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Report on Aquifer Mapping Studies in East Sikkim district, Sikkim

(AAP 2022-2023)

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CENTRAL GROUND WATER BOARD
EASTERN REGION, KOLKATA
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FOREWORD

To understand the nature and occurrences of groundwater, Aquifer geometry, dispositions & characteristics and management of groundwater resource, National Aquifer Mapping & Management Programme (NAQUIM) has been taken up by CGWB under XIIth Plan. During the Annual Action Plan 2022-2023, Aquifer Mapping studies & Management plan was taken up in North Sikkim district.

The study under the aegis of NAQUIM includes four major components namely; Data gap analysis, Data generation, Data collection & compilation and preparation of Aquifer maps and Aquifer Management Plan. It is however, to be noted that East Sikkim is one of the very few district where NAQUIM studies has never been attempted before. Therefore, the district as a whole is deficit of scientific data pertaining to dispositions of aquifers and the underlying hydrogeology. Only few spring data through the initiative of Government of Sikkim (Rural Development) and District Irrigation Project reports through PMKSY initiatives are available and those have been utilized in framing the management plan for the present report.

This report incorporates information from various reports published by Geological Survey of India (GSI), hydrometeorological data from IMD, published reports of Central Water Commission(CWC), DIP project reports of PMKSY, various papers published for Sikkim state from noted journals, etc. Hydro-geological data is sourced from the scientific studies of CGWB pertaining to groundwater explorations, hydrogeological surveys, chemical analysis and outsourcing explorations being taken up for data generation.

Compilation of this report, evaluation of data and preparation of relevant maps and their reproduction in the form of present report is outcome of the efforts given by Miss Zumchilo T. Ezung, Scientist-C (HG) under the supervision of Dr. Indranil Roy, Scientist-D (OIC/NAQUIM).

Hydrometeorological data interpretation has been done by Dr. Nilamoni Barman, Scientist-B (HM). Hydrochemistry, including analysis and interpretation has been provided by Dr. Suparna Datta (Asst. Chemist) & Atalanta Narayan Chowdhury (Asst. Chemist). The geophysical survey and data interpretation has been done by Dr. K. C Mondal, Scientist-D (GP) & Sujit Sarkar, Scientist-D (GP).

Effective method of dissemination of the existing technical information to different user agencies is an important aspect of NAQUIM which plays a very vital role in the safe and optimal development of groundwater resources in our country. In this regard, Central Ground Water Board has taken up a great initiative in incorporating NAQUIM project since 2012 to fulfill this directive. It is much anticipated that, this report will become an important tool not only for various user agencies, Engineers, Scientists, Administrators, Planners and others involved in groundwater planning, development and management but also to the common people to make them aware of local groundwater issues and its sustainable management.

(Dr Anadi Gayen)
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EXECUTIVE SUMMARY

The study area is East Sikkim district of Sikkim covering a total geographical area of 954 sq. km. North latitudes of 27˚8'3.84" to 27˚25'31.08"and East longitudes of 88˚26'27.96" to 88˚56'5.28". There are a total of 10 blocks in East Sikkim namely, Khamdong, Rakdong Tintek, Nandok, Martam, Ranka, Duga, Parakha, Pakyong, Regoh and Rhenock. The altitude range is from 300-5000 amsl. The total population of East Sikkim district is **283583** as per 2011 Census.

The normal annual rainfall is in the tune of 3332.30 mm. The average monthly rainfall is 325 mm and number of rainy days is 135 days per year.

Physiographically, East Sikkim forms a part of the Eastern Himalayas, falls within the Central Himalayan zone characterized by Buxa Series, Daling Series, Darjeeling Series and equivalent Proterozoic and Lower Palaeozoic rocks. The area is characterized by a typical Himalayan topography i.e., a series of criss-crossing ridges and ravines. The altitude varies from 300 metres to >8500 metres above mean sea level. The district is divided into three (3) geomorphic units such as, steep hill, valley and slope. Distinct micro-morphology features of Sikkim terrain include terraces and floodplains, valley side slopes and landslide slopes, alluvial cones of different types and generations, tors, kettle shaped depressions, terrace isles, sickle shaped rags, beveled plains, undulating plains, with deeply dissected valleys, glacial or peri-glacial deposits related sedimentary structures crevasses, soil series or poly pedan, gorges etc. The soils are generally derived type and are acidic to very acidic type. The main rivers draining East Sikkim district are Tista, Dik Chhu and Rangpo Chhu. There are two major drainage basin/watershed identified in East Sikkim district. They are Rongni Chhu basin and Rangpo chhu basin. Other basin includes part of Dik Chhu and Jaldhaka basin.

East Sikkim is a non-glacialized basin with snow cover or glacier area of only about 11% of the total area. Forest cover is about 62%. Agriculture area is 16% of the total area. Paddy, maize, buckwheat, fingermillet, mustard, etc are some of the crops grown in the district.

East Sikkim is endowed with varying geology comprising of rocks with age ranging from Pre-Cambrian to Upper Pleistocene to Holocene. The different types of rocks exposed in the study area includes gneiss, schists, quartzites, phyllites, limestones, sandstones, shales, meta-sedimentaries, etc.

East Sikkim is a part of the Rangpo glacier basin which is non-glacierized. There are a number of glacial lakes and snow-fields in East Sikkim that contribute significantly to the water of resource of Sikkim. Glaciers are the perennial sources of fresh water that is discharged in the two major rivers, namely Teesta and Rangit. Groundwater occurrence in East Sikkim can be broadly

classified into two i.e., in Permafrost regions and in non-permafrost regions in the form of springs and other discharges. The water in permafrost regions occur in supra-permafrost zones where the water of remains confined to the rocks between the ground surface and the top of the permafrost area, in inter-permafrost zones which is the water that migrates through the permafrost zones and in infra-permafrost zones where water occurs beneath a permafrost sequence. The water in non-permafrost regions occurs in largely disconnected bodies under favorable geological conditions such as fractured and jointed zones in various lithological units and in weathered zones in the phyllite, schist, gneisses and quartzites. The area has high relief and steep gradient and as a result groundwater comes out as seepages and springs wherever the land surface intersects local ground water body.

As per the computation, the annual extractable groundwater resource for East Sikkim district is estimated at 3935.94 ham. The total extraction for all uses is estimated at 101.6 ham. The stage of extraction for the district stands at 2.58%, falls under ‘safe’ category.

Due to the distinct hydrogeological set up of the Himalayas, the region’s accessibility limitations and tough terrain remain as a challenge for groundwater exploration activity in East Sikkim district. Owing to its very steep topography and high rainfall, soil erosion and run-offs is very common in the region. The soil in the region is generally acidic to very acidic and therefore; it affects the productivity of crops that are grown in the region. In addition to that, East Sikkim is such a district where geological hazards are a common phenomenon like earthquakes and landslides.

The Himalayan region is blessed with adequate rainfall, but an overwhelmingly high proportion of the same is restricted to the monsoon season and natural groundwater recharge is hampered by high levels of surface runoff due to the presence of high slopes. The rural and urban water supply in the study area is highly dependent on the spring water. The technology of spring water harvesting system is recommended. However, given the importance of aquifers in understanding springs, a hydrogeological approach should be a prerequisite for any spring shed development work. In gentle sloping areas, a step in the form of a terrace has to be built in order to slow down or eradicate the momentum going downhill by the surface water. Recharge areas to be demarcated based on the hydrogeology. Periodic monitoring of spring discharge can help in future planning and management of spring water. Sensitization of the local community regarding role of hydrogeology governing recharge areas, protection of recharge areas, importance of spring water data collection etc. is necessary. Emphasis should be given to rainwater harvesting with suitable structures.

CONTRIBUTORS

Data Acquisition	:	Dr. Indranil Roy (Scientist-D)
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CONTENTS

AQUIFER MAPPING STUDIES IN NORTH SIKKIM DISTRICT, SIKKIM STATE

LIST OF TABLES

LIST OF FIGURES

CHAPTER-1

INTRODUCTION

Groundwater is one of the prime sources of fresh water contributing significantly for the survival of mankind. However, overexploitation, surface runoff, subsurface groundwater discharge has depleted the fresh groundwater availability considerably. Assessing the groundwater potential zone is extremely important for the protection of water quantity & quality, and the management of groundwater system. In this context, the National Aquifer Mapping& Management Programme (NAQUIM) has been taken up by Central Ground Water Board (CGWB) under XIIthPlan. As per the revised annual action plan groundwater management studies in North Sikkim district was taken up by CGWB, ER, Kolkata. In this report the salient features ground water occurrences, availability, resource vis-a-vis quality, development &management, scope of ground water etc. for the district have been covered.

1.1 OBJECTIVE:

The broad objective of the study in North Sikkim is Establish disposition of aquifer system in undulated hilly terrain, to quantify and check the quality of ground water resource, to study the aquifer characteristics, to suggest suitable interventions for ground water management and prepare a comprehensive Ground Water Management Plan.

1.2 SCOPE OF STUDY:

The scope of the present study is broadly within the framework of National Aquifer Mapping & Management Programme (NAQUIM) being implemented by CGWB. There are four major components of this activity viz.: (i) Data gap analysis (ii) Data generation (iii) Data collection / compilation (iv) Preparation of aquifer maps and management plan to achieve the primary objective.

As per the present scenario, there is no such as consolidated data pertaining to groundwater explorations in relation to East Sikkim district and therefore there is not much scope to bring out the underlying aquifer dispositions models for study and research purpose.

1.3 APPROACH & METHODOLOGY:

An approach and methodology adopted to achieve the major objective have been shown below step-wise.

I. Compilation of existing data
II. Identification of data gaps
III. Data generation based on data gaps
IV. Preparation of thematic maps on GIS platform
V. Compilation of Aquifer Maps and Management Plan

1.4 LOCATION, EXTENT AND THE ACCESSIBILITY:

East have a total geographical area of about 954 Sq. km. The district lies within the North latitudes of 27˚8'3.84" to 27˚25'31.08"and East longitudes of 88˚26'27.96" to 88˚56'5.28". Gangtok is the district headquarters which lies at about 5410 feet (1650 m) above sea level. There are a total of 10 blocks in East Sikkim namely, Khamdong, Rakdong Tintek, Nandok, Martam, Ranka, Duga, Parakha, Pakyong, Regoh and Rhenock. The altitude range is from 300-5000 amsl. The climate of the district varies from Tropical to Sub-Tropical to Temperate. The temperature varies between 12˚C -28˚C at low altitude places like Namli whereas, the temperature varies between 0 -10˚C in places like Khamdong. Similarly temperature is generally below 0 - 10 c in places like Gnathang. The normal annual rainfall is in the tune of 3332.30 mm.

The district has an annual extractable ground water resource of 10196.25 ham. The total extraction is 702.64 ham. The net ground water availability for future use is 9479.06 ham. The stage of development stands at 6.89 %, categorized as 'Safe'.

The location map for East Sikkim is given in **Figure-1.**

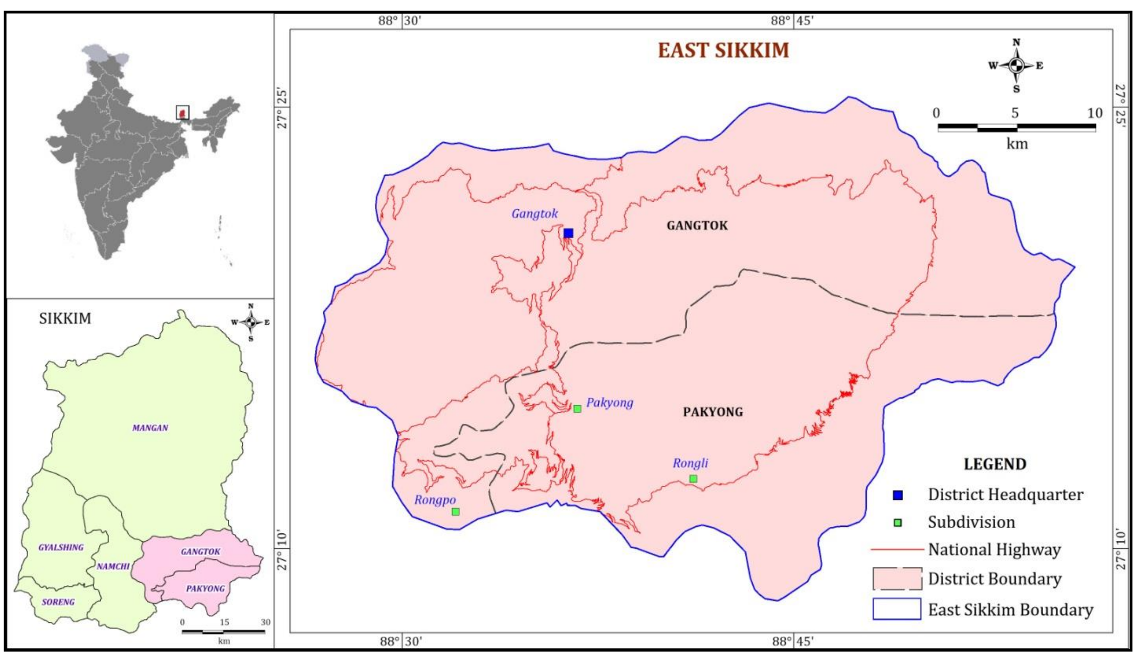

Figure-1.1: Location map for East Sikkim District

1.5 ADMINISTRATIVE DIVISION AND POPULATION:

East Sikkim district has two sub-divisions namely Gangtok and Pakyong which are now bifurcated into two different districts. East Sikkim as a whole consists of 10 blocks –Khamdong, Rakdong Tintek, Gangtok, Martam, Ranka, Duga, Parakha, Pakyong, Regoh and Rhenock. Gangtok is the district headquarter for Gangtok district and Pakyong is the district headquarter for Pakyong district.

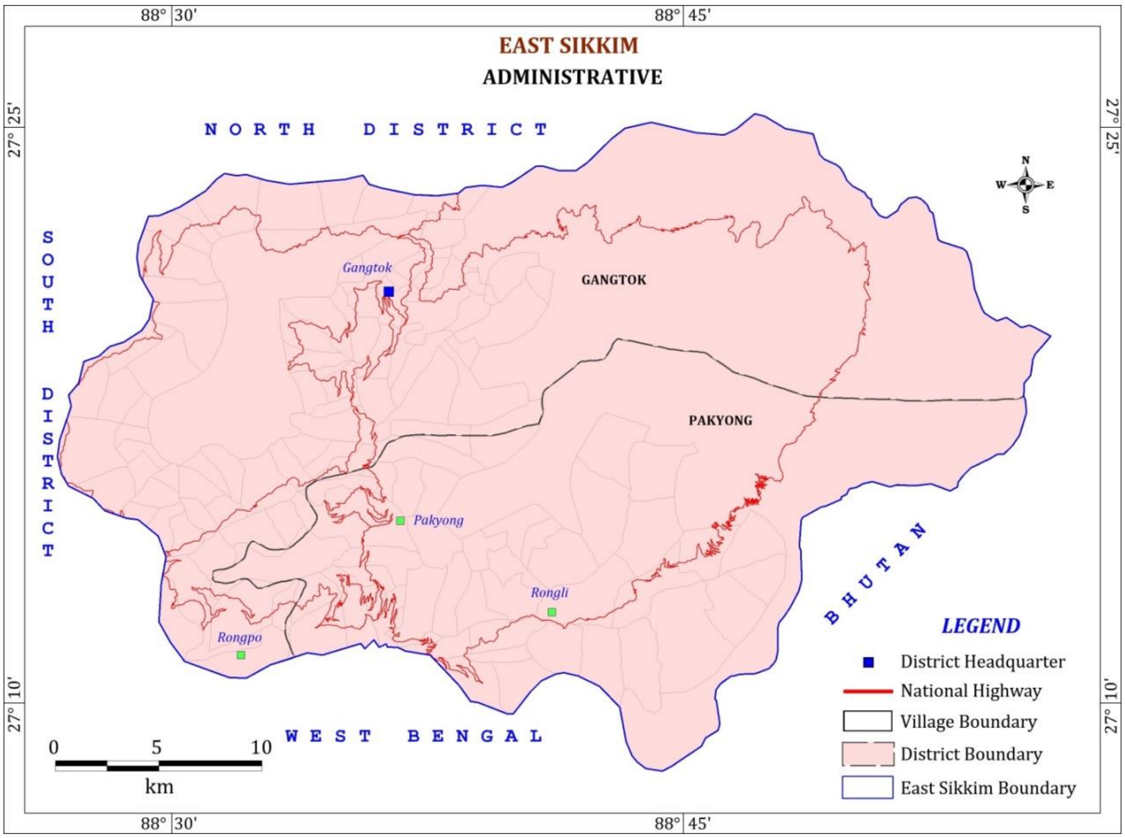

Figure-1.2: Administrative map for East Sikkim District

The administrative detail of the district is presented in **Table-1.1.**

Table-1.1: Administrative details for East Sikkim District.

Block	No. Of Gram Panchayat	No of Village
Khamdong	4	23
RakdongTintek	4	21
Gangtok	9	39
Martam	5	22
Ranka	4	23
Duga	4	24
Parakha	3	18
Pakyong	7	42
Regoh	8	37
Rhenock	4	28
TOTAL	**52**	**277**

The study area covers a total of 52 Gram panchayat, 277 inhabited village, 61567 households

Distribution of population for the study area is presented in **Table-1.2**.

Table-1.2: Population details for East Sikkim District

BLOCKNAME	MALE	FEMALE	ST	SC	TOTAL POPULATION	TOTALHOUSEHOLD
KHAMDONG	6197	5752	3120	1318	11949	2541
RAKDONG TINTEK	8456	7806	4491	816	16262	3391
GANGTOK	18624	10928	10146	1004	29552	5357
MARTAM	6349	5633	4145	792	11982	2425
RANKA	8242	7101	5285	667	15343	3098
DUGA	9686	8869	4259	1858	18555	3677
PARAKHA	4047	3960	2636	525	8007	1762
PAKYONG	11667	10828	7166	865	22495	4806
REGOH	9387	8785	3838	538	18172	4020
RHENOCK	3876	3747	1569	422	7623	1559
FOREST AREA	616	540	493	21	1156	240
TOTAL RURAL	87147	73949	47148	8826	161096	32876
TOTAL URBAN	64258	58202	31288	6479	122487	28691
TOTAL	**151405**	**132151**	**78436**	**15305**	**283583**	**61567**

(Source: Census of India, 2011)

Gangtok is the most populated block of East Sikkim with a total population of 29552.

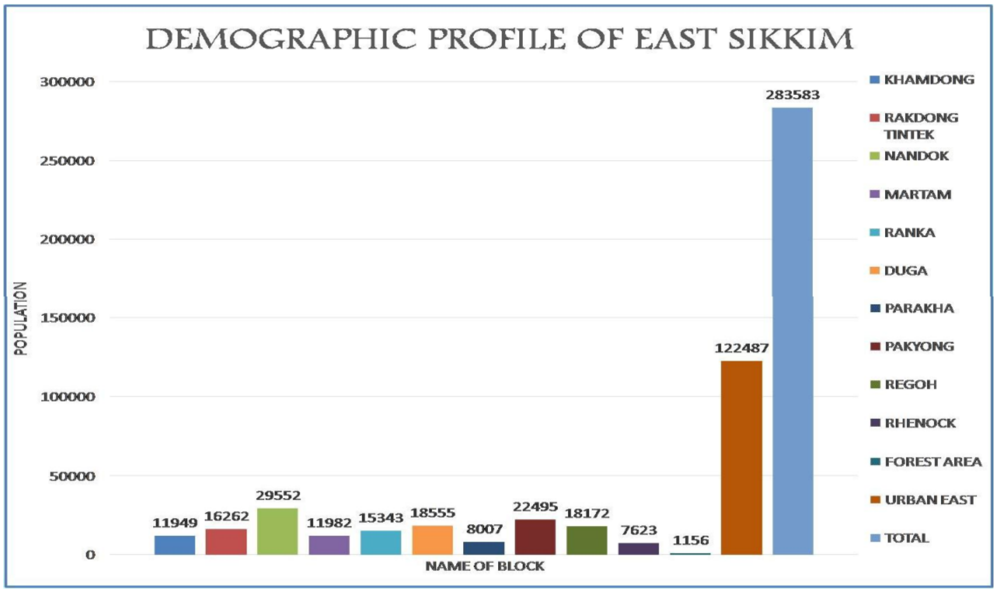

Figure-1.3: Demographic profile graph for East Sikkim district

The workers in east Sikkim are classified under four categories namely, the cultivators, the agricultural laborers, the household-industry workers and the other workers(include all government servants, municipal employees , teachers, factory workers, plantation workers, those engaged intrade,commerce,business,transport,banking,mining,construction,politicalor social work , priests , entertainment artist, etc). Of all workers, 49.9 % are cultivators, 42% are other workers, 6.5% are agricultural laborers and1.6% are house hold- industry workers in 2011. 50.7 % of the male working population was engaged as other workers, while 42.3% as cultivators, 5.3 % as agricultural laborers and 1.7% house as hold- industry workers. Among the female workers, majority of them i.e., 62.8 % were categorized as cultivators, while only 27.3% were other workers. Further, 8.5 %of the female workers were agricultural laborers and 1.4% household-industry workers.

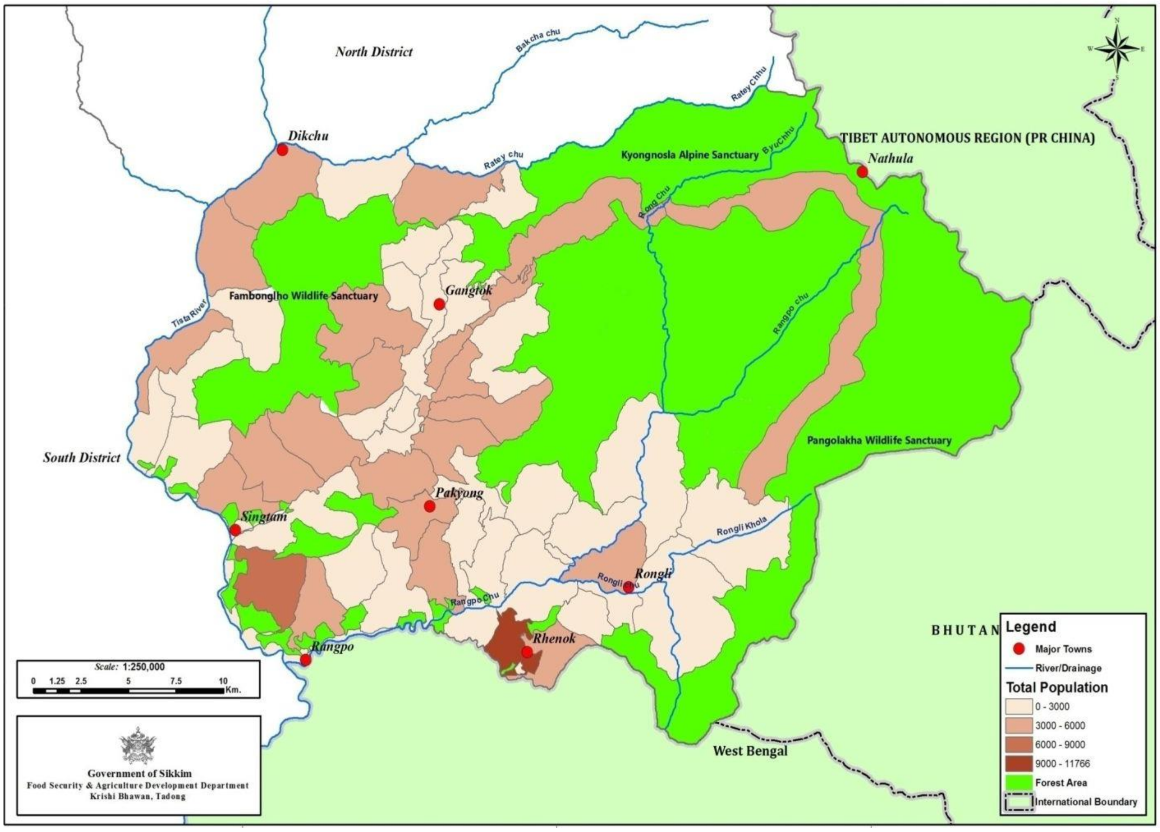

Figure-1.4: Population map for East Sikkim district

1.6 LAND-USE, CROPPING PATTERN AND IRRIGATION:

Land-use and land-cover:

Primarily the land in the study area is used for cultivation. Land-use pattern of urban and rural areas depends mainly on socio-economic factors.

East Sikkim has 595 sq. km of land under forest cover which is about 62 % of the total geographical area. Flowering species like Magnolia and Rhododendrons are available in these forests and the vegetation usually thins out in higher altitude areas and mainly comprises of scrubs and shrubs.

Agriculture is the main stay of majority of rural population of the district. About 67 per cent of the population is dependent on agriculture for livelihood. This shows that the district is predominantly an agriculture based district. The rural households have also been associated with livestock as rural tradition and substantial supplementary income. At present however, only about 16% 0f the total geographical area falls under agriculture.

Since East Sikkim generally is non-glacierized, the snow cover or glacier area is also just about 11% of the total area.

The details of the land-use pattern are presented in **Table-1.3.**

Table 1.3: Areas under different land use in East Sikkim district(Source:Bhuvan)

L 1	L 2	East-Sikkim
Agriculture	Crop land	153.64
	Current Shifting cultivation	--
	Fallow	--
	Plantation	--
Barren/unculturable/Wastelands	Barren Rocky	18.44
	Gullied / Ravinous Land	--
	Salt Affected Land	--
	Sandy Area	0.04
	Scrub Land	2.77
Built up	Mining	--
	Rural	2.19
	Urban	12.61
Forest	Deciduous	33.88
	Evergreen/Semi evergreen	548.16
	Forest Plantation	0.94
	Scrub Forest	11.66
	Swamp / Mangroves	--
Grass / Grazing	Grass / Grazing	52.80
Snow and Glacier	Snow and Glacier	108.71
Wet lands / Waterbodies	Inland Wetland	--
	Coastal Wetland	--
	River/Stream/Canals	6.26
	Water bodies	1.90

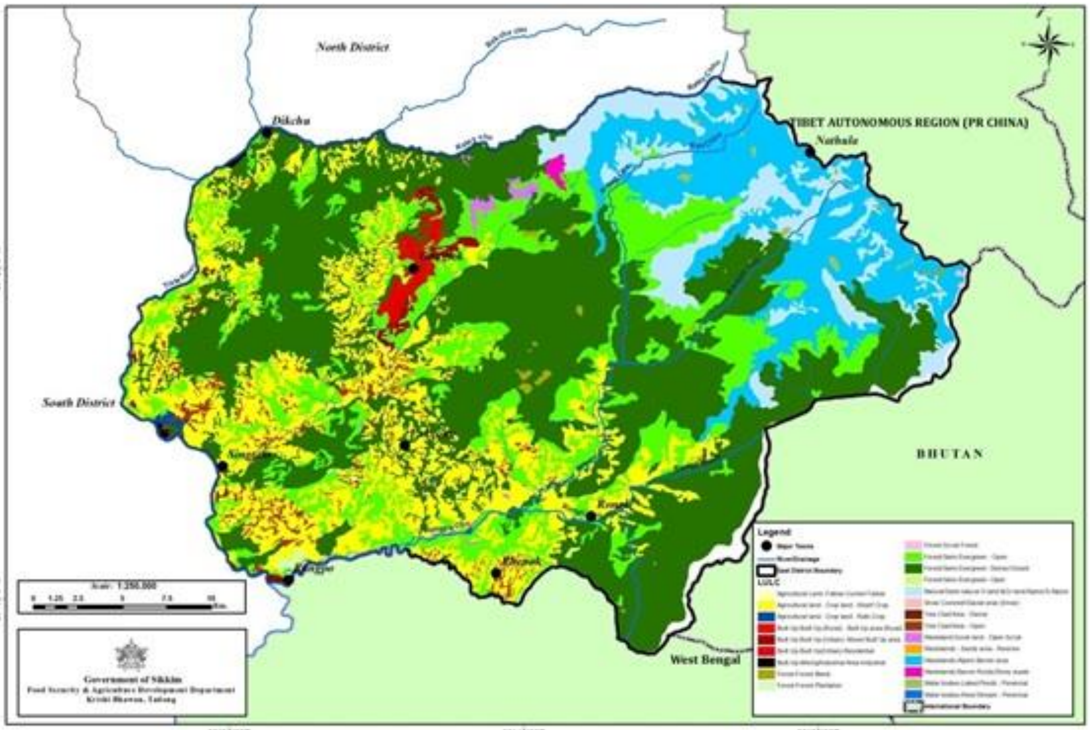

Figure-1.5: Land use-land cover map for East Sikkim district

Cropping pattern:

Paddy is the traditional food crop of the district followed by maize while wheat was introduced in the district in mid 1970s and now is the prevalent rabi crop. Maize is cultivated in dry and Paddy in the irrigated land during Kharif season. *Pahenli Dal* is the most important pulses crop being grown by the farmer of East District intercropped with Paddy. Other prominent crops include Millet, Buckwheat, pulse crops, soyabean and mustard. The recent trend has shown a decline in production of most of the cereal crops and pulses. The several factors contributing to this situation are the scarce input, scarce water for irrigation, labour problem, decreasing arable land or diversion of agriculture land to other uses. The details of the crops grown, the production and yield are presented in **Table-1.4**.

Table-1.4: Type of crops cultivated in East Sikkim district

District	Paddy			Wheat			Maize			Finger millet			Millet			Buckwheat			Mustard/rape/ soyabean			Urd/ Other Pulses		
	Area	Prod	Yield	Area	Prod	Yield	Area	Prod	Yield	Area	Prod	Yield	Area	Prod	Yield	Area	Prod	Yield	Area	Prod	Yield	Area	Prod	Yield
East Sikkim	4.87	8.79	1805	0.15	0.17	1133	8.99	15.4	1713	0.84	0.87	1035	0.2	0.24	1071	1.22	1.21	992	0.76	0.73	965	2.55	2.24	879.5

(*Area in hectares, production in tonnes and yield in kg/hectares*)

Irrigation:

Irrigation facility plays an important role for agricultural production along with the development of cropping intensity. Irrigation assists in the growing of agricultural crops, maintenance of landscapes, and re-vegetation of disturbed soils in dry areas and during periods of inadequate rainfall.

The surface irrigation estimation for East Sikkim as per the district irrigation Project report has been carried out based on the information of GPS and primary and secondary data. Recharge and draft were computed separately for command and non-command areas. The present surface water development in the district has been calculated for command area and non-command area separately for each block. As per the computation, all the blocks in the study area have been categorized as safe for surface irrigation in terms of minor irrigation and development of water harvesting structures. The overall surface irrigation development in East District was moderate. However the groundwater development through open well, deep tube well, medium tube well and shallow tube well was not found to be applicable in the district.

The irrigation status for East Sikkim is given in **Table-1.5.**

Table-1.5: Block-wise irrigation status for East Sikkim district

Block	Irrigated (Ha)	Rainfed (Ha)	Total
Khamdong	314.80	787.44	1102.24
RakdongTintek	394.80	1570.30	1965.10
Nandok	211.30	1491.63	1702.93
Martam	373.80	916.78	1290.58
Ranka	229.30	1320.98	1550.28
Duga	118.80	1127.80	1246.60
Parakha	96.80	558.09	654.89
Pakyong	469.70	1117.87	1587.57
Regoh	282.06	2365.99	2648.05
Rhenock	470.91	1116.10	1587.01
Total	**2962.27**	**12372.98**	**15335.25**

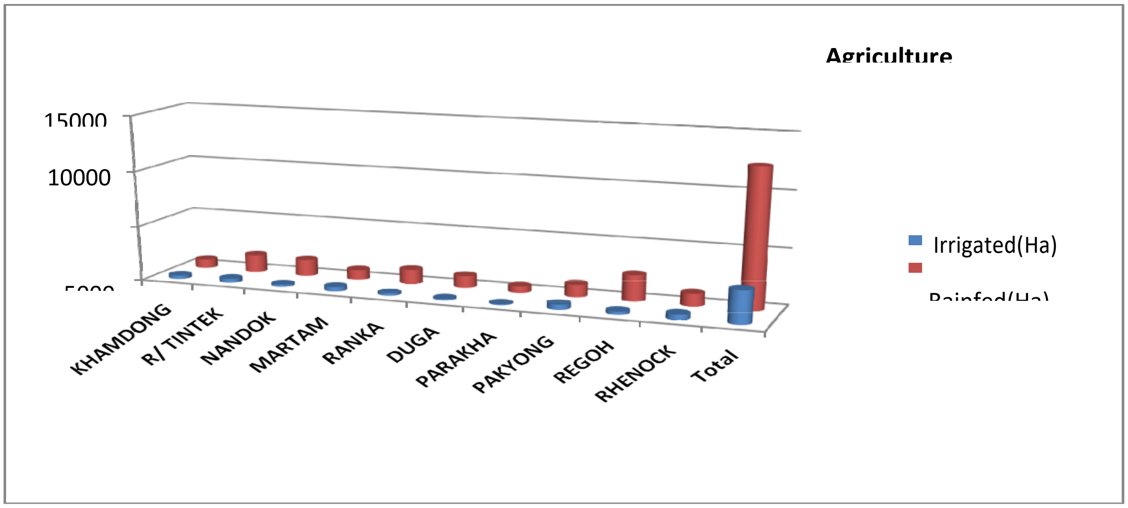

Figure-1.6: Graphical representation for agriculture status of East Sikkim district

1.7 URBAN AREA, INDUSTRIES & MINING ACTIVITIES:

Gangtok is the most populated block of East Sikkim with a population of 29552, followed by pakyong with a total population of 22495. Gangtok and Pakyong are the district headquarters for Gangtok district and Pakyong district respectively.

Industry plays a vital role in the economy of Sikkim state. The state of Sikkim as a whole has seen a great boom in the industries in the recent years and has now emerged as an industrial hub. With the acceleration in the socio-political aspect of the society of Sikkim, the growth of industry in Sikkim has been tremendous. From a totally agro-based society to an industrial hub, Sikkim state has witnessed a great economic change over time. The types of industries that are found in East Sikkim include pharmaceuticals, eco-tourism (hotels), food processing, cosmetics, corrugated boxes, breweries, etc.

As at present, there are no records of mining activities in East Sikkim.

CHAPTER-2

CLIMATE

Sikkim is characterized by a Himalayan type of climate. The district's climate is significantly impacted by the mountain's characteristics. The climatic conditions vary greatly due to the wide fluctuations in elevation ranging from 800-20,000 feet and sharp edged mountains. Relief features such as high mountains act as barriers for the movement of the Monsoon winds. There are varying climatic conditions in the district as a result of the terrain's quick changes. The district's climate is typically characterized by chilly winters and cold, humid weather all year long. In the district, the coldest months are November through March, and the rest of the year is rainy. The district's northern region doesn't have a particularly noticeable summer. Four seasons can often be used to categorize the entire year. From the middle of November through the middle of March is the winter season. The pre-monsoon season, which lasts from mid-March to May and is characterized by thunderstorms, is followed by the southwest monsoon season, which lasts until mid-October. The transition from the monsoon season to winter occurs between mid-October and mid-November.

Low temperature, high rainfall on windward slopes, comparatively dry on the leeward side and heavy precipitation in the form of snow at the mountain tops are the main features of the climate.

2.1 Rainfall:

The normal annual rainfall is in the tune of 3332.30 mm. Maximum rainfall takes place during the month of June to September. The average monthly rainfall is 325 mm and number of rainy days is 135 days per year. The amount of annual rainfall for the year 2016-2020 is given in the **Table-2.1**

Table-2.1: Monthly rainfall for East Sikkim district from 2016-2020(IMD)

Year	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2016	15.2	7.4	125.3	220.4	338.7	391.1	569.1	213.3	348.2	98.2	0.1	0.4
2017	7.7	9	112.3	266.1	315.7	318.3	485.7	400.6	274.5	83.3	6.5	0
2018	0.6	24.9	113	268.5	302.7	456	408.9	442.6	279.5	44.5	11.4	23.7
2019	2.1	49.2	102.1	203	429.4	384.7	657.7	363.9	337	70.1	3.2	11.5
2020	39.9	29.5	121.7	164.9	205.7	476.5	683.2	515.9	538.5	55.3	0.1	19.1

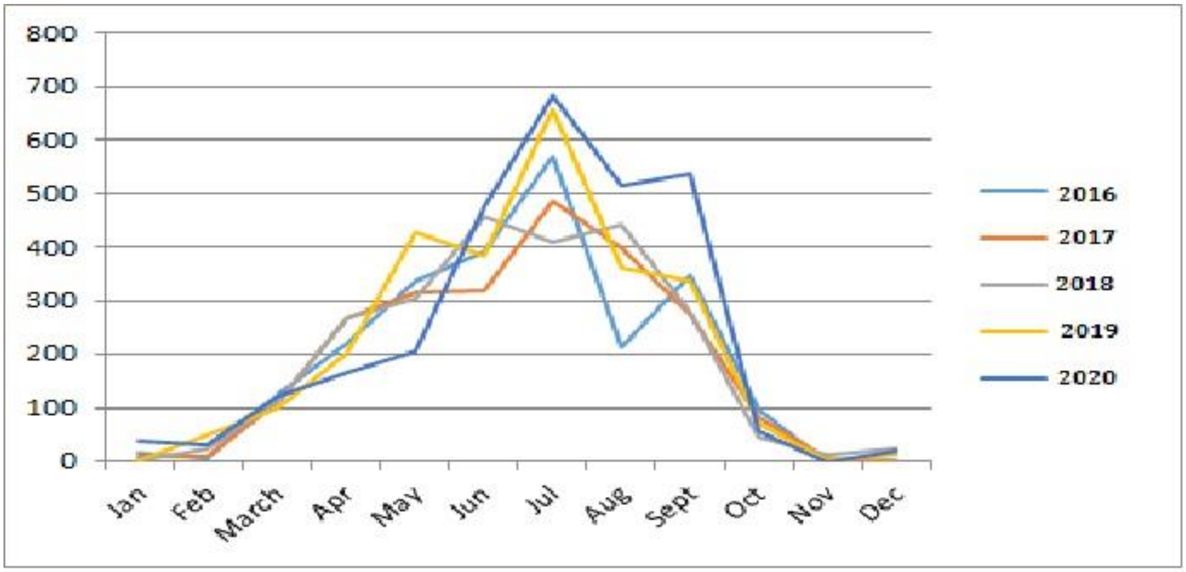

Figure-2.1: Graphical representation for monthly rainfall of East Sikkim district from 2016-2020

2.2 Temperature:

The temperature of East Sikkim generally varies between12^{0}C to 28^{0}C at low altitude places like Namli whereas, the temperature varies between 10^{0}C -20^{0}C in places like Khamdong. Similarly temperature is generally below 0 - 10^0 c in places like Nathang.

2.3 Relative humidity:

The atmosphere in Sikkim Himalayan region maintains a comparatively high Relative Humidity (RH). Due to its proximity to the Bay of Bengal and direct exposure to the Southern Monsoon, the region accommodates the highest relative humidity along the entire mountain range. The sky atmosphere normally remains humid for little longer and the north facing slopes usually experiences cold almost round the year. The RH normally recorded for ranges between 72 - 97 % during rainy season. It decreases gradually towards the lower elevations. The humidity range remained in between 74 - 84 % during the drier months of March- April.

2.4 Rainfall Trend analysis for East Sikkim district:

The aim of this study is to explore the long-term variation of rainfall (RF) and potential evapotranspiration (PET) over the Sikkim state of India. The study specifically emphasizes the impact of hydro-meteorological parameters on the water resources over the region. The climatic study of the parameters and the forecasting up to the year 2030 was also investigated.

In this study, Pre-whitening, Mann–Kendall test analysis, Sen-Slope, and Exponential Triple Smoothing (ETS) Algorithms have been utilized in the analysis of the climatic data of rainfall and potential-evapotranspiration over the region. The RF and PET data have been acquired from the

Global Precipitation Measurement Satellite system (GPM IMERG Final Precipitation L3 1 month 0.1degree x 0.1degree V06) and Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System (FLDAS) (FLDAS Noah Land Surface Model L4 Global Monthly 0.1 x 0.1 degree) with 0.1o x0.1o spatial resolution from 2000 to 2020.

Rainfall and potential evapotranspiration trend analysis: Twenty (2000-2020) years of RF and PET monthly data have been utilized for M-K trend analysis over the different districts of Sikkim. The magnitude of the trend in the time series as determined using the Sen-slope-estimator (**Table-2.3**). The analysis of trends of RF and PET variations over East Sikkim district shows large variability in the magnitude and direction of trends from one season to another. Seasonal analysis of RF indicated that the very little change in monsoon and significant change in the post-monsoon season. Whereas, in PET no significant change is observed in any season. In the winter, pre-monsoon, and monsoon seasons, no trend is observed in RF in the district. In the post-monsoon season, a negative trend is observed over the region with Sen-slope -3.3. The RF is decreasing at the rate of -3.3 in the region during the post-monsoon season.

Table-2.2: Seasonal mean RF over East Sikkim from 2000 to 2020

Year	Winter	Pre-monsoon	Monsoon	Post-monsoon
2000	--	--	419.4	26.1
2001	12.5	135.4	395.4	111.8
2002	12.8	123.5	440.3	28.6
2003	31.4	112.2	413.7	90.5
2004	19.6	123.6	370.2	73.9
2005	12.7	113.9	374.6	84.9
2006	22.7	81.3	395.8	57.6
2007	22.8	81.3	395.8	57.6
2008	5.4	103.2	435.3	49.4
2009	3.9	115.9	370.8	84.6
2010	5.0	130.3	477.0	49.1
2011	12.6	102.5	438.7	29.5
2012	12.3	108.3	422.7	37.9
2013	14.7	139.3	375.9	84.9
2014	6.7	120.7	382.8	26.0
2015	12.7	136.5	390.2	33.9
2016	8.8	120.4	384.7	58.1
2017	7.3	148.0	336.7	43.5
2018	7.3	145.1	318.2	21.9
2019	23.7	139.9	361.2	26.4
2020	22.2	136.2	485.3	26.8

Table-2.3: M-K trend and Sen-slope for RF and PET over East Sikkim in different seasons

Parameter	Season	District	M-K trend	Sen-slope
East Sikkim	Rainfall	Winter	No	-0.10728
		Pre-monsoon	No	0.996214
		Monsoon	No	-1.54973
		Post-monsoon	Yes	-3.30591
	Potential Evapotranspiration	Winter	No	-5.2E-08
		Pre-monsoon	No	3.79E-08
		Monsoon	No	-1.4E-07
		Post-monsoon	No	-7.6E-08

Table-2.4: Seasonal mean PET over East Sikkim from 2000 to 2020

Year	Winter	Pre-monsoon	Monsoon	Post-monsoon
2000	5.6	6.8	59.2	7.3
2001	4.0	7.3	51.9	11.8
2002	6.0	7.3	55.8	17.2
2003	8.3	5.6	50.3	12.4
2004	6.4	5.5	52.4	10.5
2005	6.3	4.9	47.5	9.7
2006	3.5	9.1	48.1	14.8
2007	7.5	7.5	54.5	11.4
2008	4.3	5.6	54.8	13.4
2009	4.5	6.7	48.0	13.8
2010	2.8	6.4	58.1	18.4
2011	5.8	7.0	53.2	15.5
2012	5.3	6.7	53.0	8.0
2013	5.9	3.5	52.4	18.5
2014	3.8	8.4	45.3	8.2
2015	3.4	7.0	33.5	14.8
2016	2.6	5.5	56.9	11.9
2017	5.2	11.7	49.1	9.1
2018	2.7	7.1	59.6	7.7
2019	7.5	6.2	41.3	10.5
2020	3.4	12.7	34.7	8.8

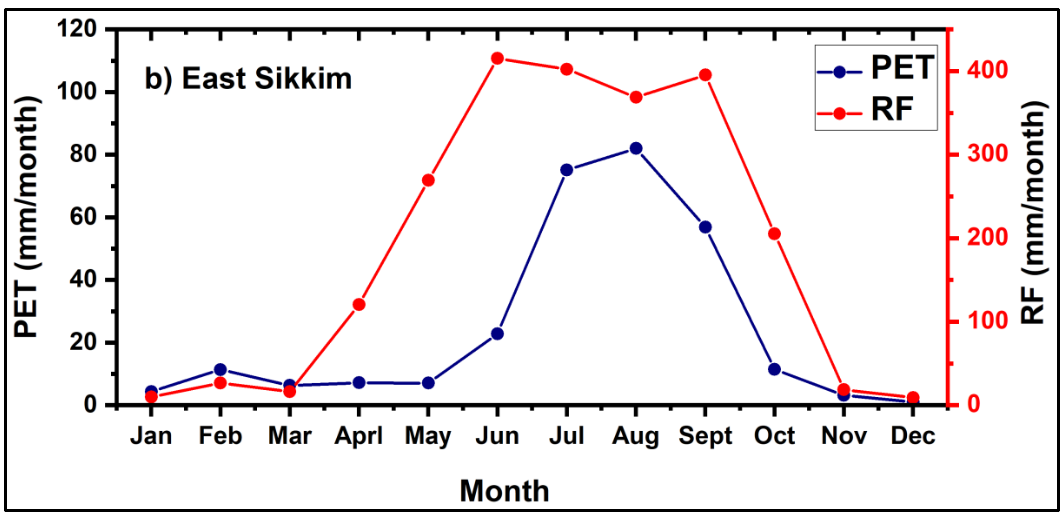

Figure-2.2: Monthly mean RF and PET over the study region

2.5 Rainfall forecasting:

The year-wise season variation of RF over East Sikkim has been analyzed. The RF is forecasted for an estimate up to 2030. For RF forecasting, ETS (AAA) technique has been utilized in this study (**Table-2.5**).

In winter season, the forecasted RF is lower than the past RF in the districts. While, during the pre-monsoon season the forecasted RF values are higher than the past RF values. In the monsoon and post-monsoon seasons, the forecasted RF values are lower than the past RF values. The difference between the forecasted and past RF is higher in the post-monsoon season in the district (**Table-2.6**).

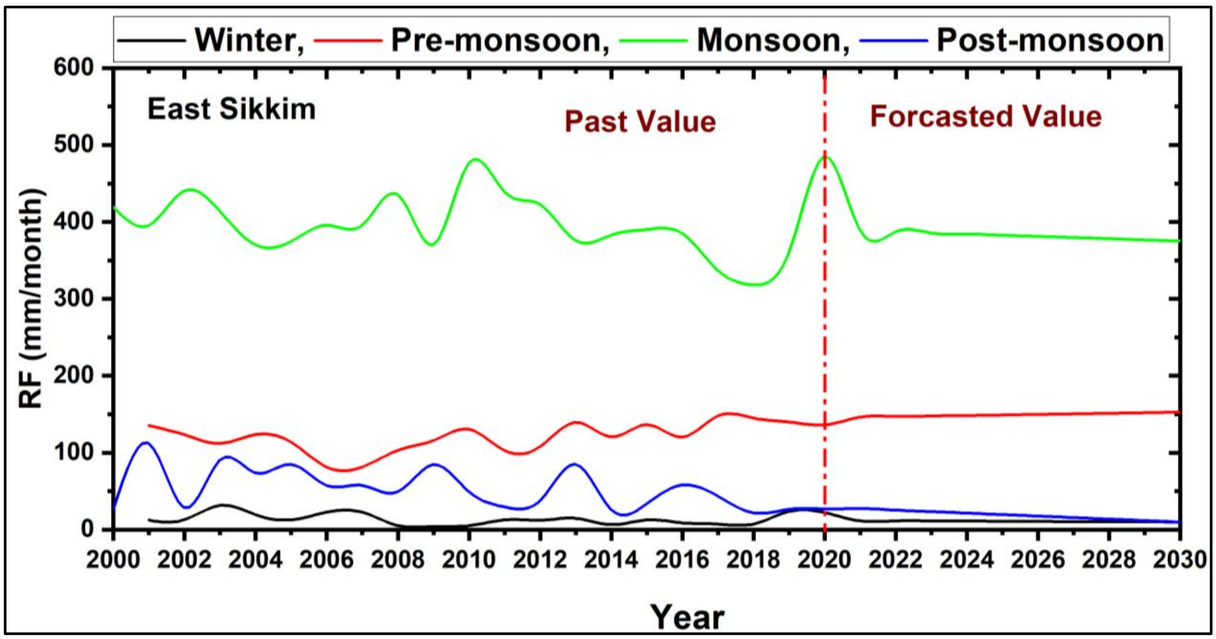

Figure-2.3: The past and forecasted RF values for East Sikkim during different seasons

Table-2.5: Past and forecasted RF over the East Sikkim region

Sikkim	District	Avg. RF (mm) (2000-2020)	Avg. forecasted RF (mm) (2020-2030)	% difference
East Sikkim	Winter	13.9	10.6	-27
	Pre-monsoon	120.9	149.3	21
	Monsoon	398.3	381.9	-4
	Post-monsoon	53.8	18.5	-98

CHAPTER-3

PHYSIOGRAPHY

East district of Sikkim is totally hilly region and the areas bordering China is usually covered with snow. The topography of the district is totally mountainous, hilly terrain.

East Sikkim forms a part of the Eastern Himalayas, falls within the Central Himalayan zone characterized by Buxa Series, Daling Series, Darjeeling Series and equivalent Proterozoic and Lower Palaeozoic rocks. The area is characterized by a typical Himalayan topography i.e., a series of criss-crossing ridges and ravines. Major ridges show NE-SW trend. The altitude varies from 300 meters to >8500 meters above mean sea level. The general profile of land elevation for Sikkim Himalayas is given in **Table-3.1.**

Table-3.1: Profile of land elevation for Sikkim Himalayas

Type of land	Level of Elevation
Lower Hills	Altitude ranging from 250 m to 1500 m
Mid Hills	Altitude ranging from 1500 m To 2000 m
Higher Hills	Altitude ranging from 2000 m To 3000 m
Alpine Zone	Altitude above 3900 m With vegetation
Snow Bound Land	Very High Mountains without vegetation & with Perpetual Snow cover up to 8598 m

The Digital Elevation Model for East Sikkim is given in **Figure-3.1.**

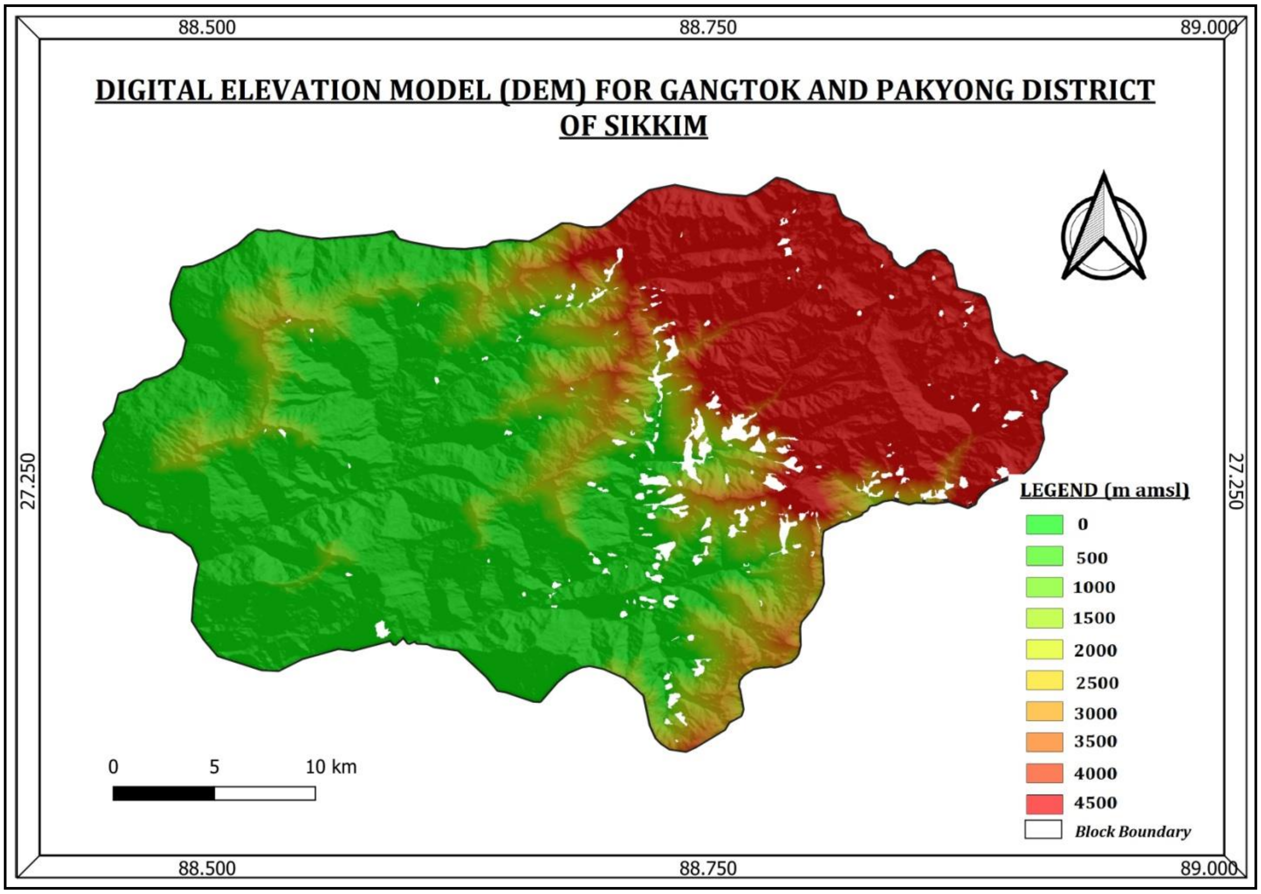

Figure-3.1: Digital Elevation Model (DEM) for East Sikkim district

3.1 GEOMORPHOLOGY:

The district is divided into three (3) geomorphic units such as, steep hill, valley and slope. The slopes in the region are highly susceptible to weathering, erosion and landslides. Distinct micro-morphology features of Sikkim terrain include terraces and floodplains, valley side slopes and landslide slopes, alluvial cones of different types and generations, tors, kettle shaped depressions, terrace isles, sickle shaped rags, beveled plains, undulating plains, with deeply dissected valleys, glacial or peri-glacial deposits related sedimentary structures crevasses, soil series or poly pedan, gorges etc. These forms have been produced by the trunk stream Teesta and its innumerable tributaries-one of the important agents of denudation and deposition which moulds the landscapeThe classification of slope provided by *Food Security and Agriculture Development, KrishiBhavan, Tadong, Gov.of Sikkim* is shown in **Table-3.1.**

Table-3.2: Details of slope categories Slope categories for Sikkim Himalayas

Slope Category	Slope class
Very steep sloping	>50%
Steeply sloping	33-50%
Moderately steep sloping	15-30%

3.2 SOIL:

There are five soil types identified in East Sikkim. They are-

Haplumbrepts and Pachic Haplumbrepts: These soils are developed on ridges with30% slope and are deep and somewhat excessively drained with fine loamy surfaces having slight stoniness and moderate erosion. The soil type is generally acidic and prone to erosion.

Typic Hapudolls and Umbric Dystrochripts: These soils are developed on ridges with15-30% slope, are deep and excessively drained with coarse loamy to fine loamy surface with slight stoniness and moderate erosion. These soils are moderately acidic and are rich in humus content.

Cumilic Haplumbrepts and Pachic Haplumbrepts: These soils are developed on ridges with slopes lessthan15%. The soils are deep, well drained, fine loamy soils with loamy surface with slight stoniness and moderate erosion. These soils are characteristic of temperate forest.

Haplodolls,Cumilic Haplodolls,typic Dystrochrepts,Cumilic Dystrochrepts,TypicHaplunbrepts etc: The soils are found on ridges with steeply sloppy hill sides(30-50%slopes),are moderately shallow to deep and well drained, silty to fine loamy soils with slight stoniness and moderate erosion. The soil is acidic and mostly found in temperate and Alpine forest.

Typic Haplo Dystrovchrepts,Entice Haplodolls,Typic Haplumbrepts, etc: These soils are found on ridges slope more than 50%. These soils are moderately deep and are developed on steep sloppy hills, are excessively drained, coarse loamy to fine loamy soil with slight stoniness and moderate erosion. The soils are moderately acidic, dark brown to dark yellow and rich in humus.

The soil map for East Sikkim is given in **Figure-3.2.**

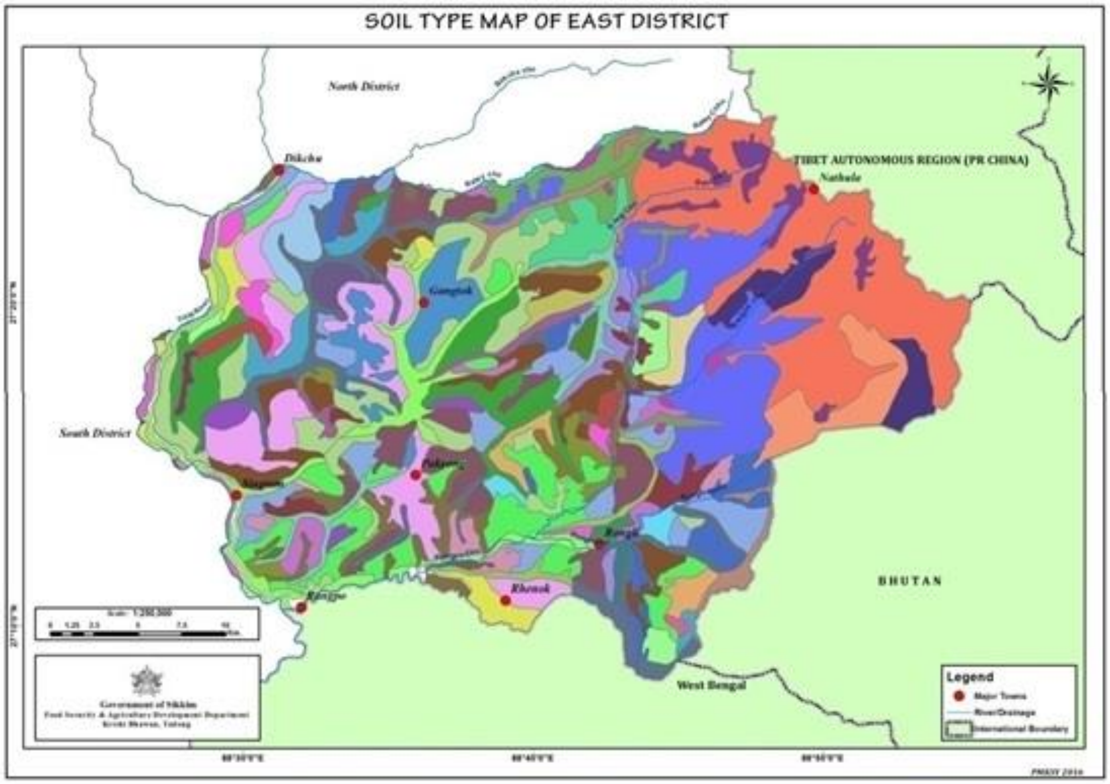

Figure-3.2: Soil map for East Sikkim district

3.3 DRAINAGE:

The landforms and drainage of Teesta river are characterized mainly by the four tiered terraces, canyons or gorge-valleys at different altitudes, asymmetric valleys, poly-profilic U-shaped glacial valleys and steps or troughs, lakes, alluvial cones, truncated ridge-spurs, terracettes (soil landscape systems), rectangular-barbed-parallel-trellis-radial to sub-dendritic drainage patterns, straight to meandering and braided channels. All these physiographic features are indicative of active processes of weathering, denudation and deposition making the area physically very sensitive. The main rivers draining East Sikkim district are Tista, Dik Chhu and Rangpo Chhu.

The watershed map for East Sikkim is given in **Figure-3.3**.

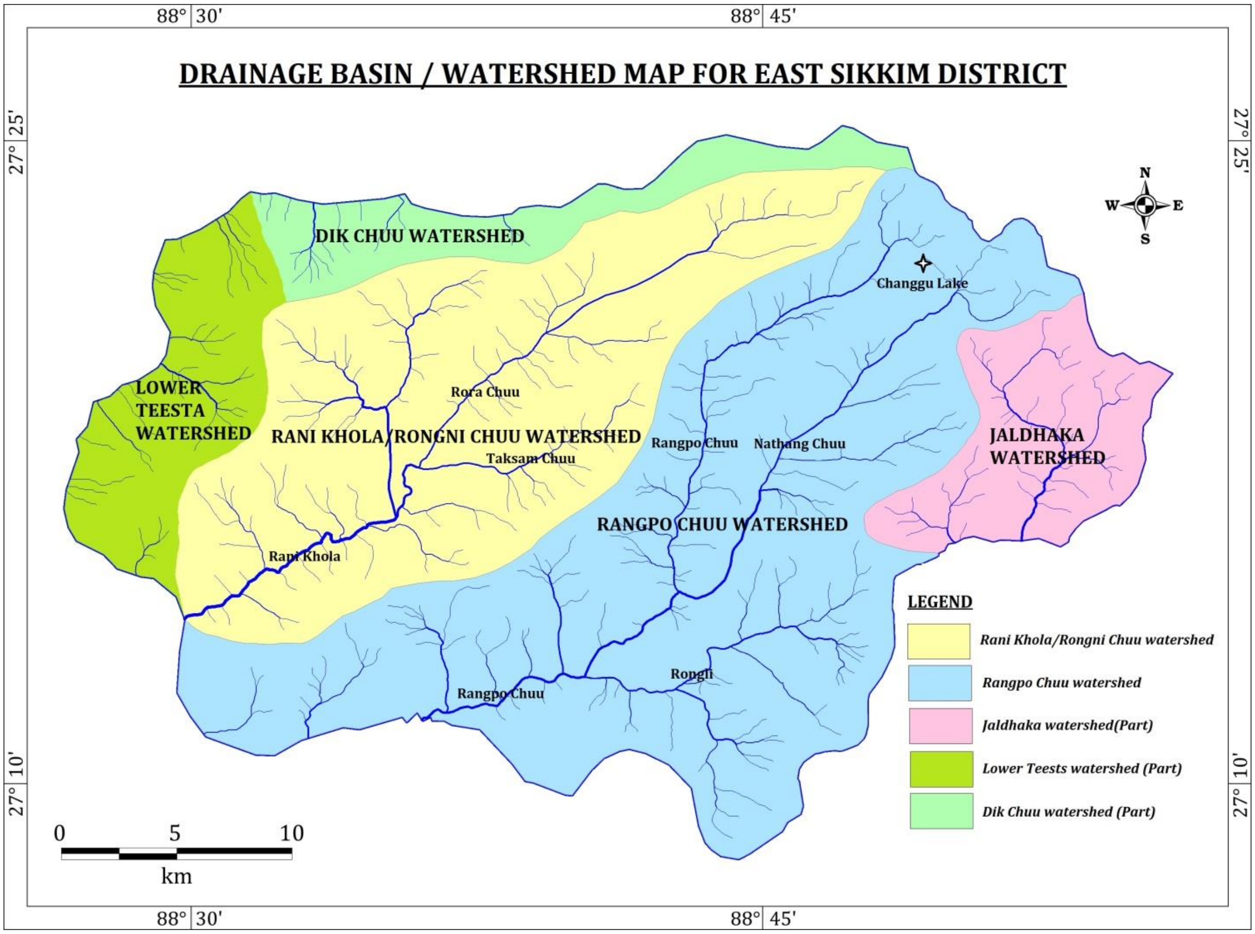

Figure-3.3: Drainage basin/watershed map for whole East Sikkim district

There are two major drainage basin/watershed identified in East Sikkim district. They are Rongni Chhu basin and Rangpo chhu basin. Other basin includes part of Dik Chhu and Jaldhaka basin.

Rani Khola (Rongni Chhu) watershed: This is a canoe-shaped basin covering an area of 25,331.1 ha and is aligned in NE-SW direction with elongation ratio of 0.62. It is bounded by the Dik Chhu watershed in the north, Rangpo Chhu watershed in its south and southeast and Teesta (lower part) watershed in the west. The main river draining this watershed is Rani Khola also known as Rongni Chhu which flows from NE to SW covering elevational range of 3,772 m (from 4,122 m to 350 m). A stream joining on the left bank either flows from east to west or from south to north or from southeast to northwest. A stream joining on the right bank either flows from north to south or from northwest to southeast. Two major tributaries of Rani Khola are Taksom Chhu and Re Chhu, which respectively joins it on the left and right banks. Gangtok, the capital town of Sikkim, is developed on the wedge between the Rani Khola and Taksom Chhu channels.

The drainage network indicates that the stretch of Rani Khola downstream of Ranipul (where Taksom Chhu and Re Chhu confluence) will have high water availability.

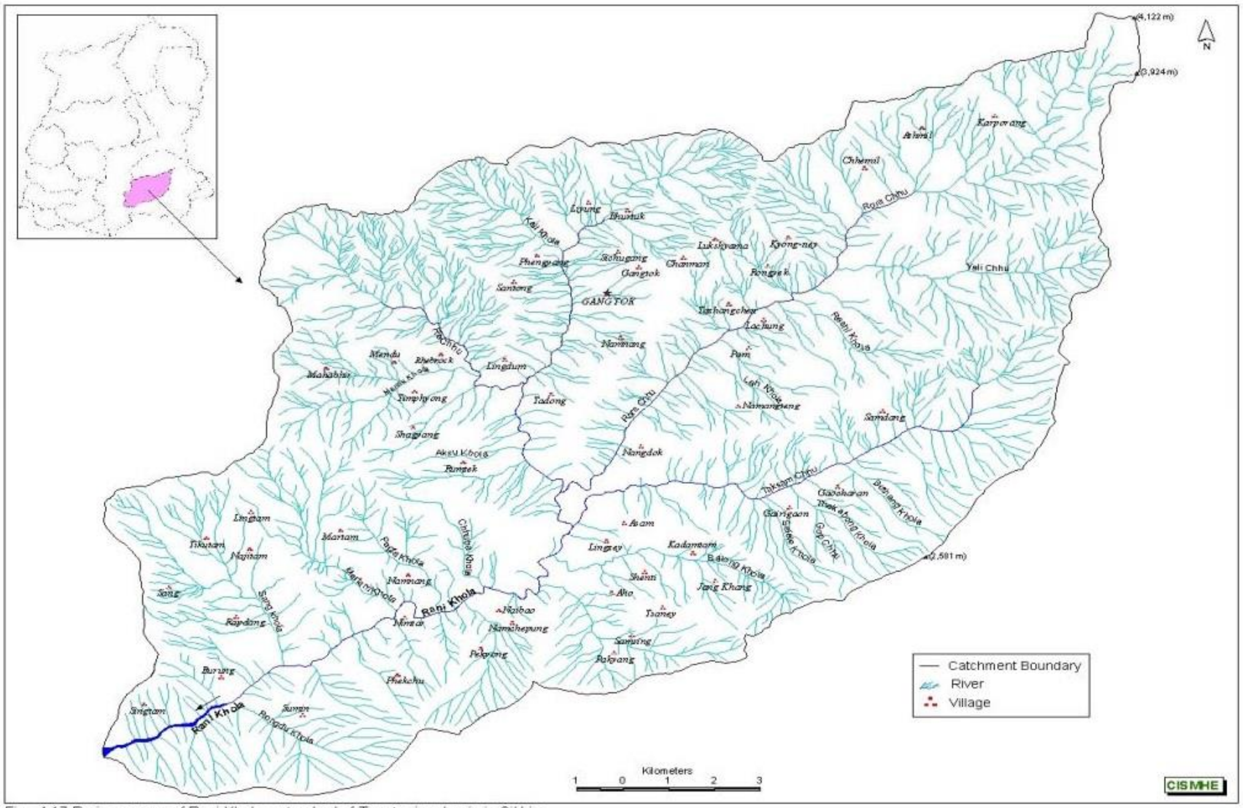

Figure-3.4: Drainage map of Rani Khola/ Rongni Chhu watershed basin

Rangpo Chhu watershed: This is an L-shaped basin covering planimetric area of 44,802.5 ha, with elongation ratio of 0.62. Rangpo River and its tributaries constitute main drainage of this watershed and lies between Rani Khola watershed in north and Jaldhaka river watershed in south-east. The main river, named Rangpo, flows from north to south and then from east to west defining a L-shaped pattern at the left bank of Teesta river. The river covers an elevation range of 4,452 m (from 4,735 m to 300 m). Along the N-S course of Rangpo several streams flowing from NE-SW joins it on the left bank. These streams separated by NE-SW trending ridges define sub-watersheds with high water availability. The right bank slopes are very steep with small streams and therefore with low water availability.

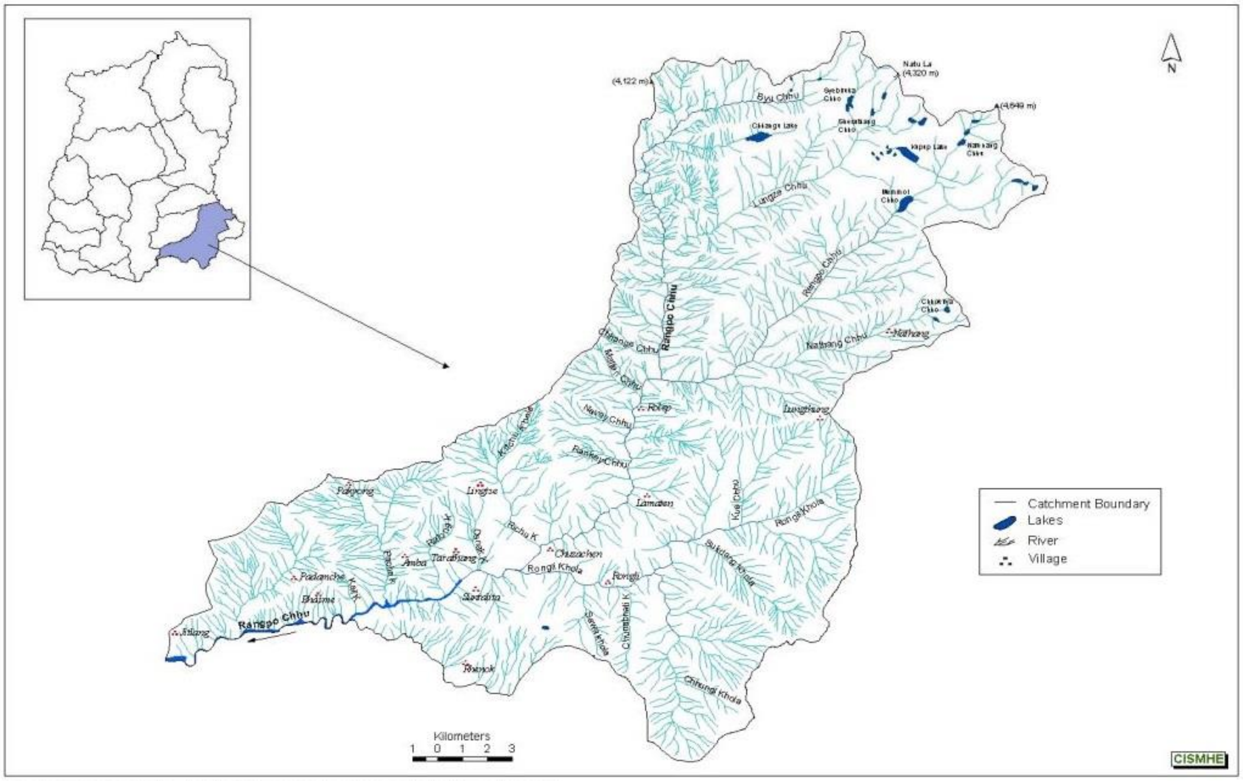

Figure-3.5: Drainage map of Rangpo Chhu watershed basin

Dik Chhu watershed: Dik Chhu watershed is a canoe shaped basin covering an area of 24,095.5 ha. The main channel, Dik Chhu, is 35 km long and flows from east to west. The elevational range covered by the main channel is 4,214 m (from 4752 m to 538 m) with relief ratio of 147. The elongation ratio is 0.61. Bakcha Chhu is the major tributary of DikChhu. The major source of water to these channels is from snowmelt, glacial lakes and seasonal rain. Important landslide that creates problems for the transportation network is B2. Besides there are some sinking zones alongside the road.

Jaldhaka watershed: Jaldhaka watershed is an arcuate shaped basin with watershed area of 7,561.5 ha. This watershed covers an elevational range of Introductory Volume – Teesta River Basin Characteristics 85 CISMHE 2,752 m (from 4,752 m to 2,000 m) and relief ratio of 221.9. It represents upper part of the Jaldhaka river; rest of the basin lies in West Bengal. The streams are fed from lakes. Jaldhaka river (also called Di Chhu) is the major channel which flows down through an arcuate valley. Major lakes in this watershed are BitangChho, Lam Pokhri, Laba Chho, Nangpo Chho, Chham Chho, and Chumpo Chho. Water availability in this watershed is high. Jaldhaka river is a tributary of Brahmaputra river. Therefore, water from this watershed flows down through West Bengal to Brahmaputra river

CHAPTER-4

GEOLOGY

East Sikkim is endowed with varying geology comprising of rocks with age ranging from Pre-Cambrian to Upper Pleistocene to Holocene. The different types of rock Formation exposed in the study area are as discussed below.

The lithological sequence for East Sikkim district can broadly be classified into following groups-

Daling Group: These are Low grade meta-sedimentaries exposed in the central part of the Daling Dome. Three distinct regional lithotectonic assemblages have been recognized within the Daling Group (sensulato) by Acharyya (1989).They are the Gorubathan Formation, Reyang Formation and Buxa Formation. Important rock type of this Group are those of Quartzite, ortho-quartzite, inter-banded Chlorite-Sericiteschists, dolostones, purple phyllite / slate, chert, pyritiferous black slate, variegated cherty phyllite, meta-greywacke, mica schist, etc.

The Gorubathan Formation consists of mappable and monotonous sequence of inter banded chlorite sericite schist / phyllite, quartzite, meta greywacke, pyritiferrous black slate/ carbon phylllite, basic meta volcanic. In some areas, intercalation of quartzite and chlorite schist are found. Gritty rocks, light green to greenish grey in colour, have been observed associated with the phyllites. These grits show a well bedded nature, with grains of greasy quartz present along the bedding planes. Together with this, conformable bands of basic intrusive occur with the units of the Gorubathan Formation.

The Reyang Formation forms a distinct sequence of thick bedded, ortho to proto quartzite, variegated phyllite/slate with minor impersistent beds of crystalline carbonates, conformable metabasites, from the type section around Reyang in the Tista River valley in Darjeeling district, transitional between the Gorubathan and the Buxa Subgroups. This litho-association is underlain and overlain by units of Gorubathan and Buxa Subgroups, respectively, in the Rangit Window Zone. Purple quartzites, pyritiferous black slates, phyllites are the common rocks associated with this Formation. Minor beds and lenses of brown, pink or yellow crystalline limestone on dolomitic limestones are also present.

Buxa Formation occur above the Reyang Formation and below the horizon of Gondwana diamictite (Rangit Pebble Slate). The Buxa formation essentially comprises an alternating sequence of thin, grey cherty mature quartzite, chert, fine grained, and finely laminated to massive grey dolostone, pyritoussericitic and variegated slates. Unlike Gorubathan and Reyong Formations, the Buxa Formation has only local distribution. It is characterized by fine grained, fine laminated to massive, grey and pink dolostone and limestone beds, often with a weathered, pitted surface.

Central Crystalline Gneissic Complex: This consists of the rock sequence in the outer part of the Tista Dome known as the Kanchenjunga Gneiss, Darjeeling Gneiss, 'Chhubakha Series' and the calc-silicates, calc-gneisses, quartzites and schists series known as the Chungthang Gneiss.

The Chungthang Formation comprises of Quartzites, Calc- silicate rocks and graphitic schist, BiotiteSchists and amphibolites**.** The Quartzites are greyish and show development of mica along the bedding planes. Under microscope they are seen to be quartz-feldspar-schist. The Calc- silicate rocks and graphitic schist are marked by several bands of marble which are milky white in color and vary in thickness ranging from 30 m to 60 meters. The marble bands show graphite concentration along the shear zones. Under microscope, the calc-silicate contains diopside, quartz, feldspar, actinolite, tremolite and calcite. The Biotitic schist with garnet and staurolite are demarcated as Rongli schist. Rongli schist represents the higher metamorphic grade equivalent (garnet, staurollite, etc) of the Daling metapelites. This schist contains abundant garnet and occasionally shows bands of flaggy quartzite. Garnet, staurolite, biotite and muscovite constitute the main minerals. Thin section show it to be fine grained quartz-sericite-muscovite-biotitic schist with prolific almandine garnet (subhedral grains), a few grains of feldspar (plagioclase) occur as re-crystallized aggregate. The Amphibole schist and amphibolites occur as lenticular sills. In some of the cases they are sulphide mineral bearing. Under the microscope the rock shows characters of hornblende-quartz-schist with hornblende, oligoclase feldspar, biotite (developed from hornblende), quartz and minor rutile as its main constituents.

The Kanchenjunga Gneiss / Darjeeling Gneiss are predominantly comprised of quartz, feldspar and biotite (with minor amounts of other minerals) and they have been classified into three types namely-banded / streaky gneisses / migmatites, Augen bearing biotite gneiss with/without garnet, kyanite, sillimanite and sillimanite granite gneisses. The banded / streaky gneisses / migmatites are biotite gneisses that are profusely intruded by granites and pegmatites and have been affected by a series of faults. Thin graphite schists are observed along shear plane or fault plane. They are generally Coarse to medium grained, grayish white to dark grey banded gneiss. The banded gneiss consists of alternating bands rich in quartzo-feldspathic material and mafic schistose components, imparting a strong s-tectonitefabric. Under the microscope the rock consists of biotite, quartz, muscovite, sericitized microcline and plagioclase feldspars. Augen bearing biotite gneiss with/without garnet, kyanite, sillimanite are gneisses that show lateral variation into a coarse grained porphyritic variety that exhibits an almost unfoliated nature with sub-rounded feldspar grains (10-12 mm across) lying scattered within the body of the rock. Under the microscope, the rock shows porphyroblasts of orthoclase and quartz, mostly arranged parallel to the foliation-planes, embedded in matrix of biotite, chlorite, quartz and plagioclase. The sillimanite granite gneisses are the Kyanite-biotite-muscovite gneiss with bands of flaggy quartzites and are a result of high grade metamorphism. Under microscope the rock reveals gneissic texture defined by quartz and feldspar (both as individual grains and as intergrowth), sillimanite, biotite, muscovite and garnet.

Lingtse Granite-Gneiss: These gneisses are sheet like bodies of coarse to medium grained, foliated to strongly lineated granite mylonite. They are streaky, banded, augen gneisses or porphyroblastic gneisses that are traversed by concordant and discordant pegmatite veins. The most important characteristic feature of the Lingtse granite is the presence of a stretching lineation. The granite is two-feldspar granite where K-feldspar predominates over plagioclase. The main constituent minerals are quartz, K-feldspar, plagioclase (mainly oligoclase), biotite, muscovite and opaque ores. Microscopic study reveals albite-oligoclase with minor amount of orthoclase forming more than 35% of the minerals assemblage.

The generalized stratigraphic succession for the Sikkim Himalayas is given below. (**As per unified legend scheme of GSI)**

LITHOLOGY	FORMATION		GROUPAGE
Variegated clay, fine and medium sand, Pebble bed	Sesela Formation		Upper Pleistocene Holocene
Tourmaline/biotite leuco granite, schroll rock/ pegmatite, aplite (Undifferentiated)	Intrusive		
Syenite /basic dyke/sill (Undifferentiated)	Intrusive		
Fossiliferous sandstone, limestone,s hale	Tso Lhamo Formation		Triassic
Boulder bed, Fossiliferous limestone and sandstone.	Lachi Formation		
Sandstone, shale, carbonaceous shale with coal	Damuda Group	Gondwana Supergroup	Carboniferous to Permian
Pebble/boulder slate, conglomerate, phyllite	Rangit pebble state Groups		
Fossiliferous limestone with quartzite	Everest Limestone Formation		Ordovician
Granite gneiss (mylonite)	Lingtse Granite Gneiss		Meso Proterozoic
Phyllite, quartzite, biotite gneiss	Everest Pelite Formation		Meso Proterozoic
Amphibole schist/amphibolite	Sill		
Dolostone, ortho-quartzite, purple phyllite/ slate, chert	Buxa Formation		
Ortho-quartzite, pyritiferous black slate, Variegated cherty phyllite, meta-greywacke	Reyang Formation		
Inter-banded chlorite-sericite schist / phyllite and quartzite, meta-greywacke (quartzo Feldspathic greywacke), pyritiferous black slate, biotite phyllite/mica schist, biotite quartzite, mica schist with garnet,with/without staurolite, chlorite quartzite	Gorubathan Formation	Daling Group	Proterozoic Undifferentiated
Banded /streaky migmatite, augen bearing (garnet) biotite gneiss with/ without kyanite, sillimanite with palaeosomes of staurolite, kyanite,mica schist,biotite gneiss,sillimanite granite gneiss	Kanchenjunga Gneiss/ Darjeeling Gneiss (Undifferentiated)	Central Crystalline Gneissic Complex (CCGC)	Proterozoic Undifferenciated
1. Quartzite 2.Garnet kyanite sillimanite Biotite schist/Garnetiferous mica schist 3.Calc-silicate,carbonaceous schist Chungthang Formation	Chungthang Formation		

The geological map for the study area is given in **Figure-4.1.**

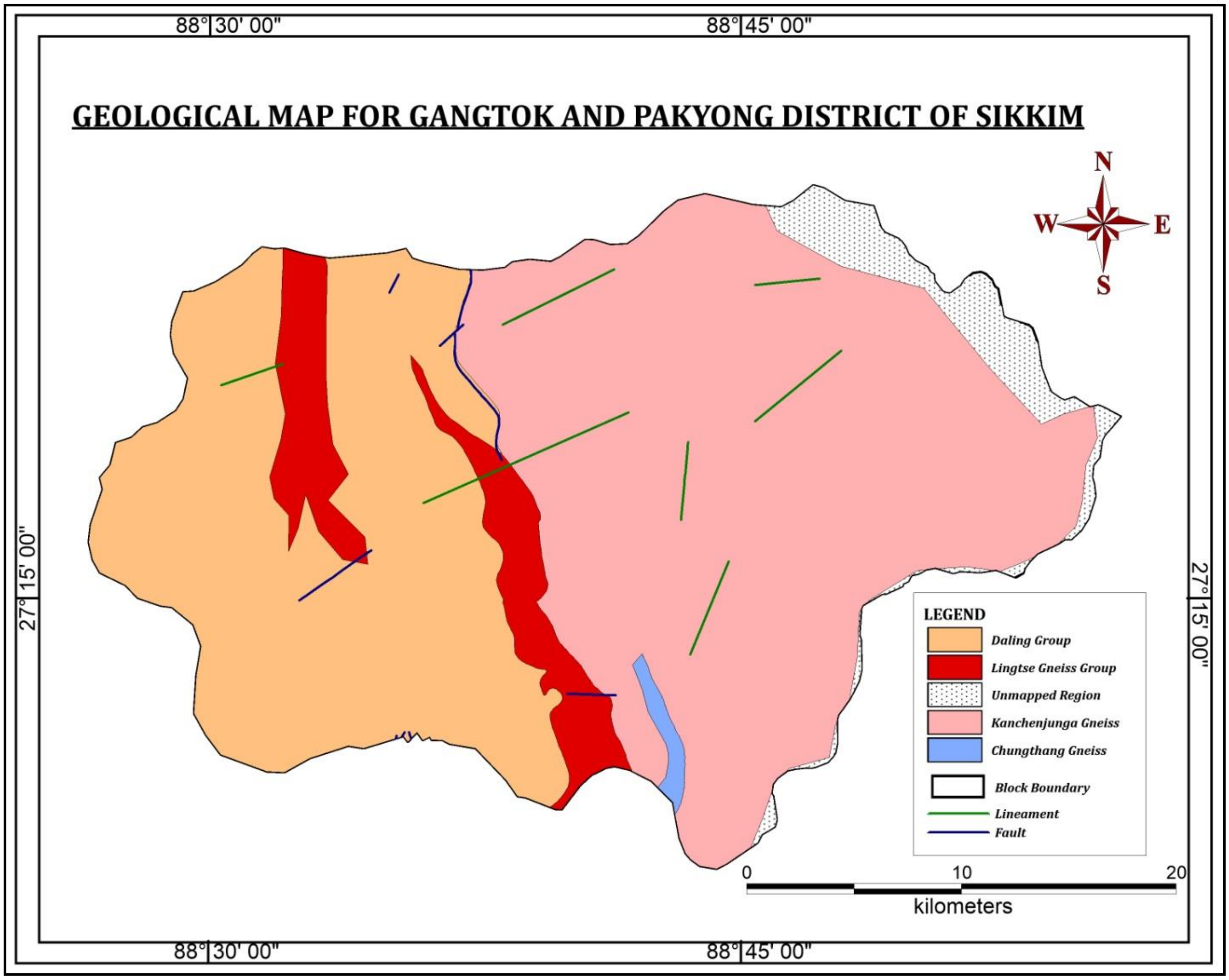

Figure-4.1: Geological map for East Sikkim district

CHAPTER-5

GEOPHYSICS

Geophysical study in field can be broadly divided into two categories, namely surface geophysical investigation or resistivity survey (VES and profiling) and borehole electrical logging.

Surface geophysical investigation is the pre- drilling approach and in ground water exploration it has many fold objectives that depends on formation characteristics likely unconsolidated, semi-consolidated and consolidated formations.

In hard rock terrain it is required to identify a) Saturated fractures/joints, faults, shear zones, dykes, quartz veins and reefs which may control the ground water occurrence/movement at varied depths, b) Thickness of the water bearing overburden (weathered residuim), c) depth to the bed rock and resistivity values and d) delineation of water filled cavities in limestone.
In alluvial areas identification of granular and non-granular formations, thickness of the individual layers and their resistivity values, identification of saline/fresh water interface etc. are required to be done. Lithology, resistivity, formation factor, formation resistivity, porosity, permeability, specific yield of water bearing formations, chemical and physical characteristics of water of a particular formation of interest can also be calculated.

Electrical resistivity investigation is also adopted in exploratory drilling program to locate a tube/bore-well site due to its wide simplicity in field proceedings and low cost of operation. To pin point an exploratory drilling site in hard rock areas in most of the cases deep fractures are identified with the help of curve break technique (Ballukarya). It also helps for mapping potential aquifers in buried stream channels and also demarcating the areas suitable for artificial recharge and prone to water logging.

The geophysical logging of water wells is a post-drilling approach to optimize the design and development of the wells in unconsolidated sediments. The main objective of geophysical logging include demarcation of boundaries between granular and non-granular zones, identification of potential aquifer zones, decisions pertaining proper positioning of screens against productive aquifers and against the caving formations, planning and management of potable ground water resources, identification of fresh/saline

The Surface Geophysical Investigations (VES) were carried out in North Sikkim during the year 2022-23 (under AAP 2022-23). 32 nos. TEM (Transient Electromagnetic Method) were conducted in East Sikkim districts covering 320 sq km area. The geophysical investigations were conducted with Coincident Loop of 40 mtr X 40 mtr by deploying Terra TEM 24.

TEM data were processed through Terra TEM Plot software from *.BIN extension file to *.TEM extension file and further to *.USF extension file. The TEM data interpretation were done through IX1D software as provided with the instrument by importing the TEM data *.USF extension file. Modelling software is used to convert the measured data to profiles of estimated resistivity vs. depth for interpretation. A "forward modelling" process is used in which a hypothetical layered-earth model is generated first and the theoretical response for that model is calculated. The model is then refined until the calculated response matches the measured field response.

After interpretation of all the TEM data it is envisaged that resistivity of the 1st geo-electric layers i.e top soil varies from 2.5 ohm-m to 8700 ohm-m and thickness is 1.0 m. The resistivity of the 2nd geo-electric layers varies from 12.3 ohm-m to 7356 ohm-m indicating weathered formation of clayey nature to compact formation. The thickness varies from 1.4 m to 4.8 m. The resistivity of the 3rd geo-electric layers of the study area are varied from 7.0 ohm-m to 25655 ohm-m indicating clayey formation to highly compact formation (Quatzite-Schist). The thicknesses of the 3rd geo-electric layers are varied from 3.4 m to 28.4 m. The resistivity of the 4th geo-electric layers are varied from 0.02 ohm-m to 31192.6 ohm-m indicating highly conductive formation to highly compact formation (Quartzite-Gneiss) and thickness varies from 8.3 m to 39 m. The resistivity of the 5th layer varies from 0.5 ohm-m to 84624.80 ohm-m indicating highly conductive formation to highly compact formation (Resistive). The thickness of the 5th layer varies from 20.1 m to depth of investigation. The resistivity of the 6th layers are varied from 0.3 ohm-m to 27951 ohm-m indicating highly conductive formation. 6th layer is the last layer of most of the study locations except Gnathang Valley area where last layer indicates highly fractured formation with the resistivity value of 16.5 ohm-m and it starts at a depth of 83 metre.

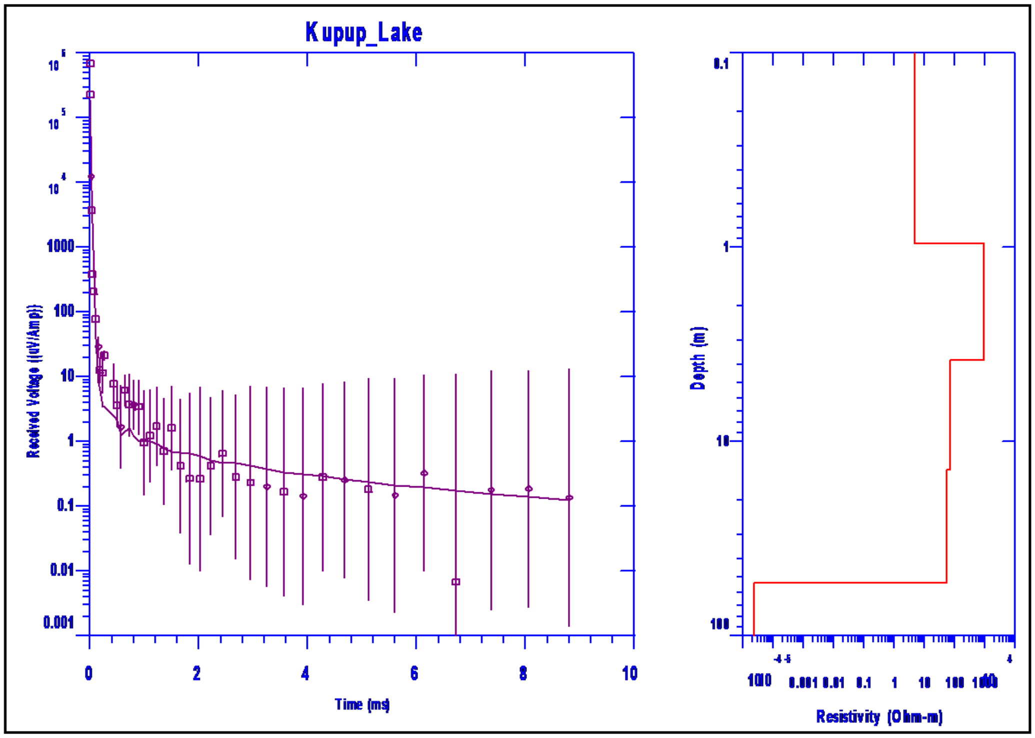

Figure-5.1: Smooth Model: Ridge Regression (Kupup Lake)

Layer	Resistivity	Layer Thickness	Cumulative Thickness	Inferred Lithology
1	3.2	1.0	1.0	Top Soil
2	972.8	2.8	3.8	Weathered Formation
3	167.3	10.4	14.1	Semi Compact Formation
4	105.7	39.0	53.2	Semi Compact Formation
5	0.5			Highly Conductive Formation

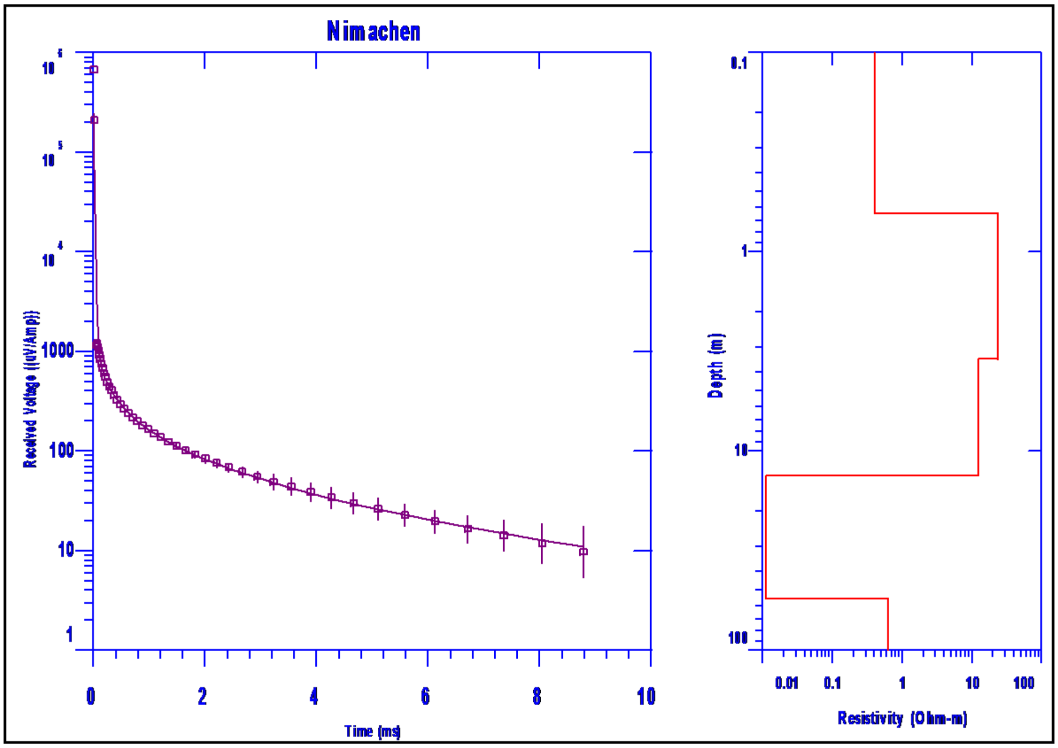

Figure-5.2: Smooth Model: Ridge Regression (at Nimachen)

Layer	Resistivity	Layer Thickness	Cumulative Thickness	Inferred Lithology
1	4.7	1.0	1.0	Top Soil
2	12.3	2.8	3.8	Weathered Formation
3	7.0	10.4	14.1	Clay
4	0.020	39.0	53.2	Highly Conductive Formation
5	1.1			Highly Conductive Formation

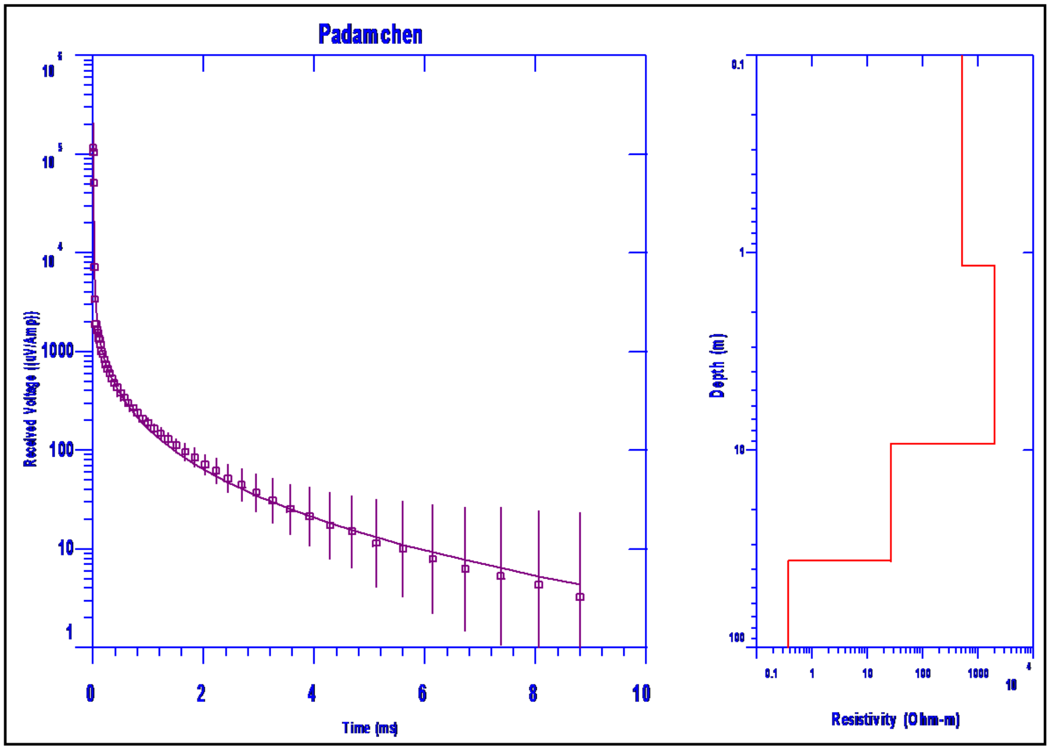

Figure-5.3: Smooth Model: Ridge Regression (at Padamchen)

Layer	Resistivity	Layer Thickness	Cumulative Thickness	Inferred Lithology
1	5.4	1.0	1.0	Top Soil
2	137.6	4.8	5.8	Weathered Formation
3	466.4	28.4	34.2	Semi Compact Formation
4	0.3			Highly Conductive Formation

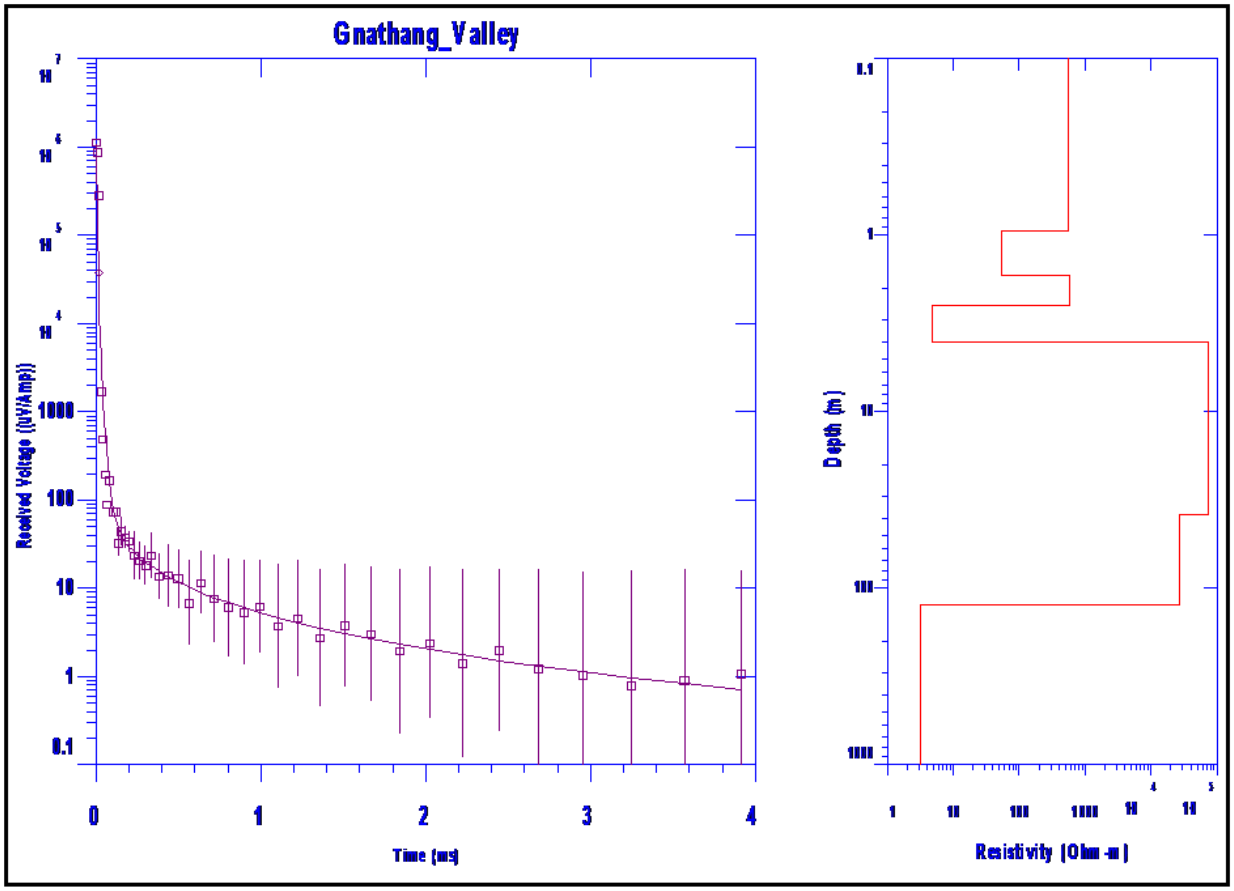

Figure-5.4: Smooth Model: Ridge Regression (Gnathang Valley)

Layer	Resistivity	Layer Thickness	Cumulative Thickness	Inferred Lithology
1	353.2	1.0	1.0	Top Soil
2	62.4	1.4	2.4	Weathered Formation
3	639.9	3.4	5.8	Semi Compact Formation
4	24.9	8.3	14.1	Fractured Formation
5	84624.8	20.1	34.2	Highly Compact Formation (Quartzite-Schist)
6	27951.3	48.5	82.7	Compact Formation (Mixed Schist Character)
7	16.5			Fractured Formation

CHAPTER-6

HYDROGEOLOGY

Hydrogeological regime for East Sikkim:

6.1 GLACIERS:

As per the glacier inventory study conducted by Geological Survey ofIndia, there are five glacier basins in the Sikkim Himalayas namely, the Zemu, the Talung, the Changme-Khangpu, the East Rathong and the Rangpo basin and out of which Rangpo basin is non-glacierized. East Sikkim is a part of the Rangpo glacier basin.

There are a number of glacial lakes and snow-fields also in East Sikkim that contribute significantly to the water of resource of Sikkim. Chhangu, Kupup, Namnang, MenmoiChho, Sherathang and Syebiruk are the prominent glacial lakes in this region. These glacial lakes and snow-fields are drained through Rangpo Chhu and Dik Chhu.

Glaciers are the perennial sources of fresh water that is discharged in the two major rivers, namely Teesta and Rangit.

Hydrogeological conditions of glaciers:

Glaciers are great repository of water. The entire runoff is contributed by glaciers during lean season. These glaciers in Sikkim have maintained recessional trend all throughout and they contribute around 80% of the total discharge during monsoon period also. Although East Sikkim falls in non-glacierized basin, the rivers that flow through the district are glacial melt waters from the upper catchment area. These frozen zones occur at elevation above 5000 m amsl.

6.2 SNOW:

Snow cover over the region in the last 10 years (2009-2018):

To investigate the glacier deposition over the region of interest, 10 years (2009-2018) of snowmelt/freeze data {Oceansat2 Scatterometer (OSCAT) Enhance Resolution Image} is used for the analysis. In this study, the snow deposition is observed in different seasons for proper realization of the glacier mass. The snow deposition is highest in April, while in January(**Figure-6.1)**scattered snow deposition occurs in East Sikkim. In April, snow deposition is concentrated in the easternmost part of the district (**Figure-6.2)**. In June, the snow cover and the thickness are reduced as compared to April owing to the higher air temperature and rainfall (**Figure-6.3)**. In September and November, no snow cover is observed over the district (**Figure-6.4**). The snow cover in the district is the seasonal deposition and total ablation that occurs during the monsoon period. The highest snow cover takes place during the pre-monsoon season. Increased melting may initially increase the volume of water in rivers, which could mean more flooding, but as snow cover recede and disappear the amount of meltwater entering rivers could decrease significantly. Such a situation would result in a substantial decline in the rates of groundwater recharge in some areas. Combined with variations in summer monsoon precipitation and surface water flows, depleted groundwater would lead to highly significant water stress in many parts of the and downstream.

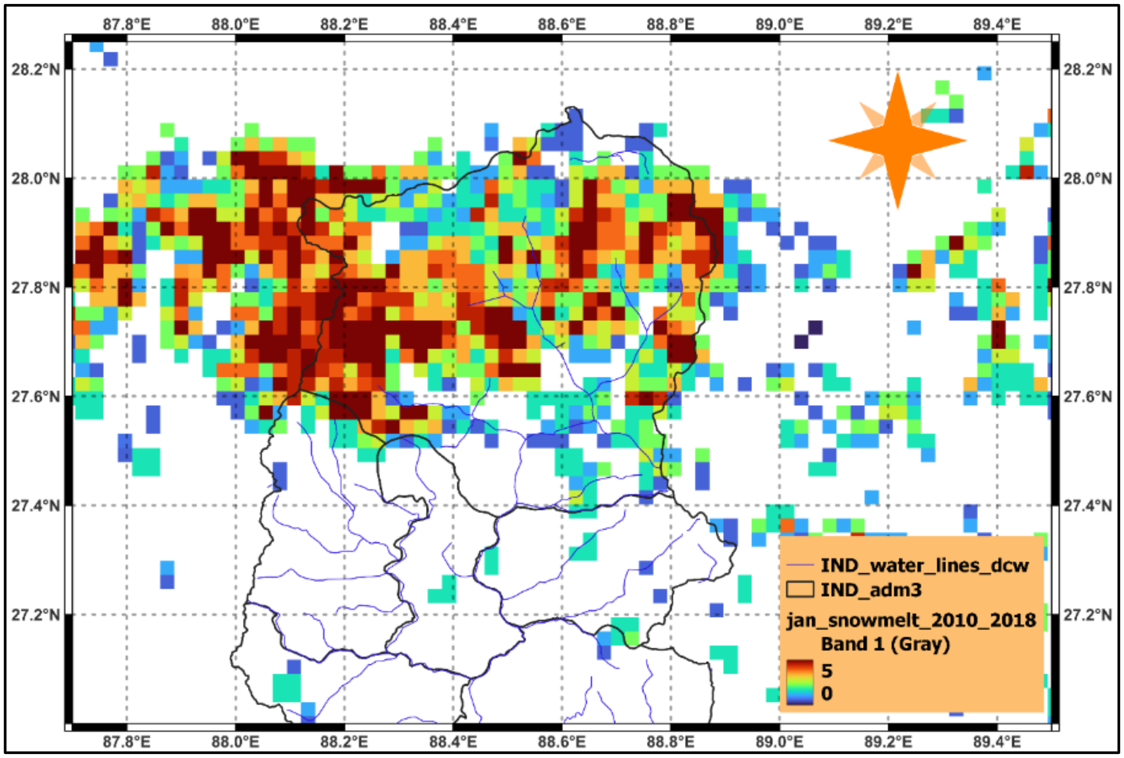

Figure-6.1: Decadal (2009-2018) snow cover map for East Sikkim district (January)

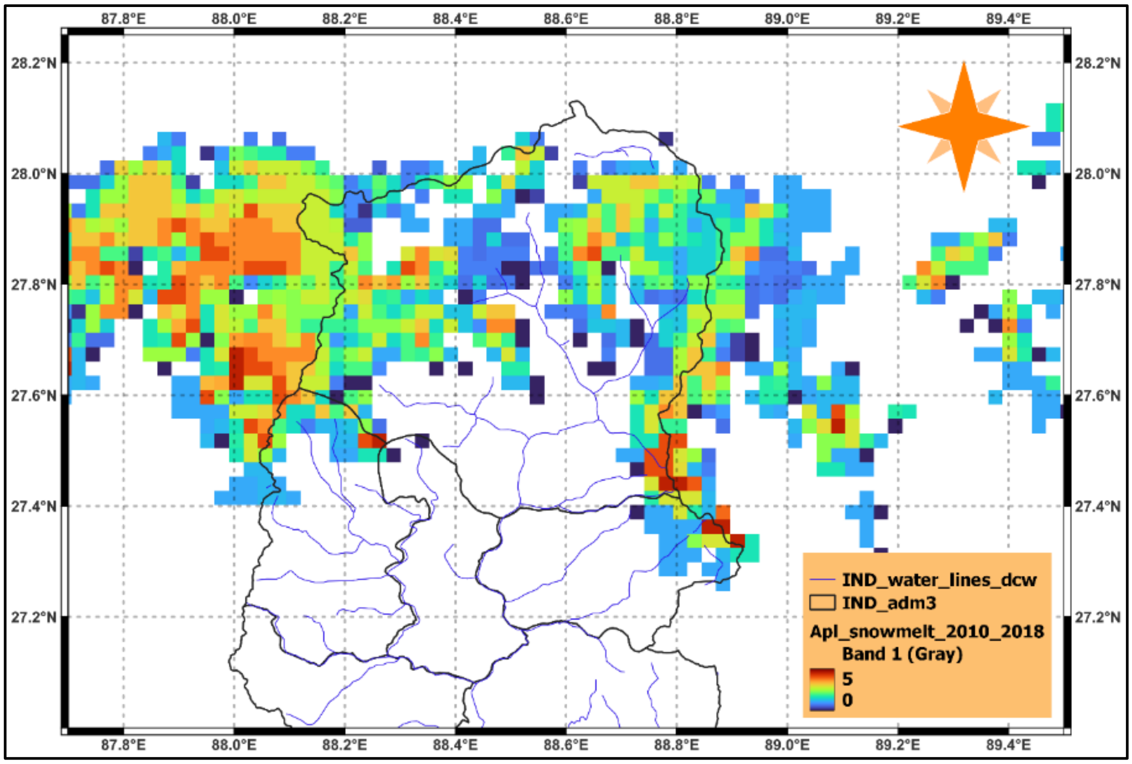

Figure-6.2: Decadal(2009-2018) snow cover map for East Sikkim district(April)

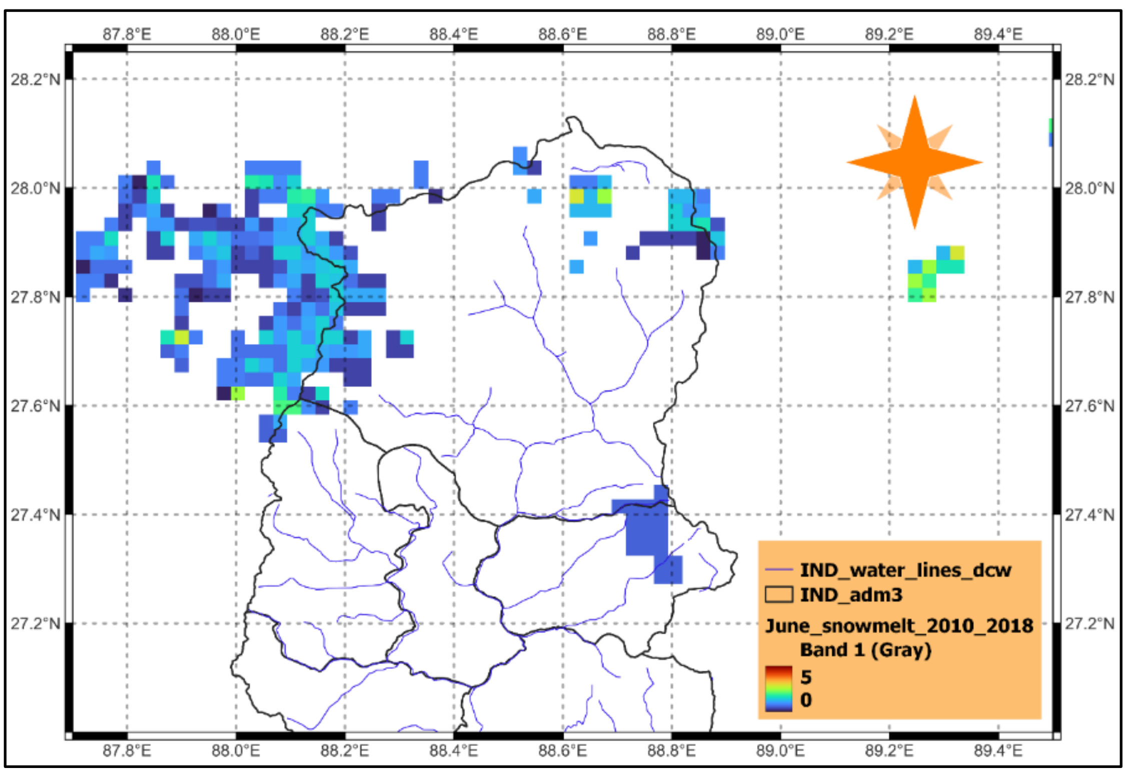

Figure-6.3: Decadal(2009-2018) snow cover map for East Sikkim district(April)

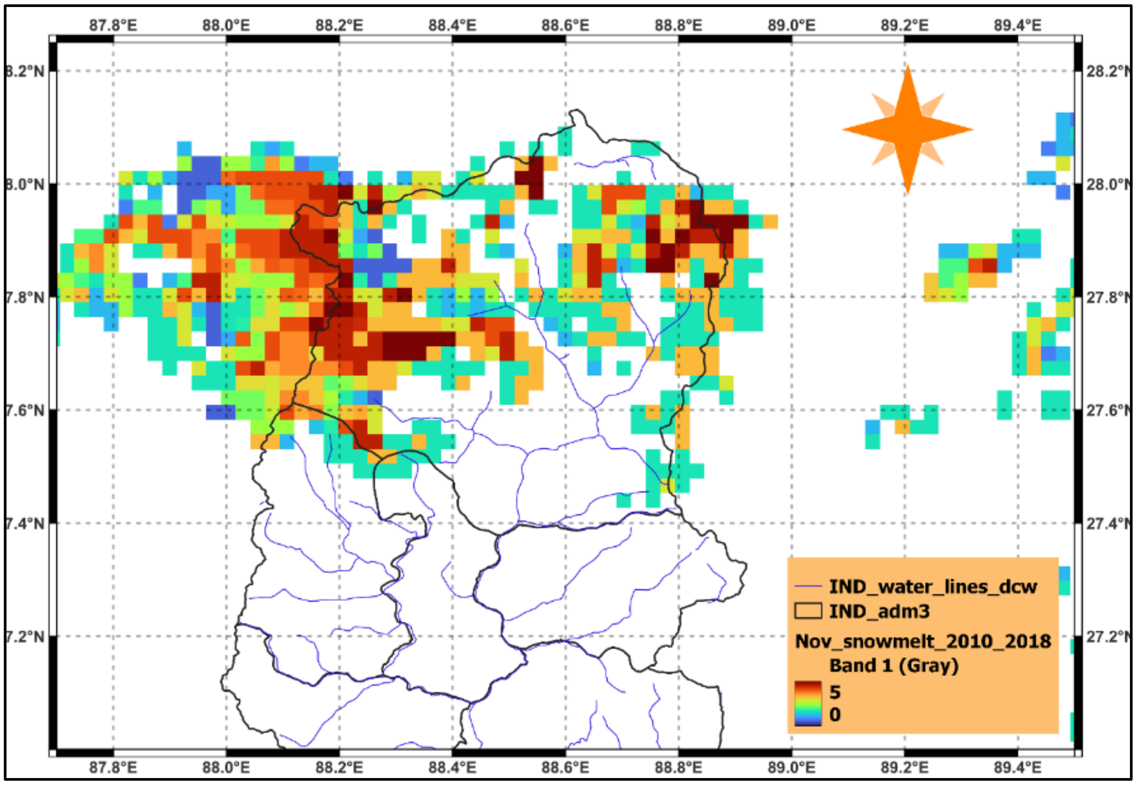

Figure-6.4: Decadal (2009-2018) snow cover map for East Sikkim district (Nov)

Hydrogeological importance of snow/snow cover:

The snowmelt water in high altitude percolates down through the soil horizons and from the cracks and fissures in the rocks. The groundwater thus formed flows along the slope and forms a water table. The water table often cuts the sloping surface at various altitudinal levels and emanates in the form of a spring. Depending upon rainfall, availability of snow melt water facilitated by the geological structure and formational characteristics of a rock, thickness and porosity of the soil horizon, the yield of the springs varies to a great extent.

6.3 OCCURRENCE, YIELD AND MOVEMENT OF WATER IN PERMAFROST ZONES:

There are types of permafrost zones where groundwater occurs. They are-

Supra-permafrost water: The water of this type remains confined to the rocks between the ground surface and the top of the permafrost area. Supra-permafrost water is unpressured. Precipitation is the chief source of recharge for the water of the active layer in summer. They also get recharged from water produced by the melting of ice-saturated rocks. Surface run-off is also another source of recharge for supra-permafrost water. In winter, the water in the active zone remains in frozen to partially frozen condition. In the course of freezing, unpressured water becomes temporarily pressured.

Inter-permafrost water: It is the water that migrates through the permafrost zones.

Infra-permafrost zone: It is the water occurring beneath a permafrost sequence. This water is found only in the liquid state. This water is contained in rocks with varying origin, age, lithology and occurs both above-zero and sub-zero temperatures. These waters are mainly confined to depressions, small grabens and river valleys of tectonic origin.

6.4 OCCURRENCE, YIELD AND MOVEMENT OF WATER IN NON-PERMAFROST ZONES:

Groundwater in the hilly state of Sikkim occurs in largely disconnected bodies under favorable geological conditions such as fractured and jointed zones in various lithological units and in weathered zones in the phyllite, schist, gneisses and quartzites. The presence of innumerable perennial springs with varied discharge is an indication of occurrence of ground water in various rock formations.

The area has high relief and steep gradient and as a result groundwater comes out as seepages and springs wherever the land surface intersects local ground water body. The primary source of groundwater in this region is through natural precipitation. Direct infiltration from rainfall through joints, fractures and weathered zones of the rocks and through soil covers is the principal mode of recharge of the springs. However, owing to its steep slope, although the area receives heavy rainfall, most of the precipitation in the area flows off as surface-run off through streams, 'kholas' and through intermittent springs. Only a fraction of total precipitation percolates down through the thickly vegetated permeable soil cover and through highly fractured rocks. Relatively flat areas like those on top of hills and ridges, saddles, spurs form the potential recharge areas, while the steeper hill slopes dominantly form the areas of spring discharge. Seepages from perennial streams make important contributions to discharge of springs, especially those located on valley sides. The catchment areas are always situated in the higher altitude. The movement of groundwater is mainly controlled by the structural set up of the area and by the physiography.

To be distinguished from springs are seepage areas which indicate a slower movement of ground water to the ground surface. Water in seepage area may pond and evaporates or flows, depending on magnitude of flow, the climate and the topography.

The springs in East Sikkim are mainly gravity springs which result from water flowing under hydraulic pressure. There are three types of springs commonly found in East Sikkim. They are Depression springs, Fracture springs and Contact springs.

Depression springs occur where the water table cuts the surface due to a sudden change in the topography. The catchment area consists of loose boulder sediments and weathered material. The recharge area for this type of spring is just above the spring itself.

Fracture springs originate along the fracture which cuts across an aquifer forming rock. The recharge area for such type of springs is along the fractures above the spring and the escarpment slope along with the spring.

Contact springs emerge at the contact of two different types of rocks. The rock below the spring is usually impermeable. The recharge area is usually on the escarpment exposure of these contacts or along with fractures if any.

The following table shows the analysis of the spring measured both Formation-wise as well as altitude (***Misra, 1977, 1978, 1979, 1980, 1981***).

Table-6.1: Details of springs Formation-wise and altitude

Rock Type	Altitude (amsl)		Discharge (lpm)		Discharge (lps)	
	From	To	From	To	From	To
Darjeeling Granite Gneiss/Darjeeling Mica Schist	500	1000	3	120	0.05	2.00
	1000	1500	2	60	0.03	1.00
	1500	2000	1	60	0.02	1.00
	2000	2500	3	30	0.05	0.50
Daling Phyllite, Dolomite, Quartzite	300	500	4	24	0.07	0.40
	500	1000	1	180	0.02	3.00
	1000	1500	1	120	0.02	2.00
	1500	2000	1	2100	0.02	35.00
	2000	2500	15	1800	0.25	30.00
Buxas Phyllite, Dolomite, Quartzite	1000	2500	1	10	0.017	0.17
	1500	2000	1	6	0.017	0.10
Gondwanas including pebbly horizon	500	1000	1	120	0.017	2.00
	1000	1500	1	100	0.017	1.67
	1500	2000	1	8	0.017	0.13

Table-6.2: List of springs that were established in East Sikkim district (NAQUIM: 2022-2023)

Location	Latitude	Longitude	Elevation (Amsl)	Sample Type	Pre-Monsoon Discharge (Lps)	Post-Monsoon Discharge (Lps)
4th Mile	27.36858	88.655548	2597	Spring	0.82	0.15
5th Mile	27.368541	88.661085	2628	Spring	0.14	1.33
20th Mile	27.377356	88.688498	3084	Spring	0.92	0.92
Thepu	27.378658	88.803569	3967	Spring	7	8
Nimachen	27.233045	88.758702	1650	Spring	2.33	3.33
Rongli	27.199953	88.692904	853	Spring	0.23	0.35
Pakyong	27.24848	88.604648	1177	Spring	0.85	0.85
32nd Mile/Ranikhola	27.264098	88.571066	674	Spring	0.18	0.18

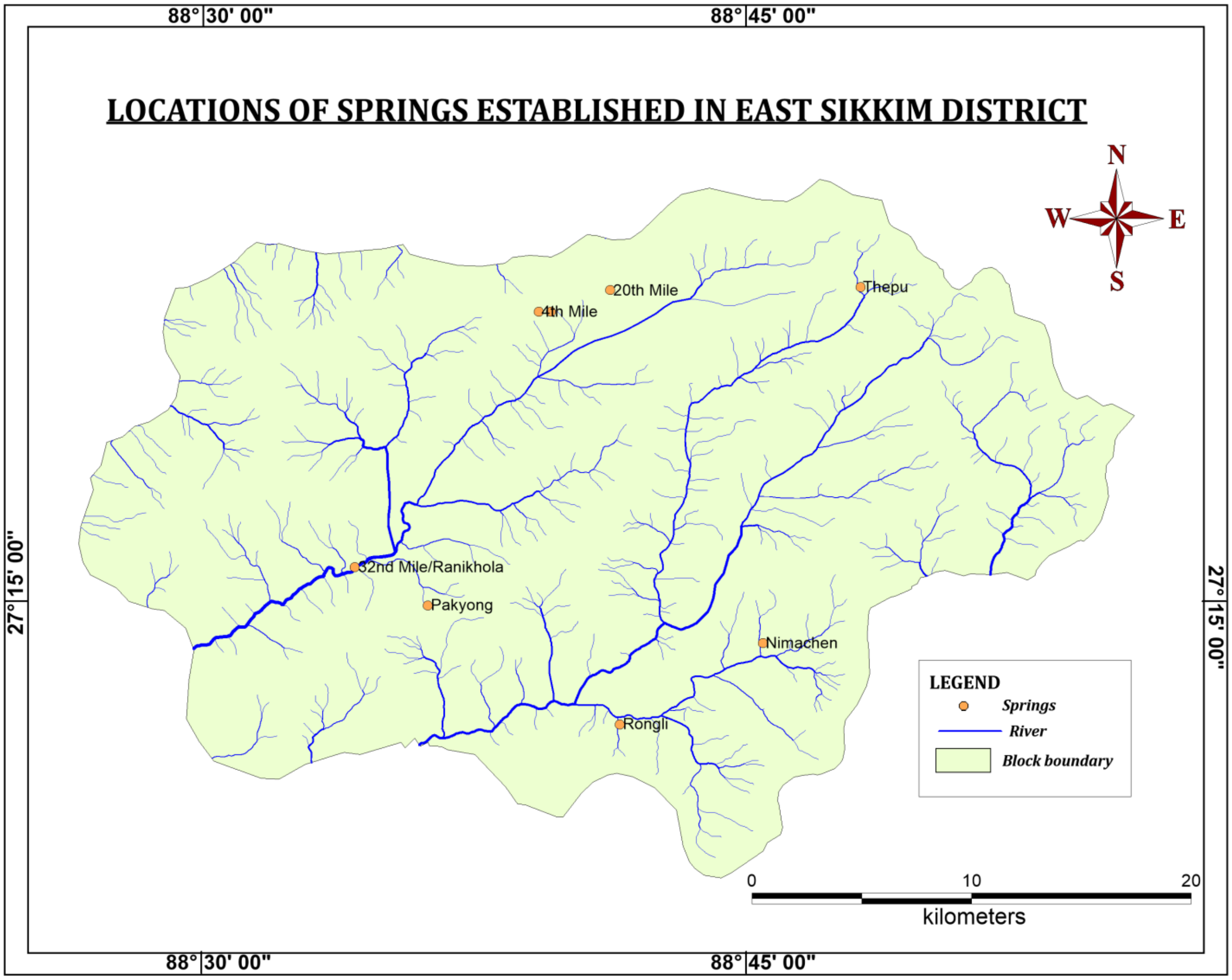

Figure-6.5: Location map for the springs/hot springs established in East Sikkim district

6.5 AQUIFER-WISE GROUNDWATER REGIME, DEPTH TO WATER LEVEL:

The depth to water level of the groundwater bearing zones cannot be measured due to the absence of monitoring stations in the state of Sikkim.

6.6 GROUNDWATER EXPLORATION IN EAST SIKKIM:

CGWB has carried out exploratory drilling at two sites in East Sikkim district in the past. One in Central Pendam and another one in Rumtek. However, the well at central Pendam was abandoned due to technical defect. The successful well at Rumtek, the details are given in the table below.

Table-6.3: Aquifer parameters from wells drilled at Rumtek, East Sikkim (Source-CGWB)

Location	Well Type	Drill Depth	Geology	Zones Tapped	SWL (mbgl)	Discharge (lps)	T (m2/d)	S
Rumtek	EW	47	Darjeeling Gneiss	7 –9 19 –20 30 –31 40 –42 46 –47	1.16	15	–	–

The well drilled gives parameters of shallow aquifer type (depth within 50 mbgl). The occurrence of water is within weathered zone and upper fractured zones. The static water level recorded is 1.16 m bgl and a discharge of 15 lps which is comparatively very high for hard rock terrains.

CHAPTER-7

GROUND WATER RESOURCES

7.1 DYNAMIC WATER RESOURCE:

The present estimation of the dynamic resources of the State of Sikkim has been carried out for the assessment year-2022. As per the norms and guidelines of Ground Water Resource Estimation Committee (GEC-2015) methodology, hilly areas with >20% slope are not to be considered for computation and calculation owing to the consideration of the area non-suitability for recharge. However, the entire state of Sikkim exhibits >20% slope. Field studies indicate presence of springs on slopes more than 20%. Rural population of the district is solely dependent on spring sources. The urban and marketing centres are dependent on water supply schemes tapping major rivers, lakes or springs. Hence, an alternative approach of resource estimation through spring discharge quantification in areas having upto 50% slopes has been attempted in the earlier resource calculation.

As per the computation, the annual extractable groundwater resource for East Sikkim district is estimated at 3935.94 ham. The total extraction for all uses is estimated at 101.6 ham. The stage of extraction for the district stands at 2.58%, falls under 'safe' category.

Ground water Recharge, Draft and Stage of Development:

Recharge Worthy areas in North Sikkim have been demarcated which excluded the areas under permafrost regions and areas having >20% slope. Further, recharge has been computed using Rainfall Recharge method and discharge has been calculated from the values of both natural discharges as well as from groundwater draft data. The Stage of Development is calculated by dividing the Annual Extractable Ground Water Resource with the Total Extraction.

The Dynamic groundwater Resource assessment-2022 results for East Sikkim district is given in **Table-7.1**

Table 7.1: Ground water Recharge, Resource and Stage of Development for East Sikkim district

District	Net Annual Ground Water Availability (Ham)	Existing Gross Ground Water Draft for All uses(Domestic/Industrial/Irrigation) (Ham)	Provision for domestic and Industrial requirement supply to 2025 (Ham)	Net Ground Water Availability for future irrigation use (Ham)	Stage of Ground Water Extraction (%)	Categorization
Gangtok	5898.25	547.93	206.42	5337.65	9.29	Safe
Pakyong	4298	154.71	30.59	4141.41	3.60	Safe

CHAPTER-8

HYDROCHEMISTY

8.1 GROUND WATER QUALITY SCENARIO:

Geochemistry of ground water is mainly dependent upon media like soil and rock through which rain water percolates, the depositional history of the rock types, composition of the rocks present, the climate of the area, presence of microorganisms, the topography of the area and anthropogenic activities etc.

Major Ion Chemistry and Hydrogeochemical Facies of East Sikkim

The geochemical evolution of groundwater can be understood by plotting the concentrations of major cations and anions in the Piper trilinear diagram. For demarcating the hydrochemical facies existing in the phreatic and fractured aquifer in the study area, Piper (1953) and the modified Piper diagram by Chadha (1999) were used.

Facies classification (Piper Trilinier Diagram) indicates that maximum groundwater samples belong to Ca-Mg-HCO_3 type in both Pre- monsoon and Post-monsoon season.

This hydrochemical type suggest that alkali earth metal has the advantage over alkali metal (Ca^{2+}+Mg^{2+} > Na^{+}+K^{+}) and weak acid anion has the advantage over strong acid anion (HCO_3^{-} > Cl^{-}+ SO_4^{2-}).

This groundwater type is generally formed from precipitation, indicating that the area is supplied with fresh water.

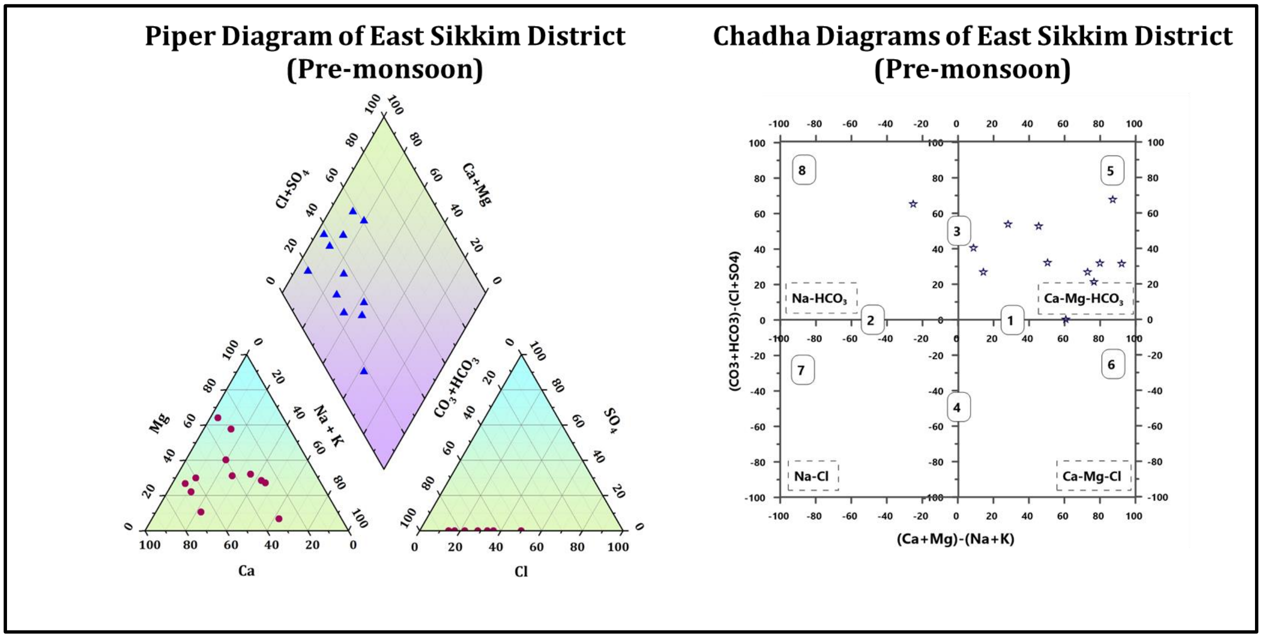

Figure-8.1: Piper trilinear diagram for hydrogeochemical facies and Modified Piper diagram (Chadha, 1999) for Groundwater samples of the Study Area in Pre- Monsoon

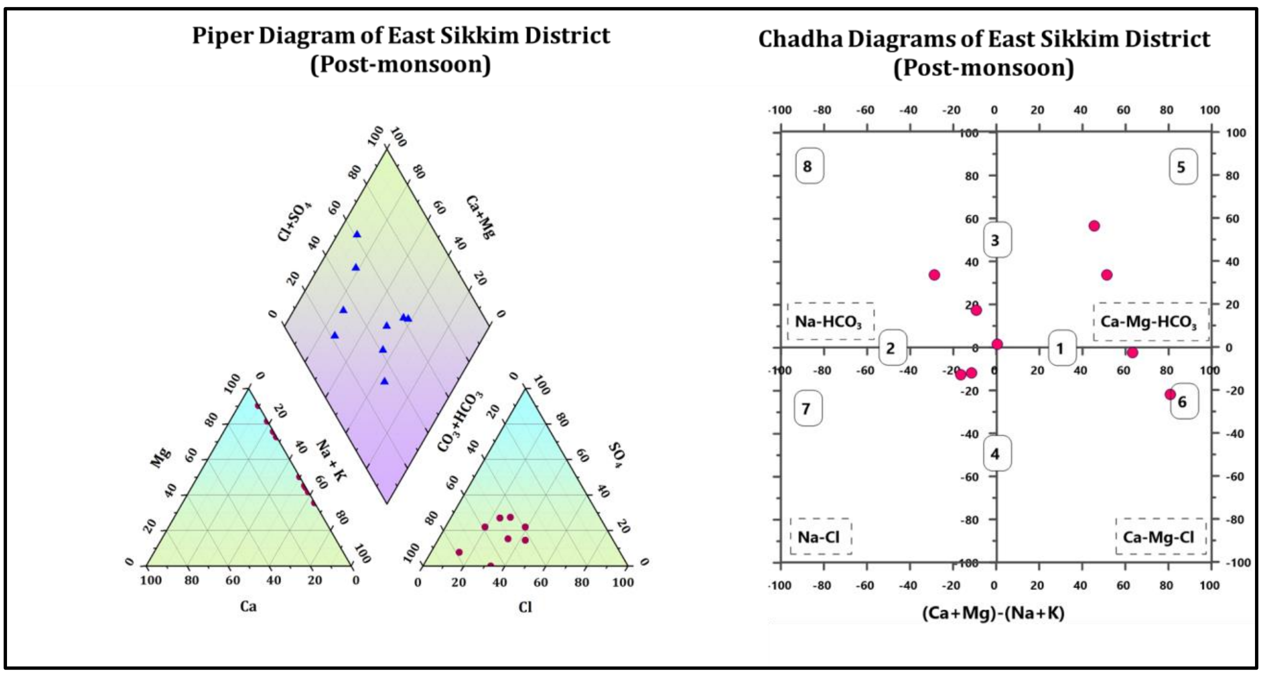

Figure-8.2: Piper trilinear diagram for hydrogeochemical facies and Modified Piper diagram (Chadha, 1999) for Groundwater samples of the Study Area in Post - Monsoon

Rock-water interaction

Rock-water interaction has been assessed by using Gibbs Diagram (Gibbs, 1970), which is a widely used method to establish the relationship of water composition and source conditions/characteristics. Three distinct fields such as precipitation dominance, evaporation dominance and rock-water interaction dominance areas are shown in the Gibbs diagram (Figure). The distribution of samples in the rock dominance region of the plot in the Gibbs diagram suggests that the major ion chemistry of groundwater is controlled by Precipitation which means the area is supplied with fresh water (**Figure-8.3**). This also corroborates the facies interpretation in the study area.

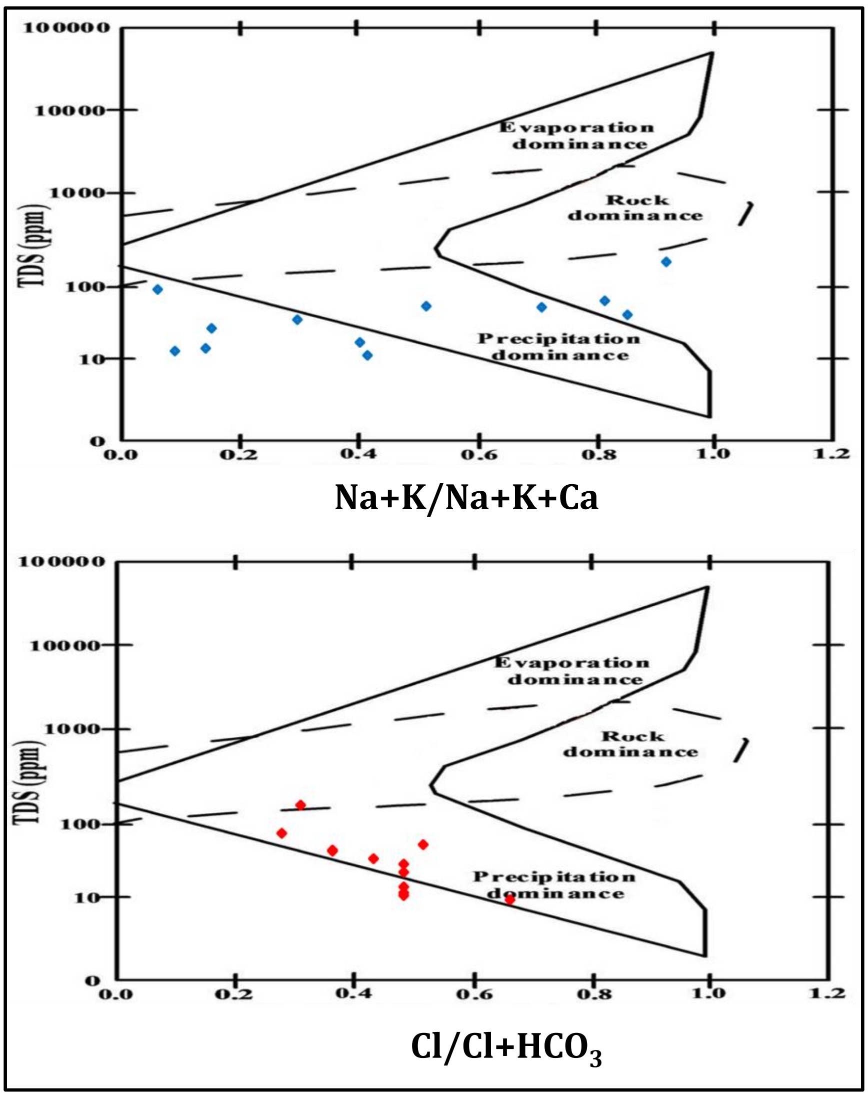

Figure-8.3: Gibbs diagram for controlling factor of groundwater quality in East Sikkim District

Since groundwater is intensively used for irrigation and drinking purposes, an effort has been made to evaluate the suitability of groundwater for drinking and irrigation purpose.

8.2 SUITABILITY FOR DRINKING USES:

Hydrogen Ion Concentration (pH): The pH content of ground water varies from 6.77 to 7.67. Minimum pH was dedected a glacier lake named as Suheli Lake of East Sikkim and the maximum pH was found in a borewell source at IOCL. East Sikkim. This indicates that ground water is in neutral in nature in East Sikkim. The rest of the samples collected from the study area in the falls within the permissible limit of 8.5.

Electrical Conductivity and Total Dissolved Solid: The wide range of Electrical Conductivity as well as TDS values indicates wide variation in dissolved constituents in groundwater in the study area. The minimum conductivity value (25.36 µS cm^{-1} at 25°C) has been observed from a spring sample at 4^{th} Mile whereas, maximum conductivity value (269.2 µS cm^{-1} at 25°C) has been observed from a bore well source at IOCL, East Sikkim.

As per the salinity hazard classes all the samples were found as suitable (i.e. EC >2250 µS cm^{-1}. In respect to TDS, all the samples were within the Acceptable Limit of 500 mg/L for drinking purpose (BIS: 2012). The drinking water standard according to BIS is given in **Table-8.1**.

Table-8.1: Chemical qualities of ground water samples in the study area showing the maximum and minimum values vis-à-vis drinking water standards (IS 10500:2012)

Constituents		IS 10500:2012		West Bengal	
		Acceptable Limit	Permissible Limit	Maximum	Minimum
pH		6.5	8.5	7.67	6.77
EC (µs/cm) 25°C	mg/L	-	-	269.2	25.36
Bicarbonate alkalinity (as $CaCO_3$)		-	-	146.4	6.1
Chloride		250	1000	17.73	3.5
Sulphate		200	400	BDL	BDL
Nitrate		45	No Relaxation	9.88	BDL
Fluoride		1	1.5	0.46	0.27
TH as CaCO3		200	600	70	10
Calcium (as Ca)		75	200	20	2
Magnesium (as Mg)		30	100	4.86	BDL
Sodium		-	-	37.68	0.09
Potassium		-	-	7.64	BDL
TDS		500	2000	173.2	14.5
Iron		1	No Relaxation	3.22	0.05
Uranium		0.03	No Relaxation	BDL	BDL
NOTE — It is recommended that the Desirable/Acceptable limit is to be implemented. Values in excess of those mentioned under 'Desirable/Acceptable' render the water not suitable, but still may be tolerated in the absence of an alternative source but up to the limits indicated under 'Permissible Limit' in the absence of alternate source' in col 3, above which the sources will have to be rejected.					

Distribution of Major Cations:

Calcium, Magnesium: The alkaline earth metals are two important Cations in ground water which have been analyzed. Calcium and Magnesium concentration in ground water varies from 2 to 20 mg/L and Traces to 4.86 mg/L respectively. All the samples are within the Acceptable limit.

Sodium, Potassium: The concentration of Na ranges from 0.09 mg/L to 37.68 mg/L. The concentration of K ranged from 2.6 to 6 mg/L.

Distribution of Major Anions:

Chloride, Bi-carbonate and Carbonate are the major anions present in ground water the study area.

Chloride: Chloride content of ground water in East Sikkim varies from 3.5 to 17.7 mg/L. Ground water with very low chloride and sodium contents points towards remarkably fresh nature which is almost equivalent to rain water. It is to note that ground water which is being replenished every year directly from rain water is not enriched with high chloride content.

As per BIS (2012), the Acceptable and Permissible Limits of Chloride in drinking water are 250 mg/L and 1,000 mg/L respectively and all the locations are found to have Chloride concentration within the Desirable or Acceptable Limit.

Bi-carbonate: Bicarbonate concentrations in ground water increases as it progresses towards the valley possibly due to absorption of carbon dioxide from atmosphere. The direction of enrichment of bicarbonate ions coincides, by and large, with the direction of ground water flow. The value of Bi-carbonate alkalinity in the study area ranges from 6.1 to 146.4 mg/L.

Nitrate: As per BIS (2012), the Permissible Limit of Nitrate in drinking water is 45 mg/L. In the study area Nitrate content ranged between Trace to 9.88 mg/L. The maximum concentration was found from Thepu army base camp, which is a spring source. The rest of the samples in the study area were found to have Nitrate concentration within permissible limit (**Table-8.1**).

Hardness of Ground Water: Calcium and Magnesium, Carbonate and Bicarbonate are the important constituents that give a measure to hardness of ground water. The hardness (temporary hardness) as $CaCO_3$ in the water samples range from 10 to 70 mg/L. The quality of groundwater in terms of Total Hardness as $CaCO_3$ has been found as Soft in nature. As per BIS (2012), the Permissible limit of Hardness in drinking water is 600 mg/l. All of the samples were found to have Hardness within the Permissible Limit.

Table-8.2: Hardness Classification of groundwater of the study area

Water Class	TH as CaCO3 in mg/L	% of Samples (Phreatic aquifer)
Soft	<75	100
Moderately Hard	75–150	-
Hard	150–300	-
Very Hard	>300	-

Iron: As per BIS (2012), the Permissible Limit of Iron in drinking water is 1.0 mg/L. In the study area, Iron concentration ranged between 0.05 to 3.22 mg/L. The maximum Concentration was found from a borewell source at IOCL. The rest of the samples were found to have Fe concentration within the permissible limit (**Figure-8.1)**.

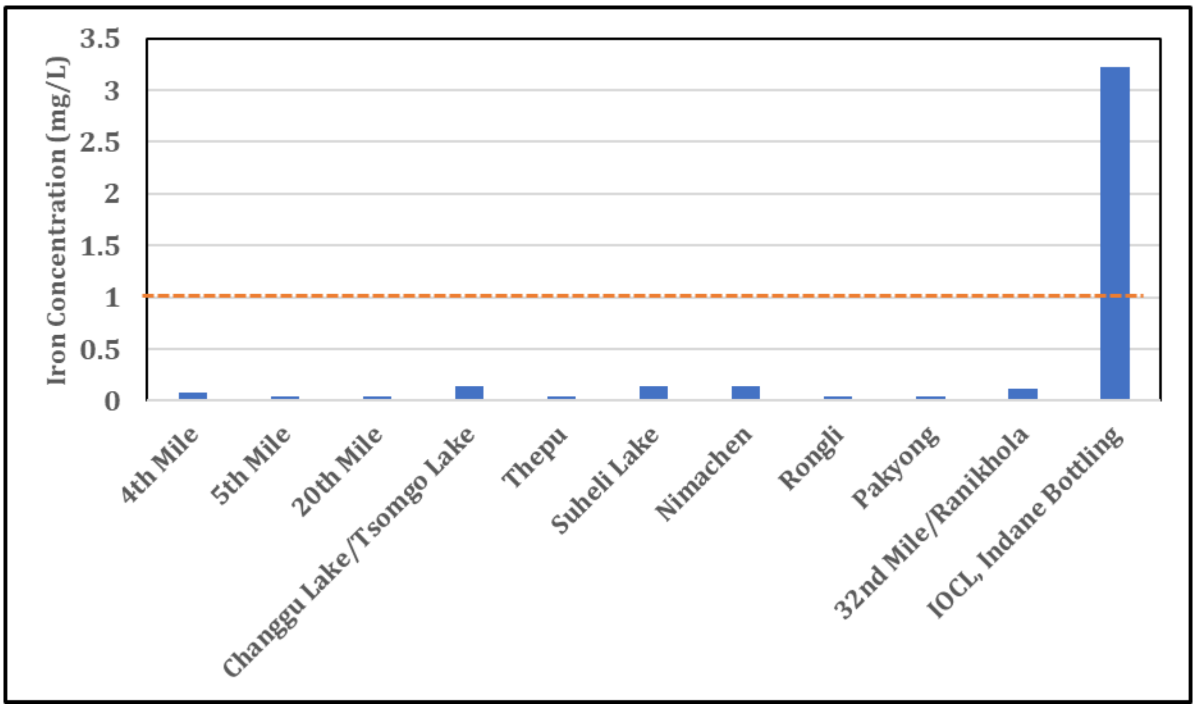

Figure-8.4: Distribution of Iron in the Ground Water of East Sikkim

Fluoride: BIS has recommended the acceptable limit of 1.0 mg/L for fluoride in drinking water, which can be extended to 1.5 mg/L of F in case no alternative source of water is available. Water having fluoride concentration of more than 1.5 mg/L are not suitable for drinking purposes. Fluoride content analyzed from the samples of the study area ranged from 0.27 to 0.46 mg/L. The samples were found to be within the desirable limit in the study area.

Uranium: As per recommendation of WHO the maximum permissible limit of Uranium is 0.03 mg/L. Water having Uranium concentration of more than 0.03 mg/L are not suitable for drinking purposes. Uranium content in the analyzed samples from the study area was found to be within safe limit.

8.3 SUITABILITY FOR IRRIGATION USES:

Table-8.3: Summarized result for various indices to assess the suitability of the groundwater for irrigation

Indices	Range	Water Class	Maximum	Minimum	Average
SAR	< 10	Excellent	2.21	0.01	0.45
	10 to 18	Good			
	18 to 26	Moderate			
	> 26	Unsuitable			
SSP	< 50	Good	59.98	3.5	29.77
	> 50	Unsuitable			
RSC	< 1.25	Good	1.3	-0.2	0.05
	1.25 to 2.50	Moderate			
	> 2.50	Unsuitable			
PI	> 75	Good	148.57	79.76	125.60
	25 to 75	Moderate			
	< 25	Unsuitable			

Electrical conductivity and percentage sodium: EC and Na play a crucial function in determining the fitness of groundwater for agricultural purpose. The higher amount of Na in agriculture water will increase the Na content to the cropland which leads to changed soil permeability. As a consequence, the soil becomes hard to plow and unsuitable for the seeds germination (Qian et al., 2016). Percent Sodium (%Na) is an expression to find the Na content in irrigational water. The percent sodium is obtained by the formula given below.

$$\%Na = \frac{(Na + K)}{(Ca + Mg + Na + K)} * 100$$

**All values in meq/L

When classified on the basis of percent sodium alone, the samples were found to be in suitable category except for a few locations (**Table-8.3**).

Permeability index: **Doneen (1964)** developed a PI-based diagram to categorized the water for irrigation. Long-term irrigation water imposes the impact on soil quality. Sodium, calcium, magnesium, and bicarbonate ions present in water influence the soil permeability (**Raghunath, 1987**). PI can be calculated by the formula given below.

$$PI = \frac{Na + \sqrt{HCO_3}}{Ca + Mg + Na} * 100$$

**All values in meq/L

Based on this classification, all of the groundwater samples fall in class 1 types ; All the samples are appropriate for agricultural uses (**Table-8.3**)

Residual sodium carbonate: It is used to know about the harmful consequences of carbonate and bicarbonates on the excellence of water for agricultural purpose (Eaton, 1950). RSC can be estimated by the formula given below:

$$RSC = (HCO_3 + CO_3) - (Ca + Mg)$$

**All values in meq/L

On the basis of RSC basics, water can be categorized into three categories such as RSC<1.25 is suitable for irrigation, 1.25<RSC>2.50 is marginally suitable and that >2.50 is unsuitable for irrigation. In the present study, it was found that all the samples fall into the safe category

*Sodium adsorption ratio (SAR)***:** Sodium adsorption ratio (SAR) is a measure of the suitability of water for use in agricultural irrigation, because sodium concentration can reduce the soil permeability and soil structure (Todd 1980). SAR is a measure of alkali/ sodium hazard to crops and it was estimated by the following formula:

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

where ,sodium, calcium, and magnesium are in meq/L.

The SAR value of water for irrigation purposes has a significant relationship with the extent to which sodium is absorbed by the soils. Irrigation using water with high SAR values may require soil amendments to prevent long-term damage to the soil, because the sodium in the water can displace the calcium and magnesium present in the soil. The calculated values of SAR in the study area vary between 0.01 and 2.21 (Table-8.4). The classification of groundwater samples based on SAR values are shown in **Table-8.3**. The SAR values of all the samples are found within the range of excellent category.

The reflections from the overall survey carried out in the study area revealed that the water collected from different sources such as springs, glacial lakes, river, borewell etc. in and around East Sikkim district are of excellent quality in respect to the analyzed physico-chemical constituents and the quality is comparable with rain water. As per drinking water suitability, the water is suitable for drinking and household uses. However, the bacteriological contaminants, if any, may be removed before consumption. In one borewell sample, Iron Concentration exceeded the Permissible limit. The quality of groundwater in terms of Total Hardness as $CaCO_3$ has been found as soft in nature. In respect of suitability assessment for Irrigation water, the ground water of majority of the study area was in suitable category in respect to the Irrigation Indices.

Table-8.4: Details of samples collected from various sources in East Sikkim for chemical analysis (NABL, RD, ER)

Sl. no.	Lab Code	Well ID	Location	Source	Lat	Long	Date of Sampling	Temp (˚C)	pH	EC	TH	Ca	Mg	Na	K	CO3	HCO3	Total Alk as CaCO3	Cl	NO3	SO4	F	SiO2	TDS	Fe
1	C - 466/22	E1	4th Mile	Spring	27.36858	88.655548	02-05-2022	14.7	6.9	25.36	10	2	1.2	0.92	0.35	0	6.1	5	3.5	2.42	0	0.28	0	14.45	0.079
2	C - 467/22	E2	5th Mile	Spring	27.368541	88.661085	02-05-2022	12.3	6.92	29.13	15	2	2.4	0.09	0.32	0	12.2	10	3.5	0	0	0.34	0	16.17	0.047
3	C - 468/22	E3	20th Mile	Spring	27.377356	88.688498	02-05-2022	7.6	7.44	144.40	70	20	4.9	2.22	0	0	73.2	60	7.1	3.48	0	0.39	0	82.69	0.047
4	C - 469/22	E4	Changgu Lake/Tsomgo Lake	Glacial Lake	27.376263	88.760871	02-05-2022	3.6	7.59	33.87	15	2	2.4	0.73	0.6	0	12.2	10	3.5	3.11	0	0.42	0	20.28	0.142
5	C - 470/22	E5	Thepu	Spring	27.378658	88.803569	02-05-2022	4.9	7.1	44.16	20	6	1.2	1.02	0.34	0	12.2	10	3.5	9.88	0	0.27	0	29.71	0.047
6	C - 471/22	E6	Suheli Lake	Glacial Lake	27.36737	27.36759	02-05-2022	10	6.77	31.04	15	4	1.2	0.54	0.39	0	12.2	10	3.5	0	0	0.29	0	17.42	0.142
7	C - 472/22	E7	Nimachen	Spring	27.233045	88.758702	03-05-2022	16.3	7.03	65.57	30	12	0.0	3.82	1.25	0	24.4	20	7.1	0	0	0.41	0	37.02	0.142
8	C - 473/22	E8	Rongli	Spring	27.199953	88.692904	03-05-2022	20.1	7.56	94.71	35	8	3.6	4.84	2.03	0	42.7	35	7.1	1.45	0	0.46	0	53.56	0.047
9	C - 474/22	E9	Pakyong	Spring	27.24848	88.604648	03-05-2022	20.4	7.22	69.73	20	4	2.4	6.91	1.36	0	30.5	25	7.1	1.69	0	0.31	0	42.4	0.047
10	C - 475/22	E10	32nd Mile/Rani khola	Spring	27.264098	88.571066	06-05-2022	22.8	7.42	102.80	30	6	3.6	9.52	1.42	0	42.7	35	14.2	0.22	0	0.28	0	61.31	0.11
12	C - 481/22	E11	IOCL, Indane Bottling	Bore well	27.19015	88.496738	11-05-2022	27.1	7.67	269.20	55	18	2.4	37.68	7.64	0	146.4	120	17.7	0	0	0.42	0	173.2	3.224
13	C - 482/22	E12	Martam	Bore well	27.257721	88.547248	11-05-2022	22.1	7.46	93.07	30	6	3.6	7.25	0.8	0	42.7	35	7.1	0.63	0	0.37	0	51.83	0.173

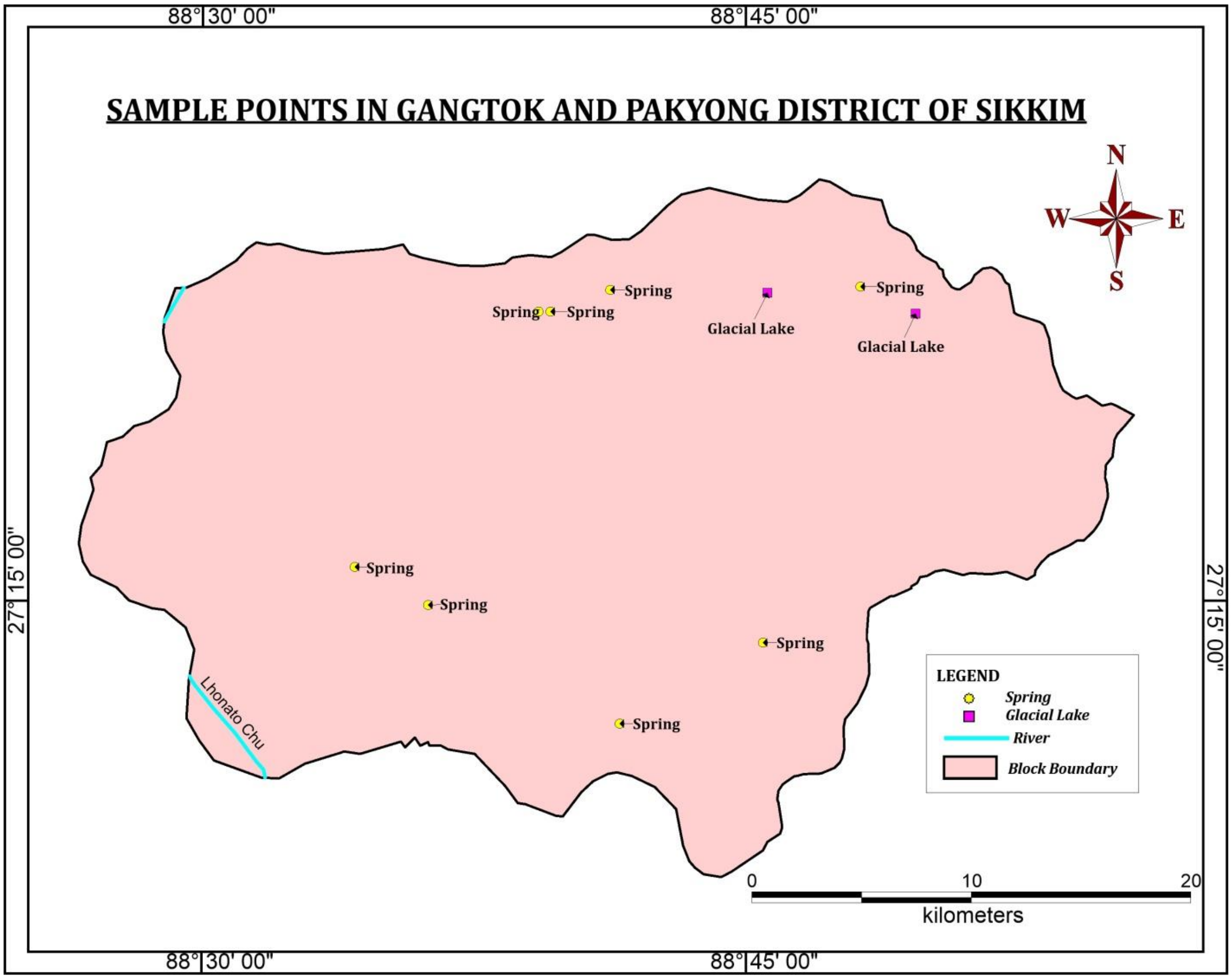

Figure-8.5: Map showing sample collection points from various sources in East Sikkim district

CHAPTER-9

GROUNDWATER RELATED ISSUES

9.1 HYDROGEOLOGICAL CONSTRAINS FOR DRILLING IN THE HIMALAYAS:

Due to the distinct hydrogeological set up of the Himalayas, the region's accessibility limitations and tough terrain remain as a challenge for groundwater exploration activity in Sikkim district. In general, the rocks prevailing in the district are very hard and massive and thus may be problematic to be penetrated even by the DTH rig operated by pneumatic pressure. During drilling operation in other districts of Sikkim, the loss of air (which helps in hammering the rock formation for piercing) through the dry and wide fractures encountered. Moreover, the water already obtained in such fracture/weathered zone may be lost by draining through the fracture zones encountered at greater depth due to the possible interconnection of the later zone with some springs or streams situated at a further lower level. Above all, there is the universal problem of finding any suitable site/ location for placing the drilling machine in the recommended potential area due to the lack of proper communication road for transportation of rig and other materials/machines.

9.2 SOIL EROSION PROBLEM:

Owing to its very steep topography and high rainfall, soil erosion and run-offs is very common in the region. Soil erosion reduces crop productivity and contributes to the pollution of adjacent watercourses, wetlands, and lakes. Four erosion classes have been identified in Sikkim viz, slight erosion, moderate erosion, severe erosion and very severe erosion. They need immediate attention for soil and water conservation.

9.3 SOIL ACIDITY:

The soil in the region is generally acidic to very acidic. The acidity in soil affects the productivity of crops that are grown over the area.

9.4 GEOLOGICAL HAZARDS:

North Sikkim falls in high seismic zone. The relief of the area is such that the district is frequented by hazardous landslides especially during the monsoon period. The area undergoes a regular process of denudation and remains unstable for majority of the time. Many of the cultivated areas with crops are also lost due to landslides.

9.5 RISK OF BACTERIAL CONTAMINATION IN URBAN CENTRES:

The densely populated urban area of Gangtok does not have a combined drainage system to drain out the storm water and waste water from the buildings. The estimated solid waste generated in Gangtok city is approximately 45 tonnes. Only around 40% of this is collected by

UDHD, while the remainder is indiscriminately thrown into Jhora, streets and valleys. The collected waste is disposed in a dump located about 20 km (12 mi) from the city. There is no waste collection from inaccessible areas where vehicles cannot reach, nor does any system of collection of waste exist in the adjoining rural areas.

CHAPTER-10

GROUNDWATER DEVELOPMENT AND MANAGEMENT

10.1 GROUNDWATER DEVELOPMENT THROUGH SPRINGS AND OTHER SUSTAINABLE PRACTICES:

The Himalayan region is blessed with adequate rainfall, but an overwhelmingly high proportion of the same is restricted to the monsoon season and natural groundwater recharge is hampered by high levels of surface runoff due to the presence of high slopes. Rather than“gushing”surface water, groundwater oozing, trickling and flowing in the form of mountain springs ensure water security for a sizeable part of the rural population. These springs are fed by groundwater and are largely recharged by rainwater infiltration.

The rural and urban water supply in the study area is highly dependent on the spring water. Urban households in the district are supplied by the central water system maintained and operated by the Public Health and Engineering Department (PHED). The main source of PHED water supply is the Ratey chu River located about 16 km (9.9 mi) from the city, at an altitude of 2,621 m (8,599 ft). Its water treatment plant is located at Selep. The river Ratey chu is snow-fed and has perennial streams. Since there is no habitation in the catchment area except for a small army settlement, there is little environmental degradation and the water is of very good quality. 40 seasonal local springs are used by the Rural Management and Development Department of Sikkim Government to supply water to outlying rural areas. The entire city drains into the two rivers, Ranikhola and Roro Chu, through numerous small streams and Jhoras. Ranikhola and Roro Chu rivers confluence with Teesta River. These two rivers are the major source of drinking water to the population downstream.

The technology of Spring water harvesting system is recommended for those hilly areas where untapped perennial source of water (spring) is situated at higher elevation than the common place of storage in a targeted village so that water can be conveyed through low cost pipe under the influence of gravity. For conservation of yield of natural springs and its supply to the downstream areas, **Spring Boxes** are constructed which serve as collectors for spring water. They can be used as storage tanks when a small number of people are being served and the source is located nearby the users. When large numbers of people are served, the water collected in the spring box flows to larger storage tanks. The spring sources should also be cleaned periodically, wastage of water should be minimized and should be treated before use for drinking.

Spring shed development works may be taken up in the upstream, while the main benefits in terms of increased discharge will be visible in downstream. This can be feasible by providing incentives to the upstream land owners with spring shed development activities like better water regime, horticulture and fodder plantations.

Implementation of spring development may be done using mechanical, vegetative and social measures. Mechanical measures involves digging trenches and pits along contours, gully plugging, bunding of terraces and making the inward sloping, stone and mud built water retention structure, de-silting of dried up ponds and lakes, etc. Vegetative measures involves plantation of low water demanding and shallow rooted grass/shrubs/trees. Social measures such as ban on grazing, fuel wood and fodder cutting and social fencing of the recharge area may be taken up. An integration of all these measures will result in the development of springs and help in augmenting the discharge of the springs downslope.

There is a growing perception that climate change impacts, manifested in the form of rising temperatures, more intense precipitation patterns and longer winter droughts, have further reduced the natural groundwater recharge (Tambe et al 2011). In addition, recent studies in the adjacent Darjeeling hills indicate the perceived impact of climate change in the form of less snow in the mountains and intense but short episodes of rainfall that increases runoff, causing poor accumulation and recharge of water, thereby resulting in the drying up of water sources (Chaudhary et al 2011).

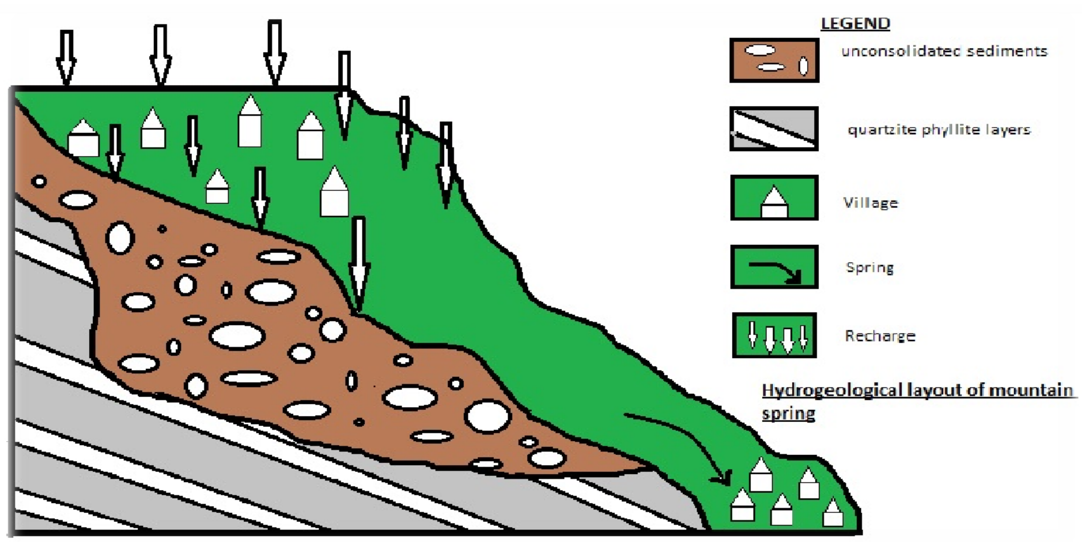

Figure-10.1: Schematic representation for recharge in mountain springs

While spring water is perceived as a public resource, the majority of the springs and their recharge areas (not necessarily on the same slope as the spring) are located in privately owned farmers 'fields. Paddy cultivation involving flooding of the fields and terraced cultivation are ideal land use forms in the spring recharge area feeding their natural recharge. Wherever there is sloping land, the surface runoff is higher and there is scope for supplementing natural recharge through artificial techniques. Usually on steep slopes, rain-water leaves the site quickly down through the main valley. Rainwater, coming from the top of the mountain has an enormous momentum going down owing to the force of gravity. As the water goes downwards, it accumulates much more water. So the force it produced is so enormous that it starts eroding the soil whenever it touches.

In gentle sloping areas, a step in the form of a terrace has to be built in order to slow down or eradicate the momentum going downhill by the surface water. This practice is called **Terrace Farming** and is highly prevalent in hilly terrain. On every terrace, the water will just spill over to another terrace until it reaches the lowest terrace down the mountain**.** What terracing does (when done correctly i.e following the contours) is, it spread the water from the valley to the ridges that effectively slows down and pacify the speed of water and harvest more rainwater. Thus, providing better crop irrigation. Terracing permits more intensive cropping than would otherwise be possible. This is most useful for growing crops which are highly water intensive such as rice, wheat, barley, tea, etc.

However, hydrological studies conducted in Mamlay watershed of South Sikkim district have indicated that the sediment load becomes very high during rainy season in all the streams owing to high intensity rainfall, steep slopes and cultivation on terraces carved out of steep slopes. High overland flow, soil loss and nutrient loss has been estimated to be high from open agricultural fields (9.6% of the rainfall) and least in Cardamom forestry (2.17%) (Rai & Sharma, 1998) .The hydrological studies are thus indicative of the fact that in the fragile watersheds, agroforestry needs to be practiced replacing agriculture in the sloping areas. Such practice would help in soil and nutrient conservation consequently enhancing the soil fertility and productivity. An inverse relationship was found between forest floor interception and soil erosion. Therefore, it can be recommended that the dense mixed forest cover should be maintained **at higher elevations** to regulate and ensure stream flow and also to minimize the risk of landslides.

Spring shed development works may be taken up in the upstream, while the main benefits in terms of increased discharge will be visible in downstream. This can be feasible by providing incentives to the upstream land owners with spring shed development activities like better water regime, horticulture and fodder plantations.

Implementation of spring development may be done using mechanical, vegetative and social measures. Mechanical measures involves digging trenches and pits along contours, gully plugging, bunding of terraces and making the inward sloping, stone and mud built water retention structure, de-silting of dried up ponds and lakes, etc. Vegetative measures involves plantation of low water demanding and shallow rooted grass/shrubs/trees. Social measures such as ban on grazing, fuel wood and fodder cutting and social fencing of the recharge area may be taken up. An integration of all these measures will result in the development of springs and help in augmenting the discharge of the springs downslope.

Given the importance of aquifers in understanding springs, a hydrogeological approach should be a prerequisite for any springshed development work. Hydrogeology enables classification of springs in any area. All springs can be classified and named.

Recharge areas to be demarcated based on the hydrogeology. The typology of springs, complex distribution patterns of springs and related hydrological factors imply that the size and location (distance from spring) of recharge areas be kept flexible during spring management programmes.

Periodic monitoring of spring discharge aids better understanding of springs which then can feed in future planning and management of spring water. Sustained monitoring imperatives must be added and retained in such programmes.

Sensitization of the local community regarding role of hydrogeology governing recharge areas, protection of recharge areas, importance of spring water data collection etc. is necessary, almost as a non-negotiable aspect of post-programme efforts.

Concrete paving of dried up lakes should be completely banned as it can block spring water inflows in to the lake. Dhara Vikas (physical measures in recharge areas to augment spring water inflows in to the lake) can help rejuvenating dried up lakes.

Spring discharge, seasonality and sustainability depend on aquifer properties i.e. Storativity and Transmissivity. Every aquifer has its own range of these properties based on local hydrogeology. Artificial recharge to augment spring discharge thus has a certain limit to which it can be achieved. To cope up with the increasing demand and the changing climate a particpatory community based approach based on scientific observations would need to be built into all such programmes.

10.2 GROUNDWATER MANAGEMENT PLAN FOR IRRIGATION PURPOSE:

East Sikkim, being a very hilly area with varying degree of slopes, constructing big irrigation canals running across the length & breadth of the district is not feasible and entails a very high capital cost & maintenance cost. The majority of farmers are also just marginal farmers and they are not able to provide irrigation to the crops through costly means. The cultivation is done mainly by springs and surface water from Kholas. Ground water is available in highly dynamic state and unavailable for useful purpose in the highly sloping topography. Hence extraction of groundwater for irrigation purpose is practically zero. Springs, both seasonal and perennial are the main source of available water. Availability of abundant stream water during the summer allows for growing of paddy which the farmers carry to their field through temporary channels. Otherwise almost all the crops are grown rain fed. The topography again is a big constraint in developing a suitable water application method. Design/ layout of drip irrigation, sprinklers etc., are difficult and entail high cost due to difference in pressure head in every terrace/ field. Hence, a more pragmatic approach is to go for micro irrigation and better methods of water application, like small water harvesting structures, roof water harvesting and water saving application methods like sprinklers, drips, porous pipes etc.

Strategic planning and management as per District Irrigation Plan (DIP): It may be mentioned that the water sector has very strong linkages with all other developmental activities as well. In view of fast changing development scenario, it is emphasized that the key priorities and identified strategies cannot be considered as static and firm. These need to be reviewed and improved upon from time to time. In this regard a comprehensive "Strategic Plan for District Irrigation" has been prepared through geospatial approach by the district implementation Committee.

The selection of suitable sites for various water harvesting structures has been done as per NMSA (National Mission for sustainable Agriculture) and NMMI (National Mission for Micro Irrigation) guidelines. The following table provide strategic action plan for irrigation for North Sikkim district and estimated costs and period of implementation through PMKSY.

Table-10.1: Strategic Action Plan for Irrigation in East Sikkim District under PMKSY:2016-17 to 2021-22

Ministry	Component	Activity	1st Year		2nd Year		3rd year		4th Year		5th year		TOTAL	
			Quantity (Nos/Hec/KM)	Amount (Rs in Lakh)	Quantity (Nos/Hec/KM)	Amount(Rs in Lakh)	Quantity (Nos/Hec/KM)	Amount(Rs in Lakh)	Quantity (Nos/Hec/KM)	Amount(Rs in Lakh)	Quantity (Nos/Hec/KM)	Amount(Rs in Lakh)	Quantity (Nos/Hec/KM)	Amount(Rs in Lakh)
MoWR	Har Khet ko Pani	Surface Minor Irrigation	24	1200	73	3650	74	3700	74	3700	72	3600	317	15850
		RRR of Water Bodies			20	1000	17	850	9	450			46	2300
		Total		1200		4650		4550		4150		3600		18150
MoA&FW	Per Drop More Crop	Lift Irrigation	0	0	13	390	11	330	7	210	0	0	31	930
	Other - Intervention	RRR of Water Tank												
		50 cum	2	4.62	36	83.16	27	62.37	5	11.55	-	-	70	161.7
		20 Cum	5	3.3	169	111.54	160	105.6	79	52.14	57	37.62	470	310.2
		10 Cum	10	5.3	234	124.02	272	144.16	174	92.22	149	78.97	839	444.67

	Per Drop More Crop (Micro Irrigation)	Non- DPAP (Drip)												
	Horticulture	Wide Spaced Crop (S&M)	40	29.2	314	229.22	411	300.03	181	132.13	147	107.31	1093	797.89
		Close Spaced Crop(S&M)	10	10.7	161	172.27	199	212.93	100	107	76	81.32	546	584.22
		Close Spaced Crop (S&M) <1.2 m	9	11.25	170	212.5	207	258.75	99	123.75	72	90	557	696.25
	Per Drop More Crop	Non- DPAP Sprinkler)	232	247.08	563	599.6	765	814.725	352	374.88	264	281.16	2176	2317.44
	Per Drop More Crop	Roof Cum Rain Water 10000 litres Capacity	190	180.5	687	652.65	723	686.85	461	437.95	400	380	2461	2337.95
	Other - Intervention	Harvesting Structure 20000 litres Capacity	85	104.55	398	489.54	447	549.81	248	305.04	194	238.62	1372	1687.56
		Secondary Storage structures (Topping With MGNREGA)												
		50 CUM rcc Water Tank Community Tank	5	22.65	66	298.98	76	344.28	30	135.9	21	95.13	198	896.94
		30 Cum RCC Water Tank (do)	10	33.8	128	432.64	154	520.52	57	192.66	46	155.48	395	1335.1
		Bore Well (DeeP 100 m)	2	25.22	11	138.71	10	126.1		0		0	23	290.03
		50 cum Steel demountable tank - do-)	8	44.64	66	368.28	63	351.54	29	161.82	4	22.32	170	948.6
		HDPE Tank of 2000 Litres Capacity	90	14.4	433	69.28	470	75.2	205	32.8	170	27.2	1368	218.88
		Conveyance Water Pipeline in Km	69	146.28	786	1666.32	885	1876.2	339	718.68	210	445.2	2289	4852.68
		HDPE Pipes	180	3.6	1450	29	2138	42.76	492	9.84	293	5.86	4553	91.06
		Total		887.09		6067.71		6801.825		3098.36		2046.19		18901.17
DoLR - MoRD	PMKSY													
	Watershed	Water Source Development	58	4.52	22	1.72	42	3.28	33	2.58	14	1.09	169	13.18
		Percolation Tanks	17	15.3	19	17.1	32	28.8	30	27	25	22.5	123	110.7
		Fishery ponds/cattle pond	47	14.1	19	5.7	31	9.3	37	11.1	20	6	154	46.2

		Total		33.92		24.52		41.38		40.68		29.59		170.08
DoRD - MoRD	Convergence with MGNREGA	Roof Cum Rain Water Harvesting Structure 10000 litres Capacity	190	36.1	687	130.53	723	137.37	461	87.59	400	76	2461	467.59
		Roof Cum Rain Water Harvesting Structure 20000 litres Capacity	85	20.4	398	95.52	447	107.28	248	59.52	194	46.56	1372	329.28
	Other Interventions	Secondary Storage structures												
		50 CUM rcc Water Tank Community Tank	5	6.6	66	87.12	76	100.32	30	39.6	21	27.72	198	261.36
		30 Cum RCC Water Tank (do)	10	9.4	128	120.32	154	144.76	57	53.58	46	43.24	395	371.3
		50 cum Steel demountable tank -do-)	8	3.28	66	27.06	63	25.83	29	11.89	4	1.64	170	69.7
		Conveyance Water Pipeline in Km	69	32.43	786	369.42	885	415.95	339	159.33	210	98.7	2289	1075.83
		Total		108.21		829.97		931.51		411.51		293.86		2575.06
GRANT TOTAL				**2263.148**		**11596.71**		**12366.09**		**7741.226**		**2399.23**		**39796.31**

10.3 Artificial Recharge and Rainwater Harvesting:

Rain Water harvesting is a must practise in hilly areas. Apart from roof-top rain water harvesting, building small tanks on slopes will also help the flowing down water to accumulate which can be used for gardening or watering plants,etc. There is rainwater potential in the hilly areas to harvest for irrigation purposes because of its high annual average rainfall and availability of suitable landscape. In this type of condition, developing rainwater harvesting technologies for irrigation would be very useful for local agricultural production by constructing small water reservoirs in upstream hilly canyon. Rainwater can be harvested to irrigate both hilltop and hill slope areas by pumping and the valley areas by gravity flow.

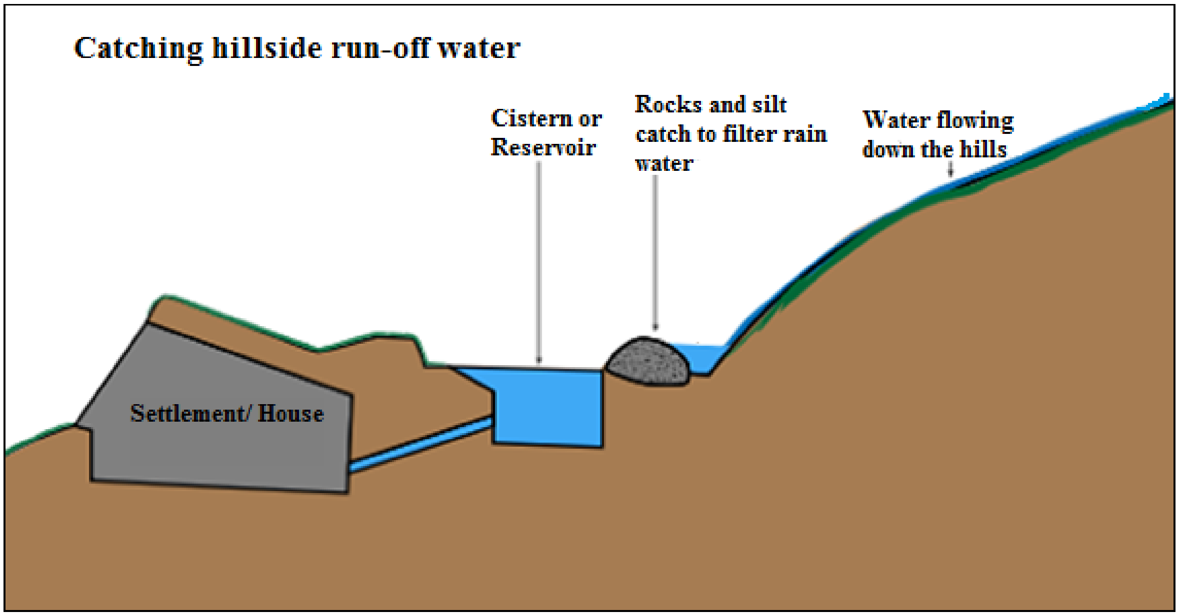

Figure-10.2: Schematic representation for rainwater harvesting in hilly regions

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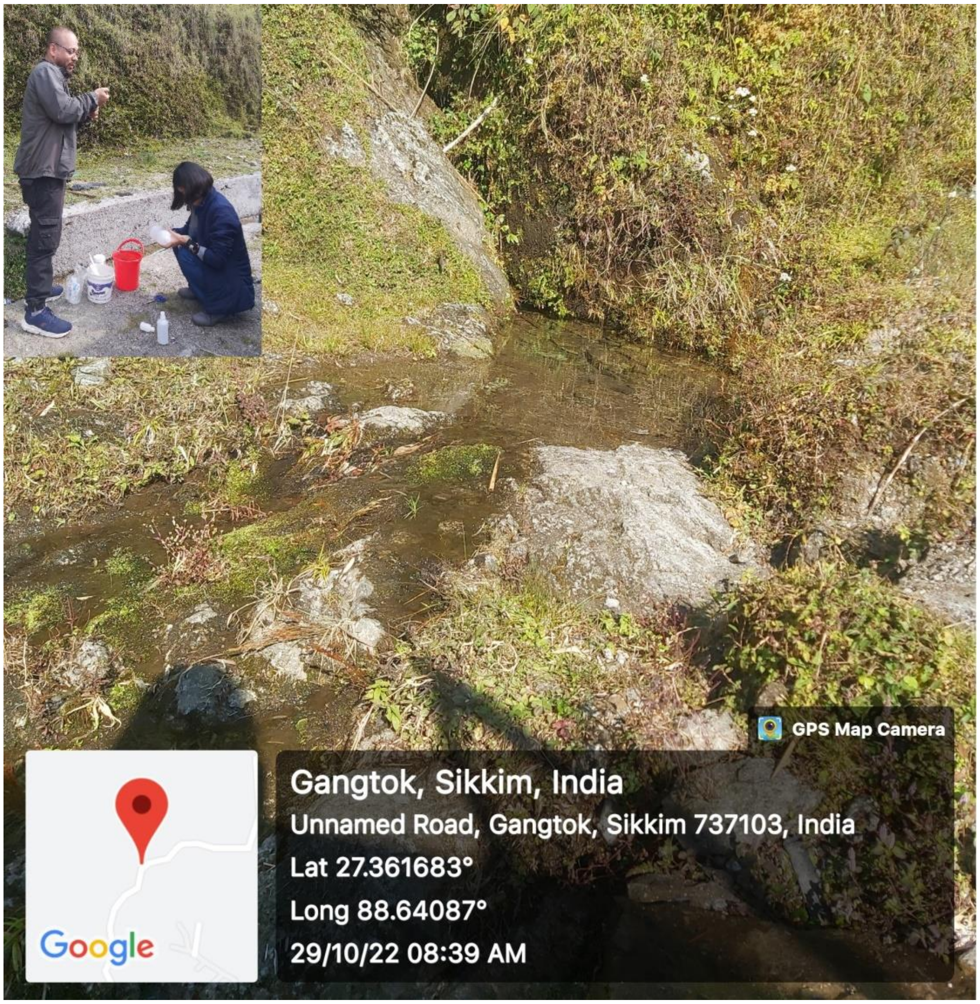

Figure-A: Spring at 4th Mile (27.36858, 88.655548), Gangtok district, East Sikkim

Figure-B: Spring at 5th Mile (27.368541, 88.661085), Gangtok district, East Sikkim

Figure-C: Spring at 20th Mile (27.377356, 88.688498), Gangtok district, East Sikkim

Figure-D: Spring at Thepu army camp (27.378658, 88.803569), Gangtok district, East Sikkim

Figure-E-: Spring at Nimachen (27.233045, 88.758702), East Sikkim

Figure-F: Snow covered valley at Nathang, East Sikkim

Figure-G: Spring at Rongli (27.199953, 88.692904), Gangtok district, East Sikkim

Figure-H: Spring at Pakyong(27.24848, 88.604648), Gangtok district, East Sikkim

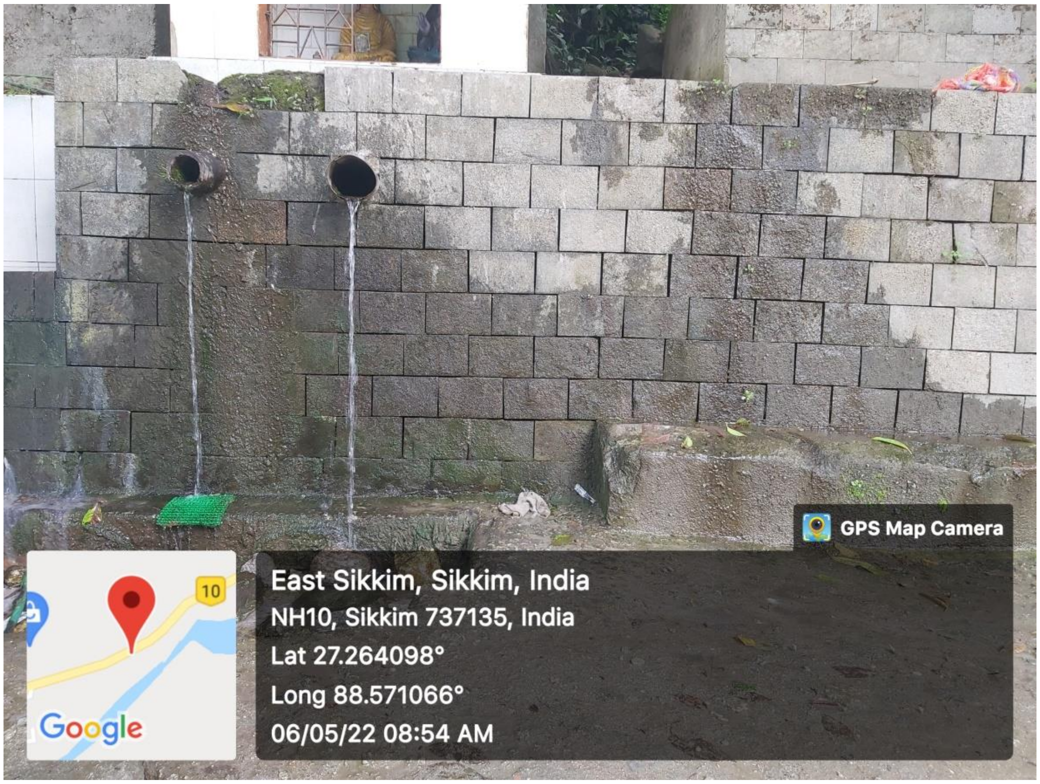

Figure-I: Spring at 32nd Mile, Ranikhola (27.264098, 88.571066), East Sikkim

Figure-J: Water sampling at Chhanggu Lake (27.376263, 88.760871), East Sikkim

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