all of which have a deep concern with nature. Sacred groves are such micro-spatial units where devotees of a particular religion come for retaining their mental sanctity[63].

Devithaan is a patch of land near springs dedicated by local communities to deities, or their ancestral spirits. This place is kept sacred with other natural flora and fauna. This sacred grove has helped in great extent in preserving the water resources in the area. It prevents human interference in the source area. It helps in preventing spring from pollution because they are considering holly sites. Additionally, it also prevents water from biological contamination and keeps water clean for potable use. However, these practices enable to protect the immediate area near the springs; does not help to protect the actual recharge areas[64]. Such kind of practices needs to be done in taking much larger catchment area.

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[59] Terminalia myriocarpa

[60] *Alnus nepalensis*

[61] *Bischofia Javanica.*

[62] *Duabanga sonneratioides.*

[63] Madhukar Upadhya, "Traditional Techniques for Water Harvesting," *International Centre for Intigrated Mountain Development,* (2009):24-26.

[64] Laura Coulson, "Spring Development in Sikkim," accessed March 16, 2014. url: http://www.sikkimsprings.org/dv/research/Final_Coulson%20.pdf.

Plate IV.2: Devithaan or sacred grove of Bhulkey Spring, Duga Block.

IV.2.c Spring-shed developments

The implication of rainwater harvesting is to make optimum use of rainwater at the place where it falls i.e. to conserve it without allowing it to drain away. The rainwater has environmental advantage and purity over other water alternatives[65]. The rainwater harvesting not only helps to conserve water but it also saves energy which is required to operate a centralized water system designed to treat and pump water. It also lessens soil erosion and flash floods caused by runoff, as some rain water is captured and stored. Most importantly rainwater harvesting is useful and significant in recharging aquifers. One such example is spring-shed development under Dhara Vikas[66], a government sponsored programme. The whole mechanism for spring-shed development is based on geohydrology techniques understanding the local geology, groundwater dynamics, climatic conditions and the spring discharge and its characteristics.

With considering these parameters, recharge area of spring will be identified and appropriate techniques will be adopted such as a trench, pit dams, drains etc. During monsoon, the surface runoff water flows into the trenches, stored, gets infiltrated and recharge the underground aquifers. The ultimate result of such practices is the

[65] H.P Singh et al.,"Narrowing the demand and supply gap through water harvesting- a case study of Kutlehar area in Shiwalik Hills of lower Himalaya," International Journal on Emerging Technologies, (2011): 103-108.

[66] A spring shed development programme for rural water security initiated by RM&DD, Government of Sikkim.

augmentation of spring discharge even in dry periods and to make springs perennial. The spring- shed development under Dhara Vikas showed a promising result in different areas of Sikkim.

With an aim to rejuvenate and augment the discharge of springs, Dhara Vikas programme was carried out in Duga Devithaan source. This mechanism included engineering measures, vegetative measures and social measures. Unfortunately, the project could not be successful due to two reasons- (i) Unavailability of land which was actually required for the project, (ii) destruction of trenches under private lands.

IV.2.d Rooftop water harvesting

Rainwater is valued for its purity and softness. It has nearly neutral pH and is free from impurities such as salts, minerals and other natural and man-made contaminants. Rainwater is collected from roofs or other impermeable surfaces and is stored for non-domestic purposes especially during scarcity condition. The collected water can be used for non-potable such as irrigation, cleaning utensils, toilet flushing etc.

In the upper belt village named Budang and Gadi, the rain water harvesting techniques is adopted by most of the household. These two villages are under acute water problem. The reason behind acute water shortage is because of –

(i) Disappearance of Dhaap Lake, which used to be the main source of water,

(ii) Non availability of natural springs in the area.

The water supply which they have now is in miserable condition as such the water has been brought through the pipelines from other distant area. The member of household has to wait for more than nine days for their number. In order to ensure equity on water distribution and to avoid water conflict, they have introduced a system where a household gets water every after nine or more days.

In order cope with water shortage, rainwater harvesting technique is essentially developed in this village. Rooftop water harvesting is a process of collecting of runoff during rains from impermeable surfaces on houses or close to houses, its storage in water proof vessels and its subsequent use for the inhabitants of the houses. The mechanisms of rooftop rainwater include the preparation of channel either of bamboo, rubber pipe or tin horizontally perpendicular to the channel of roof ends. With the help of pipes, the water is stored in cemented tanks. People use this stored water during lean periods not only for household and agriculture purpose, they use it even for drinking purpose which is very rare.

Plate IV.3: A roof-water harvesting in Budang village.

IV.2.e Rainwater harvesting pit for vegetable cultivation

The state government has been giving extra effort to develop rainwater harvesting techniques to meet the agriculture water requirements in the drought prone areas. One of the important developments is rainwater harvesting pit. The technique includes the rectangular pit dug on the ground with 5 ft. height, 20 ft. breadth and 30 ft. length. These are covered with thick plastic which does not allow rainwater to penetrate onto the surface. The construction of such pit is usually preferable in the top of cultivable land so that it would be easy to supply the water down slope. The stored water is used for basically for growing vegetables. However, it does not support water for extensive agricultural farming because of small storability.

People have identified the drawbacks of such structures. Most of the water is lost through evaporation due to openness and lack of roof. Therefore, they can use only fifty per cent of this stored water.

Plate IV.4: A rainwater harvesting pit for vegetables which is basically made above the field (a), a closer view of rainwater harvesting pit (b).

IV.2.f Improving water storage infrastructure

Building household, community and village level storage tanks to strengthen the water storage infrastructure. The farmers innovatively utilize these storage tanks by harnessing the flow of springs during night time (which was earlier going waste) to fill up these tanks, which is used during day time for domestic use as well as minor irrigation of kitchen garden, green house crops etc. The discharge of existing spring water during night time which was earlier unutilized, is now being used efficiently by storing it for diversified use during daytime.

In an effort to strengthen the resilience of the local communities, water storage tanks are being constructed in the villages. These tanks store the spring water discharge during night time and hence enhance the drinking water security of the vulnerable local communities.

IV.2.g Efficient usage of water

The input of modern techniques in water management has helped to utilize the water resource in an efficient way. It actually reduces the water wastage by controlling the amount of water used or delivered. The introduction of drip irrigation system and sprinkler head in the area has helped farmers to utilize water in an efficient way.

Iv.2.g.1 Drip irrigation system

Drip irrigation is also known as trickle irrigation system. It is water saving irrigation method that applies water slowly to the roots of plants by depositing the water either on the soil surface or directly to the root zone, through a network of valves, pipes, tubing, and emitters, with the goal of minimizing water and fertilizer usage. The high efficiency of drip irrigation results from two primary factors. The first is that the water soaks into the soil before it can evaporate or run off. The second is that the water is only applied where it is needed (at the plant's roots) rather than sprayed everywhere[67].

The drip concept is the latest technological breakthrough in the field of irrigation though simple in nature; it aims at providing controlled and precise water application at low rates for longer duration through a low pressure delivery system at frequent interval. This system works best for plantation cops, and controlled conditions like that in Green houses but not sustainable for cereal crops. The on-farm handling of water is very important besides developing water sources to ensure round the year irrigation. The application of drip/micro-irrigation helps in increasing productivity by 30 percent to 100 percent with 50 percent to 70 percent saving of water (Tambe et al; 2012). Thus drip irrigation is becoming a major component of precision farming. With the use of drip irrigation system, the production and productivity of various horticultural crops have increased substantially in the area.

IV.2.g.2 Sprinkler head

Consisting of a sprinkler head & a stand, it is a handy water application device for irrigating vegetables in green houses etc. Water from the tank is connected to the inlet by means of poly pipes. Area covered by one sprinkler is up to 30 ft. diameter depending on the pressure head and the ht. of the sprinkler. After the plot is wetted, the sprinkler can be

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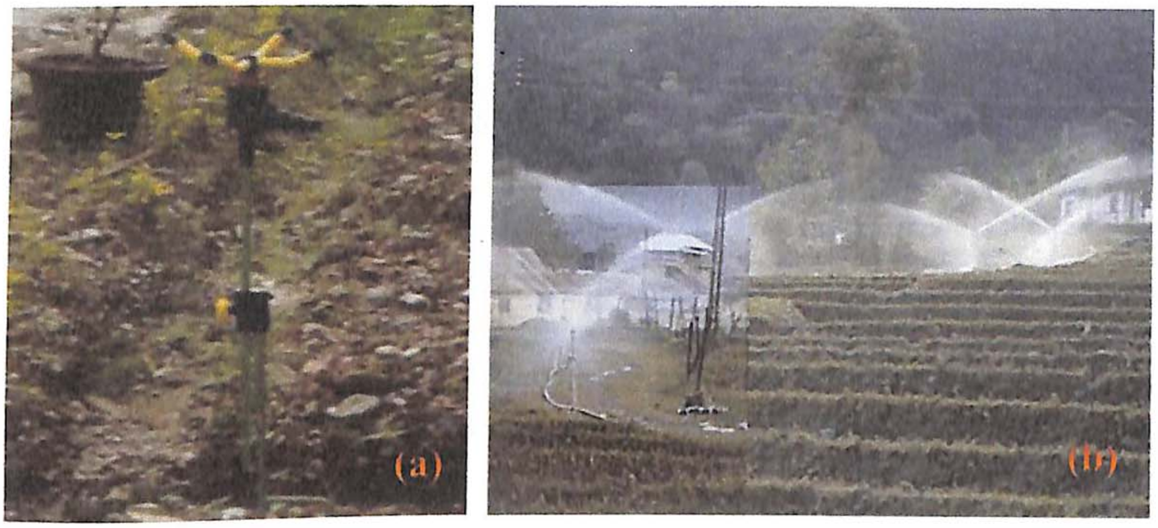
67 "Sikkim AGRISNET," accessed May 8, 2014. url: http://www.sikkimagrisnet.org/General/en/watermanagement1.aspx.

shifted to another location or plot. This way a person can irrigate the entire area and manage other works as well.



Source: Sikkim AGRISNET.

Plate IV.5: Sprinkler Heads (a) and Sprinkler irrigation system (b).

IV.3 Causes of water scarcity; people's perception and experiences

The local stakeholders are the one who are most aware of both their water needs and the conditions of their water sources. Water users often know why the springs near them have decreasing discharge and can link that change to certain events, such as decreased rainfall or the construction activities. Villagers are aware of the changes and often have viable input to increase the water flow of the springs. Practices, perception and experiences of local people have been recorded by undertaking FGDs which are summarized in Table IV.1. Therefore, in the following paragraphs different events and activities are being discussed which they contemplate a possible reason for water scarcity in the area.

Table IV.1:

Village wise FGDs in Duga block.

Karmithang GPU.

IV.1. a

Sl. No	Group type	water status	Water conservation and management	Factors for water scarcity
		1. Lamshal Dhara- Very poor.	1. Participatory approach in management system.	1. Population growth. 2. Road construction from

1	Mixed group	2. Langri Dhara-Very poor 3. Khanal source-Very poor. 4. Sawney Dhara-Good.	2. Afforestation 3. Fencing of source area. 4. Construction of tanks for storing water.	Karmithang to Gadi. 3. Delay in monsoon.
2	Old aged group		1. Devithaan or sacred grove. 2. Plantation of plants like Dhokrey Ful and banana.	1. Longer dry periods. 2. Ground drilling in Karmithang area by water management agencies in the year 1992.
3	Woman group		1. Afforestation in private land. 2. Developed pipelines.	1. Decrease in forest cover. 2. Decreased of rainy days.

Bhurung GPU:

Table: IV.1.b

Sl. No	Group type	water status	Water conservation and management	Factors for water scarcity
1	Mixed group	1. Dhalay Dhara- very poor. 2. Teendharay-Good. 3. Nepal Dhara- very poor. 4. Dorkhey Dhara- Very poor.	1. Well-developed pipelines and water storing tanks. 2. Afforestation in private lands and road sides, seedlings provided by forest department.	1. Decrease of rainy days as such very less water gets percolated into the ground.
2	Old aged group		1. Plantation of locally accessible plants like Dhokrey Ful and Banana plant in spring source.	1. Delay in monsoon. 1. Drilling and tunneling in Jitlang (lower part) area by Madhya Bharati
3	Woman group		1. Participatory approach in management system.	1. Deforestation. 2. Road construction in the area.

Deorali GPU:

Table: IV.1.c

Sl. No	Group type	water status	Water conservation and management	Factors for water scarcity
1	Mixed group	1. Bhulkey source- very poor.	1. Participatory approach in water management. 2. Plantation of	1. Population growth. 2. Road construction has affected the spring source. 3. Delay in monsoon.

		2. Lower Changer source- very poor. 3. Samkey- very poor.	Dhokrey Ful and banana. 3. Construction of tanks and well networks of pipelines.	4. Deforestation. 5. Drilling and tunneling in Jitlang village has caused shortage of spring discharge.
2	Old aged group		1. Devithaan or sacred grove to conserve spring source area.	1. Long dryer periods. 2. Shorter monsoon season as number of rainy days has decreased.

Table: IV.1.d

Duga GPU:

Sl. No	Group type	water status	Water conservation and management	Factors for water scarcity
1	Mixed group	1. Duga Devithaan source- very poor.	1. Participatory approach in management system. 2. Artificial recharge methods initiated such as trenches were made in the recharge area but failed due to land problem. 3. Afforestation in the recharge area of spring.	1. Deforestation. 2. Abandonment of agricultural practices. 3. Tunneling and drilling by Madhya Bharati in Jitlang area.
2	Woman group		1. Improved pipelines and water storing tanks. 2. Plantation of trees in private lands and nearby forest, seedling provided by forest department.	1. Increased in population and household number. 2. Absence of effective water conservation techniques.
3	Old aged group		1. Devithaan or sacred grove. 2. Plantation of Dhokrey Ful, Kaizal and banana.	2. Longer dryer periods and short monsoon period. 3. Delay in monsoon.

Table: IV.1.e

Sajong GPU:

Sl. No	Group type	water status	Water conservation and management	Factors for water scarcity
1	Mixed group		1. Participatory approach in management system. 2. Roof water harvesting system to meet water	1. Change in rainfall pattern. 2. Population growth and increase in household number.

		1. Devithaan source-poor.	requirements during dry season.	3. Road construction.
2	Woman group		1. Water is brought through pipelines from quite far places and stored in tanks.	1. Deforestation. 2. Lack of proper distribution system.
3	Old aged group		1. Plantation of trees like Kaizal, Panisaj etc. in spring source area.	1. Outburst and disappearance of Dhaap lake water due to major earthquake of 1968. 2. Delay in monsoon

Table: IV.1.f

Gadi GPU:

Sl. No	Group type	water status	Water conservation and management	Factors for water scarcity
1	Mixed group	1. No spring in the upper area. 2. Water supply has brought from distant place. 3. Spring discharge has decreased than before.	1. Roof water harvesting is done to meet water requirements during dry periods. 2. Manual water fetching from distant sources.	1. Population growth. 2. Delay in monsoon. 3. Longer dry periods and shorter monsoon periods.
2	Old aged group		1. Plantation of Dhokrey Ful and other plants in the spring source area.	1. Deforestation. 2. Construction of roads has disrupted the spring sources as a result discharge has decreased.

Table: IV.1.g

Budang GPU:

Sl. No	Group type	water status	Water conservation and management	Factors for water scarcity
1	Mixed group	1. Non availability of springs in the locality. 2. Water supply from distant place. 3. No water	1. Participatory approach in management system. 2. Roof water harvesting is done to meet water requirements during lean periods.	1. Population growth. 2. Changing rainfall pattern.
2	Old aged		1. Manual fetching of water from distant sources. 2. Devithaan or sacred groove to protect the springs	1. Outburst and disappearance of Dhaap lake water due to major

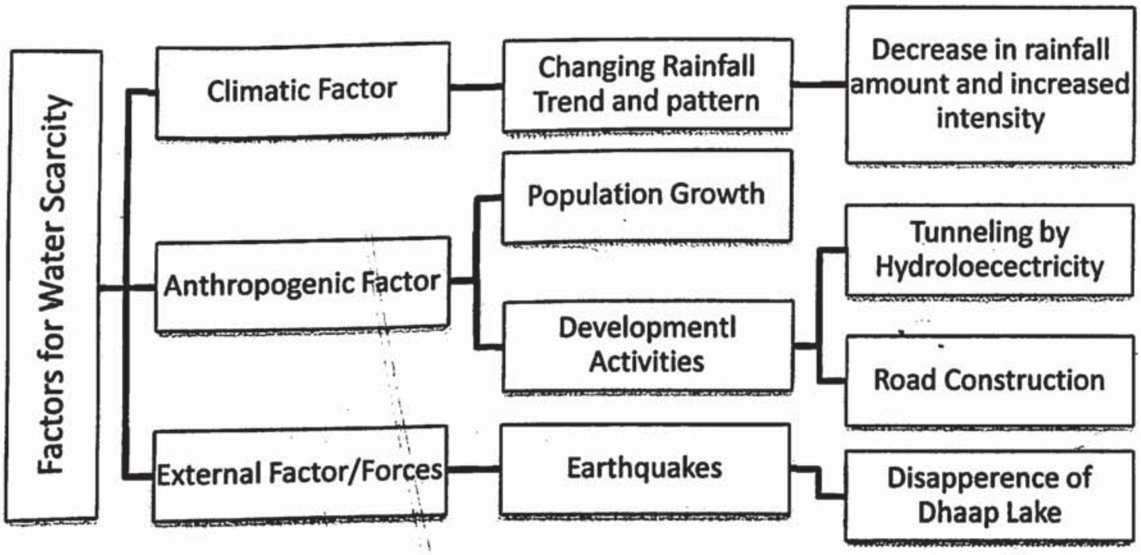
	group	during lean periods.	from human interference.	earthquake of 1968.
3	Woman group	4. A household gets water with an interval of nine or more days.	1. Rainwater harvesting pit are constructed for agricultural purposes. 2. Improved water pipelines and storing tanks.	1. Non availability of springs in the area. 2. Deforestation.

Source: Field survey (FGDs), January 2014.

[Water status has been analyzed based on spring discharge data of lean period (March- April) with a class interval of 1 to 7 liters/ minute is **Very poor**, 7 to 14 is **Poor** and 14 to 21 is **good**].

Figure IV.2:

A broad classification of factors that are responsible for water scarcity in the area.



Source: Constructed from Focus Group Discussions.

IV.3.a Changing rainfall trend

The local stakeholders perceive the untimely and unprecedented rainfall with longer winter drought is the important reason for water scarcity. The dry period is becoming longer and the monsoon period has become short and intense. Therefore it has a great impact on rain fed springs which are primary source of water in the area. Due to the impacts of climate change on precipitation patterns such as rise in rainfall intensity, reduction in its temporal spread, and a marked decline in winter rain, coupled with other anthropogenic causes, the problem of dying springs is being increasingly felt across the state[68]. It has been found a decreasing trend of rainfall amount in last three years with maximum down pour during June to August in the area.

IV.3.b Tunneling of Rongnichu Hydroelectric Project (RHEP)

The people living in the lower belt say reason for springs becoming seasonal is because of tunneling which is going on in lower part area of Duga. The vibration created by tunneling is as strong as trigger of minor seismicity. In general, tunnels do have impacts on ground water table and aquifers because they are dug in types of materials varying from soft clay to hard rock. But it needs a detailed study to understand the impacts of tunneling on existing underground aquifers of the locality.

The RHEP is a run-of-river hydro project proposed for development on the Rongnichu stream, a tributary of the Teesta River, in the East district of Sikkim. The hosting community or villages are Namli, Sumin, Duga and Kumrek.

Plate 4.6: A glimpse of tunneling at Deorali, lower part of Duga block (a), laborers working at the site area (b).

[68] S. Tambe et al., "Reviving Drying Springs: Climate Change Adaptation Experiments from the Sikkim Himalaya," *BioOne* (2012): 62.

The project will have an installed capacity of 96 MW and generate approximately 384 GWh of electricity (net) per annum. The project is being developed by Madhya Bharat Power Corporation Ltd. (MBPCL). The RHEP was allotted to MBPCL by the Government of Sikkim under the policy for private sector participation in the implementation of power projects[69].

The RHEP is a run-of river hydroelectric project that will utilize the natural flow of the Rongnichu River to generate electricity and hence does not involve the construction of a reservoir. The proposed project involves the construction of a 14 m high barrage on Rani Khola (Rongnichu) and a 12.08 km long headrace tunnel with a powerhouse on the right bank of Rangpo town and switchyard. A small diurnal storage area for peaking power during non-monsoon season is envisaged behind the barrage. The water will be diverted through an interconnecting channel from the barrage into a desilting basin before being conveyed into a head race tunnel, penstock tunnel and surge shaft. The water will pass from the penstock tunnel into the surface type powerhouse that will accommodate two 48 MW vertical shaft, pelton turbines directly coupled to vertical shaft, synchronous generators. The powerhouse shall have ventilation, cooling and heating systems and will be fitted with a heating and ventilation tunnel. From the powerhouse the water will be discharged back into Rongnichu River as it is a transbasin development, via a tail race channel.

A focus group discussion, interviews with local inhabitants of the tunnel site and field observation revealed that rivulets, streams, springs, and water seepages are rapidly disappearing in the areas causing acute shortage of drinking and irrigation water. People say that use of dynamites in underground tunneling by RHEP is the primary causes that develop cracks in aquifers resulting into water loss.

IV.3.c Seismicity and Dhaap Lake

The disappearance of Dhaap Lake is considered to be the main reason for water shortage in the area. The seismic event of the 1968 had caused violent outburst of water due to the disturbances created therein. It caused heavy loss of lives and property which lies on its

[69] Clean Development Mechanism Project Design Document Form (Cdm-Pdd). July 28, 2006.

way. It used act as a natural way for recharging underlying aquifers. The lake lied at an altitude of 1,700 meters and was surrounded by forest cover. The Lake has now become a makeshift cricket ground for the students and villagers and also serves a venue for the annual fair organized here every winter.

Plate IV.7: A glimpse of Dhaap Lake rather appearing a waste land (a), A sacred grove or Devithaan near lake (b).

IV.3.d Road construction

The construction activities such as buildings and roads have serious impacts on local hydrologic system. It involves the removal of trees and vegetation in large extent as such more storm runoff and erosion happens because there is less vegetation to slow surface run off. The construction of roads changes the water drainage pattern and also disrupts the springs and their catchment area which carries a long term impact. Natural land that used to soak up runoff is replaced by roads and large area pavements (impervious surface). This means that water that used to soak into the ground now runs off down streams. This further means underground aquifers will have less water to recharge it. This will lower the water table[70].

According to local informants, construction of road from Karmithang to Gadi and from Deorali to Bhasmey has serious impact on their Dharas. This has caused disturbance to

[70] USGS, "How urbanization affects the hydrologic system," accessed May 13, 2014. url: http://water.usgs.gov/edu/urbaneffcts.html.

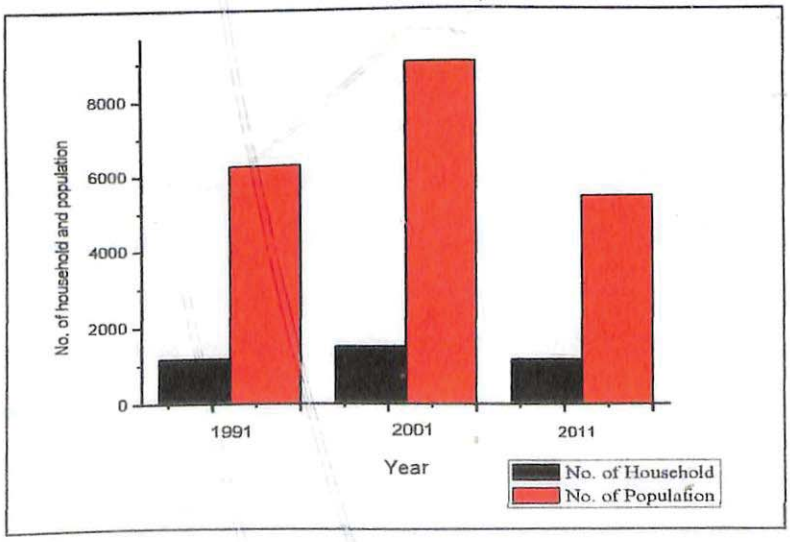
the water drainage system and disrupted the spring catchment area. During monsoon season, gully formation due to high surface run off is common in the village road.

IV.3.e Population growth

The increase in the number of population has put tremendous pressure on water resource. The water user per springs has grown drastically. According to the population census data 1991 to 2001, there was remarkable increase of population in the area from 6.2 to 7.8 thousand. The household number has also been increased from 1164 to 1478 as shown in Fig. IV.3. During 2001 to 2011, it shows that there were decrease of both household and population with 1149 and 5.4 thousand respectively. However, 2001-11 was the period which witnessed a rapid growth of developmental activities. It attracted huge number of laborers in construction sites. The important construction sites are Tunneling in Deorali, construction of huge statue of goddesses in Gadi. These people have added per head dependency on local water sources.

Figure IV.3:

Change in household and population number (1991- 2011), Central Pendam, Duga Block.



Source: Census of India.

The other probable reasons for decrease in population number seem to be the employment, education and project works. Education is important push factor for young people as most of them are living outside their village or state. A group of people engaged in other sectors are living outside villages. This might led to exclusion of some members of a household from census record/ enumeration.

IV.3.f Land use and land cover change

The impact of land use and land cover (LULC) change on the regional water balance is the most vigorous research in the international hydrological fields, and lot of research indicates that large scale LULC changes are the important factors resulting in the regional climate and hydrological cycle changes. Genxu et al (2005) had found that land use and land cover changes have great impact on the regional hydrological process in Zhangye region. With the change in different land use intensities, it had variable impacts on the recharge and discharge regime of groundwater. They found that increase of land under irrigation had enhanced the recharge of groundwater.

LULC change has been detected using ArcGIS platform. The key databases are multispectral satellite images - LISS-III image of 1990 issued by ISRO and LANDSAT image of 2013 issued by free sources. LULC of the area has been classified into seven sub types such as agricultural land, rural built up area, urban built up area, dense/closed forest area, open forest area, sand deposition and tree clant area.

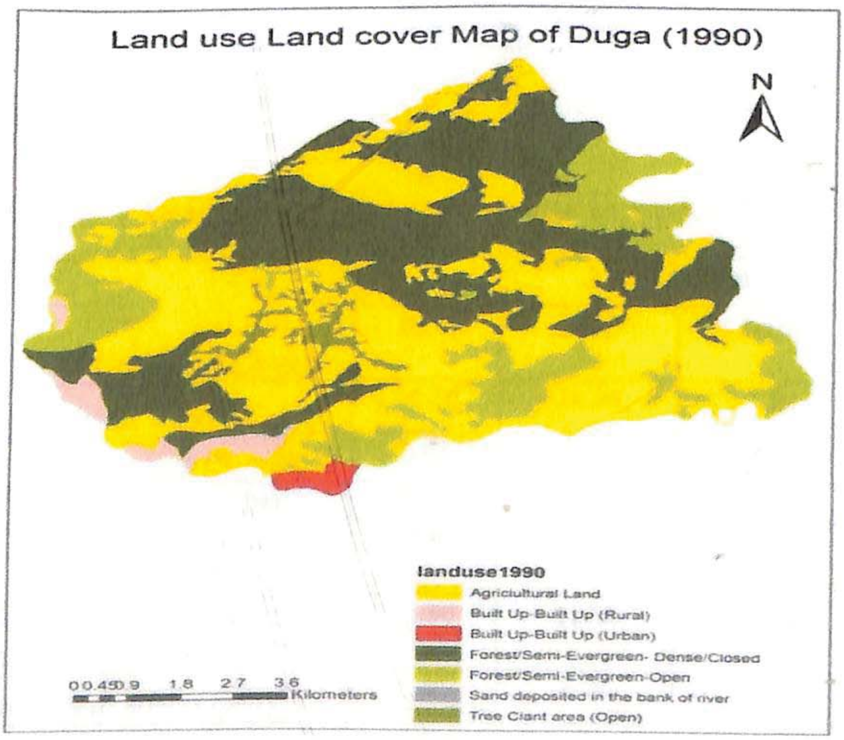
In 1990- 2013, the remarkable change in LULC is decrease of area under agriculture and open type forest and extension of open type forest area, tree clant area and built up area both rural and urban as shown in Table: IV.2. There is decrease of area under agricultural land and open type forest by 35.10 percent and 2.43 percent respectively. It is found that area under dense/closed type forest, urban built up, rural built up, and tree clant area has been increased by 5.04 percent, 10.09 percent, 10.81 percent and 36.35 percent respectively.

In two decades, the spatial distribution of land use change pattern in Duga block is – (i) The agricultural land has been decreased in upper, western and eastern part; while most of the land under agriculture is transformed into tree clant area, (ii) The semi-evergreen open forest has been transformed into agricultural land in the upper part of the area, (iii) The built up area (both rural and urban) has been extended in south- western part of the area.

Since 1995, several conservation initiatives have been taken up like implementation of the ban on open grazing in reserve forests and ban on green felling of trees in forests. This has probably helped to maintain the forest cover in the area. The negative growth of open semi-evergreen forest is probably due to degradation and fragmentation of forests led by heavy dependence for firewood and timber, high grazing pressure, poor natural regeneration and naturally slow growing nature[71].

A remarkable negative growth in agricultural practices has possible linkages with drying springs in the area. A typical example is, people used to cultivate rice before which is a form of terrace farming. In rice cultivation, sufficient water is required and holding the water in the blocked field's means sufficient water will be able to infiltrate in the ground thereby recharging the aquifers. Presently, the area under rice cultivation is very less and it is done only in the lower part area. Thus, people feels that the change in land uses could be the probable reason for diminishing discharge.

Map IV.1:



[71] S. Tambe et al., "Assessing the priorities for sustainable forest management in the Sikkim Himalaya, India: A Remote sensing based approach," *Springer*, (2011).

Map IV.2

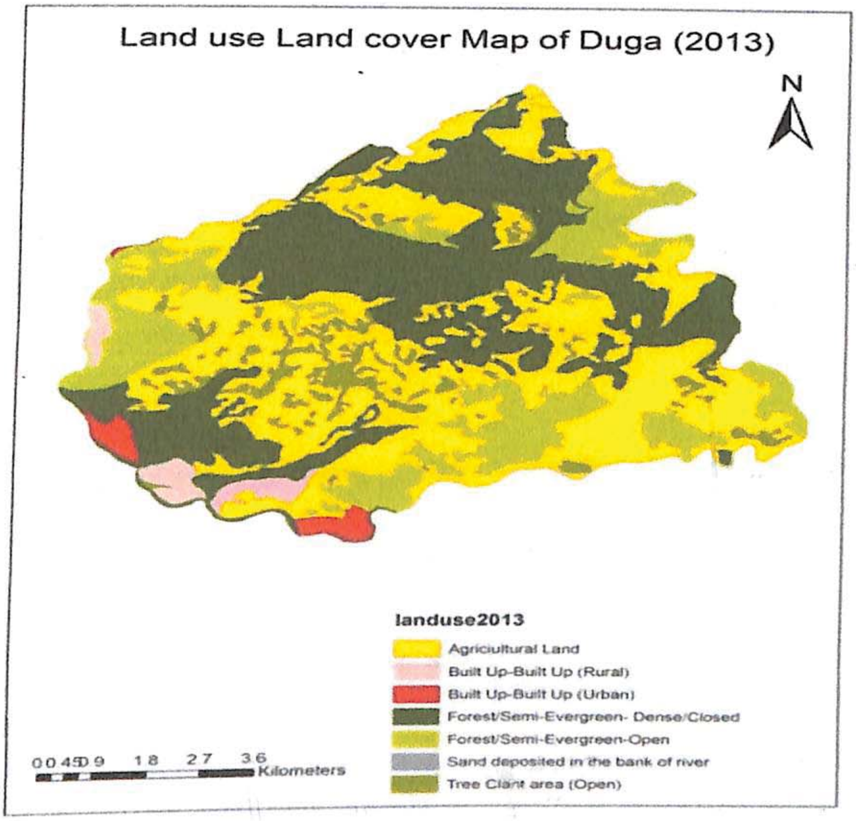


Table IV.2: Land use and land cover change between 1990- 2013.

Sl. No.	Land Use/Land Cover	Area (in Km^2)			
		1990	2013	Change	Change (in %)
1	Agricultural Land	30.20	28.36	1.84	35.10
2	Built Up area (Rural)	0.43	1.00	0.56	10.81
3	Built Up area (Urban)	0.56	1.09	0.52	10.09
4	Dense semi-evergreen forest	22.92	23.18	0.26	5.04
5	Open Semi-Evergreen forest	11.50	11.38	0.12	2.43
6	Tree Clant area (Open)	1.40	3.29	1.89	36.35

IV.4 Impacts of water scarcity: Emerging trends

In last one decade, Duga has undergone through various developmental activities viz construction of roads, construction of Block Administrative Centre (BAC), schools, physical health centers (PHE), construction of village foot paths under MGNREGA and making Gadi a tourist spot is a recent development. Other important focus is on maintaining quality and quantity of water resources. Though the state government has initiated various projects and programme to assure rural water security in the area or state as a whole but the problem of water shortage is rather increasing day by day.

Table IV.3:

Impacts of water shortage in Duga block: People's experiences.

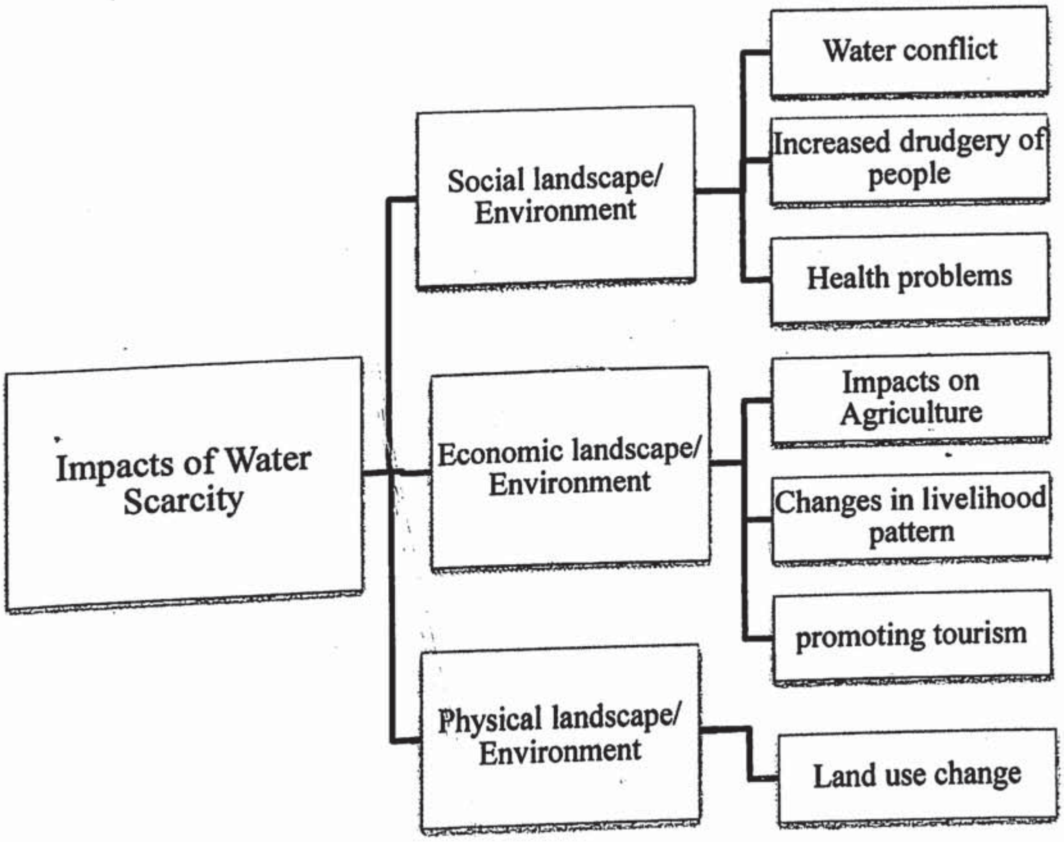
Sl. No.	GPW	Impacts of water scarcity
1	Karmithang	1. Water conflict. 2. Increased peoples drudgery. 3. Women and children have to walk longer distance to fetch water. 4. People go to Dharas even in night time to fetch water. 5. Agriculture failure. 6. Abandon of rice cultivation.
2	Bhurung	1. Less agricultural productivity. 2. More preference for vegetable cultivation. 3. Dairy Farming. 4. Very few people practice rice cultivation.
3	Kameray	1. More preference for vegetable cultivation and livestock rearing. 2. Agricultural productivity has decreased.
4	Duga	1. Agricultural productivity has decreased. 2. More preference for vegetable cultivation and livestock rearing.
5	Sajong	1. More preference for vegetable cultivation and livestock rearing. 2. Broom cultivation is highly encouraged. 3. Encouragement for turmeric cultivation which requires less water.
6	Gadi	1. Increased people drudgery. 2. Extra labor requires for water management.
7	Budang	1. Increased people drudgery. 2. Water conflict. 3. Use of stored rainwater for drinking purpose. 3. Only rain-fed crops are grown. 4. Extra labor requires for fetching water.

Source: Field survey (FGDs), January 2014.

The natural springs forms the important source of water for meeting household as well as for agricultural purposes in the area. However, it is observed that the discharge of the springs decreased as compare to past years. These springs yields very small discharge during dry periods when water is actually on high demand. The drying up of these sources has great implications on physical as 3well as socio-economic landscape of Duga in myriad ways. The local people's experiences and knowledge is being documented through FGDs as shown in Table IV.

Figure IV.4:

Impacts of Water Scarcity



Source: Constructed from Focus Group Discussions.

IV.4.a Water shortage induced conflict

After all, water is only one of many concerns perceived as socially important. The central conflict over water resources revolves around the question of the ownership, access and control over water. It is commonly understood that surface waters in India belong to the state and this is a direct consequence of usurpation of traditional and customary rights by the state in modern times. Whether the waters 'belong' to the state, however, requires closer legal examination centering on the nuances of the words ownership and control.

This has direct implications for the nature and extent of participation in water management regime in India[72].

Conflicts can arise from the use of common water resources. In order to further our understanding of such conflicts it would be appropriate to distinguish between conflicts arising through various situations. Helga Haftendron (2000) has talked about four kinds of conflict viz. conflict through utilization, pollution, relative distribution and absolute distribution. Where he describes a utilization conflict is a situation created by construction of a power-station on the upper-course of a river. The possibility of conflict increases in such cases where this construction has harmful consequences for the lower-lying states, for example, polluted waste water. The situation becomes more pronounced when the lower-lying states withhold their consent for such construction because of fears of, for example, water shortages. This could include a situation where the construction of a dam on the upper course of a river, that not only serves the electrical needs but also the major irrigational works of the lower-lying states, threatens to stem the flow of water. A relative conflict of distribution would present itself where a disparity over the use of water exists between the upper and lower-lying states. An absolute conflict of distribution would exist when there simply is not enough water to meet all the legitimate needs of the people.

Linking the conflict situation of Duga with above situations signifies more inclination towards absolute conflict. The cause for conflict is because of less discharge of springs during lean periods, which means not enough water to meet their requirements. This is

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72 Videh Upadhyay, "Water management and village groups: Role of law," *Economic and political Weekly,* (2002): 4907-4912.

creating conflict among water user community. They say, their conflict lasts long till spring does not yield enough water to meet their water requirements.

IV.4.b Increased people drudgery

Water scarcity has exacerbated the normal lives of people and has increased their drudgery. During dry seasons, springs yield small water. Due to low discharge, water does not reach to the taps. Now they have to walk longer distance to fetch water from other sources. Some people go to Dharas even during night time when Dhara is free. People have to segregate most of their time and labor for collecting water. It has been observed that woman and children are basically engaged in water collection.

Plate IV.8: People have gathered to fetch water and to wash their cloths, a few miles away from their house (a), small boys are fetching water after their school (b).

IV.4.c Health problems

The shortage of water resources has immense impacts on quantity and quality of water. Adequate supply of fresh and clean drinking water is a basic need for all human being. When there is inadequate supply of fresh water, they often rely on other sources like rainwater. The two villages like Gadi and Budang are typical example. During monsoon period, rainwater is collected in cemented tanks. This stored water is used during lean periods even for drinking purpose which may have serious health problems, which requires water quality analysis and treatment.

It is also found that increased incidence of diarrhea and other water borne diseases basically among children during June- July. It is due to consumption of water directly from the sources or school taps. However, this need further detail study on implications of water quality.

IV.4.d Impacts on agriculture and allied activities

Understanding agricultural risks and the ways of managing it are very crucial in the context of their impact on agricultural production and livelihood of the people, particularly in a water limiting environment[73]. Sikkim is an agrarian economy with predominantly rural population about 75 percent or two third of the overall work force depend on agriculture and allied activities, with only 16 percent of geographical area available for cultivation, about 17 percent of state GDP is being contributed from this sector. Small and marginal farmers own nearly 85 percent of all species of livestock and poultry, even though they own or operate less than 55 percent of the farmland and practice mixed crop-livestock farming system[74].

Agriculture exists within a symbiosis of land and water. Tambe et al (2012) found that the subtropical villages (less than 1000m) especially in the drought prone area are more vulnerable to climate change due to an increase outbreak of pest, disease and weeds. It is found that there is a reduction in temporal spread of rainfall; increase in the intensity; with a marked decline in winter rain.

The shortage of water and lack of proper irrigation system as compelled many farmers to change their cropping patterns in the area as such majority of household in the area prefers dry cropping and more incline to vegetable cultivation. Only few household are involved in wet cropping like paddy in the lower belts. According to the Village Development Action Plan Report (2011), only fifty household practices wet cropping in

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[73] K.N Selvaraj and C. Ramasamy, "Drought, gricultural risk and rural income: Case of a water limiting rice production environment, *Economic and Political Weekly,* (2006): 2739-2746.
[74] P.S Kumar,"Impact of climate change and adaptation measures," in *Climate Change in Sikkim; Pattern, Impacts and Innitiatives*, ed. S. Tambe, (2012): 219-232.

less than twenty acres of land in Karmithang GPU, Duga block. More than nine hundred household practices dry cropping in eight hundred acres of land as shown in Table IV.5.

Due to shortage of water, the majority of people are practicing vegetable cultivation. They grow vegetables four times in a year unlike other farming, which grow only twice a year. The varieties of vegetables are cabbage, cauliflower, tomato, leafy vegetables, garlic, onion, beans, broccoli and better guard. However, it is found that farmers are facing acute problem of marketing. In fact, farmers sell their surplus vegetable production

Table IV.5:

Number of Household practicing different types of farming, Central Pendam GPU, Duga Block.

Sl. No	**Rice cultivation (Khet bari)**	
1	Rice varieties	Rice: Champasari, Attey, Krishna Bhog.
2	Total households involved in *khet* systems in the village	50 Households
3	Total current area under *khet* systems in the village in acres/percentage of total land	20 Acres
4	Trend of area under rice cultivation over the last ten years	Decreased
	Dry cropping (Sukha bari)	
5	Main crop varieties	Maize, Pulses, Ginger, Vegetable
6	Total households involved in *Sukha bari* cultivation in the village	900 household
7	Total current area under *Sukha bari* cultivation in the village in acres/percentage of total land	800 acres
8	Trend of area under *Sukha bari* cultivation over the last ten years	Increasing
	Home garden (kothe bari)	
10	Main crops, main crop varieties and their productivity in the village	Potato, leafy vegetables, garlic, beans, bitter guord.
11	New varieties and their productivity in the village	Cauliflower, tomato, Broccoli.
12	Total households involved in *Kothe bari* cultivation in the village	900 household
13	Total current area under *Kothe bari* in the village in acres/ percentage of total land	20 acres
14	Trend of area under *Kothe bari* over the last	Increased

	ten years	
Horticulture and Green house		
15	Main crop varieties	Tomato, cauliflower, cabbage
16	Total households involved in Modern Farming Techniques in the village	80 household
17	Total current area under Modern Farming Techniques in the village in acres/ percentage of total land	10 acres
18	Trend of area under Modern Farming Techniques over the last ten years	Increasing

Source: VDAP Report; 2011.

to State Co-operative Supply and Marketing Federation Ltd (SIMFED) but they take bulk production only. In case of small production, they have to sell their own and they do not get preferable price.

Livestock rearing is the important source of income in the area. The livestock wealth is seen as significant asset to the farmers, which provides nutrition and economic support. It is found that eighty percent of people keep one or two livestock. Dairy farming is found to be important source of cash income and it also helps to maintain soil nutrients in form of manure. However, the changing climatic condition; leading to scarcity of water and prolonged dry period is adding more risk for livestock rearing. The lack of fodder during dry periods is the main problem that farmers are facing now.

The scarcity of water has compelled some farmers to leave the fields barren or prefer for tree plantation in their private lands. But the tree plantation has added risk of increased attack of wild animals and birds on agriculture. In order to prevent harm from wild animals, people have started growing broom and turmeric; which are climate resilient crops and has no wild animals attack. Moreover, the declining water resources in the area has not only raised the marginal operational cost, but also gave rise to a situation of diminished farm output and lowering net returns. This indicates the fact that the cost of natural resource depletion is disproportionately born by the resource poor farmers because they are unable to invest in technology, and hence, remain excluded from its beneficial ambit.

IV.4.e Changing livelihood pattern

Duga block portrays an agrarian economy. It remained dependent on agriculture for the majority of their income, either as owners, lessees or laborers. However, the proportion of income coming from agriculture fell and households became increasingly dependent on other sources of livelihood. More frequently and prolonged dry period have resulted in failure of agricultural practices and that led to diversification of livelihood options. The political and institutional forces are the main driving forces behind generating other livelihood options. The state governments has introduced various schemes and programme for the economic upliftment of the rural community such as pesiculture, sericulture, carpentry training etc. but the number of beneficiaries are small.

Likewise, MGNREGA has helped the people in great extent to accelerate their lives. It is found that one member from each household are engaged in MGNREGA. Generally, women are engaged in agricultural activities for running their house and for nurturing children. The failure of agricultural productivity had deteriorated their economic condition. But their engagement in MGNREGA has not only given them a livelihood opportunities but it also assured social and economic empowerment.

The state government has sanctioned Nishani Devi Kali Bhawani project, which take in the construction of Goddess Kali statue at crest of Gadi village. This idea is similar to converting Namchi, south part of Sikkim into tourist destination. Namchi is a drought prone area falling in the rain shadow of the Darjeeling Himalayas. This pilgrimage complex is adorned by a massive statue of Lord Shiva and the Sai Baba temple in the foreground. Lakhs of tourists visited in this new destination in the first year itself, resulting in an additional contribution to the State's economy and providing employment to thousands of people.

Community centered natural resource management and biodiversity conservation based on the principles that biodiversity must give itself by generating economic benefits particularly, for local people has become popular tool in the state or in resource management as a whole. The premise is that eco-tourism depends on maintaining attractive natural landscape and rich flora and fauna; therefore, helping communities earn income as an economic alternative. The two villages, Gadi and Budang are almost set to alter into eco- tourism landscape. The village homestays, bamboo house, long adventurous trekking footpath route which starts from Gadi to Pakyong are the important recent development in the area.

To conclude, the conservation and management of natural springs highly remained on the domain of traditional knowledge of people in community level. With a history as water abundant village, an efficient traditional knowledge for water management had not prevailed. Their conservation and management strategy is largely bounded by cultural beliefs and traditional know how conferred from their ancestors. Despite the government's repeated assertions in recent years on the need for a decentralized, people oriented and demand driven water management, these have not been converted into implementable solutions.

The lack of defined group is adding more difficulties in spring management at community level. While policy initiatives exist with regard to water user associations, watershed associations, and legal strategies are a much-needed prerequisite in order to evolve satisfactory working relationships between local bodies' institutions and networks of formal and informal village groups engaged in water management[75]. The state intervention and initiation of various schemes and programme with respect to protect their water sources and confirming them with water tanks and taps has stimulated the condition for some extent. However, the shortage of water is rather increasing day by day. This is led by interplay of climate change and anthropogenic factors; leading to depletion of natural resources and threatening to livelihood of local community. This has also led to diversification of livelihood options as adaptive measures to environmental change. But the issues of equity, accessibility and sustainability are other concerns that need to be understood.

It is observed that main drivers leading to depletion of water resource or natural springs are perceived to be changes in climatic condition leading to erratic and irregular precipitation pattern, anthropogenic factors such as construction activities, deforestation and biological interferences in the catchment area and external forces like earthquakes,

[75] Videh Upadhyay, "Water management and village groups: Role of law," *Economic and political Weekly*, (2002): 4907-4912.

floods etc. However, the latter one needs further in-depth study. It is perceived that shortage of water has immense impact on socio- economic and physical landscape of the area. It led to failure or loss of agricultural productivity; further leading to livelihood hardships among the local community.

CHAPTER V

SUMMARY OF CONCLUSION

Summary

This study is an attempt to understand the environmental implications of natural springs. In the following paragraphs, chapter wise summary has been discussed precisely.

I The Himalayas is often considered as third pole in terms of fresh water which is locked in ice caps. Most of the perennial rivers originate from it. However, the people living there are primarily dependent on natural springs for meting their water requirements.

I.2 Sikkim is blessed with number of natural springs, which forms the primary source of water to both urban and rural population. More than 80 percent rural population of the state is dependent on natural springs for household as well as agricultural purposes. Therefore, understanding springs dynamics is utmost important for the sustainable development of springs.

I.3 The studies revealed that due to various factors such as climate change, anthropogenic factor and external forces, these springs are either drying up or have become seasonal. This has led to shortage of water and has posed a great challenge on existing water management system. Additionally, the shortage of water has impacted on physical as well as socio-economic structure in myriad ways.

II The nature of springs has direct linkages with geographical setting of an area. The recharge- discharge regime of springs largely depends on catchment area characteristics and local climatic condition including geology, land use cover, vegetation types, nature of soil, precipitation and temperature.

II.1 The prevailing temperature of Duga Block ranges between 4^0 to 30^oC at lower altitude which is around 700 m and at 1^0 to 25^o C at moderate altitude of around 1750 m. It receives highest mean rainfall in the month of August (1466±233) and diminishing trend starts from onset of September which goes on till February. The month of March to April is observed as the driest period.

II.2 Soil is mostly derived from parent rocks such as schist, gneiss and colluvial materials. The characteristic of soil varies from place to place due to topographical variations. The texture of the soil is loamy sand to silty clay loam. Soils are generally acidic in nature having the pH value of 5.0 to 6.0. A brown red and yellow soil is found in a small area in lower part.

II.3 Forestry and agriculture are the main land use type. Out of total agricultural area, the eighty percent is under rain fed farming. The land under irrigation is twenty-five acre, unirrigated is five hundred acre, waste land is twenty hectare, cardamom farming is two hectare with a per capita land holding of two acre.

II.4 The lithology of Duga basically composed of lingtse gneiss in patches and interbanded chlorate- sericiteschist/ phyllite and quartzite and blotetit quartzite of Gorubathan formation of Dailing Group. The outcrop of schists has also been found during field visit.

II.5 The sacred grove or landscape is the important traditional way to conserve natural resources. The Gadi sacred landscape lies in the crest of Gadi village. Gadi has a historical significance. In fact, it is a fort built by the monarch of Sikkim, the then chogyal Chador Namgyal to resists the invasion of Bhutanese army. During one of the invasion by Bhutanese army, the princess Pendi took shelter there and so the name of the village Pendam from her name. This place including the grove is preserved as sacred area in contemporary time as well.

III The clear understanding of spring dynamics including catchment area characteristics, climatic condition and human action would help in managing springs in long run. With this regard, the chapter three demonstrated the linkages between spring discharge and catchment area characteristics. It has also focused on relationship between spring discharge and rainfall pattern of the area.

III.1 The catchment area of thirteen springs varied considerably from one another with regard to geology, spring type, vegetation cover, land use and land ownership. Linkages between spring catchment area characteristics and spring discharge have been analyzed. The geology of spring catchment area found to be main controlling factor for the amount and pattern of spring discharge. A positive correlation has been found between spring discharge with geology and land use type. This means, the changes in rock type or land use practices in spring catchment area may result in increase or decrease of spring discharge. While no relationship have been found between spring discharge and spring type.

III.2 Based on ACWADAM framework, their discharge trend, probable nature of aquifer feeding spring and aquifers attributes has been analyzed. As a result, the nature of aquifers feeding these springs are unconfined and the discharge trend of thirteen springs found to be three different types- (i) High and perennial discharge, (ii) Low and perennial discharge, and (iii) Widely ranging discharge and seasonal. Likewise, the aquifers attributes such as storability and transmissivity found to be three types depending on other geohydrological parameters of springs viz; (i) Slow flow and moderate to large storage, (ii) Low storage, and quick transmission, and (iii) Slow flow and low storage.

III.3 The rainfall trend of last three years has been analyzed. It found that the amount of rainfall has decreased drastically. High rainfall variability has seen in the area. An intense rainfall has been observed from the month of June to August, leaving other months with relatively less rainfall. The positive correlation has been between rainfall and spring discharge. The peak spring discharge found to be perfectly coincided with peak rainfall period. This indicates, spring is highly dependent on local rainfall for recharging underlying aquifers.

III.4 As a result, the temperature and electrical conductivity further supported that rainfall forms the primary source for recharging aquifers. The high temperature during lean period signifies that ground water table has reached the lower level and particular water is coming out from deep beneath the ground. The electrical conductivity increases during the lean season as a result of flow of relatively older water out of the storage. The decrease in the conductivity is due to an increase in the flow of the low conductivity recharging water (precipitation) into the springs.

III.5 The pH of spring water showed seasonal variation ranges from 5.53 to 7.15. The World Health Organization's permissible standard for water pH is 5.5 to 8.5. Thus, the pH of spring water holds a favorable condition.

IV Water resource management is an important parameter for the development of any nation as it directly relates to the development and growth of the economy. The management encompasses the process of maintaining its sustainability and pristinely condition as well as harnessing its full potential for various uses. The lack of efficient water management system may often reflect into a crisis situation. Thus, the fourth chapter focuses on existing water management strategy of the area. It also underscores the impact of limiting water resource on socio-economic and physical landscape.

IV.1 It is found that status of 80 percent spring is very poor with discharge of 1 to 7 L/Min, 14 percent is poor with discharge of 7 to 14 L/Min and only 8 percent is good with the discharge of 14 to 21 L/Min. More than five hundred household are dependent on 13 springs with an average dependency of 38 household per springs. Some springs yields less than 1 L water per minute during lean seasons, which is not sufficient to meet people's water requirement. Thus, people have to rely on other sources like rainwater. The consumption of untreated rainwater may have various health problems.

IV.2 The strategies with regard to conservation and management of springs are largely based on participatory approach. The springs are considered common property resource. Their conservation largely depends on traditional know-how and practices handed down from their ancestors

IV.3 The water end-user group and NGOs are found to be active in community level. Modern conservation inputs are being made accessible by the state government in form of plantation, spring shed developments, rainwater harvesting techniques, strengthening of storage efficiency and water use etc.

IV.4 The local people perceived that causes for diminishing water resource are because of climatic change; leading to changing rainfall trend, the anthropogenic factors such as population growth, deforestation, construction including the road and hydroelectricity project and the external forces such as earthquake. The interplay of these entire factors further exacerbates impacts on socio-economic as well as physical environment.

The Duga represents a rural agrarian economy. The agriculture and livestock rearing forms the perennial livelihood options of the local community. The natural springs are the primary source of water for meeting household as well as for agricultural requirements in central Pendam and west Pendam villages of Duga block. People have observed that springs are becoming seasonal and yields relatively less water than before. The area frequently experienced draught like situation in the recent past. This study underscores the decline of spring discharge or becoming seasonal has been led by multiple factors such as change in climatic condition, anthropogenic factor, and external forces. The interplay of all these factors has remarkable impacts on spring recharge- discharge regime.

The steep and irregular topography presents variability in catchment area characteristics of springs including geology, land use, vegetation and rock type. All these indicators regulate the water yield and nature of both perennial and seasonal springs. These catchment area characteristics have found to be positively correlated with spring discharge pattern. This further implies that catchment area characteristics are the controlling factor which has strong linkages with spring recharge and discharge process.

The natural springs are considered as common property resource in the state. Their conservation and management largely depends on water users or local community. With a history of being water abundant village, the traditional knowledge for water management has not been developed to a remarkable level. Their conservation technique is largely bounded by cultural beliefs and traditional know how conferred from their ancestors. Most of the sources are preserved as *Devithaan* or sacred groove. The vegetative measure such as plantation of *Dhokrey phool* and *Kera* makes an important water conservation tool. These measures are being adopted in spring source or discharge points, which actually needed to be done in the recharge area. The inclusion of larger area would result in healthy spring yield. The state government has initiated scientific techniques for water management. Some of these are rainwater harvesting pits, drip irrigation methods, developing spring sanctuaries, establishing house and community level reservoirs. This has assisted to ameliorate the situation to some extent but the water problem is rather increasing day by day.

The shortage of water is one of the key factor that is leading to gradual environmental change in the area. The environment here not only refers to the physical or natural world, it also embraces the social and economic milieu at large. The depleting springs has increased the livelihood hardship of the local community. People drudgery and social conflict for water is increasing progressively. The traditional farming like rice cultivation is abandoned in some parts, which used to act as natural recharging system for underground aquifers. The limitation of water resource has compelled the farmers to either change their cropping pattern or leave the field barren. Now, they are more inclined to dry farming, vegetable cultivation and tree plantation. The livestock rearing has also become difficult due to lack of fodder during dry periods.

With an idea to regain the economic stability in the area, tourism is being recognized as a potential source. It is an important means of achieving socio-economic development. The principle of eco-tourism depends on maintaining attractive natural landscape and rich flora and fauna; therefore, helping communities earn income as an economic alternative. The village homestays, bamboo house, long adventurous trekking route which starts from Gadi to Pakyong are the important recent development in the area. The adoption of new development like tourism in water stress fragile environment itself is a big dilemma that further creates the issues of compatibility and sustainability.

The shortage of water resource has also posed a serious threat on quality of water as well. It has compelled the people to rely on other sources like rainwater. They store rainwater on tanks and reservoirs through rooftop rainwater harvesting during monsoon season. They usually use this stored water during lean period not only for household purpose, but largely for potable use also. This untreated water has led to various health problems.

Suggestions

- A participatory approach is required to manage water resources. This will help to resolve the conflicts, assure community participation and manage water resources in an efficient way.
- Form Water Users Associations (WUAs) to monitor leakage, water supply, regulate use of water and to help conserve water.
- Automatic weather stations (AWS) have to be installed in various parts to monitor climatic data such as rainfall, temperature, humidity, sunshine etc. This will enable to capture the micro climatic variability and their impacts.
- An adequate forest cover has to be maintained in the spring catchment area and the wasteland and barren land needs to be transformed to agricultural field or plantation field.
- Improve and disseminate traditional knowledge on water harvesting and conservation and need to mainstream traditional practices as water management strategies.
- Strengthen water storage capacity by providing household and community level storage tanks and reservoirs especially in villages located in crest of hills where there is recurrent water shortage.
- The scientific research is required to revive Dhaap Lake. This may resolve the perennial water problems of Gadi and Budang village.
- The Integrated watershed management programme should be implemented in larger area of the state.
- The microbial analysis of both spring water and rainwater is required to analyze the water quality. The consumption of stored rainwater and untreated spring water may lead to various health problems.

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