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Geospatial analysis of Socio-Economic Health Gnathang Valley and Sikkim-Himalayas

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ABSTRACT

Sikkim, the tinniest but erudite state housed in north east Himalayas of India, which has diverse cultural, religion and ethnic identity. The organic state with hilly steep terrain, Sikkim has diverse economy stressing on agriculture, hydropower, Ayurveda and tourism. The Gnathang valley is nestled in east Sikkim in a glacial snow-covered canopy with many ethnobotanical flora and fauna, but with a little knowledge of regular geomorphological and socioeconomical changes during this decade. The geoinformatics and change detection studies are conducted using satellite imagery, Remote Sensing data by constructing geographical and geomorphological maps like slope, aspect, elevation maps, land use changes, of the Sikkim state in recent years. But the socioeconomic survey is directed for the collection of primary data by questionnaire survey and analysing the data for submissions and recommendations. Presently, the residents of the Sikkim state are financially backward though educationally and heritage wise strong. Tourism, organic agriculture, surge in Micro, Small, and Medium Enterprises (MSME) are focusing areas for augmenting societal and economic values of Sikkim. The Government have stressed upon investment in countryside setup like roads, energy, electrification, communication, diversifying rural employment and improving rural-urban. The east Sikkim is among the leading states to inculcate SDG 10 (Reduced inequalities), SDG 13 (Climate change impacts), SDG 3 (Good health and wellbeing) and quality education (SDG 4) but the sectors need strengthening are Zero poverty (SDG 1), Food for all (SDG 2), Strengthening women power (SDG 5) and Life on land (SDG 15).

Keywords: *GIS/RS, topography, Sikkim Himalayas, rural economy, organic farming, homestay (eco) tourism.*

Introduction

The Himalayas in the north of Indian peninsula is segmented based on elongation (Longitudinally) as the Western Himalayas (Kashmir and Himachal Pradesh), Central Himalayas (Uttarakhand), Eastern (Sikkim, Bhutan, Darlings and Arunachal Pradesh) [1]. Also depending on geo-dynamic implications in Indian Himalayas, the stratigraphy (Latitudinally) compartmentalised as sub-Himalayas, Lesser-Himalayas, Greater-Himalayas and Tethyan Himalayas. The geology and Sikkim and Darjeeling have geological similarity. Geographical Information system (GIS) and Remote Sensing (RS) has added to the social scientists work easier, faster and amalgamated method make it more perspectives in their work, [2], [3],[4].

Sikkim, (latitude 27^0 04' to 28^0 07' and longitude 88^0 00' to 88^0 55') between the Tibet and Nepal in mid-Himalayas. The state was formed as a monarchy by Namgyal dynasty (1642), to spread Buddhism during17th century. Later in 1835, it was possessed by Britishers including the present Darjeeling district. Sikkim as Indian protectorate, becomes independent became a democratic state with her independence, abolishing the monarchy's governance and become India's 22nd state in 1975. https://sikkim.pscnotes.com/history-of-sikkim/formation-of-sikkim-as-the-22nd-state-of-india-1975/

Gnathang Valley in east Sikkim is a canopy of Yak herders above 4500m called the Nature's Paradise. The valley is famous as old Silk Route between China and India in past. The yak herders, originated from Tibet dwell amongst between streams befuddle the valley.

The valley is covered with about 1.5m of snow in winter but in summer it converts as a panoramic place of visit. It is 80km from Gangtok, the capital of Sikkim and also called Ladakh of East Sikkim [5].

Sikkim is a superimposed cultural over natural landscape shaped by the socioeconomic imprints and guided by climate vagaries. The land is flooded in Indian summer monsoon days, snow covered in winter, and a paradise during transition. Amidst extreme events, landslides, earthquakes and Glacial Lake outburst floods, the residents of Sikkim disrupt their connectivity, food chain and electricity and their main source of livelihood the tourists. The Sikkimese live in both lower and mid- Himalayas with diverse economic and societal integrity. The Gnathang valley was chosen as the canopy nests both the people in dual topographies [7](Fig 1).

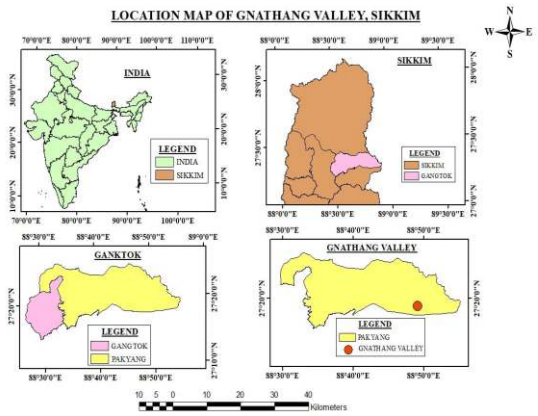


Fig 1: The index map of the Gnathang valley, Gangtok in Sikkim state, India

The Sikkim state is one among the most socio-economically growing state with politically unwavering and better-governed states in India [9], considering 23 glaciers during 1991–2015 in Sikkim Himalayas and reported that the glaciers have retreated (17.78±2.06ma−1), deglaciated (5.44±0.87%), and inferred about surge in snowline altitude (SLA) by ~7ma−1 and debris cover of 16.49±2.96%. This glacial change occurs due to climate impacts and cause disasters like floods, cloud bursts, flash floods and landslides in Sikkim [10], [11], [12]. The Himalayas is threatened as per the IPCC [AR-6], has prompted and reported increased landslides, flash floods, and other extreme rainfall events (EREs) associated with rising temperatures [13].

The study Area: Sikkim, the 2nd smallest State in India, has an area of 7096 sq km and least populated in the country, with 610,57TH people (2011 census). Its Rural Population is 74.85% and density of population is 86 per/sq.km. The number of BPL households is 21.618Th with a population of 101.618 people. Sikkim's GSDP raised Compound Annual Growth Rate (CAGR) @15.86% between 2015-16 and 2019-20. Literacy rate is 81.4% higher than India's average. Agriculture is the key player of her rural economy, projected as 60% of the total population's livelihood is based upon agriculture [14], 15]). The small state extends 113km from north to south and 64km from east to west [16]. Various studies pertaining to the glacial-geomorphological topographies around Thangu area, in North Sikkim [17]), Dzuluk Village, East Sikkim [18], South Lhonak Lake in Sikkim and a few rural areas. The environmental risks, proper connectivity, climate change impacts, fragile Himalayan ecosystem and fabric need rigorous studies [19], [20].
It is pertinent to study the geomorphology, ecology and socioeconomic status of the people of the east Sikkim people and plan for their overall development.

The Objectives of study:
The aims and objectives of the present study is classified in to two parts i.e. Geoinformatics study of the state and socioeconomic study of the people in a small tourist valley, Gnathang, as follows:

- ✓ To inherit knowledge about the physical landscape and land use using GIS and RS methodology about the Geo-bio-hydrology of the Sikkim valley.
- ✓ To analysis the socioeconomic occupational structure, demography pattern, sex, cast, education and, age-sex structure in the Gnathang valley.
- ✓ To obtain an idea and to find out the problems, as well as to suggest remedial measure for the purpose assisting the people in the planning process of the study area.

Methodology:
To access the geography, geomorphology, fluviology, lithology and glaciology of an area is easy, timesaving and accurate with high-resolution data use. The geographical information system (GIS) and remote sensing (RS) methodology for knowing steep, difficult and inaccessible terrain, the popular method used in India are the integration of (GIS/RS) analysis, supplemented by limited ground-trothing through Unmanned Aerial Vehicles (UAVs or drones) and field surveys, [21], [22]. The GIS/RS methodology used are:

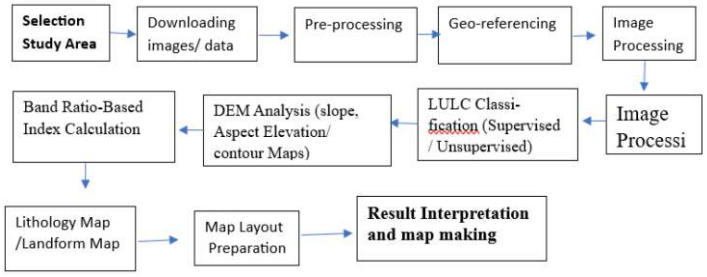


Fig 2(a): (a) the flow chart for studying of the physical features of Sikkim Himalayas,

Field survey is the most important part in the geography. Geography is not perfectly complete without field survey. In this course without field survey the geographical knowledge become incomplete. It is Very important as it helps to gather required information so as the problems under investigation is studied in depth as per the predefined objectives. It develops an understanding and sensitivity about the culture and people of Field area.

FLOWCHART OF A FIELD STUDY:

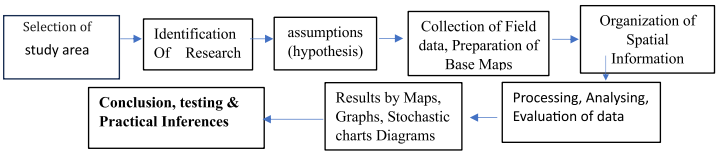


Fig 2(b): Flow chart for field survey work of the Gnathang Valley Sikkim

Present study is a combined process of both GIS/RS methodology to know about terrain features and field socioeconomic survey of Gnathang valley, Fig 2 (a) and Fig 2 (b)

Physiography study area
Sikkim state in India is housed in North Eastern Himalayas (NEH) comprises of the Northern Mountains. The state lies in the mid-Himalayan mountains is hilly. The hilly region has elevational range lies between 300m to 7000m. The major portion of the state towards the Northwest housed in foothills of the famous third-highest peak in the world, the Kanchenjunga (8598 meters). About nearly 67% of its hilly expanses are dense mountains permanently snow-covered, comprises of glaciers like Zemu, Talung, and Lhonak etc.

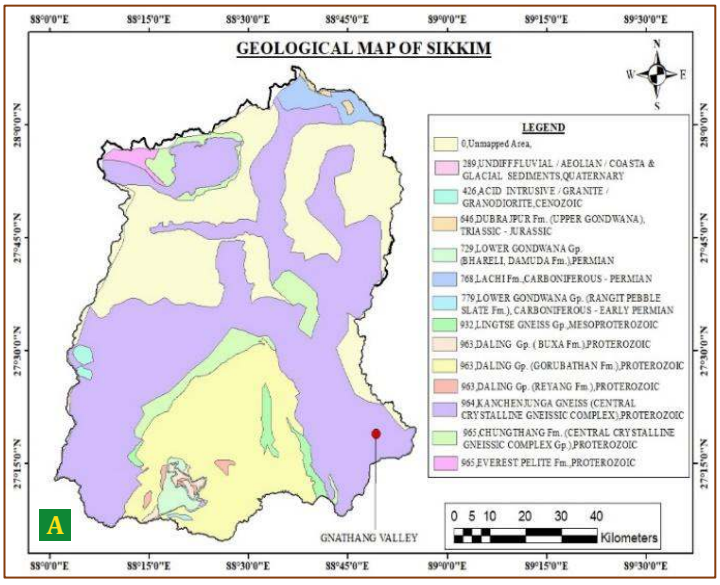
Glaciers: The glaciers a storehouse for water and it is studied by many researchers that the climate change impacts are significantly reflected by reduction in the glacier area. The glaciers in Himalayas are showing a declining trend proceeding mostly from the NW to E. The glaciers in Eastern Sikkim hav retreated from 63.9m/yr to 3.9 m yr−1 and the reduced area is of ~2.53% (0.08% yr−1) in the stydy zone, [23],[24],[25].

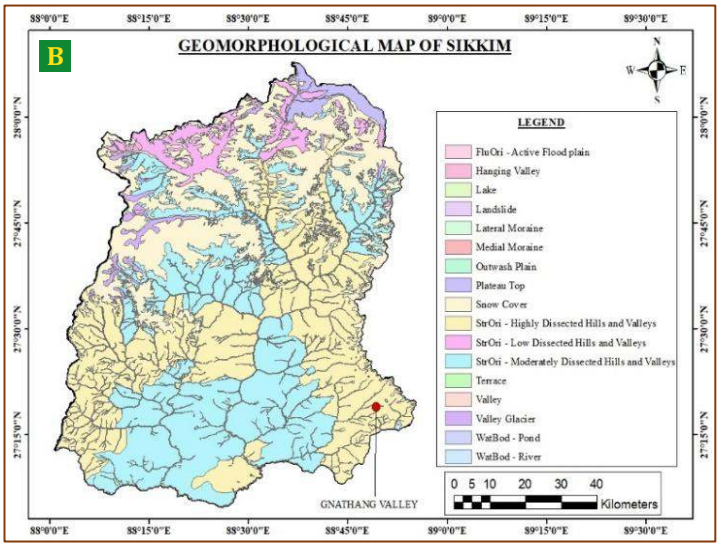
Geographical Features Sikkim:
The state Sikkim is positioned in the Eastern Himalayas. The Darjeeling-Sikkim is overlain by pre-Cambrian metapelites, Darjeeling and Daling group. The Sikkim is disconnected by the Singalila range from Nepal (in West) in the west, Tibet (in northeast) and Bhutan in the southeast. The Sikkim-Darjeeling is housed in Main Central thrust and formed by inverted metamorphism [16]. The ironic biodiversity of Sikkim involves the alpine meadows, rhododendrons, orchids, Bysons, fishes, birds and butterflies, The lower altitudes in sub-tropical are bounty orchid varieties, cardamom, orchards and terraced rice fields. The mountainous state Sikkim, encompasses the lesser, Central, and the Tethys Himalaya.

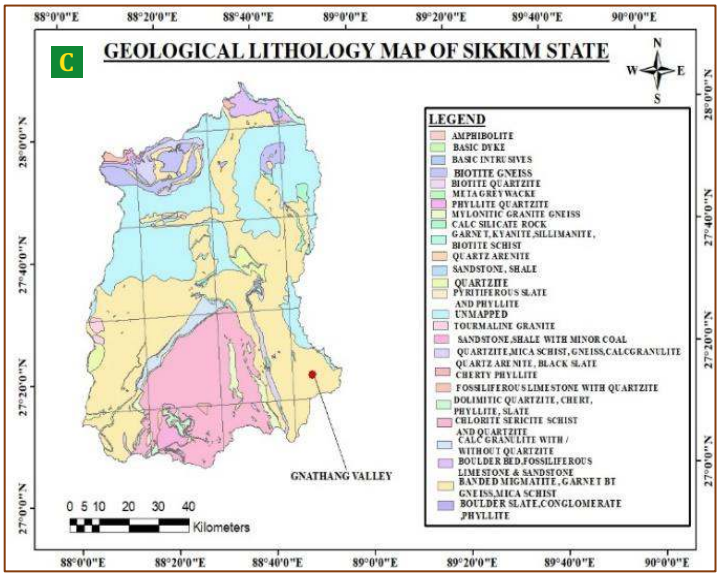
In lesser Himalayas, the state possesses many of flat flood plains land in southern Sikkim. The north Sikkim has steep escarpments, and so has lean population.

Flora and fauna: All over Sikkim Forest and snow-covered areas the Snow- Leopard, Ghoral, Thar, Yaks, wild Ass, Red Panda, Bharal or Blue Sheep, Shapiare are dwelling. The Sikkim's pride, the the Red Panda is endangered as per International Union for conservation of nature (IUCN). The famous Kanchenjunga National Park (KNP), The Singba Rhododendron Sanctuary (North), the Maenam Wildlife Sanctuary (south) and the Fambong Lho Wildlife Sanctuary house the species like Himalayan black bear, red panda, blood pheasant, civet cat and many species of animals, birds (black eagle) and butterflies. Other sanctuaries such as Rabongla (South Sikkim), Yumthang (North Sikkim), the Keyongsla Alpine Sanctuary, and the Barsey Rhododendron Sanctuary (West Sikkim) houses many beautiful flowers, claiming Sikkim have its unique biodiversity.

Geology of Sikkim: East district has identical geological features to the Eastern Himalayas comprising of five geological units and are identical to Kanchenjunga gneiss, Darjeeling gneiss, Chungthang schists and gneiss, lingtse granite gneiss and daling group of rocks, and the rock strata are consisting of Phyllite, Quartzites, Slates, and Schist of Pre-Cambrian age.







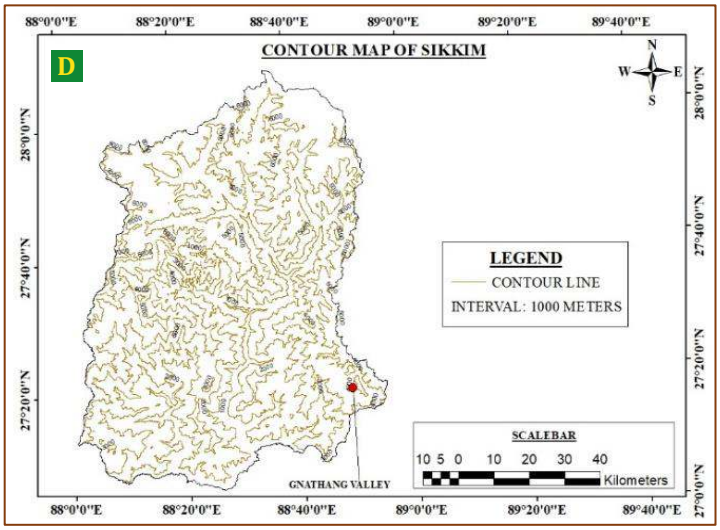


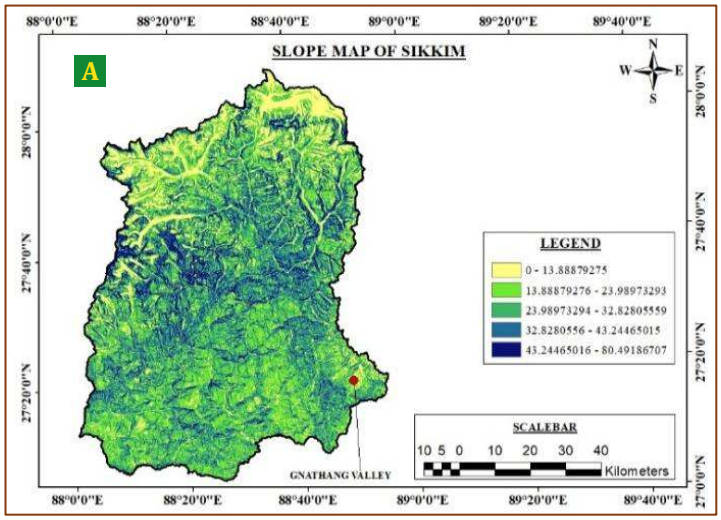
Fig 3: (a) The geological map (b) the geomorphological map (c) the lithological map and (d.) The contour map of the Sikkim state

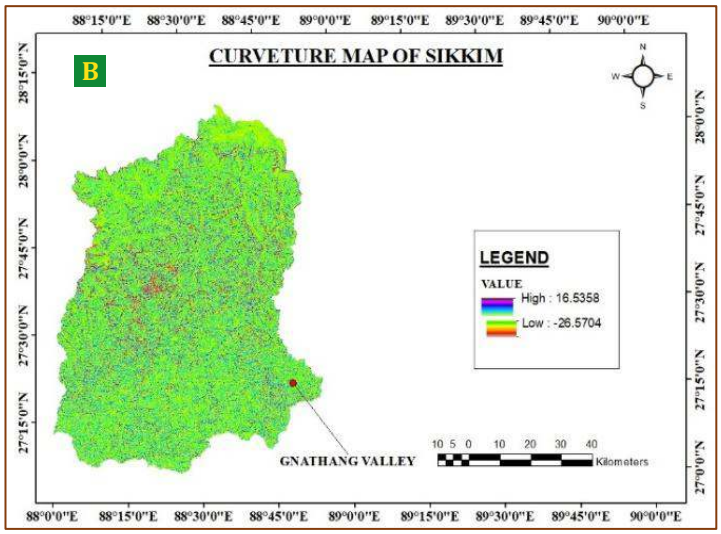
The river flood plains are Quaternary old alluvial deposits developed in the flood plains of the drains and rivers. Various structural disturbances like fractures, faults, joints, folds etc. are reported in the rocks. The lineaments exhibit geological formations and their trend are from different directions.

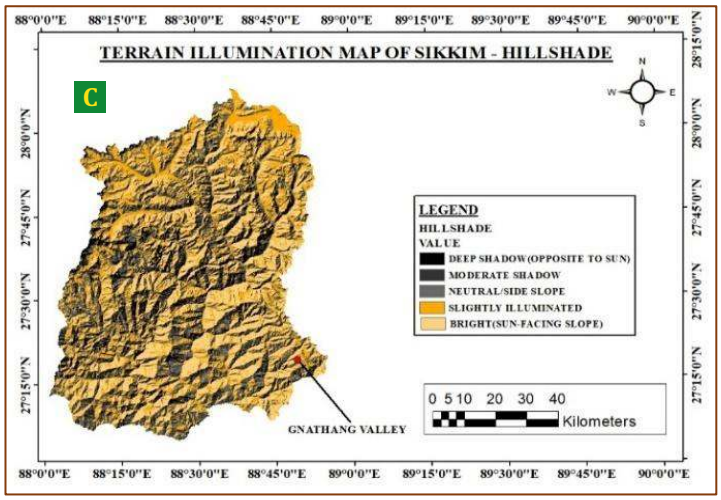
Forest in east zone: The east zone of Sikkim has total geographical area 964Km^{2}out of which the forest cover is 71.17%. Out of which the very dense category is 162 Km^2, 396 km^2 is occupied by the dense and rest 121 km^2 is open forest. The physiographic units are hills, valleys and sloppy mountains.

Lithology of Sikkim: Sikkim, the north-eastern part of India, has four districts, i.e. east, west, north and south. It is the eastward extension of the Nepal Himalayas with fold, thrusts and complex tectono-stratigraphic sequences. The northern, western and eastern zones of it have hard massive gneiss. The central and southern zone are made up of soft, schistose and thin slate rocks extending different depths (30-150m). Phyllites and schists cause landslides and erosion. The soils are coarse having reduced organic mineral content [26].

Topographical studies: The physiographical studies of the area and the topographical studies of the area like slope, curvature, Aspect and DEM maps, are made and their elevational characteristics are analyzed, Fig 4 (a-d)







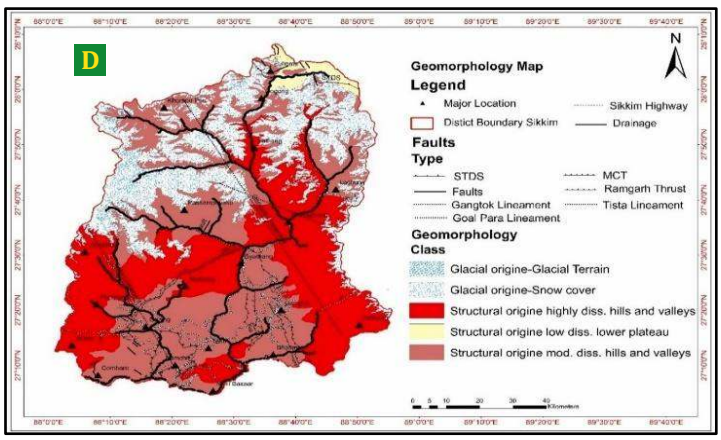
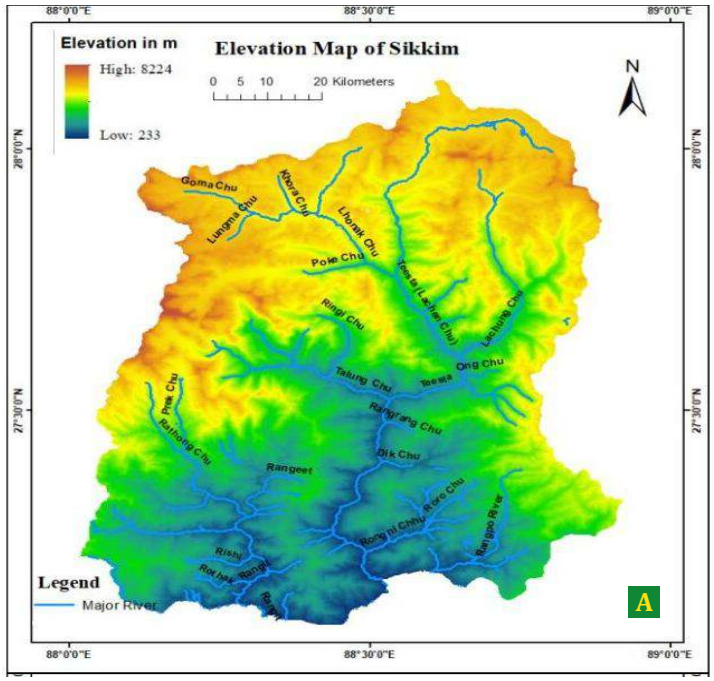
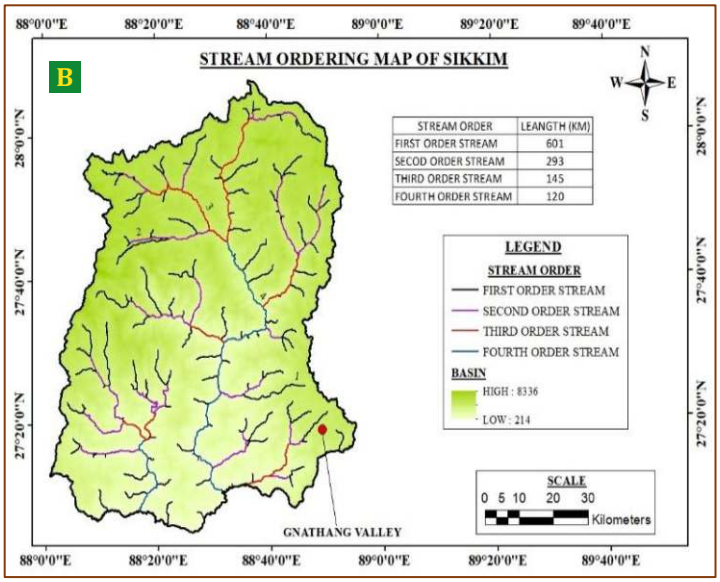


Fig 4 (a-d): The slope map (b) The curvature map (c) The Hillshade map (d) The Geomorphologic fault type and classification of sikkim

The river system: The Teesta (Flowing N-S), the Rangeeta (Rangpo Chhu and Dik Chhu in Gangtok dist.). are the lifeline rivers of the Sikkim state. The River Teesta originates from the Zemu Glacier (above the Lachen Monastery) and its major tributaries are the Goma Chhu (river) from north and Lachen Chhu joins at Chung Thang. The other tributaries of the Teesta are the Longbo Chhu, the Lachung Chhu, the Poke Chhu, the Rangphap Chhu, the Umran Chhu, the Dik Chhu, and the Rongpo Chhu. The River Rangeet emanates from Rathong Glacier and flows north to south initially and later from west to east. The major tributaries of the Rangeet are the Kayam Chhu, the Rongdung chhu, The Relli chhu, the Rathong chhu Kalej khola, the Rishi Khola, and the Ramam khola. The river Rangeet. The river Rangeet joins the River Rangeet at Triveni between Teesta Bazar and Melli Bazar.





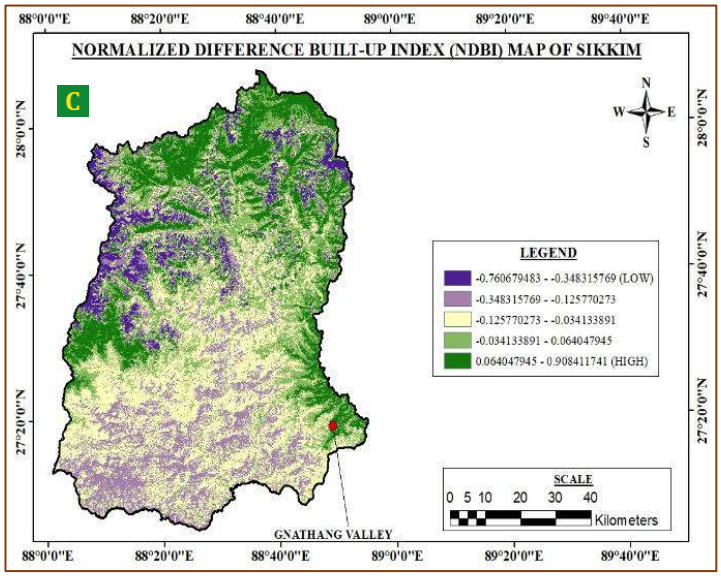


Fig 5(a-d): (a) The major river map, (b) The stream order map (c) The NDBI map (d) The NDMI map, ***(Source modified: 10.26668/businessreview/2023.v8i3.1086)***

Climate Change Impacts

As per IPCC AR-6 the eastern Himalayas is exposed to climate change (CC), undergoing fast warming than the globe. The impacts are glacier retreat, changed precipitation, and increased extreme rainfall events (ERE) (≈76events/yr). Alteration in snow fabric poses high vulnerability due to fragile and dependence on glacial meltwater**,** leading to risks for water balance, ecosystems fragility, and stake holder's diverse livelihoods. Stronger governance is obligatory to augment resilience for the vulnerable group. The livelihood modification, value-added water management, capacity building and climate-resilient agriculture are the key solution to the strategies. Disaster Preparedness, water resources management, sustainable infrastructure and proper management of disasters are basic sustainability the state needs under exacerbated by CC conditions (Panda et al, 2020, Mishra et al., 2023).

The Teesta River basin covers the state and is the largest river system, and its basin is up to the 5th order. The drainage pattern is dendritic, following the characteristic of a region with uniform lithology. The physiographic features, flood risk assessment, GLOF and understanding how surface features influence runoff and the landslide. The NDBI values are normally low in Sikkim due to extensive forest cover. The NDMI values are typically high due to significant moisture content, and high vegetative cover and all in high-altitude, snow-covered areas, indicating.

Sikkim is prone to and a hub for disasters, particularly landslides along the cut slope of the NH, SH and other hilly roads. It is due to erratic monsoon, extreme rainfall events, Earthquake, Glacial Lake outburst Floods (GLOFs), Ice and debris avalanches, Floods/Flashfloods, climate change effects, and anthropogenic activities like dams, urbanisation, etc.

Socioeconomic status of the Sikkim state:

Sikkim's has an environment of fragile mountain ecosystems that needs to be studied because it has profound climate change impacts. The state possesses typical and unique biodiversity, and it is a real-world that is famous for organic farming, no taxes and sustainable policies. The environment, biodiversity and ecosystem fabric is presently under jeopardy and deteriorating due to global warming and the climate change impact. Climate change impacts are prominent in Sikkim as springs are drying, river flows are altered. The geographical signatures are receding glaciers, warm climate, depleted snowfall, erratic SW monsoon, Himalayan weather and upward migration of the species. Flash flood, Land slide and the glacial lake outburst floods are the common disasters. Sikkim's glaciers, lakes, and forests are water reservoirs and the flash floods, cold waves and Landslides etc., [15]

About 72% of the state households are dependent on agriculture with small land holdings (average ≈0.62Ha). As per NABARD's Report 2023-24, the state has 129.006thousand households in Sikkim, 93.288Th are rural households comprising 79% small and marginal farmers in the Sikkim state owning only 39% of agricultural land. The allied farm activities of these people are dairy, piggery, etc. The economics of Sikkim based on tourism, 100% organic farming, retail trade, Govt. services, pharma units, private enterprises, etc. Under these conditions, the farmer producer organisations (FPOs) are an effective solution for enrichment of the income of farmers, through collective produce that enhance the supply and value chain of those respective commodities. The climate change impacts have raised challenges to agriculture that needs to be addressed. Priority corners need to be identified and stressed upon the climatologically harsh state [16].

Socioeconomic Survey of Gnathang Valley:

Natural Setting of the Study Area

The Himalayas being the highest range in the world produces diversity and diversified social and cultural groups in these different parts for example from Sherpa in Nepal to Lamas in Tibet from Gorkha in Sikkim –Darjeeling to Garhwali in Uttarakhand, from south to north Himalayas can be classified in four parts – the Outer Himalayas or the Siwalik Range, Middle Himalaya, Grater Himalaya and Trance Himalaya or Tethys Himalaya. Siwalik is absent in Sikkim, Darjeeling Himalayas where the gradient is quite steep. It leads to deep more struggles on the local people for their sustenance. But contradictorily this slope favours the production of highest quality tea and orange such physical harshness and rich resource set and unique identity to this region. East Sikkim is full of natural serenity and high range mountains. This region is close to India-China border around Nathula-Zuluk region. The Doklam plateau is also very close to this region which is just 35 km from this village and can be seen from a view-point.

Study Area at a Glance:

The study area has been chosen to get an idea about the village life of very cold high altitudinal Himalayan landscape along the India-China border. How far the people of highly difficult environmental situation previous natural resources to the people are one of the major objectives of this study. The study is conducted almost 570 km away from the college just to view the non-environmental relation in the lap of Himalayas. Now to describe the study area. It can be said that it is a challenging environment to live and people has to straggle always as for their sustenance. Almost few months remain highly chilling conditions with snow fall and the rest few months is left for work. The economy is mostly depended on the production of "Tea" and "Tourism" in Darjeeling. Therefore, few months where tourist arrival is less the people of this locality does not have much work to do and their income also gets minimized. For this present study area Gnathang Valley near Upper Pelling of North Bengal has been selected (Table 2).

Table-2: The salient features of the Study Area, Gnathang valley at a Glance

Name of the Mouza/Village	Gnathang Valley
Latitudinal Extension	27°18'01" N to 27°17'46" N
Longitudinal Extension	88°48'54" E to 88°49'12" E
Country, state, district, Village, Locality	India. (Sikkim, Pakyong, Gnathang Valley, In between Old Baba Mandir and Zuluk (70 km. from Gangtok)
Area	486 Hectares
Population	350 persons
Assembly constituency	Gnathang–Machong Assembly constituency
Drainage	Tributary of Rangpo River (Third largest river of Sikkim)
Main Occupation	Border Road Construction and Tourism
Educational Status	Low
Main Source of Drinking Water	Natural Spring

Location of the Study Area:

Geographically, Gnathang Valley is located in the eastern part of Sikkim along the Indo-China border in between Old Harabhajan Baba Mandir and Zuluk. It is a small high-altitude village in close proximity to famous Kupup Lake and Zuluk village. The village is located in a strategic location along the famous Silk Route. The region is also a source of a tributary of Rangpo River (i.e. tributary of Teesta River). Gangtok is the nearest town, which is 70 km away from here. Road transport is the only mode of transport except for helicopter service for defence personnel. The location of study area can be described with in two ways - The village is extended in between 27°18'01" N to 27°17'46" N & 88°48'54" E to 88°49'12" E.

History of Gnathang valley

Gnathang valley has a temple and a small Monastery in the valley, which has a memorable past history related to the British-Tibet invasion. In 1888, the Britishers army intended to remove Tibetans from Sikkim.

On 21 May 1888, there was an encounter between Tibetans and British Defences at Gnathang Valley. The fight lasted for 03 hours, Tibetans withdrew. As a memory, the memorial park of the British warriors is there at Gnathang valley. Gnathang valley is so-called as Ladakh of East Sikkim.

Geology Nathan Valley:

The Himalaya is geologically a complex mountain system. East district of Sikkim is a part of the Eastern Himalayas and exhibits identical geological features as in other parts of the Eastern Himalayas. Five geological units encountered in the district are Kanchenjunga gneiss, Darjeeling gneiss, Chungthang schists and gneiss, Lingtse granite gneiss and daling group of rocks consisting of Phyllite, Slates, Quartzites and Schist of Pre-Cambrian age. Quaternary deposits of alluvium are sporadically developed along the streams and rivers.

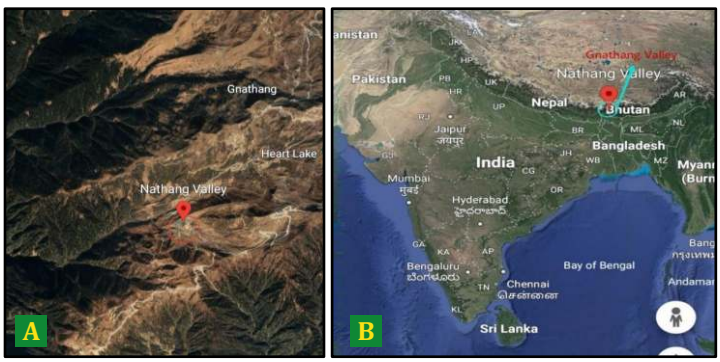


Fig 6 (a to b): The study area map of Gnathang Valley in Sikkim, India

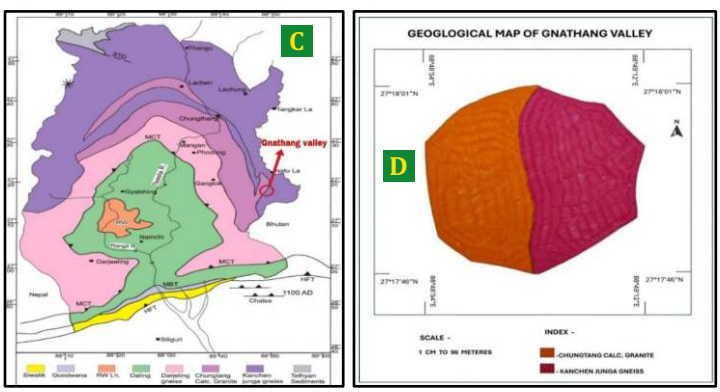


Fig 6 (C and D): The geological map of the Sikkim and the Gnathang valley

Physical Setting

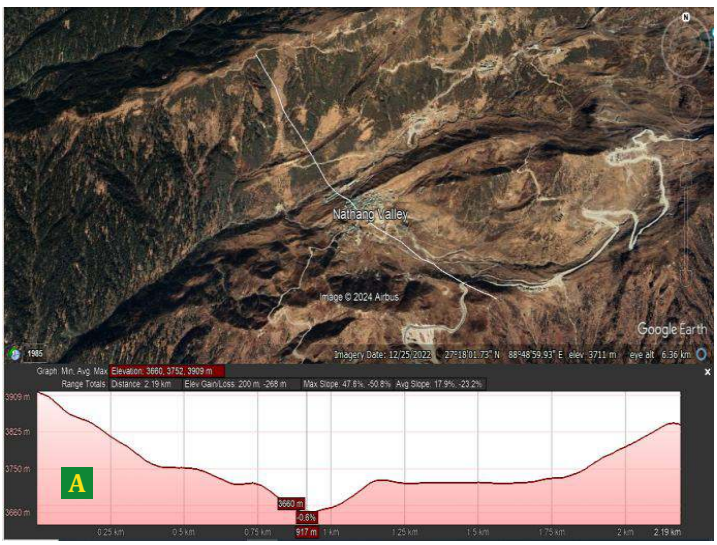
Due to different sets of structural disturbance, numerous fractures, faults, joints, folds etc. have developed in the rocks occurring in the district. Prominent lineaments as displayed by geological formation in the area trend along N-S, E-W, NE-SW, ENE-WSW and NW-SE directions.

Table-3: Geology of Sikkim-Darjeeling Region url: https://doi.org/10.1016/j.qsa.2023.100144)

Group	Subgroup/formation	Lithology	Age
Gondwana	Damuda Formation	Sandstone, coal & Carbonaceous shale	Permian
	Lingste Granite Genesis	Sheared Granite genesis (Mylonite) rich biotite	Meso- Protozoic
Daling group	Gorubathan formation	Schist /phyllite quartzite, Meta-greywacke, Pyrite ferrous black state, mica schist with garnet etc.	Proterozoic un- differentiated

Physiography:

Physiographically, the region is located in high altitude Himalayan region of Sikkim. There are highly complex with an innumerable variety of micro and macro relief forms present. It is a plateau type region near to Doklam Plateau of Indo-China Border. The average elevation ranges in between 3600 meters to 4000 meters (13000 ft. above MSL). The study area is a valley which is 300 meters trough region. The region can be divided into two zones – High hills and Valley region (middle hills).



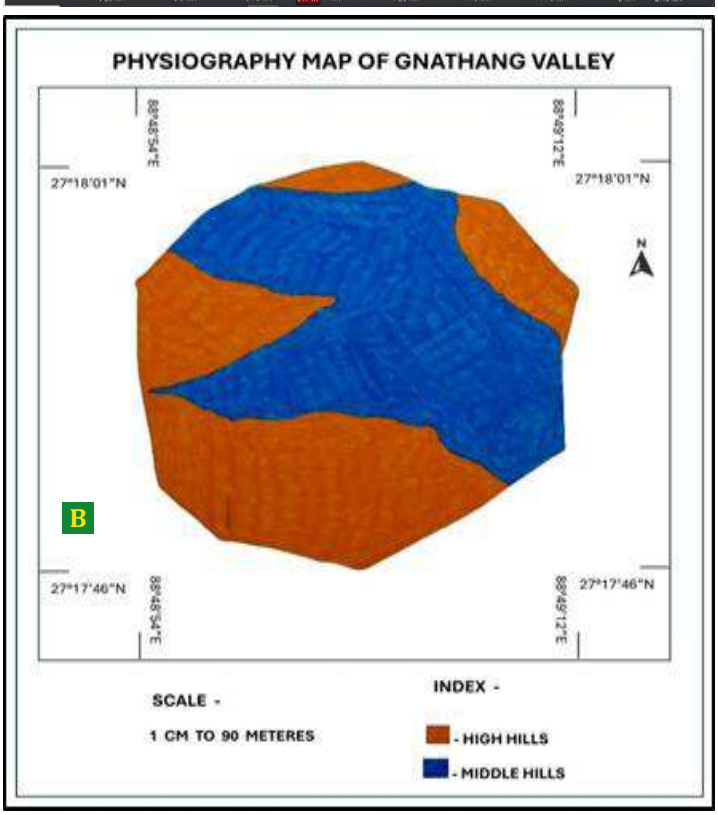
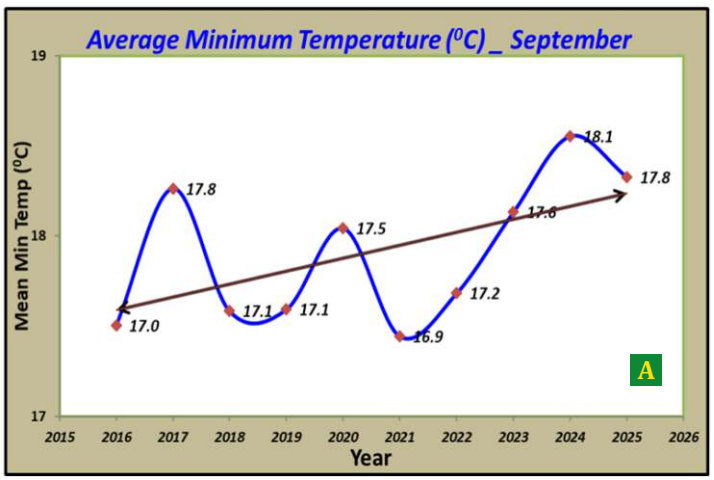


Fig 7 (C and D): Elevation Profile and physiography of Gnathang Valley (Source: Google Earth),
The valley is ≈300m d/s from its close peaks;
Source modified -https://doi.org/10.1016/j.qsa.2021.100039

The Climate of the area:

The players of climate of a place depends upon the meteorological parameters like precipitation, temperature, humidity, and sunshine and wind velocity. The climate comprises of mountainous tropical, temperate, and alpine settings, and in proximity to the BoB make it the most humid in the Himalayan region. The Himalayan range is dependent mostly on Indian summer monsoon, El-Nino southerly Oscillation (ENSO), Positioning of ITCZ, Westerly Disturbances and the Bay of Bengal (BoB) disturbances.



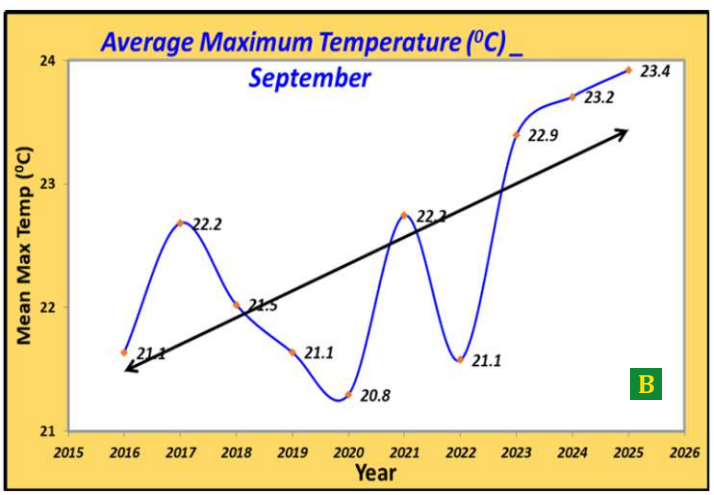


Fig 8 (a and b): The average minimum and the maximum temperature in 0C of Sikkim. (Source: https://mausam.imd.gov.in/gangtok/mcdata/monthly_wx_report.pdf

The temperature ranges between 14.9°°Con as average temperature, during summer in between 10°°C - 21°°C and during winter it is in between -7°c to 6°C. Four climatic seasons can be recognized within the region (i) pre monsoon season, (ii) monsoon season, (iii) post monsoon season, (iv) winter season. Spring and summer cannot be much differentiated.

The whole region consists of a tangled series of interlacing ridges, rising range of high peaks and which seems as the abode of snow. This configuration coupled with the altitude brings about sharp changes in the rainfall of the region. The recorded rainfall and temperature are provided below in Fig. 8 (a to C).

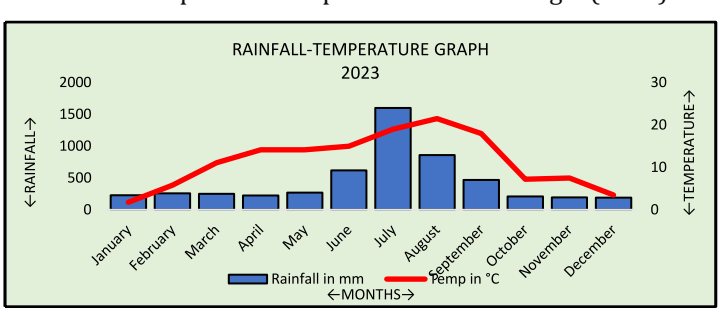


Fig 8 (C): The monthly Rainfall-Temperature Graph of Gnathang Valley, 2023
Source: www.google.com

Soil Conditions:
The soil of the upland of Gnathang valley is usually red and gritty while that of the plains are dark and more fertile. Along the banks of the Teesta, silt or silt loam predominates. Red and yellow soils are developed on the gneisses and schist formations in the higher slopes of the Sikkim Himalaya. The greater portion of the hill area lies on the Darjeeling gneiss, which most commonly decomposes into a stiff reddish loam but may also produce almost pure sand or stiff red clay. The colour of the red soil is derived from weathering of gneisses and schist due to wide diffusion rather than to high proportion of iron content in the rocks. This type of soil is mainly siliceous and aluminous with free quartz as sand. It is usually poor in lime, magnesia, iron oxide, phosphorus and nitrogen, but fairly rich in potash, some areas being quite rich in potassium derived from the muscovite and feldspar of the gneiss. River alluvium is found in the southernmost part of the district.

Renewable energy: Sikkim houses many hot springs, at Yumthang, Reshi, Ralang, Borong, and Yumesamdong which can be harnessed to generate geothermal power a source for non-renewable energy instead of thermal or hydropower. The state should give importance to the geothermal exploitation of energy.

Ethnobotany status of the Sikkim state
The Sikkim state in Eastern Himalayas is rich in alpine and subalpine plants in deciduous forests (300 to 900m), Sub-tropical forests of broad leaves (900-1800m), Himalayan wet temperate forests (100-3000m), Sub-alpine forests (300-3700m) and Alpine Forest (>3700m). These plants are used by local people for medicine, food, fodder, fuel and cultural needs. The primary inhabitants of the area such as Bhutia, Lepcha, and Nepali have profound knowledge of use of these ethnobotanical plants for ab-initio health care and primary daily use. These botanical species are becoming rare and migrating to higher elevations as markers of CC and human exploitation of nature. In Sikkim (including Gnathang), the fruits, flowers, barks, leaves, seeds, roots, etc. of the flora and the various parts and their extracts of the species are used as edible plants, ethnobotany, ethnomedicine and have necessities in various cultural and religious activities of the local communities [29],[30].

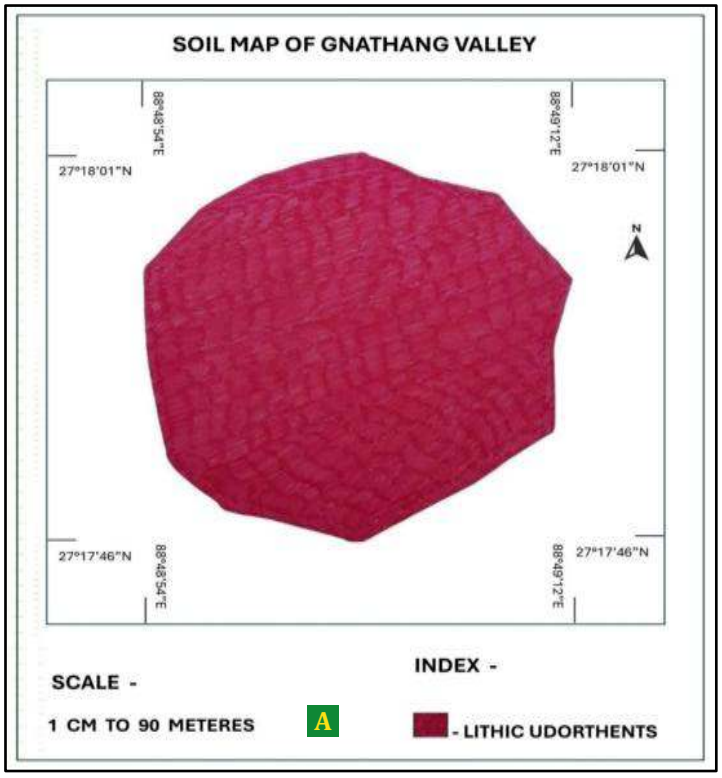
Table 3: The various ethnobotanical and medicinal species in Sikkim used for various purposes

Plant	Botanical name	Habitat	Parts used	Various uses
Lalgedi	Abrus precatorius L.	climber	Fruits, leaves, roots	sore throat, Tonsil, skin disease, pneumonia, cough, cold, abortion, urinary disorders
Bikhma	Aconitum ferox Wall.ex Ser.	Herb	Rhizomes (rigorous purification)	Asthma, cough, stomach ache diabetes, rheumatism, snake bite, toothache and blood clots
Bojho	Acorus calamus	Herb	Roots/ rhizomes	Epilepsy, Digestive, memory dis-orders, diarrhoea and flatulent colic
Banlasun	Allium wallichi Kunth	Herb	Bulbs	Cholera, dysentery, cold and Cough, reduce height sickness.
Latikaram	Hymenodictyon sp.	Tree	bark	Bark used for fever, tumours, and Hemorrhoids (Piles)
Gobre Sallaa; or Silverfir	Abies densa	tree	Leave, Strong decoction	Diuretic, Stomach & tooth ach, Menstrual Health
Jungli-istaber (Hindi),Aakhe	Fragaria nubicola	Plant	Leaves and fruits	cattle to treat diarrhoea, relief from external parasites
Sunpati	Rhododendron anthopogon D Don	shurb	Twigs,Flowers and Leaves	Indigestion, vomiting, stomach ache; lung disorders,dysentery.
Bhairungpate	Rhododendron Setosum D.Don	shrub	Leaves, stems and flowers	Young buds/leaves in wounds.
Tuwa (Nepal)	Arisaema costatum	Dried tree	Roots after neutralisation. (Not raw)	Gastric, fever, stomach problems, toothaches, skin diseases lung infections, cough, &lung issues

Source: *[31]; [32], [33], [34]*

Fig 8 (a-g): Physiography of various landscape Gnathang Valley, and water harvesting sources

Drainage:
Major rivers in the East district are the Tista and Rangit. Teesta can be called as Ganga of the state as accommodates major settlements on the banks of this river. The Teesta emerges from the Zemu glacier above Lachen Gompa. The Lhonk stream from the north joins it. Another stream Lachung rises from Pauhunri and meets the Teesta at Chumthang. The minor rivers in the district are Rani Khola, Busuk Khola, Rishi Khola and Ratey Chu.



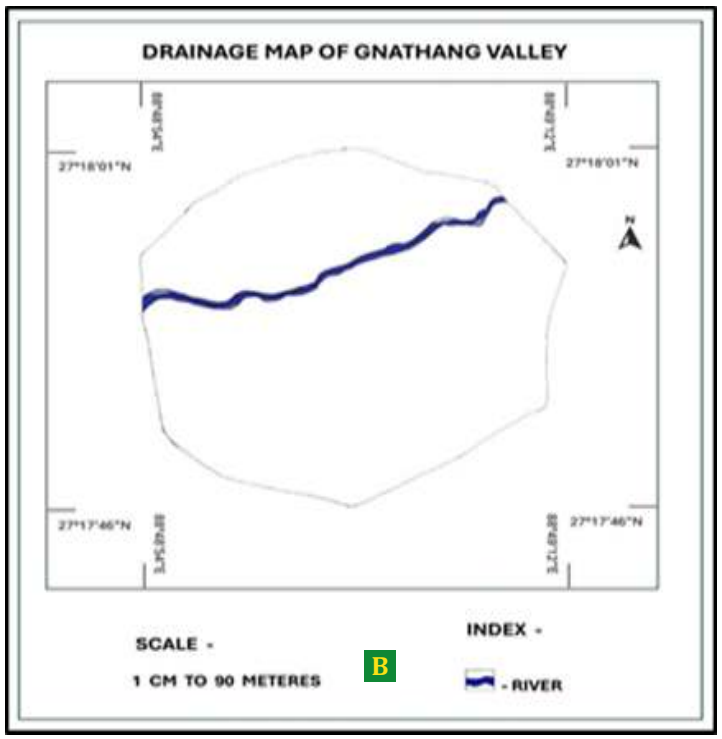


Fig 10: (a) The soil map of Gnathang Valley (b) The drainage map of Gnathang valley, Sikkim

The study area is drained by a tributary of Rangpo River (third largest river of Sikkim) in the eastern Sikkim Himalayas. These rivers are perennial in nature where the major source of water is surrounding glaciers.

Socioeconomic study (Gnathang Valley)

A door-to-door survey is made through knowledge about house hold condition of the people living there. Through this survey, information like the educational qualification of the people, age-sex structure, caste structure, income level, housing condition, living standard of the people etc. has been conducted. The following methodology has been adopted for the present survey in pre field session, field session and past field session.

The survey comprised of Pre-Field-Session, Field-Session Post Field-Session. The results are given below.

Demography

a. Sex Composition: Sex Composition of the human population is one of the basic demographic characteristics, which is vital for meaningful demographic analysis. Fig 12 (a)

b. Age-Sex Composition: Population condition can best understood through the status of Age-Sex composition. The number of People exists in different age group actually indicates the demographic structure of the region. Age sex compositions of population are important in planning for economic and social service provision, fig 12 (b).

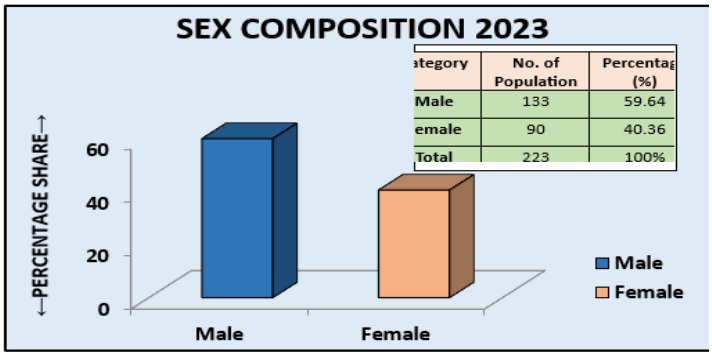


Fig 12 (a): The statistics of Sex composition in Gnathang village

In this Gnathang Valley of Sikkim household sample have been taken. According to this sample, the no. of male population is 133 (59.64%) and the female population is 90 (40.36%).

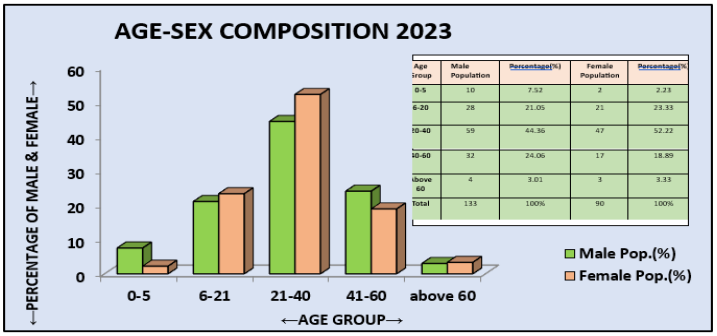
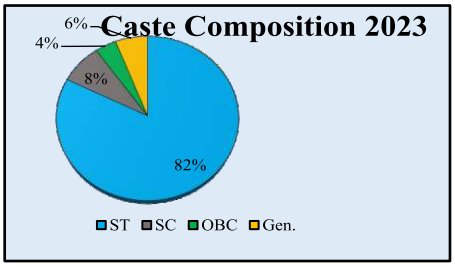


Fig 12 (b): Statistics of Human population as per survey data in the year 2023

samples have been taken. Based on those samples having most of the people exists in 20 to 40 age group. Where as in 0-5 age group has the lowest population (2.23%) exists Fig 12 (b).

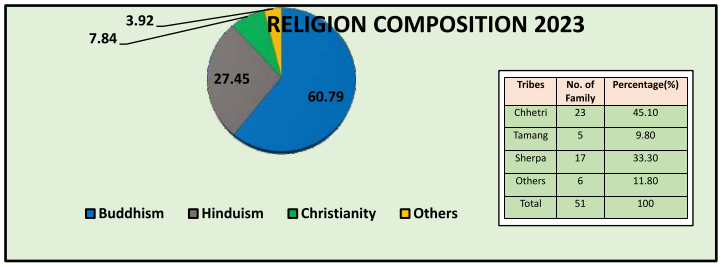
Caste Composition:



Caste	No. of Family	(%)
General	42	82.36
SC	4	7.84
OBC	2	3.92
ST	3	5.88
Total	51	100

Fig 12 (C): The Cast composition in Gnathang valley in Sikkim Field study.

Caste is a form of social stratification. As per the door-to-door survey, General caste constitutes 82.36 %, Scheduled caste (SC) are 7.84 %, Other Backward caste (OBC) are 3.92 % and Scheduled Tribes constitutes 5.88 % of total population in Gnathang Valley of Sikkim, Fig 12 (d).



Tribes	No. of Family	Percentage(%)
Chhetri	23	45.10
Tamang	5	9.80
Sherpa	17	33.30
Others	6	11.80
Total	51	100

Fig 12 (d): Statistics of the religion Composition: In the Gnathang Valley of Sikkim

Tribal composition: In Gnathang Valley there are 45.10 % family are Chhetri tribe , 9.80 % are Tamang tribe, 33.30 % are Sherpa and 11.80 % are others tribes Fig 12 (e).

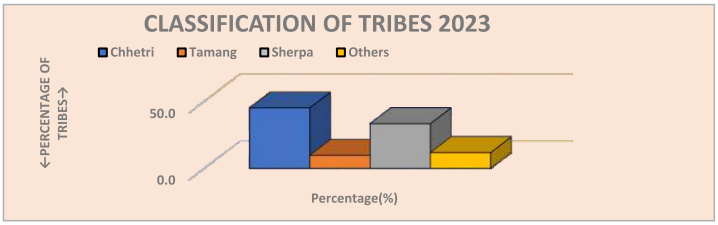
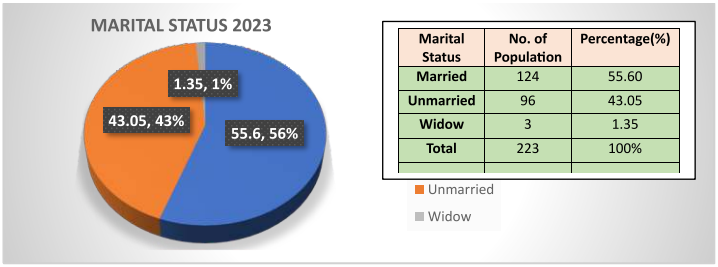
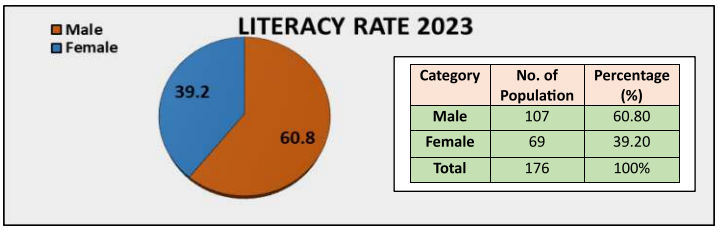


Fig 12 (e): The classification of the various tribal status in the Gnathang Valley, 2023 survey



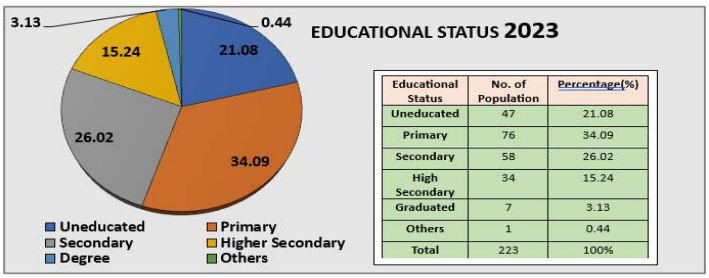
Marital Status	No. of Population	Percentage(%)
Married	124	55.60
Unmarried	96	43.05
Widow	3	1.35
Total	223	100%

Fig 12 (f): The marital status of the inhabitants of the Gnathang Valley in 2023 Sikkim, India



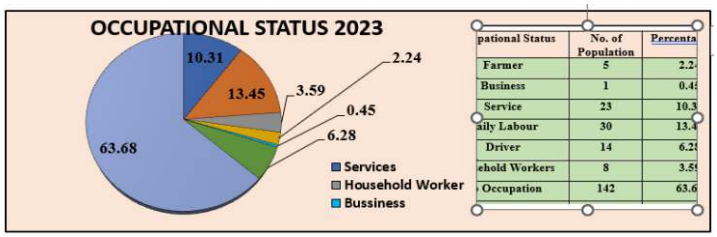
Category	No. of Population	Percentage (%)
Male	107	60.80
Female	69	39.20
Total	176	100%

Fig 12 (g): The literacy status of the inhabitants of the Gnathang Valley in 2023 Sikkim, India



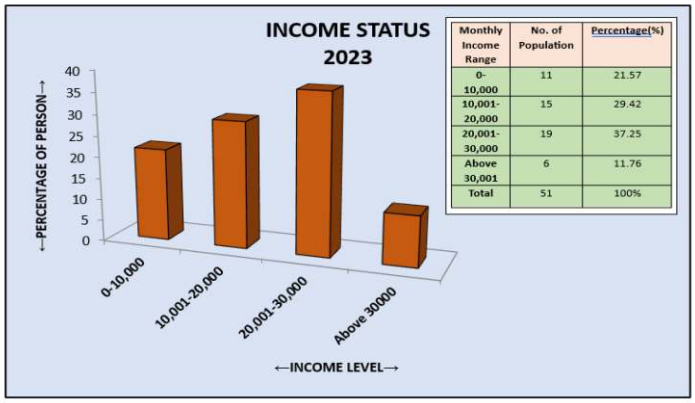
Educational Status	No. of Population	Percentage(%)
Uneducated	47	21.08
Primary	76	34.09
Secondary	58	26.02
High Secondary	34	15.24
Graduated	7	3.13
Others	1	0.44
Total	223	100%

Fig 12 (h): The educational status of the inhabitants of the Gnathang Valley in 2023 Sikkim,



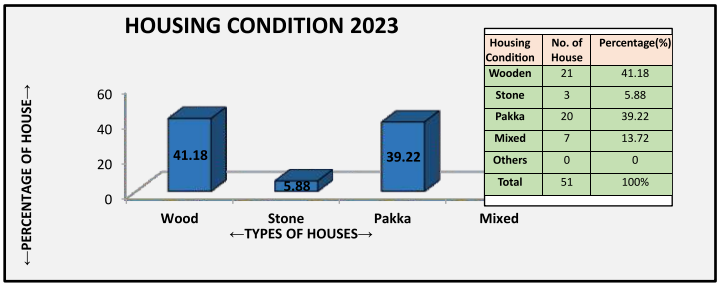
pational Status	No. of Population	Percenta
Farmer	5	2.2
Business	1	0.4
Service	23	10.3
ily Labour	30	13.4
Driver	14	6.2
ehold Workers	8	3.5
Occupation	142	63.6

Fig 12 (i): The Occupational status of the inhabitants of the Gnathang Valley in 2023 Sikkim



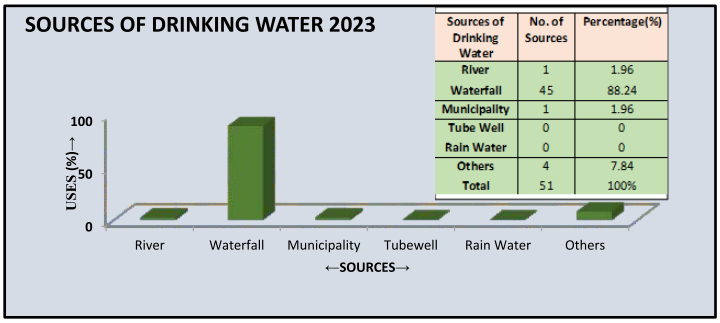
Monthly Income Range	No. of Population	Percentage(%)
0-10,000	11	21.57
10,001-20,000	15	29.42
20,001-30,000	19	37.25
Above 30,001	6	11.76
Total	51	100%

Fig 12 (j): The income status of the inhabitants of the Gnathang Valley in 2023 Sikkim



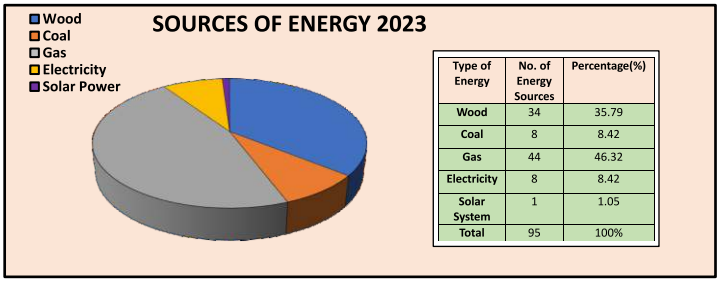
Housing Condition	No. of House	Percentage(%)
Wooden	21	41.18
Stone	3	5.88
Pakka	20	39.22
Mixed	7	13.72
Others	0	0
Total	51	100%

Fig 12 (k): The housing status of the inhabitants of the Gnathang Valley in 2023 Sikkim



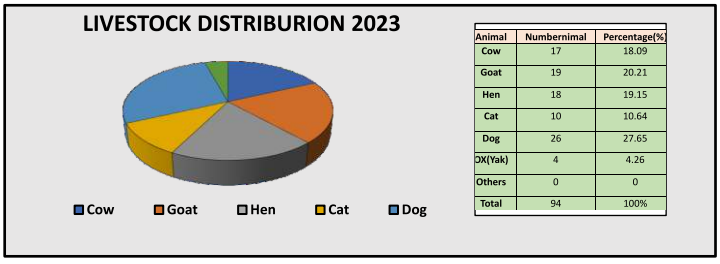
Sources of Drinking Water	No. of Sources	Percentage(%)
River	1	1.96
Waterfall	45	88.24
Municipality	1	1.96
Tube Well	0	0
Rain Water	0	0
Others	4	7.84
Total	51	100%

Fig 12 (l): The drinking water status of the inhabitants of the Gnathang Valley, Sikkim in 2023



Type of Energy	No. of Energy Sources	Percentage(%)
Wood	34	35.79
Coal	8	8.42
Gas	44	46.32
Electricity	8	8.42
Solar System	1	1.05
Total	95	100%

Fig 12 (m): The distance of drinking water source of the people of the Gnathang Valley in 2023



Animal	Numbernimal	Percentage(%)
Cow	17	18.09
Goat	19	20.21
Hen	18	19.15
Cat	10	10.64
Dog	26	27.65
OX(Yak)	4	4.26
Others	0	0
Total	94	100%

Fig 12 (n): The livestock status of the inhabitants of the Gnathan Valley in 2023 Sikkim

In this Gnathang Valley of Sikkim Program household samples have been taken. Based on those sample having most of people exists in 20 to 40 age group. Where as in 0-5 age group has the lowest population (2.23%) exists, Fig 12 (f).

Religious Composition:
Religion in India is characterised by a diversity of religious beliefs. India is a secular state with no state religion. There are four types of religion in Gnathang Valley, they are – Buddhist, Hindu & Christion . In Gnathang Valley 60.79 % of the population is Buddhist and 27.45 % of the population is Hindu and 3.92 % of the population is Christion Fig 12 (g).

Caste Composition:
Caste is a form of social stratification. As per the door-to-door survey, General caste constitutes 82.36 %, Scheduled caste (SC) are 7.84 %, Other Backward caste (OBC) is 3.92 % and Scheduled Tribes constitutes 5.88 % of total population in Gnathang Valley of Sikkim Fig 12 (h).

Marital Status:
To represent the social status of any are marital status is a good indicator. The status of Marriage determines the magnitude of migration. Total three categories have been created; mainly Married, Unmarried and Widow to show the marital status. In the Gnathang Valley, 55.60% of people are married in all overall situations. But specifically male has higher status than female Fig 12 (I).

Literacy Status:
Literacy is a key for socio-economic progress. The Gnathang village 60.80% male and 39.20% female population is literate of total literate population. Male has higher status than female Fig 12 (j).

Educational Status:
Education in every sense is one of the fundamental factors of development. The overall development of the people and society depends on the quality of education of the people. In this Gnathang Valley five categories have been made from primary to graduated and uneducated. In this village 78.92% of people are educated when as the greatest number of people has Primary level (34.09) of education. Nearly 3.13% has higher education of graduate level and only 0.44% of people has others qualification like technical course etc. Fig 12 (k)

Plate-8: Students of Gnathang valley, Sikkim
Fig 13: the occupational status of the people in the Gnathang valley, Sikkim; Primary school of Gnathang valley

ECONOMY
Occupational Status:
The village of eastern Himalaya has a diversified occupational status in terms of life and lively hood. Total six occupational parameters have been set here. The male, female comparison is also done during the survey. The result shows that only 13.45% people are daily labour and only 10.31% people are in service. In this area, there are no much job opportunities for the local people.12.56% are farmer, businessman, driver and household worker and 63.68% are unemployed also seen in this village.

Income Level:
Income is the flow of cash or cash equivalents received from work, capital or land. Total four range of income level has been set here. We can learn about the economic condition of this village from the income level of persons of this area.

Housing Condition:
Among the three necessities of human being is one of the most important properties is shelter. The rural house types of this Himalayan village an adaptation of people with the environment. As this region falls under the winter predominantly states of India, west Bengal (Gnathang Valley). Mainly three categories of house are found here – Wood, Stone, Pakka and Mixed. Wood houses are made of wood whereas Mixed houses are made of both concrete and woods. Due to poor economic condition and also winter condition most of the people reside in Wooden house (41.18%). Beside 39.22% family has Pakka house and 13.72% family has Mixed house and 5.88% people have Stone made house.

Fig 14(a); Building infrastructure (stone and wood built) in Gnathang valley, Sikkim

Access to Public Media:
In the age of Globalization, the communication has been bigger role to play in the development of human being. Public Medias like T.V, Radio, Newspaper, Mobile and others have been taken for the survey. 11.66% people are using the T.V, 0.89% are using Newspaper and 27.36% are using Mobile, and 59.64% people are have no access.

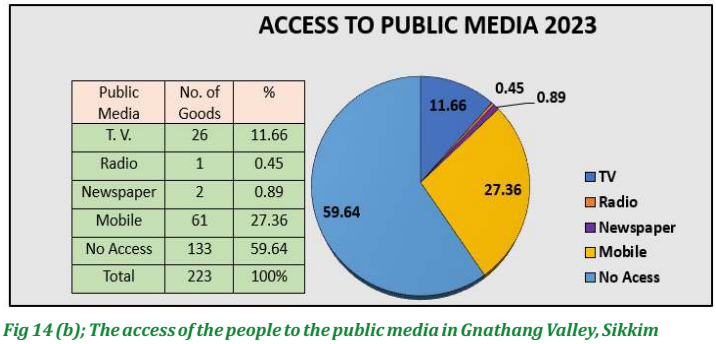
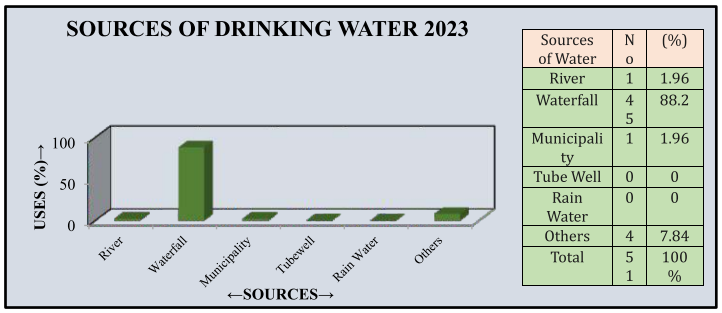


Fig 14 (b); The access of the people to the public media in Gnathang Valley, Sikkim

Sources of Drinking Water:

The Gnathang Valley village is situated in the eastern hill side of Darjeeling where drinking water is a major issue for the people. Sources of drinking water are mainly the natural springs. 88.24% family depends on waterfall's water 1.96% family depends on rivers and municipality's water and 7.84% family depends on others source. There are no Tube well or dug well in this village.

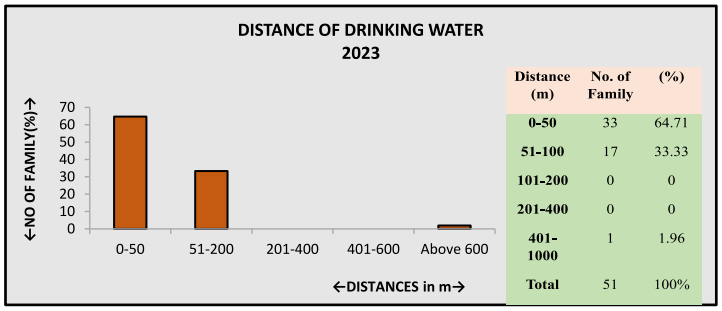


Sources of Water	No	(%)
River	1	1.96
Waterfall	45	88.2
Municipality	1	1.96
Tube Well	0	0
Rain Water	0	0
Others	4	7.84
Total	51	100 %

Fig 14 (b); The access of the people to the public media in Gnathang Valley, Sikkim

Distance of Drinking Water Facilities:

Five categories have been made to show how far a family travels to collect drinking water. It is shown that 64.71% of family travels 0 to 50 m to get the drinking water and the rest travels 51 to 100 m.

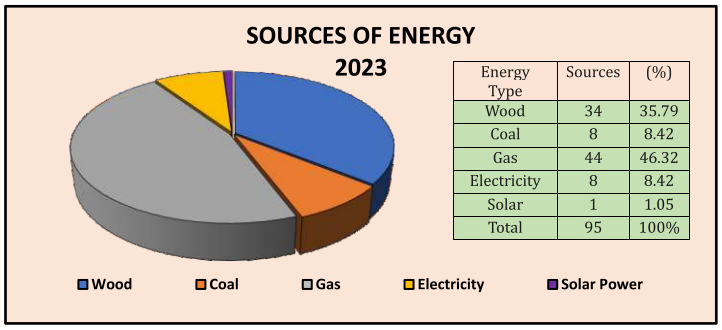


Distance (m)	No. of Family	(%)
0-50	33	64.71
51-100	17	33.33
101-200	0	0
201-400	0	0
401-1000	1	1.96
Total	51	100%

Fig 14 (c); Distance of Drinking Water Facilities of Gnathang Valley, Sikkim 2023

Sources of Energy:

Different types of fuel have been used in the village like- Wood, Coal, gas, electricity, solar power etc. Most of the families are using both gas and wood as their fuel. Wood is basically used during winter season and Gas is mainly used in rainy season. Coal, Electricity and solar power have been found very few numbers of households.



Energy Type	Sources	(%)
Wood	34	35.79
Coal	8	8.42
Gas	44	46.32
Electricity	8	8.42
Solar	1	1.05
Total	95	100%

Fig-14(d): Sources of various Energy in Gnathang valley, Sikkim, 2023

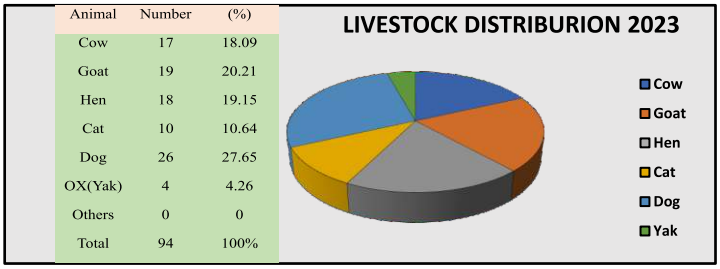
Fig 14 e: The non-renewable energy source and the Yak in Gnathang valley

Livestock Distribution:

Very little Livestock is seen in this Tea estate of the Gnathang Valley. Mainly dogs and Goats are seen almost every house. Apart from those cows, Hens, cats and also Yak are frequently found in this village.

Tourist Spot:

Sikkim is one of the prettiest hill stations in India located in the northern part of West Bengal. Kanchenjunga, the world's 3rd highest mountain peak located in the Himalayan range provides a Magnificent View (Golden View) from Sikkim and Gnathang Valley at sunset and sunrise. The traditional tourist place in Sikkim circuit, which are famous for cultural or religious tourism and can see Gangtok, Pelling, side scenes like Baba Mondir (old & new), Buddha Temple, Changu lake etc.



Animal	Number	(%)
Cow	17	18.09
Goat	19	20.21
Hen	18	19.15
Cat	10	10.64
Dog	26	27.65
OX(Yak)	4	4.26
Others	0	0
Total	94	100%

Fig 14 (f): Livestock Distribution of Gnathang Valley, Sikkim, 2023

Sustainable development goals for Sikkim:

The East Sikkim including the Gnathang valley is performing well to maintain the Sustainable Development Goals (SDGs) like SDG 10 (Reduced inequalities), SDG 13 (Climate change action plans), SDG 3 (Good health and wellbeing) and quality education (SDG 4). The strength of the Gnathang valley in east Sikkim as frontrunner is SDG 1&2 (No poverty and food security), SDG 5&6 (Women empowerment with gender equality and WASH facilities with clean water). However, the well-educated state (>80%) should have clean energy but affordable (SDG 7), and SDG 15 (life on land).

If we look at the physical condition of the village, the physical challenges are the biggest problems for the development of this area. Since it is a remote location surrounded by mighty snowy peaks, communication to the local urban centre is a threat. The region and roads are covered with thick snow during winters and generally it gets closed for some time. Medical facilities are also lacking in this region. Only Army health centre near Old Baba Mandir (5 km. away) is the sole medical service centre. In case of emergency, people have to rely on Gangtok or Siliguri. Lots of cultural and socio-economic problems are also seen in the village and they are Low Income levels of the Gnathang people, Low standard of living, insufficient electricity, paucity in sufficient drinking water supply, inadequate healthcare facilities, less communication, less dwelling infrastructure, insufficient education etc.

Planning

Several problems have been highlighted during the field survey which needs proper attention. The local government and the N.G.O.s should initiative to ameliorate migration problems. As per the field study several planning for the Tea Estate has been identified. They are poor supply of drinking water, more educational institutions, emphasizing organic farming, skill development, more new Health care Centres, fighting cold, Training for emergency relief, increasing non-renewable energy, efficiently solving electricity crisis, improving connectivity, improving MSME, enhancing employment

opportunities, child care, women empowerment and social security so that the citizens shall be prosperous and eco-conscious.

Discussion:

Sikkim, housed in the NE part of Indian Himalayas, with pristine natural exquisiteness, ironic cultural heritage, and liberal policies is gradually becoming prominent gradually. It is small size (7096 Km^2) and agriculture, tourism, and hydropower. sparse population density is driving the state's economy and sustainable growth. The exceptional geography, ecology, and socio-economic status deliver a strong footing for innovative its economic planning and future growth. Present investigation delves into Sikkim's future projections and plans for socio-economic growth [34].

Sikkim, the Organic State have launched the Sikkim Organic Mission in 2010, to implement nature-based farming on a war-footing mode and was declared as "First Organic State" on 18th January 2016 by the Hon'ble PM of India. The state federal institutions initiated numerous action plans like Promotion of Farmers promotion organisations (FPOs), Organic Certification and "Buyer-Seller" meets, marketing outlets, MSME activities, processing/value addition for organic produce.

The socio-economic diversion of the people of the state is dependent on hydropower, tourism, organic farm products and their marketing, Entrepreneurship, cultivating Micro, Small, and Medium Enterprises (MSME), employment, communication and spread of Buddhism. The state is in want of all-weather transportation and connectivity, sustainable infrastructure and power. To achieve a sustainable and socio-economic developed state it necessary to augment environmental protection, quality education, Skill development, societal harmony, quality health care, education, WASH facilities and ecology preservation. The Tourism must be developed without its impact on the environmental and socio-cultural aspects of the tranquil valley.

Conclusion

The social economic background of the Gnathang Valley gives a tremendous out look to the life and status of the people in a high-altitude village along Indo-China border. The place is a treat to the eyes of the tourists who come to experience this harsh life. At the same time, the physical condition is very challenging for the residents in terms of ease of life and facilities and amenities availability. The region is now well-connected to Gangtok and Siliguri through Border Roads. The famous Silk Road via Zuluk was once a major trade route for India and China. The strategically important Doklam Plateau is also very near to this region. The harsh environment prevents the development activities in this region. Over the last fifteen years Gnathang village, is developed as a tourist hub along silk corridor. The socioeconomic status of the Gnathang valley is converting to an access strip to scientists, people from naturopathy, educationalists and tourists next to the East Sikkim Himalaya's Gangtok.

The Government and few local bodies have to pay more attention to the welfare of the village. The development of drinking water facilities and snow clearance are the two major problems that are needs to be solved gently. Development of educational facilities, Electricity and make more medical centres are also required to make the villagers life more peaceful. Therefore, from this study it can be said that Gnathang Valley is the abode of peace, serenity and scenic beauty but needs more developmental activities to make the people's life more comfortable.

References

1. Pathak, L.; Baral, B.; Joshi, K.; Basnet, D.R.; Godone, D. Landslides in the Himalayas: The Role of Conditioning Factors and Their Resolution in Susceptibility Mapping. Geosciences 2025, 15, 131. https://doi.org/10.3390/geosciences15040131
2. Sultan, H.; Zhan, J.;Rashid, W.; Chu, X.; Bohnett, E.Systematic Review ofMulti-Dimensional Vulnerabilities inthe Himalayas. Int. J. Environ. Res.Public Health 2022, 19, 12177
3. Yao, Y., Wang, X., Luo, L., Wan, H., & Ren, H. (2023). An Overview of GIS-RS Applications for Archaeological and Cultural Heritage under the DBAR-Heritage Mission. Remote Sensing, 15(24), 5766. https://doi.org/10.3390/rs15245766
4. Mishra, SP., Mondal A., Mondal T. 2025. "Unveiling Societal Hydro-Morphology of the Lower Kopai River, West Bengal, India". Asian Journal of Environment & Ecology 24 (7):244-62. https://doi.org/10.9734/ajee/2025/v24i7766
5. Zhang, L., Liu, T., Yan, C., Zhang, J., Yu, R., Luo, N., & Yu, Y. (2024). Isolation, Character ization, and Optimization of Culture Medium for Local Straw-Degrading Bacteria from NE Black Soils of China. Agronomy, 14(11), 2591. https://doi.org/10.3390/agronomy14112591
6. Kundu, J., Sarkar, K., Ghaderpour, E., Scarascia Mugnozza, G., & Mazzanti, P. (2023). A GIS-Based Kinematic Analysis for Jointed Rock Slope Stability: An Application to Himalayan Slopes. Land, 12(2), 402. https://doi.org/10.3390/land12020402
7. Dar, Z. A., Gupta, S. K., Kanga, S., Singh, S. K., Meraj, G., Kumar, P., Sajan, B., Đurin, B., Kranjčić, N., & Dogančić, D. (2025). Spatiotemporal Exposure to Heavy-Day Rainfall in the Western Himalaya Mapped with Remote Sensing, GIS, and Deep Learning. Geomatics, 5(3), 37. https://doi.org/10.3390/geomatics5030037
8. Singha, K., Singh, M.A. Political stability and its effect on economy: some lessons from Sikkim Himalaya. J. Soc. Econ. Dev. 24, 340–354 (2022). https://doi.org/10.1007/s40847-022-00199-9
9. Garg PK, Shukla A, Jastrocia S, (2019). On the strongly imbalanced state of glaciers in the Sikkim, east Himalaya, India. The Sci. of the total Env. 691(2), DOI: 10.1016/j.scitotenv. 2019.07.086
10. Mishra, S. P., Samal, A. (2022). Anthropocene Bearing on Snow-Avalanche Disasters over the West Indian Himalayas: An Appraisal. International Journal of Environment and Climate Change, 12(10), 74-92. https://doi.org/10.9734/ijecc/2022/v12i1030772
11. Peng M, Wang X, Zhang G, Veh G, Sattar A, Chen W, et al. Cascading hazards from two recent glacial lake outburst floods in the Nyainqêntanglha range, Tibetan plateau. J Hydrol. 2023; 626:130155. https://doi.org/10.1016/j.jhydrol.2023.130155.
12. Banerjee, P. Long-term monitoring and forecasting of glacial lake dynamics using Landsat time series data, Google Earth Engine, machine learning, and geospatial analysis. Discov Geosci 3, 159 (2025). https://doi.org/10.1007/s44288-025-00280-w
13. IPCC AR-6, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Lee TH., and J. Romero J.,)]. IPCC, Geneva, Switzerland, 35-115, doi: 10.59327/IPCC/AR6-9789291691647.
14. Census of India 2011. District Census Handbook North, West, South And East Districts. Part XII-B, Directorate of Census Operations Sikkim.
15. NABARD, (2023). State Focus Paper for the year 2023-24; Sikkim State, Gangtok. https://www.nabard.org/auth/writereaddata/tender/2804235623SFP_SIkkim.pdf

16. Basu Sk., (2013). Geology of Sikkim State and Darjeeling district of west Bengal. Geological Society of India Bangalore.
17. Barman Simi, (2023). Geographical Background of North Sikkim Region With Special Reference to Socio-Economic Status of the Population of Mangan Village, Int Jour. of Multidisciplinary Research, 12(1), 174-180,
18. Chatterjee S, Chatopadhaya GP., (2021), Socio-Economic Condition and Environmental Problems of Dzuluk Village, East Sikkim Himalaya: A Geographical Appraisal. Int. J. of Res. in Eng. and Science (IJRES), 9 (8), 73-79, www.ijres.org 73
19. Mishra SP, Puhan JP., Mishra S., (2021). Probing the Crisis of Regional Connectivity Instigated by the Natural Disasters, Mizoram, India. International Journal of Environment and CC. 11(5): 39-59, 2021; DOI: 10.9734/IJECC/2021/v11i530406
20. Mondal P., Chowdhury A., Joshi M., (2025). Disastrous landslide events in the Sikkim Himalaya triggered by extreme early-monsoonal rainfall during May-June, 2025. Natural Hazards Research, https://doi.org/10.1016/j.nhres.2025.08.007.
21. Awan, T. A., Arshid, M. U., Riaz, M. S., Houda, M., Abdallah, M., Shahkar, M., Aghdam, M. M., & Azab, M. (2022). Sub-Surface Geotechnical Data Visualization of Inaccessible Sites Using GIS. ISPRS In. Journal of Geo-Information, 11(7), 368. https://doi.org/10.3390/ijgi11070368
22. Saha, K., Khare, R., (2025). Geospatial Technique to make Indian Cities Accessible for Persons with Disabilities. The Int. Archives of the Photogrammetry, RS and Spatial Information Sci.}, {XLVIII-G-2025}, 1791—1798, DOI:105194/isprs-archives-XLVIII-G-2025-1791-2025.
23. Govindha Raj BK, Kumar VK. Remote sensing-based inventory of glacial lakes in Sikkim Himalaya: semi-automated approach using satellite data. Geomatics Nat Hazards Risk. 2013;4(3):241–53. https://doi.org/10.1080/19475705.2012.707153.
24. Pandey, P., Ali, S.N. & Champati Ray, P.K. Glacier-Glacial Lake Interactions and Glacial Lake Development in the Central Himalaya, India (1994–2017). J. Earth Sci. 32, 1563–1574 (2021). https://doi.org/10.1007/s12583-020-1056-9
25. Kumar P, Sharma MC. Frontal changes in medium-sized glaciers in Sikkim, India during 1988–2018: insights for glacier-climate synthesis over the Himalaya. I Science. 2023;26(10):107789. https://doi.org/10.1016/j.isci.2023.107789
26. Bandyopadhyay K., Halder A., Nandi S., Koley B., Saraswati S. (2022). Sikkim. book: Geotechnical Characteristics of Soil sand Rocks of India, CRC press, CH-31, 12.31Tayler and Francis group, 582-602, DOI: 10.1201/9781003177159
27. Panda S., Mishra SP., Mishra S., 2020, Disaster Risk Reduction with Resilient Built Environment in Odisha coast, India, Jr. of Xidian Univ.; 14 (5), 6024-6028; https://doi10.37896/jxu14.5/653;/
28. Mishra SP, Chakraborty T., Barik KK., 2023, Geomorphologic Changes and Ethnobotany Losses of Indian Sundarbans in Anthropocene. Current Journal of Applied Science and Technology, 42(41), 28-47, DOI: 10.9734/CJAT/2023/v42i414265.
29. Gajmer B., Sharma N., Shrestha D.G. (2015). Plants of Gnathang, Eastern Sikkim with Respect to Long Term Monitoring Programme of Indian Space Research Organization. Int. J. of Life Sciences Research, 3(4), (23-29).
30. Sharma B., Jain AK., (2021). Ethnobotanical studies of Sikkim: a review. Int. Res. J. Biological Sci., 10(4), 1-6
31. Lahiri S., Dash SS., Sinha BK., Singh P., (2013). A Preliminary Appraisal Of Community Structure Of Gnathang Valley, East Sikkim. Conference: National Seminar: Understanding Himalayan Phyto diversity In a Changing Climate at: Gangtok, Sikkim, 23rd-24th Nov 2013.
32. Tamang M., Pal K., Rai SK., Kalam A., Ahmed SR., (2017). Ethnobotanical survey of threatened medicinal plants of West Sikkim. 2(6); 116-125
33. Chettri U., Kumari swati. (2021). A list of medicinally important plants of Sikkim Himalayan region, India. JMPS 2021; 9(4): 24-27, DOI: https://doi.org/10.22271/plants.2021.v9.i4a.1307
34. Mishra Siba Prasad, Pramanik Sasmita, 2024. Go Saba Island in Indian Sundarbans: A Dystopia Allochthonous Ecosystem. Computer Research and Development 24(7), 2024