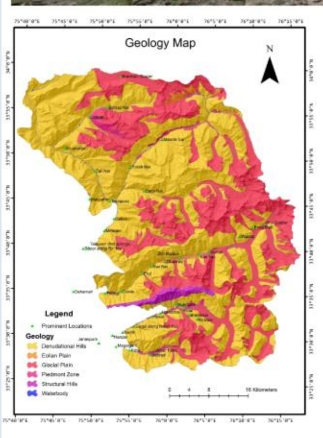
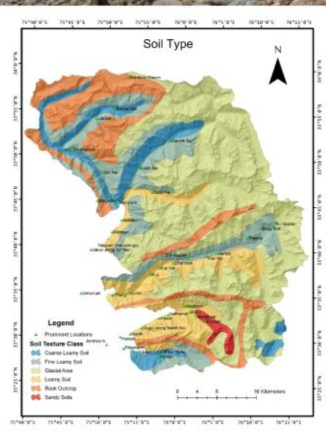
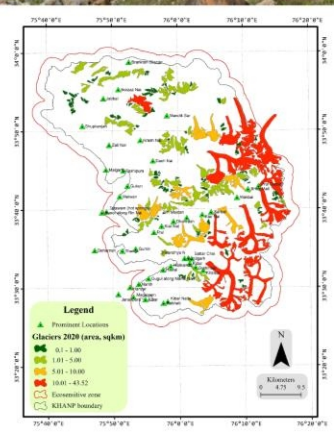
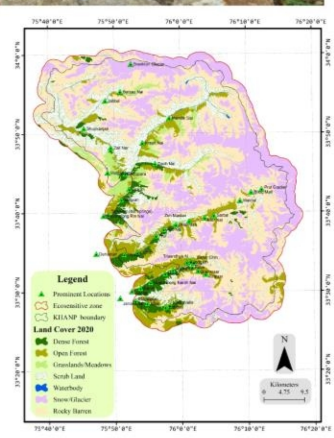
# GIS-BASED LAND USE AND ECOSYSTEM RESOURCE MAPPING OF KISHTWAR HIGH ALTITUDE NATIONAL PARK




**Department of Wildlife Protection,**
**Government of Jammu and Kashmir,**
**&**
**National Development Foundation, J&K**
**(2022)**

# Project Team

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सत्यमेव जयते

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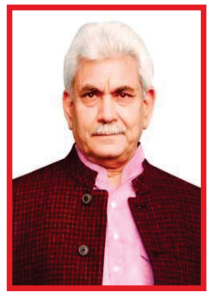

**Manoj Sinha**

# Message

I am happy to know that the Department of Wildlife Protection, J&K, with technical support from the National Development Foundation has embarked on a prestigious research project at Kishtwar High Altitude National Park.

I gather that the document titled "GIS - Based Land Use and Ecosystem Resource Mapping of Kishtwar High Altitude National Park", with detailed ecosystem resource mapping using state-of-the-art GIS based spatial analysis presents valuable information about the Kishtwar High Altitude National Park.

Protection of Wildlife and its habitats has been part of our cultural ethos since time immemorial. It is crucial to have extensive information repositories of baseline and advanced data on the protected areas of Jammu and Kashmir.

This report shall provide information on location, geocoordinates, spatial extent, and other thematic layers such as land cover, vegetation, soil, geomorphology, lithology, slope, aspect, elevation, drainage, and accessibility of the Kishtwar High Altitude National Park.

Jammu & Kashmir has unique geography and supports a rich diversity of rare and endangered flora and fauna, unique to the Himalayas. The Department of Wildlife Protection is mandated to protect and improve the wildlife habitats.

Such a scientific study will be beneficial for the park managers. It will also be helpful to anyone who wishes to know more about Kishtwar High Altitude National Park and its ecological resources.

The result of this report are encouraging and shall prepare the Department of Wildlife Protection for better conservation and management of Kishtwar High Altitude National Park which is important for the rare wildlife species and various ecological services it provides to the downstream communities.

In future, our conservation activities should be designed to protect our wildlife and generate employment opportunities for the local youth through various ecotourism activities.

I congratulate the Department of Wildlife Protection and National Development Foundation for bringing out this much-needed publication, and extend my best wishes to them for their future endeavours.

***(Manoj Sinha)***

Chief Secretary
Jammu and Kashmir

सत्यमेव जयते

Arun Kumar Mehta,
IAS

# Message

Himalayas are fascinating region of our country with unique biodiversity. Also, these regions are critical for a wide range of ecological services they provide not only to the people living in these mountains but to the millions living in the plains. The UT of Jammu & Kashmir, positioned within the Himalayas, is a very important wildlife habitat as well.

Realizing the importance of a large number of key wildlife species in Jammu & Kashmir, the Government has declared many areas as protected areas. To get updated information about the conservation status of these species, regular wildlife research activities are very important. This, besides generating latest information, also help in designing updated conservation and management strategies for these protected areas.

The Government of J&K is committed to science-based conservation of protected areas through focused research projects like the ongoing research project at Kishtwar High Altitude National Park. Our aim in the forest and wildlife departments is to strengthen science-based conservation initiatives in this region based on landscape approach, fully involving the local communities who are seen as the most important stakeholder.

I compliment the teams of Department of Wildlife Protection and National Development Foundation for making the study with respect to ecosystem resource mapping of Kishtwar High Altitude National Park and bringing out this publication titled "GIS- Based Land Use and Ecosystem Resource Mapping of Kishtwar High Altitude National Park". This will be useful for designing proper conservation and management strategies for Kishtwar High Altitude National Park. The conservation of these critical ecosystems shall significantly contribute towards meeting Sustainable Development Goals (SDG's).

**(Dr. Arun Kumar Mehta)**

Principal Secretary to Government
Department of Forest, Ecology & Environment
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सत्यमेव जयते

Dheeraj Gupta
IAS

# Message

The UT of J&K is bestowed with a wide range of altitudinal gradients from Shivalik in the lower Himalayas to the high-altitude landscapes in the higher Himalayas. Such a unique topography has made J&K a home to a diverse range of flora and fauna. Recognizing the importance of these areas the Government has notified significant wildlife habitats as wildlife protected areas. This besides helping to protect these landscapes is also important for protection of rich and endangered wildlife which these landscapes support.

I am happy to see that the Department of Wildlife Protection, Government of J&K with support from National Development Foundation and its partner educational institutions has taken lead to initiate pioneering research activities at Kishtwar High Altitude National Park. Such scientific studies provide us valuable framework for consultation and inputs from not just the local communities and NGO's but all the Government agencies active in the area.

I congratulate the Department of Wildlife Protection, Government of J&K and National Development Foundation for jointly producing this report and look forward to more such studies in future as well.

(Dheeraj Gupta)

**PCCF & HoFF,**
**J&K Forest Department**
**Chairman, J&K Biodiversity Council**

सत्यमेव जयते

**Dr. Mohit Gera, IFS**

# Message

The Himalayas form the watersheds of several of our major rivers and also home to rich biodiversity and cultures. These vast stretches of watersheds shelter wildlife populations, including several endangered species that inhabit the larger landscapes both within and outside protected areas including the village commons and revenue lands.

The Government of UT of J&K through its Department of Wildlife Protection has initiated formulation of a species management strategy that covers different aspects of ecology, biodiversity and human dimension for participatory conservation.

I am delighted to note that Department of Wildlife Protection, Government of J&K has taken the lead by facilitating the preparation of Management Action Plan and Strategy covering the entire Kishtwar High Altitude National Park which us the key conservation landscape in Jammu region.

This report provides useful information on challenges of protection and management of the National Park and for initiating suitable conservation activities accordingly. This would also act as a model for similar protection initiatives in other wildlife areas.

This pioneering and innovative efforts provides us a great start and a scientific basis for further improvement in management of the protected areas of Jammu & Kashmir. This is the first, but probably the most important step towards conservation of unique wildlife of Kishtwar High Altitude National Park.

I wish all success for a purposeful and participatory conservation activities at Kishtwar High Altitude National Park in future as well.

**(Dr. Mohit Gera)**

सत्यमेव जयते

PCCF (Wildlife)/
Chief Wildlife Warden,
Jammu & Kashmir

Suresh Kr. Gupta, IFS

# Foreword

Mountains and their mesmerizing landscape and wildlife have always fascinated all of us and me in particular since my early childhood and then latter during my early days in the forest service.

The present report is an indication of the fact on how modern technology with a wide range of space application can play a critical role in our future conservation efforts. Using latest technology for conservation and protection of our wildlife is key priority for us.

This report is the result of the hard work of teams of Department of Wildlife Protection and National Development Foundation, and is being complemented with focused research on biodiversity, nomadic communities, and local institutions. The report will also help in prioritizing sites for conservation and for designing strategies for their management for each of them in a participatory manner.

This focused and concerted research effort at Kishtwar High Altitude National Park will be a vital contribution for a unified conservation-oriented management plan, for a large and diverse landscape like this National Park. The process so far at Kishtwar High Altitude National Park is full of interesting lessons.

This ongoing research project at Kishtwar High Altitude National Park provides us a platform for healthy and critical discussions and for formulation of management strategies which will be a unique feature for our future conservation efforts. I wish to congratulate my entire team and team of National Development Foundation who have initiated this project to fill a gap in the knowledge about various aspects of Kishtwar High Altitude National Park.

I sincerely envisage collaborations with several other stakeholders for conservation and management of our large number of protected areas within the UT of Jammu & Kashmir. This will be a key contribution towards providing safe habitats to our unique wildlife and will encourage our future generations to know more about such ecosystems and to contribute towards conservation of our wildlife.

**(Suresh Kr. Gupta)**

सत्यमेव जयते

PCCF & CEO, CAMPA
J&K Forest Department

Sarvesh Rai, IFS

# Message

The mountain regions of Central and South Asia are critical for a wide range of ecological services they provide not only to the people living in these mountains but to the millions living in the plains. The UT of Jammu & Kashmir is ideally and strategically positioned within the Himalayas and this makes it a very important wildlife habitat as well.

Realizing the importance of a large number of key wildlife species in Jammu & Kashmir, the Government has declared many areas as protected areas. To get updated information about the conservation status of these protected areas, regular wildlife research activities are very important. This besides generating latest information also helps in designing updated conservation and management strategies for these protected areas.

The Government of J&K is committed to science-based conservation of protected areas through focused research projects like the ongoing research project at Kishtwar High Altitude National Park.

I congratulate the entire team of Department of Wildlife Protection and National Development Foundation for producing this valuable report with a wealth of in-depth scientific information. This was a long felt need for designing proper conservation and management strategies for Kishtwar High Altitude National Park. The conservation of these critical ecosystems is also a great contribution towards meeting our national goals set under Sustainable Development Goals (SDG's) by the Government of India.

I wish all success to Department of Wildlife Protection and hope that their upcoming reports on various aspects of biodiversity will further strengthen the conservation efforts for the National Park.

(Sarvesh Rai)

# PREFACE

Updated scientific information using lattest technology is an urgent requirement for conservation and management of our protected areas. The present report is an outcome of the collaboration between the Department of Wildlife Protection, Government of J&K, and National Development Foundation, J&K. This collaboration has been developed through a research project awarded through a EOI and accordingly National Development Foundation along with its consortium partners: Central University of Jammu, Jawharlal Nehru University, Delhi and University of Kashmir, Srinagar were awarded the research project on varius aspects of biodiversity assessment of Kishtwar High Altitude National Park (KHANP).

The report documents the spatio-temporal mapping of the land use and ecosystem resources of the Kishtiwar High Altitude National Park. It is an important protected area (PA) in the UT of Jammu and Kashmir because of its biodiversity, the role it has in maintaining regional ecological balance. The national park is an abode of important habitats and natural resources, and a source of resilience to regional climate change, food and drinking water, and other benefits to wildlife and human health.

Kishtiwar High Altitude National Park has a unique geoenvironmental setting, as seen with other similar biodiversity priority regions. This report discusses various aspects of geology, geomorphology, lithology, soil type, elevation, slope, aspect, drainage, and climate characteristics of this national park. To assess the land use / land cover changes in the Kishtiwar High Altitude National Park (KHANP) from 1990 to 2020, remote sensing and GIS-based change detection analysis were performed using satellite data for 1990, 2000, 2010, and 2020. This study aimed to assess the land use and land cover change in the KHANP using on-screen digitization or visual image interpretation technique and field-based ground surveying knowledge.

We hope that this report paves the way for effective management of the KHANP and other national parks of the UT of Jammu and Kashmir. We want to thank our research partners and local communities who supported us in thick and thin at each stage of this project; nothing would have been possible without their help and support. Finally, we believe that the chapters in this book will advance our discussion on the genesis and role of the designated conservation areas in sustaining human well-being.

***Dr. Pankaj Chandan***
***Lead PI, Research Project***
***Kishtwar High Altitude National Park***

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| | | |
|---|---|---|
| ES | – | Ecosystem Services |
| RS | – | Remote Sensing |
| GIS | – | Geographic Information System |
| UN | – | United Nations |
| NASA | – | National Aeronautics and Space Administration |
| KHANP | – | Kishtiwar High Altitude National Park |
| LULC | – | Land Use Land Cover |
| IUCN | – | International Union for Conservation of Nature |
| GDP | – | Gross Domestic Product |
| NP | – | National Park |
| PAN | – | Protected Area Network |

## EXECUTIVE SUMMARY

Resource mapping, or assessing the availability and condition of natural resources, is the first step in designing a sustainable resource development strategy. A technique for accumulating and plotting data based on the presence, distribution, access to, and use of resources within a community's economic and cultural area is known as resource mapping. The assessment process is a cyclical process that begins with establishing baseline rates or levels for various phenomena, continues with establishing trends in these measurements or conditions, and concludes with identifying the causes and impacts of such rates and trends.

Protected areas (PAs) are an essential part of worldwide conservation efforts, and their efficient management necessitates the integration of resource mapping and ecosystem services. The growing understanding of ecosystem resources, the ever-increasing number of studies indicating a link between biodiversity and ecosystem supply, and the concomitant emerging adoption of the concept by decision-making bodies necessitate a review of the ecosystem services provided by areas that offer them the most.

Modern geospatial technologies such as Remote Sensing (RS), Geographic Information Systems (GIS), and the Global Positioning System (GPS) have resulted in the development of compelling methods for surveying, identifying, classifying, mapping, monitoring, and characterization, as well as for tracking changes in the composition, extent, and distribution of a variety of ecosystem resources, both renewable and non-renewable, living and non-living in nature.

This report assesses the evidence-based mapping of ecosystem resources to support funding for establishing and managing current and prospective protected areas in the UT of Jammu and Kashmir. It presents baseline data generation and preliminary assessment of the land use/ land cover changes of one of Jammu and Kashmir's most prominent protected areas, the Khistiwar High Altitude National Park (KHANP). The park area is 2191.50 sqkm as per the latest notification of the Government of India. The boundary of the National Park shifted eastern side to exclude all the human habitations already located within the national park (21 Villages). The Park area is comprised of upper catchments of Renai, Kiyar, Nanth, and Kibar Nallas.

Kishtiwar High Altitude National Park has a unique geoenvironmental setting as is seen with other similar biodiversity priority regions. In this report, we discussed various aspects pertaining to geology, geomorphology, lithology, soil type, elevation, slope, aspect, drainage, and climate characteristics of the NP. To assess the land use/ land cover changes in the Kishtiwar High Altitude National Park (KHANP) from 1990 to 2020, remote sensing and GIS-based change detection analysis was performed using Landsat satellite data for 1990, 2000, 2010, and 2020. This study aims to assess the change in land use and land cover in the KHANP using on-screen digitization or visual image interpretation technique and field-based ground surveying knowledge.

The classification scheme adopted for classifying the KHANP land cover followed the level-1 classification scheme described by the National Remote Sensing Centre (NRSC, Hyderabad). The seven land cover classes that were classified in the KHANP are dense forests, open forests, grasslands/ meadows, scrubland, waterbody, snow/ glaciers, and rocky barren. Dense forests are lands with a tree cover of canopy density above 40% and 70% above (FSI). Open forests are lands with a tree cover of canopy density between 10% and 40% (FSI). Grasslands/ pasture are the areas of natural grass and other vegetation, predominantly grass-like plants (Monocots) and non-grass-like herbs (except Lantana species which are to be classified as a scrub). It includes natural/semi-natural grass/ grazing lands of Alpine/Sub-Alpine or temperate or sub-tropical or tropical zones, desertic areas, and man-made grasslands (NRSC). Scrubland includes forest lands with poor tree growth, mainly small or stunted trees with a canopy density of less than 10 percent (FSI). Waterbody is any significant accumulation of water, generally on a planet's surface. The term most often refers to oceans, seas, and lakes, but it includes smaller pools of water such as ponds, swamps, wetlands, or, more rarely, puddles. A body of water does not have to be still or contained; rivers, streams, canals, and other geographical features where water moves from one place to another are also considered bodies of water.

In KHANP, perennial and alpine streams were categorized as the water bodies. Snow and glaciers are the areas under snow cover confined to the Himalayan region, and they are primarily located in mountain peaks and steep slopes/high relief areas. These are the areas under perpetual snow cover throughout the year, and they are the origins of most Himalayan river systems. Rocky Barren are those ecosystems in which less than one-third of the area has vegetation or other covers. In general, this category has thin soil, sand, or rocks. In the KHANP, the majority of the land of this category included the rock outcrops, the denuded land usually found near the snow and glacier fields. In the present study, four-date images were used for change detection, i.e., TM (1992), ETM (2000), ETM (2010), and OLI (2020). The analysis of the multi-temporal land cover maps of the KHANP was assessed to reveal the changes which have taken place from 1992 to 2020.

Since the National Park had been recently declared as the conservation priority region, it has been found that the direct anthropogenic impacts (such as forest smuggling and poaching) on its flora and fauna have been minimal over the years except for grazing. It is characterized by significant topographic, climate, and altitude change, resulting in diverse species of forest vegetation in the area, particularly on the northern and eastern sides. The four prominent nallas, *Renai*, *Kiyar*, *Nanth*, and *Kibar*, have lower catchment areas that support forest growth on favorable aspects with the increasing admixture of diverse species. Presently, the dense forest cover spans about 107.75 sqkm of the NP, constituting about 3.97 % of its total area. Open forest cover spans about 253.14 sqkm of the NP, constituting about 9.33 % of its total area. Presently, the scrub class covers about 384.63 sqkm of the NP, comprising about 14.17 % of its total area. Presently, the grasslands/meadows cover about 138.20 sqkm of the NP, comprising about 5.09 % of its total area. Currently, the land under streams and alpine lakes in the National Park spans approximately 11.84 sqkm constituting about 0.44 % of its total area. In 2020, the area under snow/ glaciers spanned about 798.20 sqkm of the NP, comprising approximately 29.41 % of its total area. In 2020, the land cover of the Kishtiwar High Altitude NP was dominated by the rocky-barren class, having about 1020.00 sqkm of the national park under it and accounting for about 37 % of its area.

Snow/ glaciers have decreased almost half of their areal extent in 1992. It fell from 1578.27 sqkm in 1992 to 798.20 sqkm in 2020, recording a decrease of 780.07 sqkm (-49.43% decrease since 1992) of the area in this period. There has been a corresponding increase in the area under the rocky-barren class. Rocky-barren class increased from its areal extent of 304.83 sqkm in 1992 to 1020 sqkm in 2020, recording an increase of 715.17 sqkm (234.61% increase since 1992, nearly five times increase since 1992) of the area in this period. It is concluded that the increase of the area under the rocky-barren class corresponds well with the decrease of the area under snow/ glaciers class, indicating that the decreased size of the snow/glaciers got converted to rocky-barren.

The area under the dense forests class has increased from 69.49 sqkm in 1992 to 107.75 sqkm in 2020, recording an increase of 38.27 sqkm (55.07 % since 1992) of the area in this period. The open forest class has similarly increased in space, with its areal extent increasing from 96.90 sqkm in 1992 to 253.14 sqkm in 2020, recording an overall increase of 156.24 sqkm (161.23% increase since 1992) of the area in this period. The area under the scrubland class has overall decreased from its areal extent of 500.31 sqkm in 1992 to 384.63 sqkm in 2020, recording an overall decrease of 115.68 sqkm (-23.12% decrease since 1992) of the area in this period. The area under grassland/meadows has also decreased from its areal extent of 152.72 sqkm in 1992 to 138.20 sqkm in 2020, recording an overall decrease of 14.52 sqkm (-9.51% since 1992) in this period.

It is to be noted that the decrease of the area under scrubland and grassland/meadows class corresponds well with the increase of the area under open forest class, indicating that the decreased area of these classes got converted to open forest. Overall there has been no significant change in the waterbody class since 1992.

In 2020, the total number of glaciers found in the KHANP was 177. In the year 2020, the total area under glaciers in the KHANP is 532.97 sqkm. It accounts for 23.90% of the total area of the NP. In 2020, the total volume of glaciers covered by 532.97 sqkm of area constituted about 36.16 cubic kilometers of ice volume or approximately 36.16 Giga tones of water. Nearly 88 % (155 No.) of these glaciers are categorized as very small (0.1<1 sqkm) and small (1 - 10 sqkm). Since small glaciers are sensitive to minor temperature changes, these are the first to get affected by global warming and regional climate change. The snow distribution in the KHANP keeps on changing throughout the year. The hydrological cycle of the Himalayan watersheds usually starts from October 1. Before this date, whatever proportion of the previous year's snow is present will generally stop melting. The new snow that falls after this date adds the water to the following year's supply in the watershed's drainage system.

The grasslands of this national park are rich repositories of enormous biodiversity and medicinal plants besides serving as fodder grounds for nomads' livestock. Presently, Grasslands or meadows cover about 138.20 sqkm of the NP, constituting approximately 5.09 % of its total area. Moist alpine pastures are found at elevations more significant than 3,200 m in various prominent places of Kishtiwar, such as Wadwan valley, Margan Pass and Sinthan Pass. Most herbs found in this park have tremendous medicinal and economic values associated with them, as local tribal communities use them. But over the past few decades, their reckless exploitation rendered them vulnerable to extinction, as is the case with *Saussurea costus*, *Gentiana kurroo*, *Podophyllum hexandrum*, and many other plant species. The local inhabitants use about thirteen essential medicinal herbs to cure common ailments and diseases explicitly found in the KHANP.

The efficient resource allocation for prioritized conservation of different parks can only be achieved if the strategy is based on biodiversity, threat, cost, and many other essential factors. Above all, the planning must be rigorously formulated. Allocation of conservation resources, like any problem in decision theory, requires a broad goal, a specific objective, a set of constraints, a set of possible actions that form a strategy, and an understanding of the system dynamics provided by equations that link the efforts and limitations to the objective.

In protected areas such as Kishtiwar High Altitude National Park in India, the decision-makers need to start developing baseline information to pave the way for the comprehensive resource allocation strategy. For conservation measures, the central government funds national parks massively, but allocating the required funding for prioritized conservation efforts has to be determined scientifically. Whether more stress has to be laid on watershed management that eventually affects the sediment retention services or the focus needs to be on conserving biodiversity. This scientific question can only be resolved once an understanding of the basic function of the land system processes operating in the NP is developed. In this report, vegetation change, water resource mapping, and its change over the years have been assessed. This forms some of the initial baseline data required for the successful resource allocation for conservation. We propose to initialize further research by evaluating the sediment retention and water yield services provided by the natural vegetation of the NP. By doing so, we can almost cover 85% of the science behind a successful resource allocation strategy for the KHANP.

# CHAPTER-1

# CHAPTER – 1
# ECOSYSTEM RESOURCE MAPPING AND PROTECTED AREA NETWORK

Resource mapping, or assessing the availability and condition of natural resources, is the first step in designing a sustainable resource development strategy. A technique for accumulating and plotting data based on the presence, distribution, access to, and use of resources within a community's economic and cultural area is known as resource mapping. The assessment process is a cyclical process that begins with establishing baseline rates or levels for various phenomena, continues with establishing trends in these measurements or conditions, and identifies the causes and impacts of such rates and trends. Mitigation is a feature that refers to the steps that must be taken once policies, directives, and impacts have been studied. The technique required for this form of continuum evaluation is made up of four important functions (4-M's – mapping, measuring, modeling, and monitoring). Thematic and quantitative baseline data (current or historical) are compiled spatio-temporally through mapping. Measuring is a more thorough mapping method that relies on the quantification and documentation of the attributes of the phenomena. Modeling is the process of describing and recreating the current, past, or future behavior of a system under inquiry using exact and frequently mathematical input-output relationships. The process of regularly analyzing the state of the environment by noticing shifts or changes in natural occurrences and human activities is referred to as monitoring.

Perhaps, since ecosystems provide considerable benefits to humans, there is an increasing consensus among the stakeholders to incorporate them into resource management decisions. However, quantifying proved difficult until spatially explicit models based on RS/GIS showed promising results in analyzing the trade-offs for effective decisions for natural resource conservation. We have demonstrated the overall influence of ecosystem resources on the whole earth system in Fig. 1.1. This figure holistically addresses the complicated relationship and possible trade-offs between resources, the human socioeconomic system, and the natural capital within the whole biosphere.

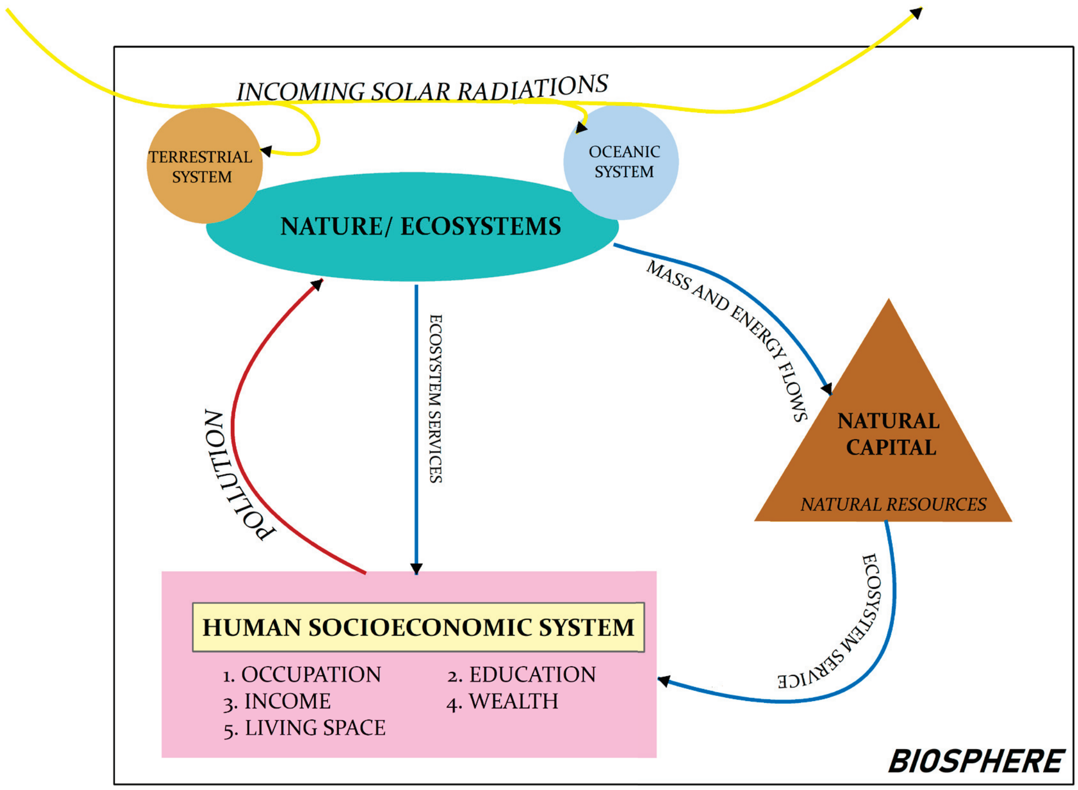


**Fig. 1.1** The complex web of interactions of ecosystem resources within the biosphere

## 1.1. Ecosystem resource mapping and Protected Area Networks

Protected Areas (PAs) are an essential part of worldwide conservation efforts, and their efficient management necessitates the integration of ecosystem resources. The growing understanding of ecosystems, the ever-increasing number of studies indicating a link between biodiversity and ecosystem supply, and the concomitant emerging adoption of the concept by decision-making bodies necessitate a review of the ecosystem services provided by the areas that offer them the most.

Different paradigms have characterized the establishment of PA around the world, ranging from the original "wilderness" paradigm to other new models that recognize the role of locals and the maintenance of their practices as critical to preserving the inherent features of the area (e.g., biodiversity or landscapes).

Despite the observed evolutionary trend, various theories coexisted, and no single model fits the optimum approach for determining a natural landscape as PA. While some argue for the importance of cultural landscapes (which are typically less intensive, human-dominated, and multifunctional, and which often serve as habitats for several threatened species that have become adapted to those areas as a result of their original habitat degradation), there are also arguments for re-wilding as a strategy for species recovery.

Discussing the philosophy and views on protected areas helps to frame the potential role of economic valuation of ecosystem services (here broadly defined as the benefits humans derive from ecological functioning, whether natural or human-dominated), as it reveals that decision-making in this regard is not always a simple process, involving a resource allocation problem marked by stakeholder conflicts and different opportunity costs. In a nutshell, defining the establishment of a PA entails deciding on geographical boundaries based on protection goals, determining which levels of protection are appropriate, whether they should be different within the protected area, determining which resources are required, and determining how to allocate them best.

Despite the numerous challenges that conservation efforts face, the use of economic valuation of ecosystem services as a tool to ensure that the economic benefits provided by protected areas are appropriately considered in decision-making and in such a way that ecological heterogeneity is captured, as well as bringing the spatio-temporal dimension of economic value into the specific case of protected area management, is critical. Fig. 1.2 depicts these conceptual reasons and how they lead to successful conservation efforts around the world. The rationale for assigning a certain resource to a specific category is determined by the resource evaluation's definition features, awareness of the trade-offs, and final purpose of assessment. It focuses on the ideas that underpin the successful development and execution of modeling methodologies in various future ecosystem resource assessments. Market valuation methods based on current pricing for commodities and resources exchanged in marketplaces are known as price-based techniques. On the other hand, worth transfer uses financial data collected at one location and time to infer the economic value of environmental goods and services at a different place and time.

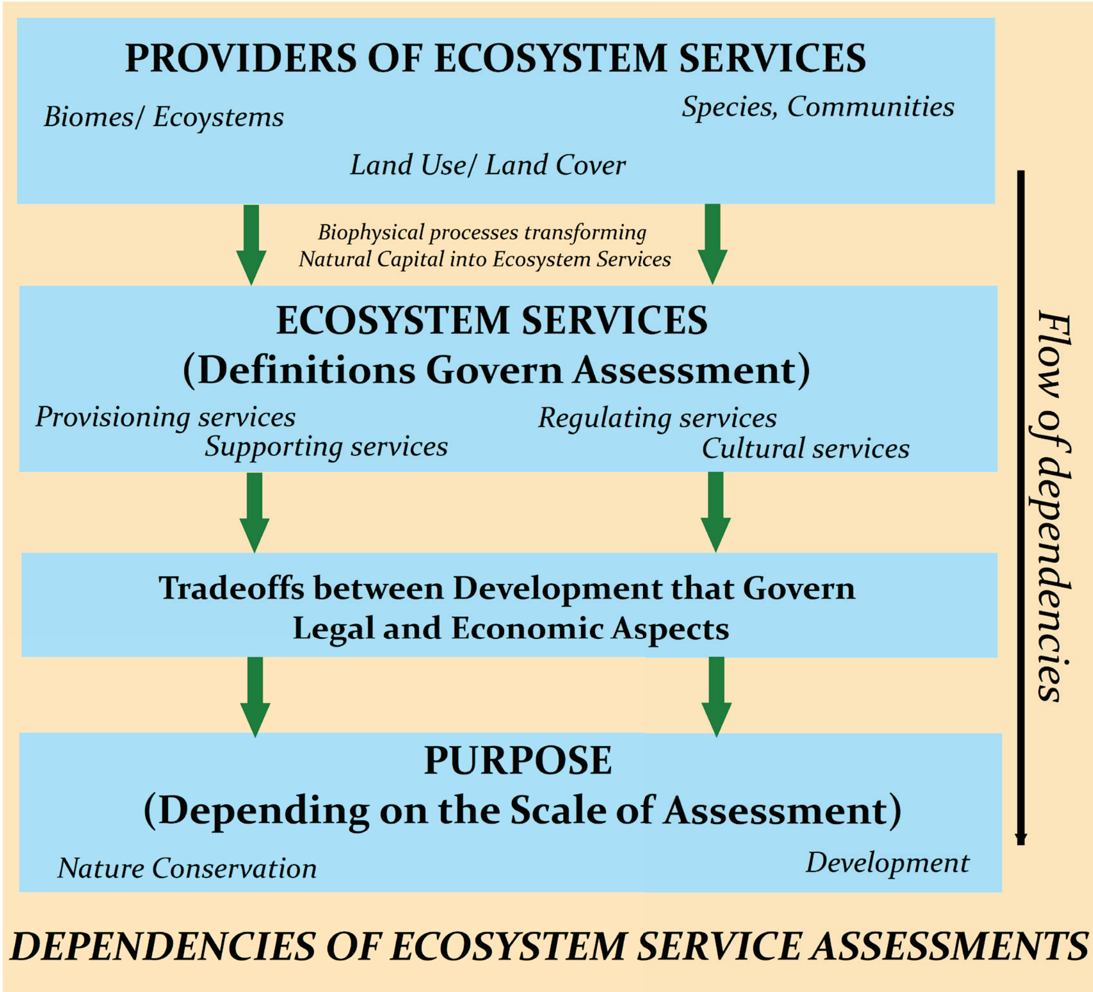


**Fig. 1.2** The conceptual dependency of ecology, economics, and legal aspects on the ecosystem resource (services) assessments

Value transfer included a variety of methodologies that differed in terms of the level of detail and information changes made and the accuracy of the estimations obtained. The most widely discussed method is the use of unit value transfer. In practice, unit value transfer combines information on the quantity of ecosystem resource units delivered at the research region with values for ecosystem resource brought from a different place and context, expressed as a value per unit (e.g., per area). The modification of transferred values is not sorted off, even though unit values can be altered to reflect changes between the research and policy sites (e.g., income and price levels).

### 1.2. Mapping and economic valuation of ecosystem resources

Following the analytical approach, mapping and economic value of ecosystem resources are restricted depending on the relevance to local stakeholders once data availability and readiness for use have been assessed. However, mapping economic values without mapping the biophysical dimensions are impossible. Based on this fact, and to emphasize that maps of different dimensions of resources can provide distinct insights for PA management, both biophysical and economic values must be calibrated. Fig. 1.3 demonstrates how resource providers, beneficiaries, administrative organizations, and natural capital govern human well-being. Any altercation in this intricate web, whether in the flows of welfare, monetary dispensations, demand/ supply, or the disbursement of bonuses, shall affect humans' well-being.

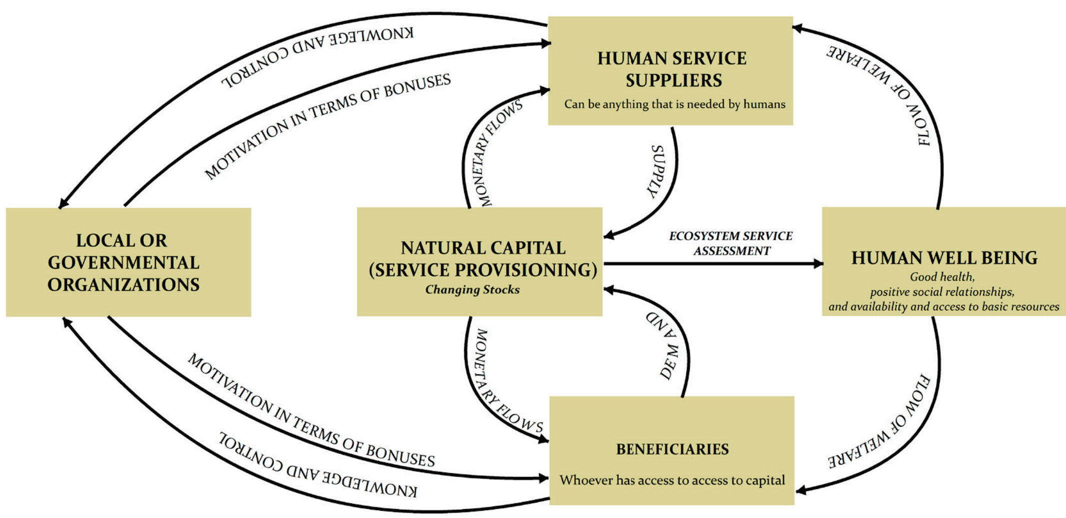


**Fig. 1.3** Economic Valuation and ecosystem resources (services) are intricately webbed in the human social system

The success of conservation initiatives is determined by the successful engagement and participation of targeted actors (stakeholders). How stakeholder participation is encouraged may also influence its success, particularly when it is viewed as a legal requirement (in the form of launching a public consultation period) rather than based on a belief in its effectiveness or validity. Active public participation is still minimal in Jammu & Kashmir. It is frequently viewed as a significant source of conflict between managers and local stakeholders and thus as a substantial threat to fulfilling conservation goals. Participants in the local stakeholder workshop must be aware of the national park's benefits to reach a consensus and integrate resource mapping and their value into KHANP management plans (Fig. 1.3).

The technique for selecting the most relevant methodology for an ecosystem resource assessment is shown in Fig. 1.4. The first two steps in determining the most appropriate approach for any ecosystem resource assessment, namely determining the resource to be assessed and comprehending the scale, requirements, conservation, and development trade-offs, are the most critical. The varying grey colors in the picture represent the process' maturity and development. As can be seen, the approach is dependent on a number of parameters.

Furthermore, any resource mapping poses the issue of estimation precision and how to account for geographic variability. For example, estimating erosion regulation reveals limits that could be attributable to our data sources. Furthermore, any model for predicting erosion control considers a worst-case scenario, which may or may not be realistic. On the one hand, the sole technique is mapping erosion regulation based on potential erosion using the USLE model. On the other hand, the economic value of erosion regulation must be calculated using a constant unit value, and the potential spatial variability of the economic value must be taken into account. Because water quality and availability (as well as regulation services sought by local stakeholders) are the key resources and have economic worth, they must be included. Any resource assessment study should focus on determining how and why economic valuation and mapping may be integrated into the context of local protected area management as part of a more extensive ecosystem resource assessment analytical framework.

## 1.3. Methods of mapping and economic valuation of ecosystem resources

The methods for mapping and analyzing ecosystem resources in terms of monetary values primarily entail measuring and accounting for regional variation in their economic value and arranging this data to aid decision-making and policy instrument design. Economic methods operate on the right side of the resource cascade model to quantify the benefits to people. As a result, any economic mapping or assessment relies heavily on biophysical data and methods to measure ecosystem capacity. Biophysical mapping is mainly based on land-use/land-cover (LULC) classifications derived from the most recent satellite images (Landsat OLI 8, 2020). Since the 1960s, economists have devised several methods for calculating the economic value of services, particularly those that are not priced or traded in markets, to address the wide range of valuation issues raised by applying economic analyses to the complexity of the natural environment. There is a significant distinction between approaches that generate new or original information from primary data (primary valuation methods) and those that employ existing knowledge in new policy contexts.

Based on their annual flow or usage, the resources could be evaluated in standard monetary units, Rs, inflation-adjusted. At first, method selection is influenced by the type of data provided and the approach's cost-effectiveness. The following works may be referred to for a full overview of the economic valuation foundation and methods: Bateman *et al.* (2011), Marta-Pedroso *et al.* (2014a), Koetse *et al.* (2015), and Meraj *et al.* (2021) (Fig. 1.4).

The three levels of uncertainty that can be observed in ecosystem service assessments are depicted in Fig. 1.5. Uncertainties arising from technical issues are at the heart of the problem. If a meaningful ecosystem resource evaluation is to be carried out, the problem must be understood technically and holistically.

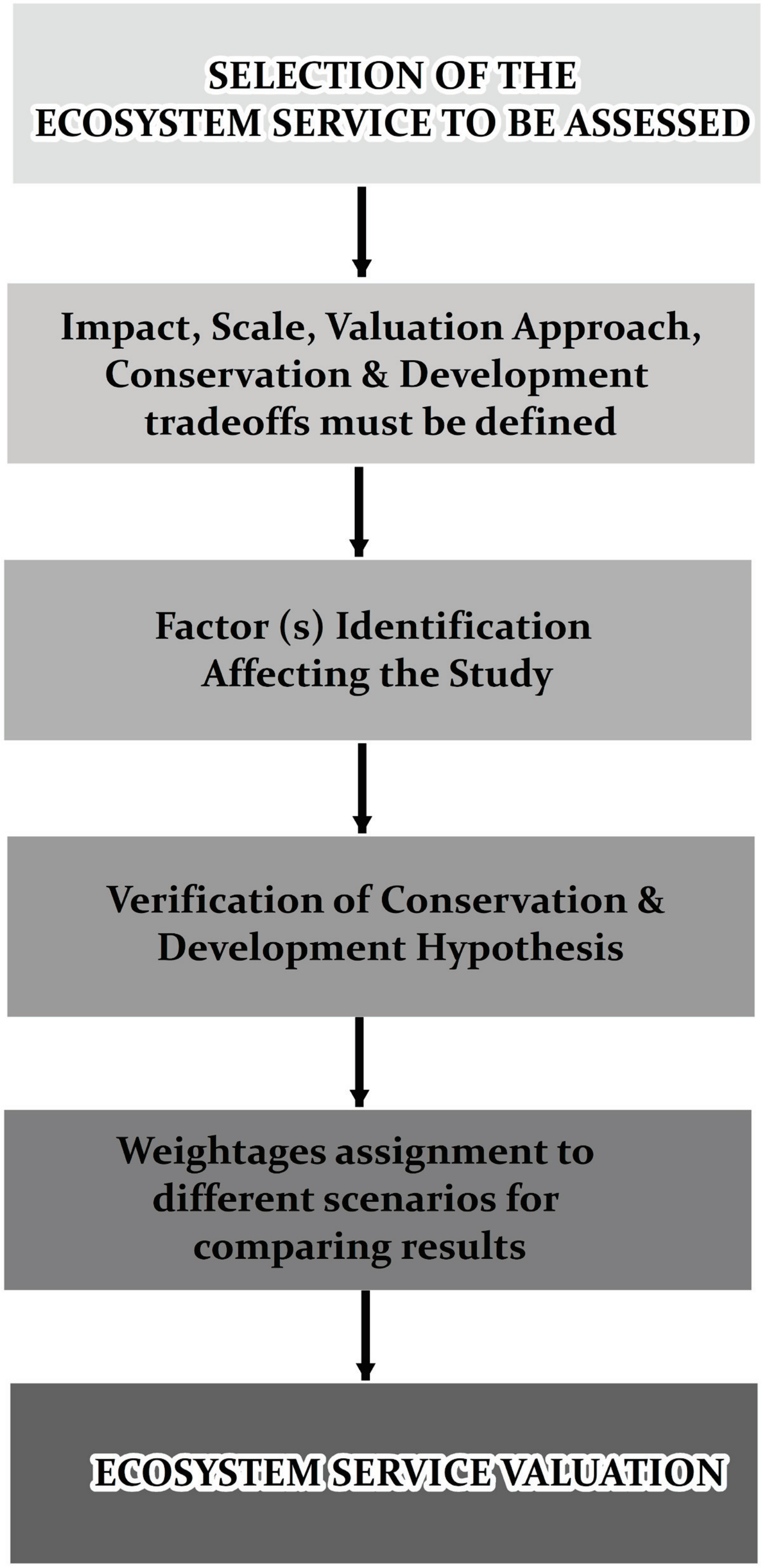


**Fig. 1.4** The most appropriate approach to choose the method for an ecosystem resource assessment. The different shades of grey depict the level and maturity of the stage

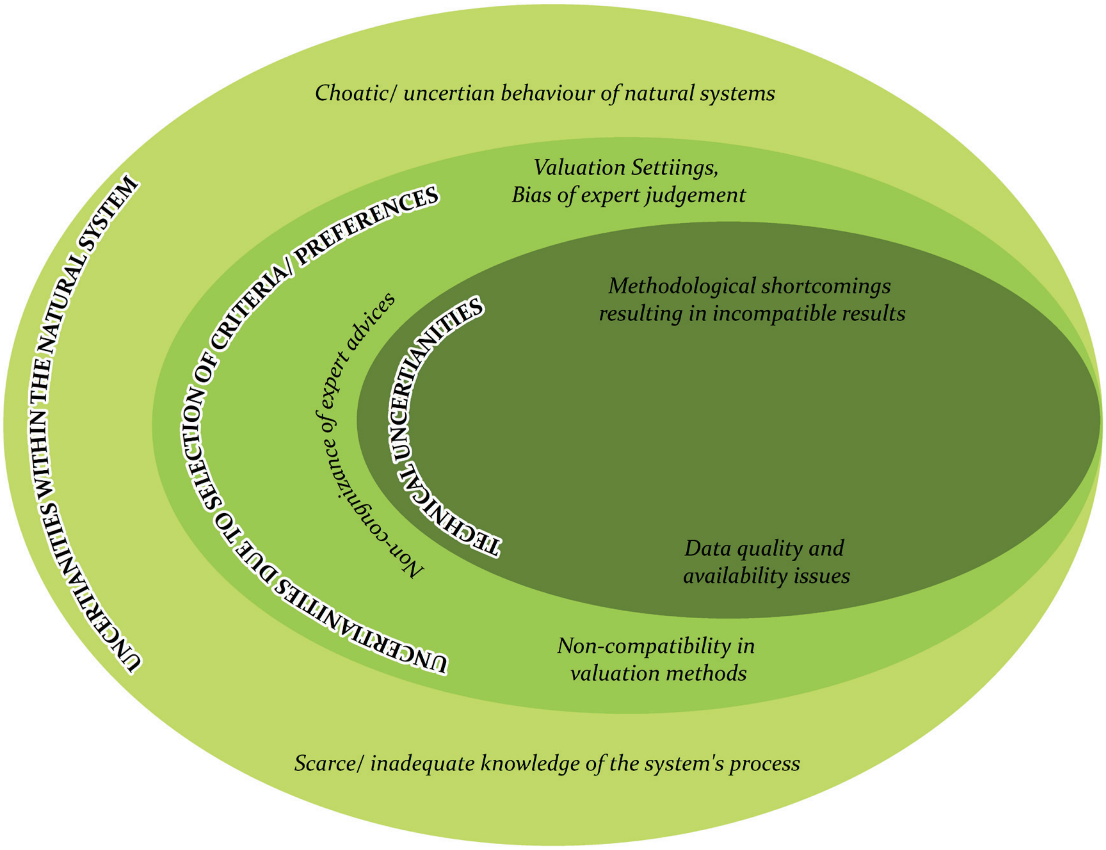


**Fig. 1.5** The uncertainties associated with the ecosystem resource is shown using a stacked Venn diagram

It is critical to combine biophysical spatial heterogeneity with economic valuation as a prerequisite for informed PA and support management actions, investment guidance, or PES planning and zoning (Payments for Ecosystem Services). As the park's restrictions are tightened, the value of each environmental function increases. This suggests that agricultural management in confined park areas prioritizes preserving other ecosystem resources over grazing benefits. On the other hand, grazing follows the opposite tendency, with its value declining as park protection increases, as evidenced in numerous national parks in Jammu and Kashmir, such as Dachigam National Park.

The environment that typically contributes the most to the park's overall worth is natural vegetation. This distinction between forest ecosystems holds true for the value of cultural and regulatory functions per hectare. The importance of forests as multifunctional ecosystems with a significant economic value has long been recognized in the literature. Grazing lands in the park provides the highest value of provisioning services. As a result, the value of preserving the landscape mosaic is recognized, as diverse ecosystems offer different services and contribute to social well-being.

### 1.4. Remote sensing and GIS for ecosystem resource mapping and assessment

Modern geospatial technologies such as Remote Sensing (RS), Geographic Information Systems (GIS), and the Global Positioning System (GPS) have resulted in the development of compelling methods for surveying, identifying, classifying, mapping, monitoring, and characterization, as well as for tracking changes in the composition, extent, and distribution of a variety of earth resources, both renewable and non-renewable, living and non-living in nature, as well as for tracking changes in the composition, extent, and distribution. Remote sensing (RS) is essential for delivering geo-information in a spatial/ temporal format and determining, expanding, and monitoring the earth's overall capacity. Arial observations of land, oceans, and atmosphere have become vital for protecting the global environment, reducing catastrophic losses, and achieving sustainable development, particularly during natural and human-caused disasters. Crop inventory and forecasting, analyzing drought and flood forecasting, and monitoring and regulating land usage could all benefit from this information. India is now one of the world's major providers of earth observation data, with a wide range of geographical, spectral, and temporal resolutions to meet the needs of a wide range of key national development applications.

GPS delivers globally precise positional coordinates, making it indispensable for determining the geographic location and creating context. GPS is an important monitoring technique since it provides for the acquisition of current, cost-effective in-situ data. GIS allows for the presentation of geospatial data, which is a convenient and effective way of transmitting complex information, such as natural resources, and raising our awareness of them. GIS also allows for the collecting, editing, storage, and analysis of spatial data, which is essential for planning and decision-making. Because it enables a geographical examination of natural resources and environmental concerns, the technology has been a game-changer. The key point is that GIS allows us to investigate problems by modeling a variety of phenomena and investigating their relationships, such as to cause and effect correlations, in a place-based context, allowing us to comprehend complex, interconnected challenges on local to global scales. While each of these ways is valuable in dealing with the assessment, their utility differs depending on the continuum element. While remote sensing is great for determining rates and trends, GIS is great for determining causes and effects. However, combining such spatial technology with other analytical approaches to obtain more precise data and increase our understanding of natural resource management is frequently desirable.

### *1.4.1. Geoinformatics – an emerging science*

Remote sensing, geographic information systems (GIS), global positioning systems (GPS), and simulation models are all part of geoinformatics, which is a fast-increasing field of research. The combination of these technologies allows for the capture of high-resolution real-time data via remote sensing, data administration, and analysis via GIS, ground truth data georeferencing via GPS, and the integration of all data into an information system and usage for a specific purpose. It's a new topic of study that brings together elements from numerous disciplines that deal with geographical data. Every input data is geocoded, which means it has a three-dimensional address and is associated with a position on the earth's surface. This is a key aspect that distinguishes geoinformatics from other disciplines of information technology. Thus, geoinformatics is the use of information technology to the study and management of earth resources.

### *1.4.2. Remote Sensing*

The technique of detecting, identifying, defining, and quantifying surface properties and associated processes from a distance without making physical contact is known as remote sensing. Remote sensing detects Electro Magnetic Energy (EME) that is reflected, scattered, or emitted by various surface features on the planet and is detected by the sun or the sensor (microwave sensor). It employs both passive and active sensors. Passive sensors detect natural radiations produced or reflected from the earth. On the other hand, active sensors produce their own electromagnetic radiation (e.g., LIDAR, RADAR). Radiance, not reflectance, is the term used to describe the radiation detected by a remote sensor from a scene or a specific location. Remote sensing satellites can determine surface properties by detecting and measuring spectral signatures. Remote sensing gathers multispectral, multisensor, and multi-temporal data, allowing for the creation of accurate, timely, and cost-effective natural resource information. Remote sensing can also be characterized as optical or microwave sensing. Sensors detect solar energy reflected/scattered or emitted from the planet in the visible, near-, middle-, and thermal infrared wavelength ranges, generating images similar to those captured by a camera/sensor situated high in orbit.

### *1.4.3. Aerial Remote Sensing*

Aerial photography was the first method of remote sensing, and it is still the most widely used. Images shot using a camera mounted on an airplane while flying over the ground at a predetermined height, depending on the aerial photography's scale and the camera's focal length, are known as aerial pictures. Following photographs typically overlap by 50 percent to 65 percent, which is required for stereo viewing and stereo pairing analysis. One of the key advantages of aerial photography is that it provides a three-dimensional image of the area/object when viewed via a stereoscope. Vertical/oblique aerial photographs, black and white aerial images, infrared aerial images, multispectral aerial images, and low or high altitude aerial images are all available. Aerial photographs are chosen at a given scale and type depending on the study's goals. Aerial pictures are especially useful when the area under study is small. Aerial remote sensing (aerial photography) has been used by the Survey of India and other Indian organizations to make maps of topography, geology, soils, forests, and land degradation.

### *1.4.4. Satellite-based remote sensing*

In 1960, the Television and Infrared Observation Satellite (TIROS-1) was launched, carrying a single-band television camera that returned the first cloud photos of the earth. This was the first weather satellite operated by the National Oceanic and Atmospheric Administration (NOAA) of the United States from April 1960 to July 1966. The United States of America successfully launched the Earth Resources Technology Satellite (ERTS-1) in 1972, subsequently known as LANDSAT, ushering in a new era of satellite remote sensing for natural resource assessment and monitoring.

Remote sensing has a wide range of applications that are growing all the time. The future of remote sensing is bright, thanks to the availability of a number of satellites, including the Indian Remote Sensing (IRS) Satellite, their sensors' expanding range and sensitivity, and sophisticated picture processing and interpretation capabilities. Remote sensing is now generally recognized as a critical instrument in meteorology, agriculture, crop damage and stress assessment, geology, hydrology, land use planning, urban development, ecology, and pollution monitoring, among other fields. Land use mapping, soil resource evaluation, and terrain analysis have all changed as a result of the low cost of remote sensing data. With the launch of the Landsat series of satellites by NASA in the United States, the SPOT satellite by France, and the Indian Remote Sensing Satellite (IRS) by the Indian Space Research Organization (ISRO), Ministry of Space, Government of India in the early 1970s, there has been an increasing reliance on satellite imagery for inventory and monitoring of natural resources in India and abroad. The NRSA Data Reception Station in Shadnagar, near Hyderabad, receives data from active IRS satellites such as IRS-1C, IRS-1D, IRS-P3, IRS-P4 (OCEANSAT), IRS-P6 (RESOURCESAT-1), and TES (Technology Experiment Satellite).

### *1.4.5. Geographical Information System (GIS)*

A Geographic Information System (GIS) is a database management system that efficiently stores, retrieves, manipulates, analyzes, and visualizes cartographic or thematic spatial data. A geographic information system (GIS) is a computer-based system that can manage large amounts of spatial data from a variety of sources, including field surveys, aerial surveys, and space remote sensing, as well as previously prepared maps and reports. This requires combining information from several sources onto a single platform. It requires accurate entity matching and data integrity across data sets. The key components of GIS are data intake, data encoding, data management, data analysis and modification, and data presentation or output.

Any mappable data has both spatial and non-spatial characteristics. For example, a feature with the property Z may exist at an X, Y coordinate point. The qualities can be qualitative (e.g., land use, geology, etc.) or quantitative (e.g., elevation, population, etc.), and they may change over time (e.g., temperature, land use, population, etc.). The majority of GIS data is made up of these three elements: location, attribute, and time. The ability to link each item of information to other spatially distributed (cartographic) data determines its true value, regardless of its source. Only if the various bits of data are saved in GIS format is this possible. The geographical reference cartesian or latitude/longitude coordinate system has proven to be an effective technique of integrating data sets, and this concept, maybe more than any other, is responsible for GIS's success.

The majority of GIS provides a feature that allows you to query data sets. It is feasible to answer more difficult questions and solve a far broader range of issues by running random queries through data sets of information. Geographic information systems (GIS) are commonly used to answer questions about location, condition, pattern routing, and modeling. The location inquiry comprises querying a database for information about a certain location (for example, what is the population of a specific area or tract?). The condition question, on the other hand, requires finding sites that display specified characteristics (for example, what is the change in traffic flow along roads?). The remaining topics are more involved and need spatial analysis in some way. The routing problem comprises finding the best (quickest, shortest, most picturesque, etc.) route between two points (e.g., which is the nearest surgeon specialist). The pattern question allows environmental and social scientists and planners to define and analyze the distribution of phenomena as well as the mechanisms that drive it (for example, is there a pattern in the distribution of diseases thought to be caused by radiation exposure?). The final question allows for the comparison of several world models (for example, how will a 20-centimeter rise in sea level affect different parts of the globe?).

The Geographic Information System (GIS) was used to combine spatial data on a number of resource themes and create alternative development plans for places with unique primary production activities. The suitability of various combinations of land characteristics such as soil, groundwater quality, slope, landform, and land use/land cover is linked to primary production activities using the GIS package's rule-based decision capabilities.

### *1.4.6. Global Positioning System (GPS)*

The Global Positional Technology (GPS) has altered positioning perceptions, despite its origins as primarily a navigation system. The Navigation System with Time and Range Sensitivity The Global Positioning System (NAVSTAR GPS) is a satellite-based radio navigation system that offers a precise three-dimensional position, navigation, and time information to appropriately equipped users. GPS receivers passively receive signals but do not transmit them. At any given time, there are at least 24 GPS satellites in operation. The satellites, which have a 12-hour orbital period, are operated by the US Air Force. Individuals are tracked precisely using ground stations. Each GPS satellite has an atomic clock and communicates information about its location and time. All GPS satellites work in unison to ensure that these repeating signals are transmitted at the same time. The distance between the GPS satellites can be estimated by calculating the time it takes for their signals to reach the receiver. The receiver can calculate its three-dimensional position by measuring the distance between at least four GPS satellites.

The majority of hand-held GPS systems have a 10-20 meter position accuracy. To improve precision, a technology known as Differential GPS (DGPS) is used. The installation of a second receiver in a "known" point nearby is required for DGPS. Positions obtained by roving devices are adjusted using observations made by a stationary receiver (Base station), resulting in a precision of greater than one meter.

Accurate navigation, hydrography, maritime geodesy, and geophysical and cadastral investigations are done using geoinformatics. This innovative surveying approach has a wide range of applications in a variety of industries, thanks to GPS's well-established high precision in pinpointing sites separated by a few hundred meters to a few thousand kilometers. Geodetic control surveys, which require the development of precise control points, are one of the most important applications. Earth subsidence and landslides are examples of mass changes that need to be monitored.

### *1.4.7. National (Natural) Resources Information System (NRIS)*

The National (Natural) Resources Management System (NNRMS) was decided to be backed up with a comprehensive information system for decision-makers to ensure ecologically responsible growth and optimal resource utilization. To that end, the Department of Space launched the National (Natural) Resources Information System (NRIS), which aims to provide decision-makers with information on natural resources like land, water, forests, minerals, and soils, as well as socioeconomic data like demographics, amenities, and infrastructure. The integration of multiple data sources would improve decision-making and contribute to the achievement of the Sustainable Development Goals of the Integrated Mission for Sustainable Development (IMSD). NRIS is being implemented on a national scale by the Department of Space in collaboration with several entities, including ISRO centers, the Department of Space, State Remote Sensing Centers, and private entrepreneurs across India. The NRIS is represented as a network of GIS-based nodes containing information on spatial resources. The NRIS node (district/state) consists of integrated spatial and non-spatial data elements, such as map inputs from remote sensing and traditional sources, as well as non-spatial data on socioeconomic and infrastructure issues at the village level.

### *1.4.8. Broad overview of the remote sensing and GIS applications in resource mapping*

Crop studies, drought monitoring and assessment, soil moisture determination, soil survey and mapping, land use/land cover mapping, wasteland mapping, watershed management, urban and regional planning, weather and climate studies, and flood mapping and damage assessment are just a few of the broad natural resource management application areas in which significant progress has been made in recent years in the country.

#### *Crop Investigations*

In agricultural studies, remote sensing and GIS can be divided into inventorying/mapping and management. While RS data is primarily utilized for inventory (for example, agricultural acreage estimation, crop condition assessment, and crop yield forecasts), it is also used for management (cropping system analysis, precision farming, etc.) RS data must also be linked to a variety of other spatial agro-physical/environmental data using GIS capability.

The use of remote sensing (RS) data to forecast agricultural production has been extensively investigated in India and many other parts of the world. The Monitoring Agriculture with Remote Sensing (MARS) initiative, established for the Commission of the European Communities (EEC) by the Joint Research Centre (JRC), delivers up-to-date agricultural information to European agricultural policymakers. It has shown how remote sensing, geographic information systems (GIS), and historical datasets may be used together to improve agricultural classification. Here are a few of the specific tasks for which Remote Sensing data and technology have been widely used, either alone or in conjunction with GIS:

- *Forecasting crop production*

Identifying crops, determining their acreage, and forecasting their output are all part of crop production forecasting. Crop identification and discrimination are based on each crop's unique spectral signature. The spectral reflectance of a typical crop shows pigment absorption in the visible range, high reflectance in the near-infrared area due to the internal cellular structure of the leaves, and absorption in the short wave infrared region due to water content. (i) The leaf area index (LAI) and ground cover %, (ii) development stage, (iii) cultural practices, (iv) stress situations, and (v) canopy architecture determine the spectral response of a crop canopy. A crucial determining factor is the underlying soil/water. Each crop has its unique design, growing season, and other features, allowing RS data to be used to differentiate them. Multi-date data can be used to identify two crops that have identical spectral signatures on a given date (confusion crops). The ratio of near-infrared to red radiance has been found to be a helpful indicator of crop vigour. Several of these characteristics are used to identify crops, forecast yields, and measure crop health.

- *Calculation of the acreage*

Quantitative analysis of minor changes in spectral data is required for the identification and discrimination of various crops/land cover classes, which is generally performed via digital image processing techniques. Finding sample sites of various crops/land cover classes on the image based on obtained ground truth, establishing signatures for distinct training sites, and classifying the image using training data are the main processes in the acreage estimation technique. Previous studies have mostly relied on single-date data corresponding to the crop's near-maximal vegetative development stage. Historically, estimating acreage at the district level has been done by evaluating all available data. Estimating crop acreage over large areas, such as states, necessitates the handling of a large amount of data, enhanced ground truth data collection operations, and so on. In this case, sampling techniques-based procedures were developed and successfully deployed. Based on crop concentration data, agrophysical, and/or agroclimatic characteristics, the study region is divided into homogeneous strata, and sample segments from each stratum are analyzed. In general, digital data analysis involves ten percent of the population. At the strata and research area/state levels, the results are aggregated using appropriate statistical processes. Furthermore, since the 1995-96 season, multi-date IRS-1C/1D, WiFS, and LISS-III data, a supervised hierarchical classification approach, and agro-meteorological yield models have been used to make national-level forecasts for wheat production in India's important wheat-growing states. The lack of cloud-free optical sensor data is a major problem, especially during the Kharif season. It was studied if microwave sensor data collected in the C band at large incidence angles might be used to estimate and monitor rice crop area during the Kharif (monsoon) season. All varieties of lowland cultivars were classified with 90% accuracy using temporal data obtained throughout the rice transplanting, vegetative, and grain filling stages. Using LISS-III data with high spatial resolution, a variety of horticulture crops, such as mango, coconut, areca nut, orange, and banana, could be identified and their area calculated.

- *Forecasting yields*

Crop genotype, soil attributes, cultural practices (e.g., irrigation, fertilizer), climatic circumstances, and biotic influences such as weeds, diseases, and pests all have an impact on yield. The spectral data of a crop provides a complete picture of the impact of all of these factors on its growth. RS data or derived parameters are directly related to yield; RS data are used to estimate many biometric characteristics that are then used as input parameters in a yield model; and RS data are used to estimate numerous biometric characteristics that are then utilised as input parameters in a yield model. The crop canopy's spectral index (NIR/Red, Greenness, and NDVI) indicates the crop's growth and deterioration as a function of several time-dependent characteristics at any given point in time. Using space-borne data at maximum vegetative cover and other growth profile parameters such as leaf area index, attempts have been made to establish a relationship between yield and spectral index (LAI).

- *Forecasting Agricultural Output Using Space, Agro-meteorology, and Land-based Observations (FASAL)*

Recognizing that remote sensing data cannot provide a stand-alone system for creating multiple and trustworthy forecasts, and recognizing the vital importance of agro-meteorology in determining crop growth and yield, a new programme, FASAL, has been conceptualized and is being institutionalized. A pilot study using FASAL multiple forecasting systems was carried out in Orissa. Forecasts for rice and wheat at the national level are being prepared as part of the FASAL project's technique development, employing multi-date microwave and optimal data, respectively, and a hierarchical categorization approach. FASAL has been spread to eight more Indian states.

- Crop *condition* evaluation

Efforts are being made at the Space Applications Centre (SAC) in Ahmedabad to develop a technique for identifying and monitoring crop stress and conditions using satellite data. In the Vanthali taluk of Junagadh district, Landsat MSS data were used to detect moisture stress in groundnut crops. While resource satellites like IRS and Landsat can provide precise geographic information on crop condition, their utility for regional or large-area crop condition research is restricted because to their relatively long repetition cycles and massive data volume. Ajai and Sahai (1986) proposed combining relatively high-resolution earth resources satellite data with coarse-resolution meteorological satellite data to measure agricultural quality (NOAA-AVHRR). Liu and Kogan (1996) tracked large-scale drought patterns and their climatic repercussions for vegetation using NDVI images collected from NOAA-AVHRR GVI (Global Vegetation Index) data. The VCI (Vegetation Condition Index) and the TCI (Temperature Condition Index) were developed by Kogan (1994) for drought monitoring. TCI is the proportion of brightness temperature compared to its maximum amplitude, whereas VCI is the percentage of NDVI relative to its largest amplitude (taken from NOAA-AVHRR channel 4). India created the National Agricultural Drought Assessment and Monitoring System (NADAMS) in 1986, which integrated NOAA satellite RS data with ground observations of rainfall and agricultural conditions.

- *Analysis* of the cropping system

The component method of agricultural research was recognised in the mid-1980s as insufficient to maintain the level of agricultural output achieved during the Green Revolution era. A systemic approach that takes into account the interaction of agriculture's biotic and abiotic components over time and space is being considered as a possible option to achieving sustainable agriculture production. As a result, the cropping system technique was developed, which involves examining cropping patterns and associated management requirements in order to maximize the benefits derived from a particular resource base under specific environmental conditions. A sustainable agriculture system must be chosen based on available water, suitability for long-term production increases in a given agro-climatic zone, as well as household, market, and pricing demand.

- Drought surveillance and assessment

Crop conditions must be monitored at regular intervals during the crop growth cycle in order to determine appropriate therapeutic activities and estimate the possibility of production loss. The VI, which is calculated from space-borne data, is sensitive to crop moisture stress and can be used as a proxy for agricultural drought. Since 1987, the "National Agricultural Drought Assessment and Monitoring System (NADAMS)" has been monitoring drought throughout the Kharif (south-west monsoon) season using temporal NOAA-AVHRR data to construct the Normalized Difference Vegetation Index (NDVI) (NDVI). To infer stress conditions, the current season's NDVI profile is compared to that of a normal year. In-situ rainfall and other agricultural practises observations, as well as the availability of AWiFS data, is required to perform this analysis. The precision of drought evaluation has risen greatly thanks to the availability of microwave satellite data. During the monsoon season, the National Agricultural Drought Monitoring System (NADAMS) initiative uses satellite-derived NDVI data to provide district-level information fortnightly.

- Determination of soil moisture

Determining the moisture content of the soil is important in a number of ways. Microwave remote sensing has the potential to measure subsurface moisture, while other remote sensing techniques can be utilized to identify and designate areas with various degrees of soil moisture. Irrigation engineers and agriculturists alike need to know this information. Additionally, single frequency, polarisation, and look angle SAR data were used to create models for assessing soil moisture.

***Soil survey and mapping***

For agricultural planning, soil data is required. It's a three-dimensional quantity that demands not only image interpretation but also soil profile investigation across several places. Satellite data enables profile investigations to be reduced, their location optimised, and soil association borders to be delineated. Satellite remote sensing data has mostly been used in analogue (picture) and digital formats for research purposes. Visual interpretation and computer-aided interpretation are the two approaches for interpreting satellite data. Visual interpretation techniques were used in India to delineate soil interactions. A combination of physiographic and photo element approaches complemented by limited field verification has been extensively utilised because to its adaptability to a variety of terrain conditions and mapping scales. In India, soil maps demonstrating the relationship of Great Groups, subgroups, and families have been generated by state and national level organisations using a combination of satellite and aerial data.

The mapping of soils at various scales, ranging from 1:250,000 to 1:50,000, with the abstraction level of subgroups/associations thereof and family association, is possible because to the combination of remote sensing data and supplementary information such as lithology and physiography. High-resolution stereo pictures have been demonstrated to be useful for providing information on soil resources at 1:12,500 scales, which is necessary for micro-level optimal land-use planning. Furthermore, derivative data such as land capability, land irrigability, erodibility, reclamability, and crop suitability has been obtained, allowing for the construction of an optimal land use plan and the implementation of appropriate land reclamation operations.

***Mapping land use/ land cover***

Data flow has been made easier in a range of applications thanks to remote sensing technology. Earth observation satellites are essential tools for mapping and monitoring changes associated with urbanisation, as well as identifying tourism development places and their impact on flora and wildlife, mining, and the transportation network. Furthermore, remote sensing techniques allow for the examination of a difficult terrain's complex land use/land cover system as well as the creation of complete management plans. The multispectral data from the IRS-1A/1B/1C/1D satellites was used to create national landuse/land cover maps at the district level. In terms of spatial resolution, spectral band addition, stereoscopic image acquisition, and temporal resolution, IRS IC/ID are more capable than IRS IA/IB. The imaging sensors on IRS-IC/ID satellites are a panchromatic camera with a resolution of 5.8 metres, a linear imaging self-scanner (LISS-III) with a resolution of 235 metres, and a wide field sensor (WiFs) with a spatial resolution of 188 metres. The combined PAN + LISS-III data are being used to map landuse/land cover on a 1:50,000 scale for several projects, including the National (Natural) Resource Information System (NRIS) of the Department of Space and the Natural Resources Development Management System of the Department of Science and Technology (NRDMS). The LISS-IV camera on board the IRS-P6 (Resourcesat-1) satellite, which was launched in October 2003, is now gathering multispectral data with a spatial resolution of 5.8 metres. This information will be particularly useful for land use mapping at Levels III and IV, which is difficult to do with IRS-LISS-III data.

The purpose of a landuse/land cover categorization system is to enable and organize/group the multitude of accessible information within a logical framework so that systematic inventory and mapping, as well as the incorporation of landuse characteristics obtained from satellite and other sources, can be done. At a scale of 1:25,000, the established paradigm for land use/land cover classification is applicable to remote sensing satellite data. The NRSA-developed landuse/land cover classification system (NRSA, 1989) looks at the distinctions between Level-I, Level-II, and Level-III land use/land cover classes. Level-I provides a broad classification of numerous landuse classes, whereas Levels II and III provide more detailed information on individual landuse classes.

***Analyses of land use and land cover change in a mountainous terrain***

The difficult topography and inaccessibility of mountainous locations make acquiring information necessary for effective natural resource management practically impossible. Remote sensing has proven to be capable of providing this type of data. Ghosh *et al.* (1996) looked into land-use changes in the Pranmati watershed in Chamoli district, part of the Ganga's catchment basin. To combine remote sensing data with other geographical and non-spatial data, the ARC/INFO software was employed. A basic classification technique was employed to examine changes in land cover/land use in relation to elevation, slope, aspect, and bioclimatic classes. A GIS software tool was used to examine the suitability of land exploited for agricultural extension between 1963 and 1993.

The agricultural land expansion was found to be greatest at elevations of 2200-2400 m and slope slopes of 20-30°. When topographic considerations are taken into account, south-east and west-facing slopes expand the most. It is estimated that 15% of vegetative cover was lost between 1963 and 1993. However, it was shown that forest cover renewal was greatest between 1600 and 2000 meters, with the bulk of slopes between 20 and 30 degrees.

The quality of alpine grazing lands can be analyzed using remote sensing and GIS. Using Sentinel satellite-based NDVI maps, various studies have assessed the changing quality of the grazing lands throughout the growing season. This way, the carrying capacity and the potential impact of overgrazing on such lands have been effectively evaluated.

***Mapping of wastelands***

Current information on their geographical position, aerial extent, and spatial distribution is required for planning the development of degraded lands, including erosion-affected and waterlogged soils. Village records, which are essentially statistical in nature, have traditionally been used to compile information on various sorts of wastelands. In recent years, the types of wastelands, their correct spatial distribution, and the timely availability of information have become increasingly important to the country's planners. Remote sensing is a huge step forward in collecting data on natural resources. Land degradation research includes determining the scope of the problem, the severity of the harm, and the degree to which the situation is reversible or manageable in practice.

Maps depicting the breadth, spatial distribution, and degree of degraded lands, salt-affected soils, waterlogged areas, and shifting cultivation, to name a few, were created at 1:250,000 and 1:50,000 scales using multispectral data from space. A thirteen-tier classification system has been established to distinguish between cultivable and uncultivable wastelands. A digital atlas exists in India currently. Land reclamation and soil preservation programs are being developed using this information. There are 63.85 million hectares of wasteland in the country. A settlement, a forest compartment, and a micro watershed are all represented on each map.

Both visual and digital analyses of satellite data were used to map the wastelands. 532 of the 584 districts were mapped using visual analysis of satellite data, while the remaining 52 districts were mapped using digital analysis. Image attributes such as tone, colour, texture, pattern, shape, size, and association were used to create and map a number of wasteland categories. Aside from wasteland classifications, the final maps incorporated the transportation network (roads, trains), habitations, and village boundaries to help planners locate various wastelands on the ground during the formulation and execution of various wasteland management and reclamation programmes.

The countrywide wasteland mapping project covered 316.64 million hectares, including 584 districts, out of the country's 328.72 million ha geographical area. Jammu and Kashmir has 12.1 million hectares of unexplored land. Wastelands covered 63.85 million hectares (20.17 percent) of the total geographical area of the 584 districts. The distribution of wastelands by category reveals that land with or without brush has the most significant share (6.13 percent), followed by underutilized forestland (4.44 percent ). The former can be found primarily in India's southern states, while the latter may be found all around the country.

Due to snow cover and degraded forest, a high percentage of area under wasteland exists in Jammu & Kashmir (64.55 percent) and Himachal Pradesh (56.87 percent); Nagaland (50.69 percent), Assam (25.52 percent), Manipur (58 percent), Meghalaya (44.16 percent), and Mizoram (19.31 percent) due to shifting cultivation; Kerala has a minimum of 3.73 percent wastelands due to water resource exploration and monitoring.

***Mapping Water Bodies***

Multispectral data has long been used to map and monitor the aerial extent of surface water bodies/reservoirs. Multi-date satellite photos are used to update reservoir area capacity curves to aid in computing storage capacity. End-of-season review of canal command regions at a disaggregated level and diagnostic examination of problematic distributaries to enable follow-up remedial management are two examples of satellite remote sensing capabilities currently available for irrigation water management. The Indira Gandhi Nagar

Pariyojana has demonstrated a system for calculating crop water requirements using remote sensing and GIS capabilities in conjunction with collateral data for two command regions.

For accessing subsurface/groundwater, hydro-geomorphological maps portraying groundwater prospect areas on a scale of up to 1:25,000 can be created. The underlying rock formations, their structural fabric and geometry, and their surface expression influence groundwater dispersal in space and time. Remote sensing data provide information about the geology, geomorphology, structural pattern, and recharge conditions that eventually define the groundwater regime when paired with adequate ground truth information. Groundwater prospect maps have been developed using satellite and ground data to identify prospective drilling locations. These maps indicate the yield range at different depths and possible locations for recharging aquifers and water collecting facilities. This kind of work has contributed to discovering potable water supplies for underprivileged villages. As part of the Rajiv Gandhi National Drinking Water Mission, additional detailed maps at a scale of 1: 50,000 have been generated in a GIS framework for ten priority states. Feedback indicated a greater than 90% success rate when wells were drilled based on RS data's groundwater prospect maps. These maps have been routinely used to locate prospective groundwater sites in and around troubled villages. Remote sensing can also be used to find suitable recharging areas for aquifers, such as porous lithologies, maximum fractures, severely weathered regions, flood plains, and null slope regions.

Surface water bodies have been mapped, their spread monitored, and water volume empirically estimated using synoptic and recurring data from EO satellites. Irrigation scheduling has been made easier by tracking reservoir expansion over time. Snowmelt runoff forecasts are based on IRS-AWiFS and NOAA–AVHRR data. Reservoir management boards have used these estimates to better plan their water resources.

***Mapping and managing of watersheds***

To ensure the most efficient use of natural resources, watershed-based development programs are being implemented. A watershed is a natural hydrological unit that comprises a defined area within which all rainfall-runoff eventually flows through a particular channel at a specific location, as is frequently characterized. Watershed management planning requires information on the natural resources of the watershed. The watershed's various attributes, such as the stream network (drainage), physiography, land use, vegetation/forest cover, and snow cover, can be mapped and monitored using remote sensing data. Delineation and Codification of watersheds; prioritization of watersheds; a complete soil inventory of the catchments' very high and high priority watersheds; treatment of the catchments' very high and high priority watersheds; and evaluation and monitoring of the treatment's impact are all part of the strategic planning process used to build watersheds. This is crucial for watershed water and land resource conservation and management in order to maximize productivity.

***Resource mapping for regional and urban planning***

Infrastructure development is crucial for the success of any country, but it is vital for a developing country like India. The country has completed various infrastructure development projects by combining high spatial resolution remote sensing data with powerful image processing technologies, GIS, and GPS. Vision and development plans for metropolitan regions, road alignment and rural road connectivity, rating of micro-hydropower plant locations, and extensive facility and utility planning are among the physical infrastructure projects. Other critical areas being addressed include urban flood modeling, urban environment and impact assessment, automated feature extraction techniques for roads, urban drainage planning, and modeling, disaster-resilient 3D city models, peri-urban area mapping and monitoring, solid waste/landfill sites, archaeology, and heritage building site identification, and utility GIS.

***Areas of future emphasis for resource mapping using RS/GIS technology***

While data from various earth observation systems have been widely used in different natural resource management domains, there are still gaps. The data requirements for the application at various degrees of detail have not been met. Identifying and quantifying short-term and marginal crops grown on fragmented land holdings, particularly during the Kharif season; improved yield models; detection and quantification of crop stress caused by nutrients or pathogens; information on the subsurface horizons of the soil; soil loss determination and identification of lands affected by the sheet and rill erosion; and determining the depth of water in reservoirs, as well as the depth and quality of groundwater

Many large-scale national-level applications in the fields of sustainable agriculture, water security, environmental security, weather, climate change studies, infrastructure development, and disaster monitoring and mitigation may be enabled with the launch of satellites (some of which are already operational), such as IKONOS-II, Quick Bird-2, Resourcesat-1, Cartosat-1&2, SPOT-5, RISAT, Advanced Land Observation Satellite (ALOS), and Hyperion.

### 1.5. Aims and objectives of this work

The key objectives (and outcomes) of this work are underlined below

1. Generation of the corrected project area boundary (KHANP Boundary).
2. Land use/land cover (LULC) change maps of 1990, 2020, 2010, and 2020 in geo-database and statistics for understanding the changing LULC and formulating management strategies
3. Change assessment with statistics and cross-matrix table; map compositions; point vector layer showing locations of a specific change—geo-tagged photographs, especially for the LULC change areas through the mobile application.
4. Administrative layer containing district boundary, district name in GIS format. Base layer containing roads, settlements, water bodies, and drainage.

# CHAPTER-2

# CHAPTER – 2
# KISHTIWAR HIGH ALTITUDE NATIONAL PARK, DESCRIPTION OF ITS GEOENVIRONMENTAL SETTING

This chapter uncovers various aspects of the geoenvironmental setting of the Kistiwar High Altitude National Park. The data presented and analyzed in tables and figures are primary data generated specifically for the present work. The park is 2191.50 sqkm as per the latest notification of the Government. The boundary of the National Park shifted eastern side to exclude all the human habitations already located within the national park (21 Villages) (Fig. 2.1). As per the new proposal, no human settlement is situated in the National Park. The area under National Park is wild, impregnated with a number of perpetual snow-capped peaks, glaciers, mountains, alpine meadows and scrub, subalpine forests, and temperate forests forming a very crucial part of the ecosystem of the National Park and the sustenance of river Chenab downstream. It comprises the habitat of some of the rarest and endangered species such as Snow leopard, Himalayan brown bear, Ibex, musk deer, Golden eagle, Lammergeier (Vulture), pheasants such as Himalayan monal, western tragopan, cheer, and other birds.

The park area is comprised of upper catchments of Renai, Kiyar, Nanth, and Kiber Nallahs and includes compartments such as 75, 76, 77, 78, 79, and 80 of Marwah Forest Range and the compartments such as 24c, 24d, 24e, 24f, 24g, 24h, 24i, 24j, 24k, 24l, part of 29d beyond Hokrar, 29e, 29f, part of 30c beyond 1km from kibber village, 30d and 30e of Dachhan Forest Range and the un-compartmentalized high altitude areas in the upper catchments of these nallahs are also part of the national park. The track is mostly precipitous, rough, and rugged. The National Park area comprises steep slopes and high ridges broken by rocky cliffs and mostly narrow valleys.

The notification regarding the intention of Govt. for constitution of Kishtwar High Altitude National Park covering an area of 425 sq km in pursuance of section 35 of J&K Wildlife Protection Act,1978 was issued vide S.R.O.No.135 dt:10-04-1990 with its following boundaries:

| | | |
|---|---|---|
| a) East | = | Very high mountain range (Brammah to Nunkun) |
| b) North | = | River Rin Nai and Zanskar Mountain |
| c) West | = | River Marwah and Human Habitation |
| d) South | = | Orographic left ridge of Kiber Nallah |

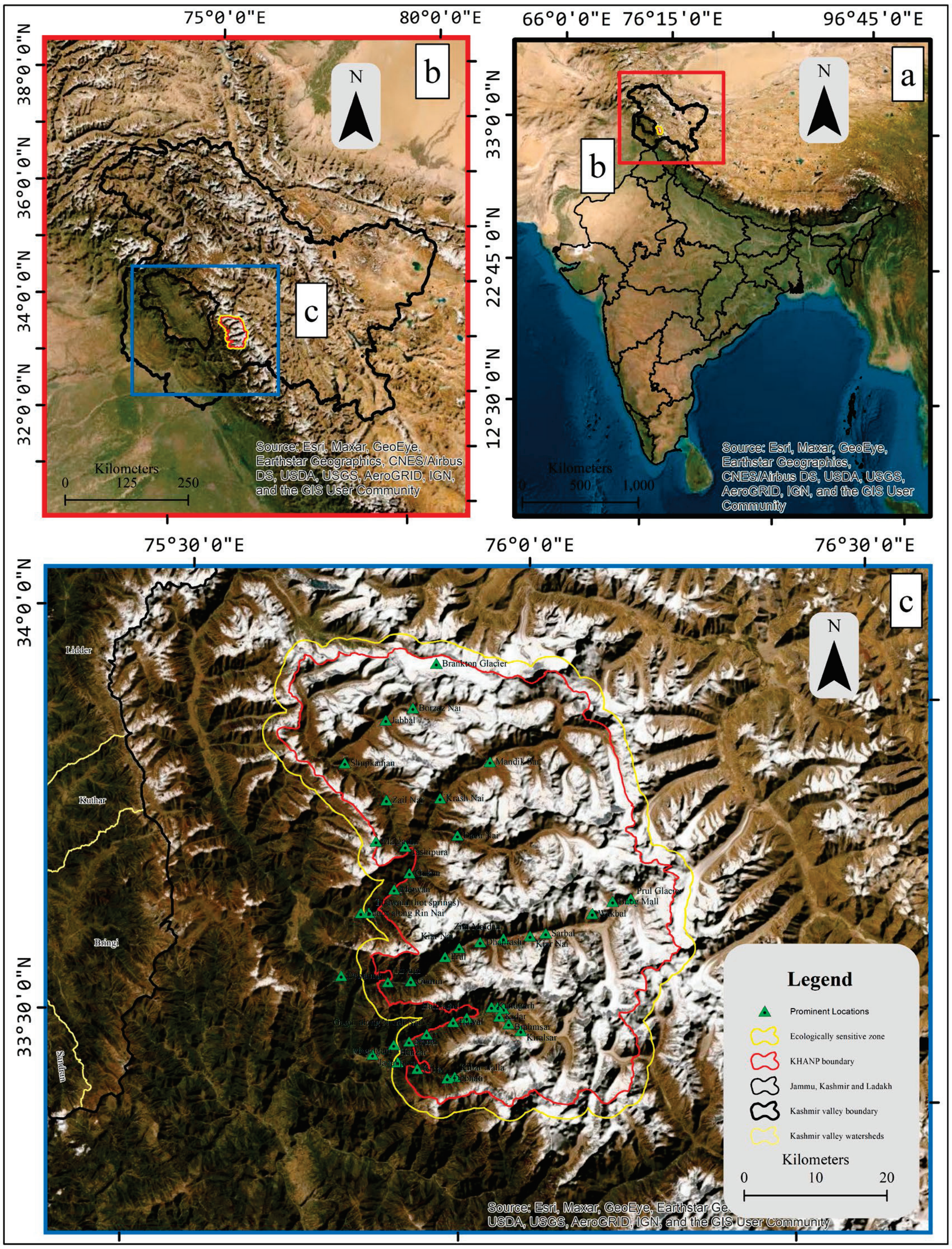


Fig. 2.1 Location map: **a** The location of the erstwhile state of Jammu and Kashmir in relation to India (Red Square); **b** The location of Kishtiwar High

Altitude National Park in relation to Kashmir valley (Blue Square); **c** The location of Kishtiwar High Altitude National Park in relation to Kashmir valley (Blue Square). The map coordinates are in the UTM 43 (North) World Geodetic System (WGS-1984) reference system

As per the new proposal, the boundary of the National Park is as follows.

- East: The ridge separating Kargil District from Kishtwar district
- North: The ridge separating the watersheds of Kainthal and Kulhoyan Nallahs
- West: The permanent villages in the bank of Renai, Kiar, Nanth, and Kiber nallahs
- South: The orographic left ridge of Kiber nallah from Brammah peak up to Kiber village

The National Park spreads from the watershed ridge to the first permanent village downstream.

Kishtiwar High Altitude National Park has its unique geoenvironmental setting, as is seen with other similar biodiversity priority regions of the country. In the following sections, geology, geomorphology, lithology, soil type, elevation, slope, aspect, drainage, and climate characteristics of the NP are discussed.

### 2.1. Geology of KHANP

It has been found that KHANP comprises six geological classes. The highest geological class found in the NP is of Denudational Hills comprising of 1304.21sqkm (59.51%) followed by Glacial Plain (794.48 sqkm, 36.25%), Piedmont Zone (31.84 sqkm, 1.45%), Structural Hills (31.79 sqkm, 1.45%), Eolian Plain (20.73 sqkm, 0.95%) and the least area found under Waterbody class (8.45 sqkm, 0.39%) (Table 2.1, Fig. 2.2 and 2.3).

**Table 2.1** Area under different geological classes found in the Kishtiwar High Altitude National Park

| S No. | Geology | Area in Sqkm | Percent Area |
|---|---|---|---|
| 1 | Denudational Hills | 1304.21 | 59.51 |
| 2 | Eolian Plain | 20.73 | 0.95 |
| 3 | Glacial Plain | 794.48 | 36.25 |
| 4 | Piedmont Zone | 31.84 | 1.45 |
| 5 | Structural Hills | 31.79 | 1.45 |
| 6 | Waterbody | 8.45 | 0.39 |

The general rock formation of the National Park belongs to the Central Himalayan Crystalline group. The geological formation is the result of succession from Precambrian to Triassic. The rocks are at pieces strongly folded. The rocks are composed of mainly granite, gneisses, and schist with occasional marble beds. The soil is mostly alluvial with gravel deposits. The soil cover of the area is shallow with alkaline to natural in reaction.

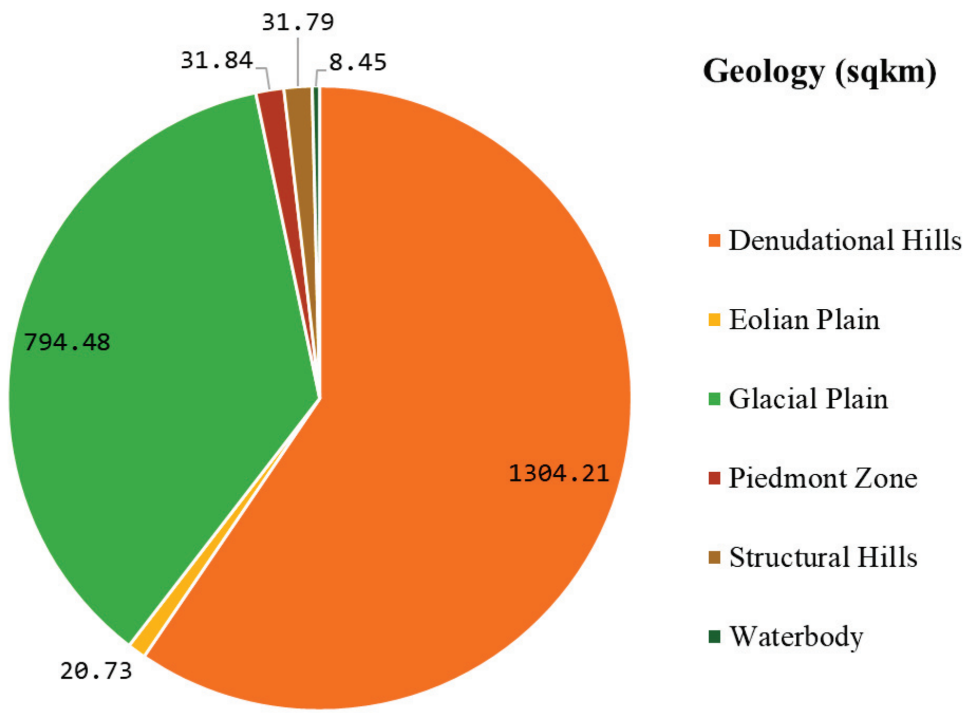


**Fig. 2.2** Pie-chart representing the relative area of geological classes in the Kishtiwar High Altitude National Park

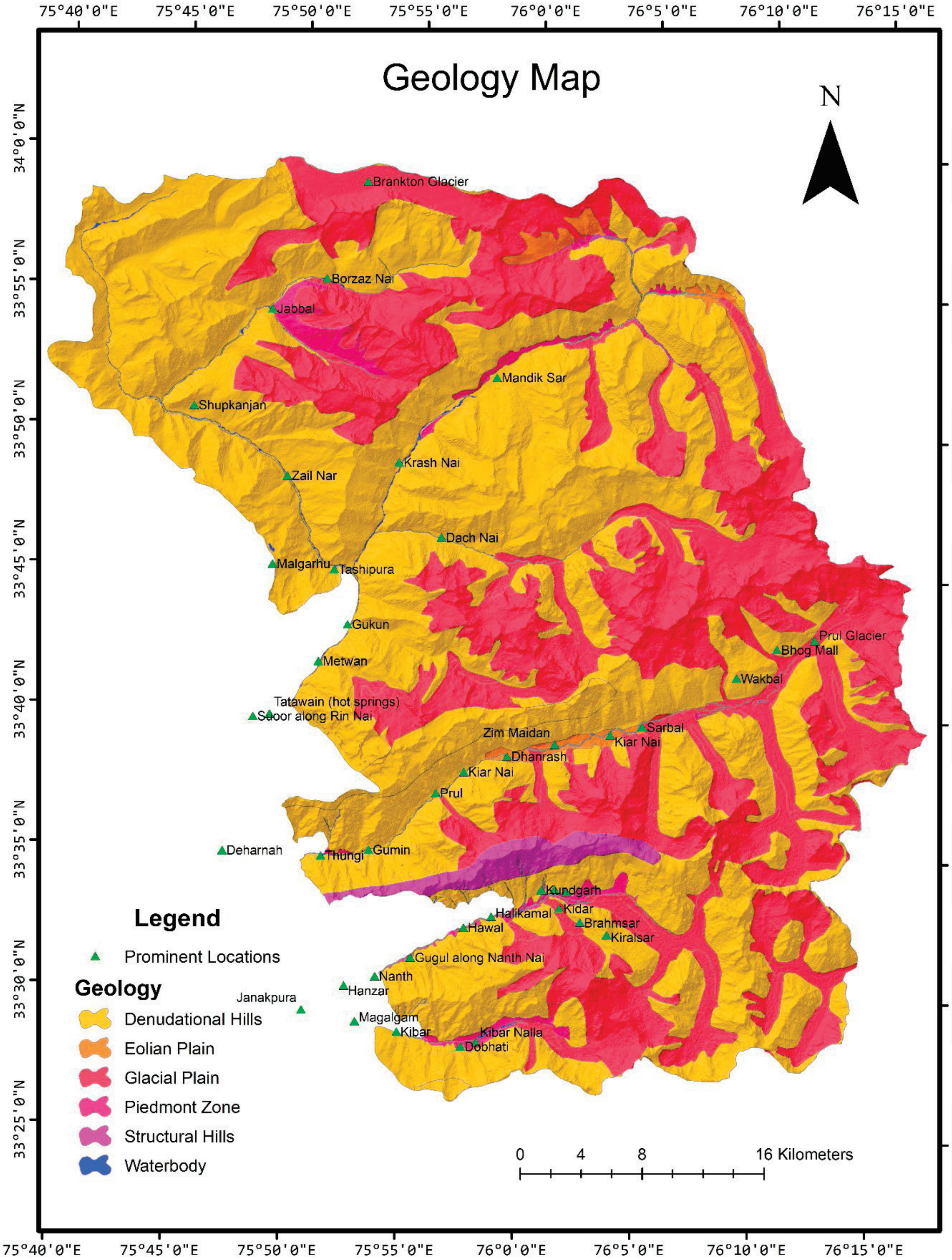


**Fig. 2.3** Spatial distribution of geological classes in the Kishtiwar High Altitude National Park

### 2.2. Geomorphology of the KHANP

It has been found that KHANP comprises of 17 geomorphological classes, although only 15 have significant areal extents. The highest geomorphological class found in the NP is of massive type denudational hills (small) comprising of 1087.31 sqkm (49.61%) followed by glacial valley (702.80 sqkm, 32.07%), ridge type denudational hills (114.59 sqkm, 5.23%), dome type denudational hills (small) (69.00 sqkm, 3.15%), morainous plains (47.65 sqkm, 2.17%), dome type denudational hills (large) (39.25 sqkm, 1.79%), ridge type structural hills (large) (30.28 sqkm, 1.38%), terminal moraine (29.74 sqkm, 1.36%), talus cones (21.15 sqkm, 0.97%), bazada (16.59 sqkm, 0.76%), lateral moraine (15.00 sqkm, 0.68%), lower peidmont slope (13.00 sqkm, 0.59%), alluvial fan (3.12 sqkm, 0.14%), intermountain valley/structural valley (1.73 sqkm, 0.08%), and the least area was found under upper piedmont alluvium –deep (0.19 sqkm, 0.01%) (Table 2.2, Fig. 2.4 and 2.5).

**Table 2.2** Area under different geomorphological classes found in the Kishtiwar High Altitude National Park

| S No. | Geomorphology | Area in Sqkm | Percent Area |
|---|---|---|---|
| 1 | Alluvial fan | 3.12 | 0.14 |
| 2 | Bazada | 16.59 | 0.76 |
| 3 | Dome type denudational hills (large) | 39.25 | 1.79 |
| 4 | Dome type denudational hills (small) | 69.00 | 3.15 |
| 5 | Flood plain | 0.00 | 0.00 |
| 6 | Glacial outwash | 0.09 | 0.00 |
| 7 | Glacial valley | 702.80 | 32.07 |
| 8 | Intermountain valley/structural valley | 1.73 | 0.08 |
| 9 | Lateral moraine | 15.00 | 0.68 |
| 10 | Lower peidmont slope | 13.00 | 0.59 |
| 11 | Massive type denudational hills (small) | 1087.31 | 49.61 |
| 12 | Morainous plains | 47.65 | 2.17 |
| 13 | Ridge type denudational hills | 114.59 | 5.23 |
| 14 | Ridge type structural hills (large) | 30.28 | 1.38 |
| 15 | Talus cones | 21.15 | 0.97 |
| 16 | Terminal moraine | 29.74 | 1.36 |
| 17 | Upper piedmont alluvium -deep | 0.19 | 0.01 |

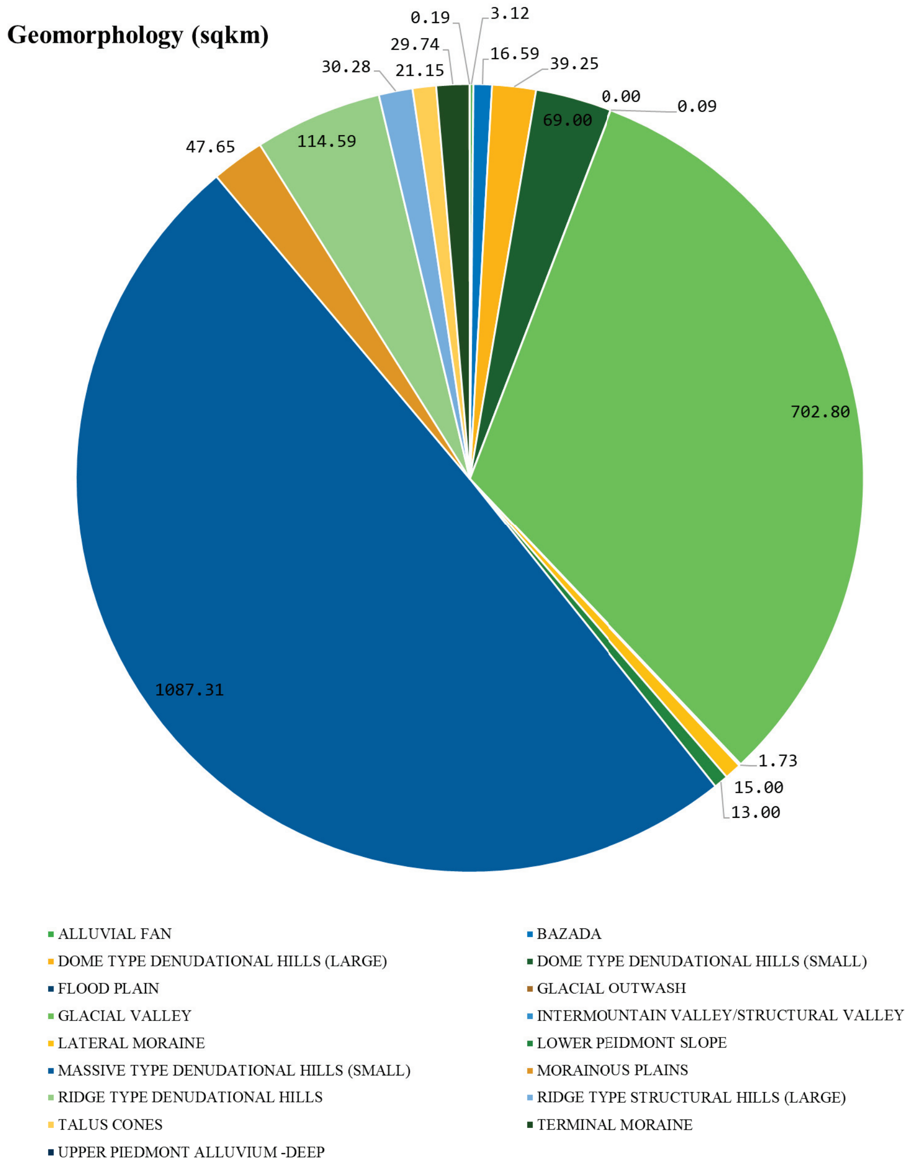


**Fig. 2.4** Pie-chart representing the relative area of geomorphological classes in the Kishtiwar High Altitude National Park

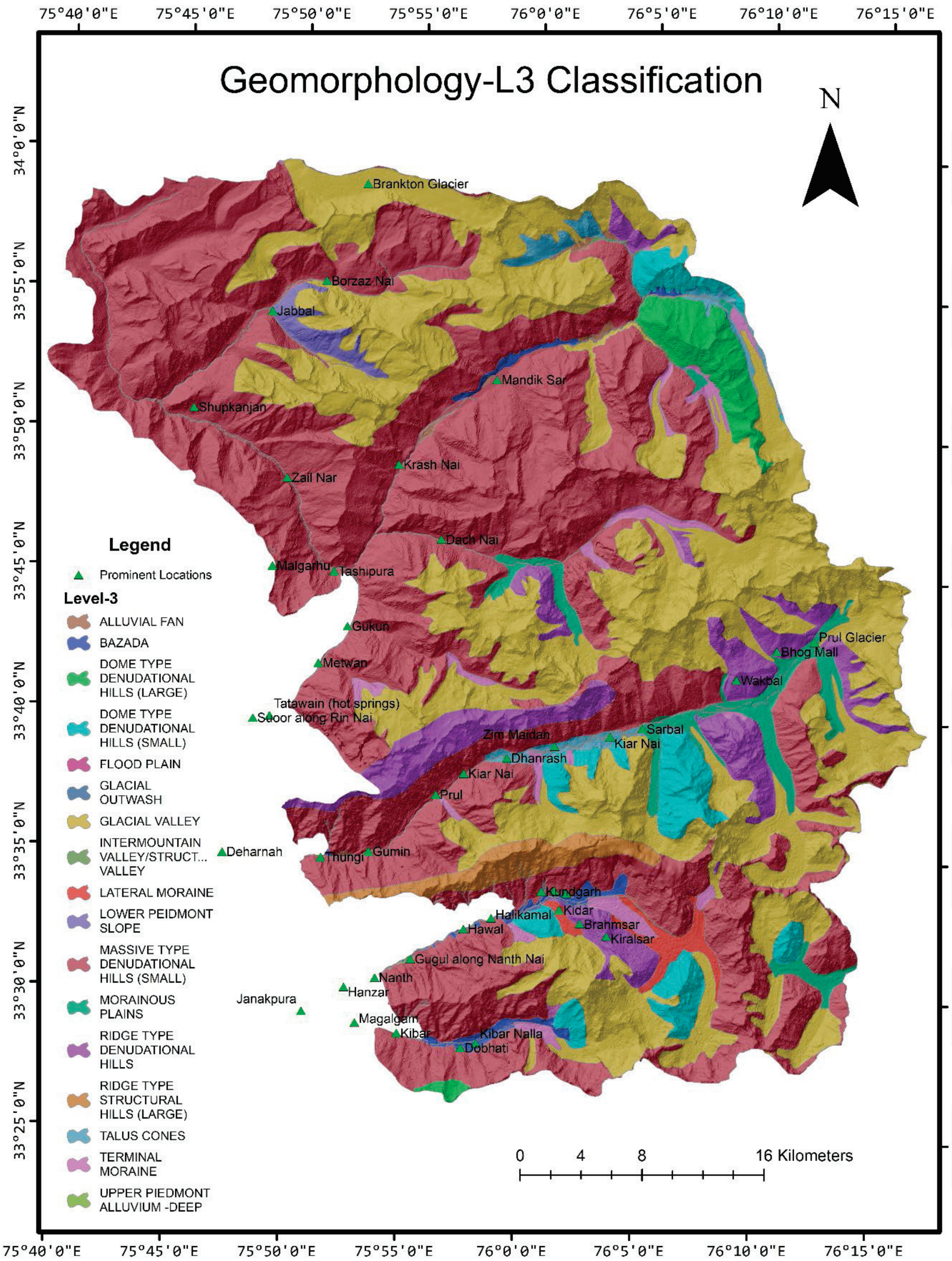


**Fig. 2.5** Spatial distribution of geomorphological classes in the Kishtiwar High Altitude National Park

### 2.3. Lithology of KHANP

It has been found that KHANP comprises five lithological classes. The highest lithological class found in the NP is of Shists with Gneiss Mixed covering of 2125.41 sqkm (96.98%), followed by Gravel Sand Silt (46.42 sqkm, 2.12%), Waterbody (8.42 sqkm, 0.38%), Bedded Limestone (5.66 sqkm, 0.26%), and the least area was found under Sand Silt with Clay (5.60 sqkm, 0.26%) (Table 2.3, Fig. 2.6 and 2.7).

**Table 2.3** Area under different rock grain lithological classes found in the Kishtiwar High Altitude National Park

| S No. | Lithology | Area in Sqkm | Percent Area |
|---|---|---|---|
| 1 | Bedded Limestone | 5.66 | 0.26 |
| 2 | Gravel Sand Silt | 46.42 | 2.12 |
| 3 | Sand Silt with Clay | 5.60 | 0.26 |
| 4 | Shists with Gneiss Mixed | 2125.41 | 96.98 |
| 5 | Waterbody | 8.42 | 0.38 |

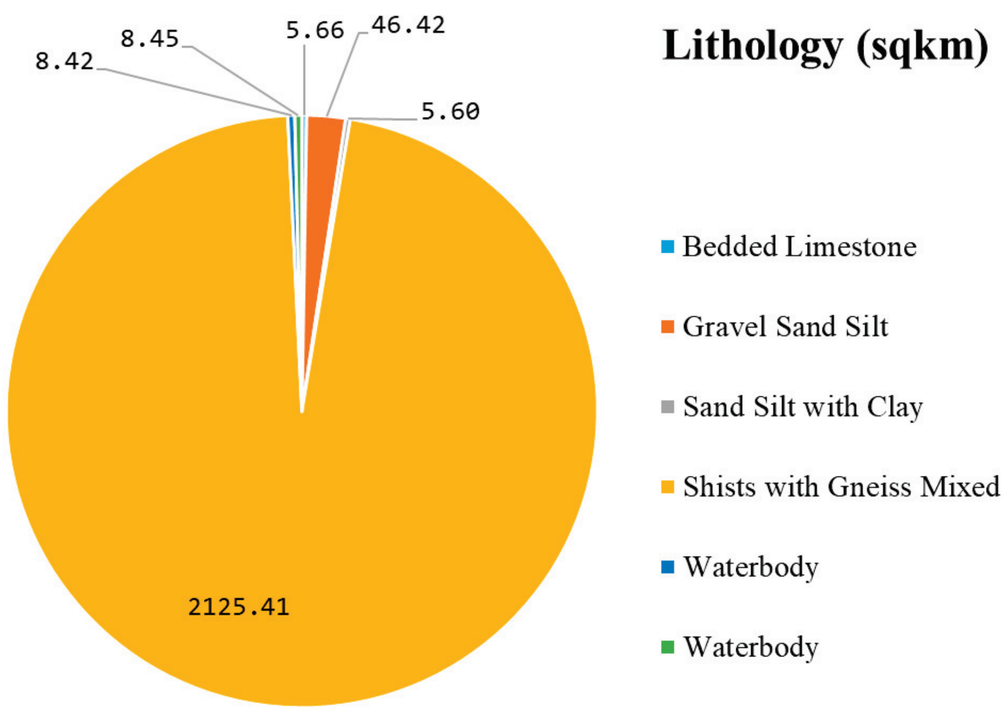


**Fig. 2.6** Pie-chart representing the relative area of lithological classes in the Kishtiwar High Altitude National Park

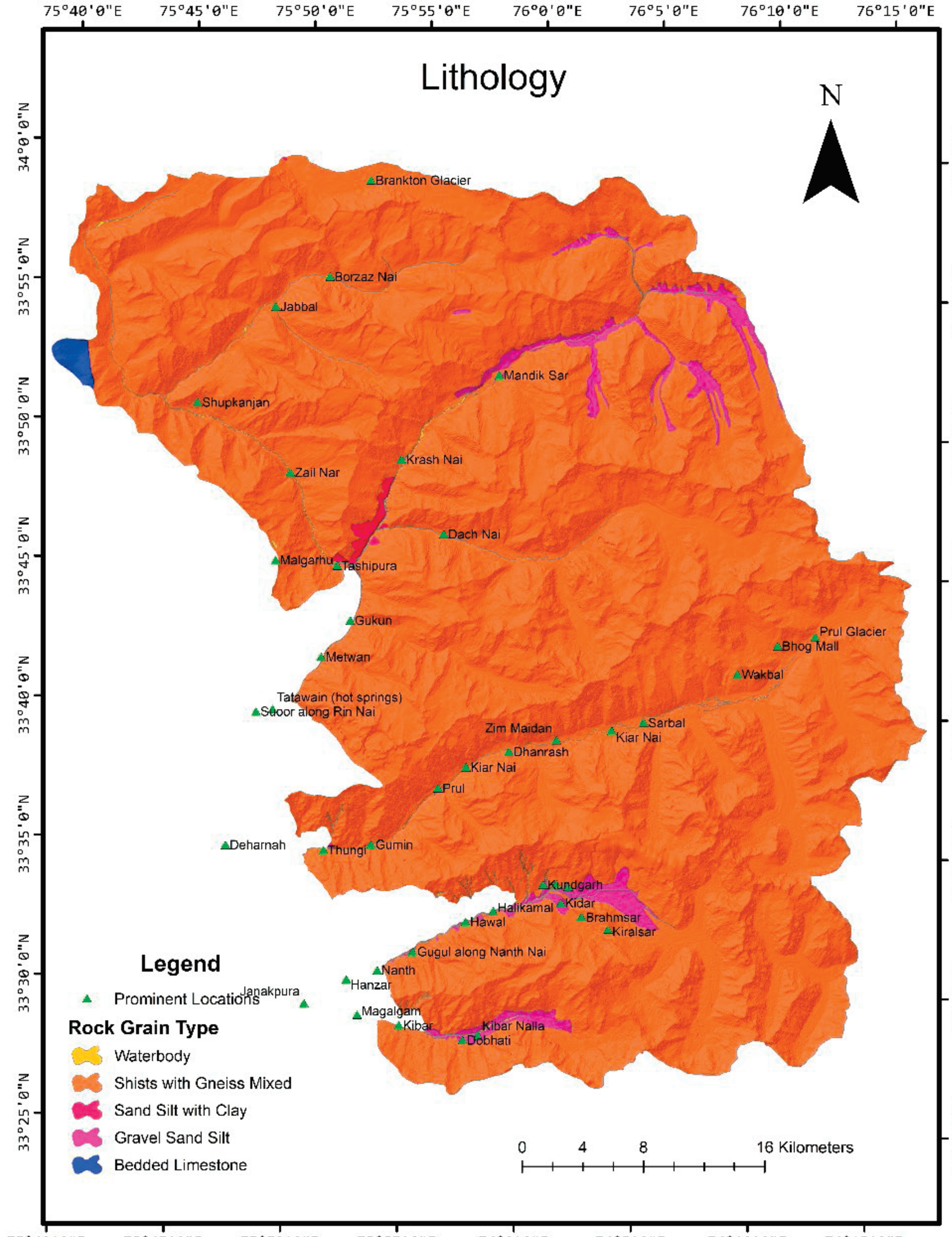


**Fig. 2.7** Spatial distribution of lithological classes in the Kishtiwar High Altitude National Park

### 2.4. Soil Types of KHANP

It has been found that KHANP comprises six soil types. The highest class found in the NP is of Glacial Area covering 978.2 sqkm (44.6%), followed by Fine Loamy Soil (367.7 sqkm, 16.8%), Rock Outcrop (343.9 sqkm, 15.7%), Loamy Soil (291.4 sqkm, 13.3%), Coarse Loamy Soil (185.6sqkm, 8.5%), and the least area was found under Sandy Soils (24.6 sqkm, 1.1%) (Table 2.4, Fig. 2.8 and 2.9).

**Table 2.4** Area under different soil types found in the Kishtiwar High Altitude National Park

| S No. | Soil Type | Area in Sqkm | Percent Area |
|---|---|---|---|
| 1 | Coarse Loamy Soil | 185.6 | 8.5 |
| 2 | Fine Loamy Soil | 367.7 | 16.8 |
| 3 | Glacial Area | 978.2 | 44.6 |
| 4 | Loamy Soil | 291.4 | 13.3 |
| 5 | Rock Outcrop | 343.9 | 15.7 |
| 6 | Sandy Soils | 24.6 | 1.1 |

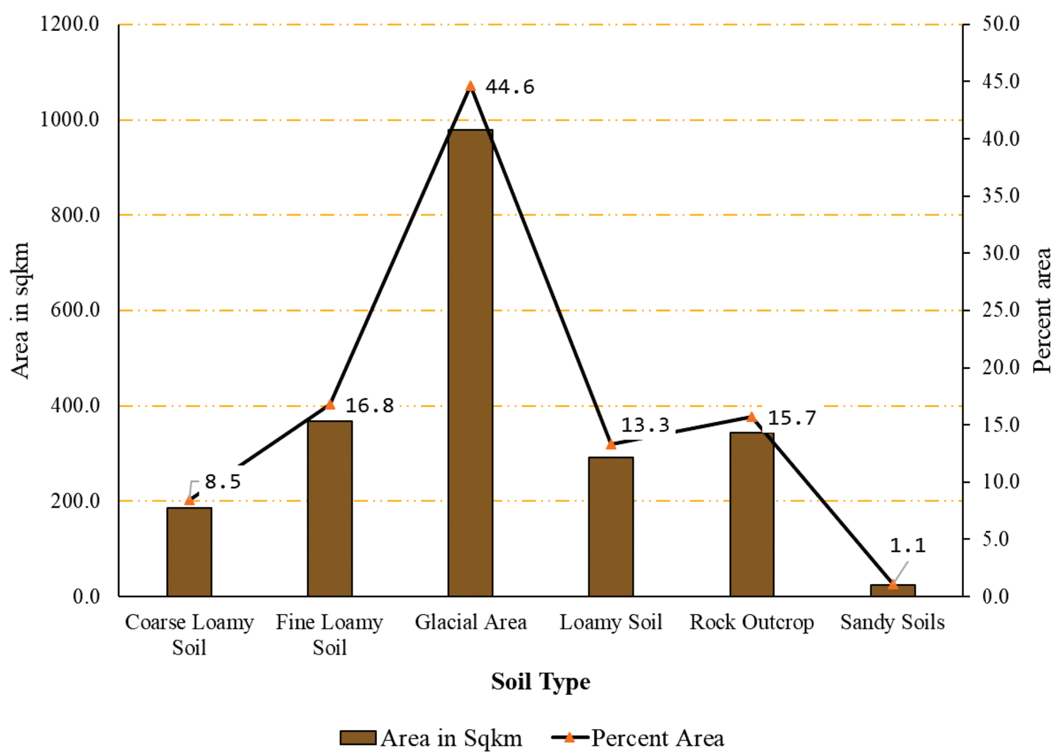


**Fig. 2.8** Column graph representing area (in sqkm and percent) of soil classes in the Kishtiwar High Altitude National Park

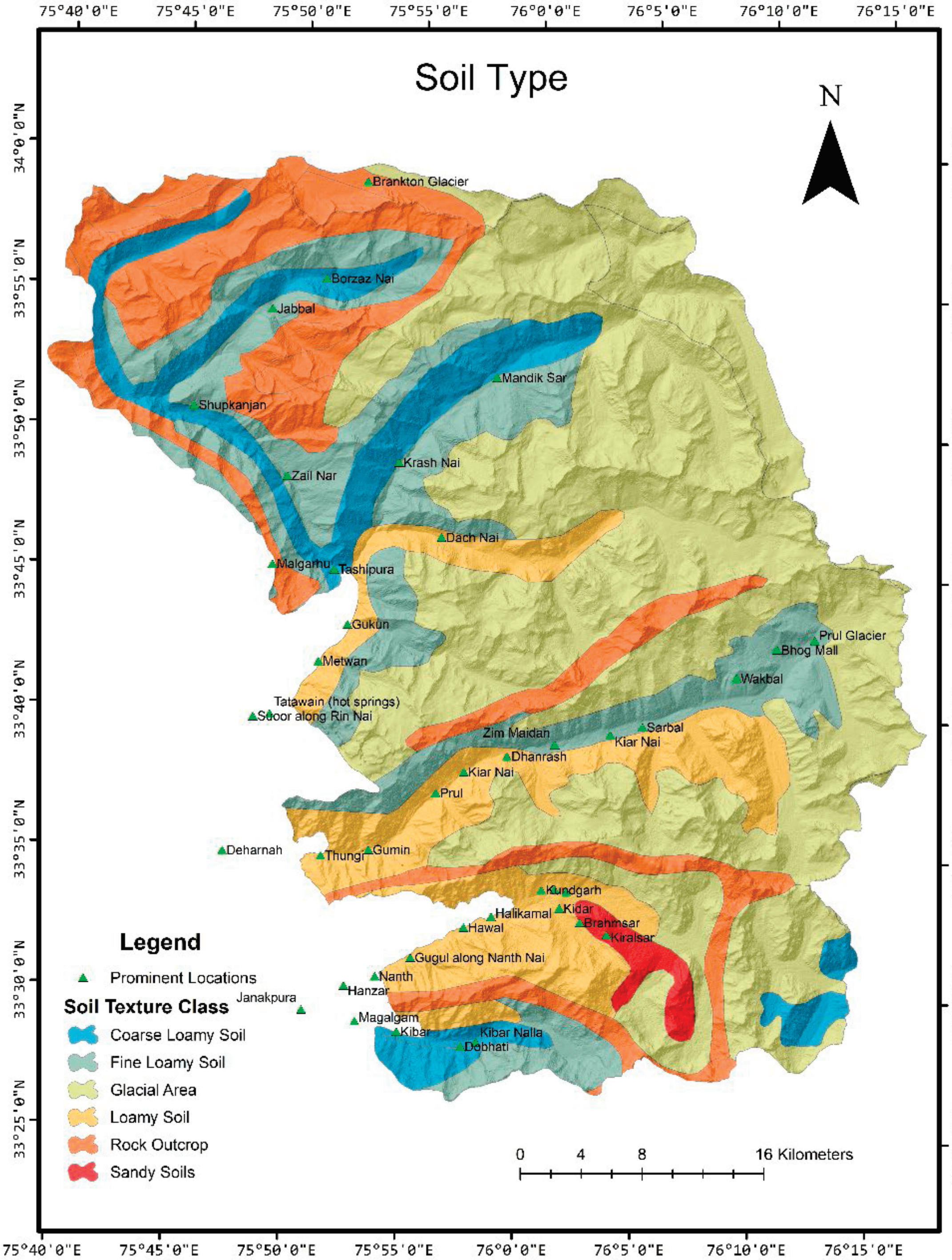


**Fig. 2.9** Spatial distribution of soil classes in the Kishtiwar High Altitude National Park

### 2.5. Elevation profile of KHANP

The elevation ranges from 2148 meters to 6504 meters in the KHANP. For the ease of analysis, we divided the elevation into ten classes. It was found that is of 4576m-4822m class comprising of 366.51 sqkm (16.72%) followed by 4327m-4575m class (356.82 sqkm, 16.28%), 4061m-4326m class (317.71 sqkm, 14.50%), 4823m-5098m class (308.41 sqkm, 14.07%), 3768m-4060m class (263.00 sqkm, 12.00%), 3435m-3767m class (190.65 sqkm, 8.70%), 5099m-5459m class (182.46 sqkm, 8.33%), 3026m-3434m class (96.58 sqkm, 4.41%), 5460m-6504m class (64.16 sqkm, 2.93%), and was the least 2148m-3025m elevation class found (45.15 sqkm, 2.06%) (Table 2.5, Fig. 2.10 and 2.11).

**Table 2.5** Area under different elevation classes found in the Kishtiwar High Altitude National Park

| S No. | Elevation (m) | Area in Sqkm | Percent Area |
|---|---|---|---|
| **1** | 2148-3025 | 45.15 | 2.06 |
| 2 | 3026-3434 | 96.58 | 4.41 |
| 3 | 3435-3767 | 190.65 | 8.70 |
| 4 | 3768-4060 | 263.00 | 12.00 |
| 5 | 4061-4326 | 317.71 | 14.50 |
| 6 | 4327-4575 | 356.82 | 16.28 |
| 7 | 4576-4822 | 366.51 | 16.72 |
| 8 | 4823-5098 | 308.41 | 14.07 |
| 9 | 5099-5459 | 182.4 | 8.33 |
| 10 | 5460-6504 | 64.16 | 2.93 |

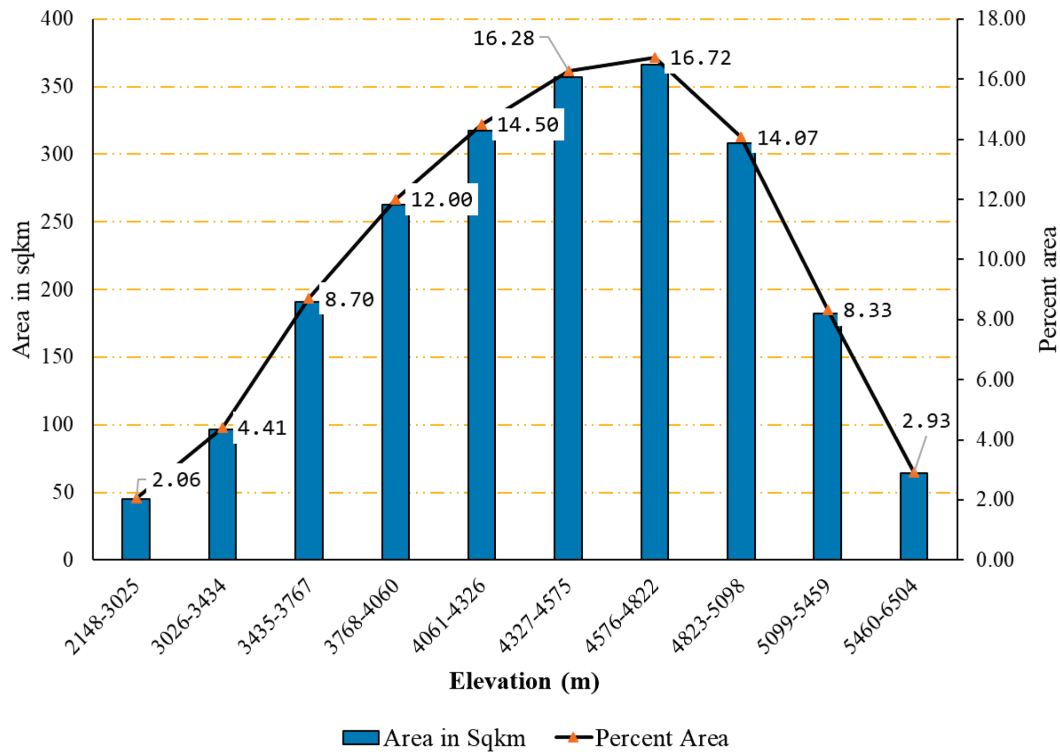


**Fig. 2.10** Column graph representing area (in sqkm and percent) of elevation classes in the Kishtiwar High Altitude National Park

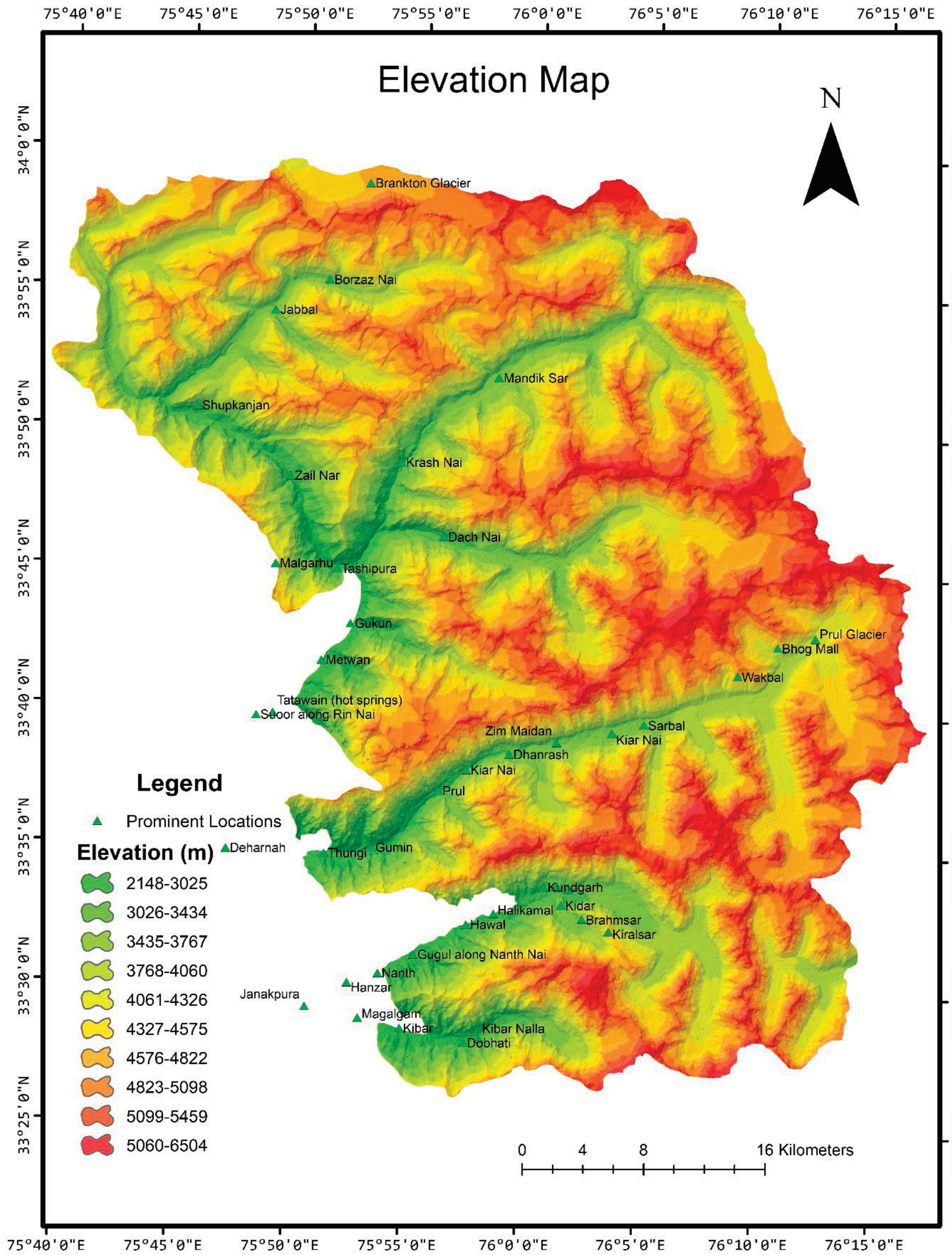


**Fig. 2.11** Spatial distribution of elevation classes in the Kishtiwar High Altitude National Park

### 2.6. Slope profile of KHANP

The slope ranges from 0 degrees to 83 degrees in the KHANP. For ease of analysis, we divided the slope into six classes. It was found that maximum area was found under the slope class 24° -33° covering of 547.51 sqkm (24.98%) followed by 34° -42° class (434.46 sqkm, 19.82%), 14° -23° class (422.15 sqkm, 19.26%), 0-13° class (361.43 sqkm, 16.49 %), 43° -53° class (306.28 sqkm, 13.98 %), and the least area was found under 54° -83° class (119.67 sqkm, 5.46 %) (Table 2.6, Fig. 2.12 and 2.13).

**Table 2.6** Area under different slope classes found in the Kishtiwar High Altitude National Park

| S No. | Slope in degrees | Area in Sqkm | Percent Area |
|---|---|---|---|
| 1 | 0-13 | 361.43 | 16.49 |
| 2 | 14-23 | 422.15 | 19.26 |
| 3 | 24-33 | 547.51 | 24.98 |
| 4 | 34-42 | 434.46 | 19.82 |
| 5 | 43-53 | 306.28 | 13.98 |
| 6 | 54-83 | 119.67 | 5.46 |

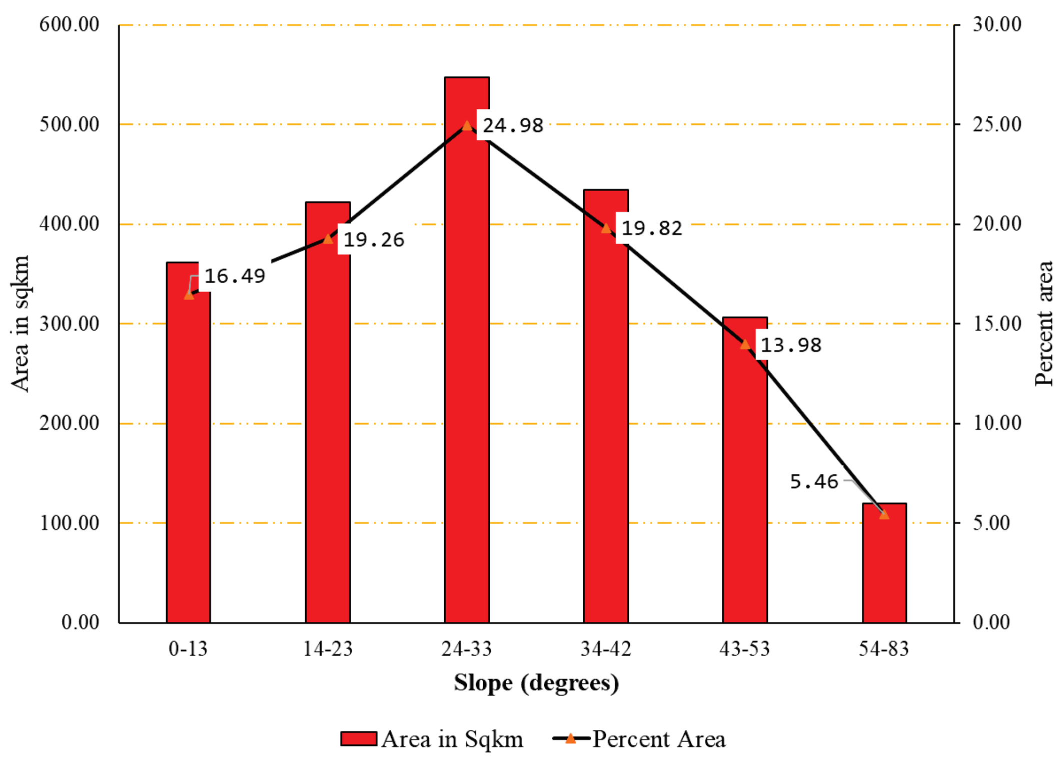


**Fig. 2.12** Column graph representing area (in sqkm and percent) of slope classes in the Kishtiwar High Altitude National Park

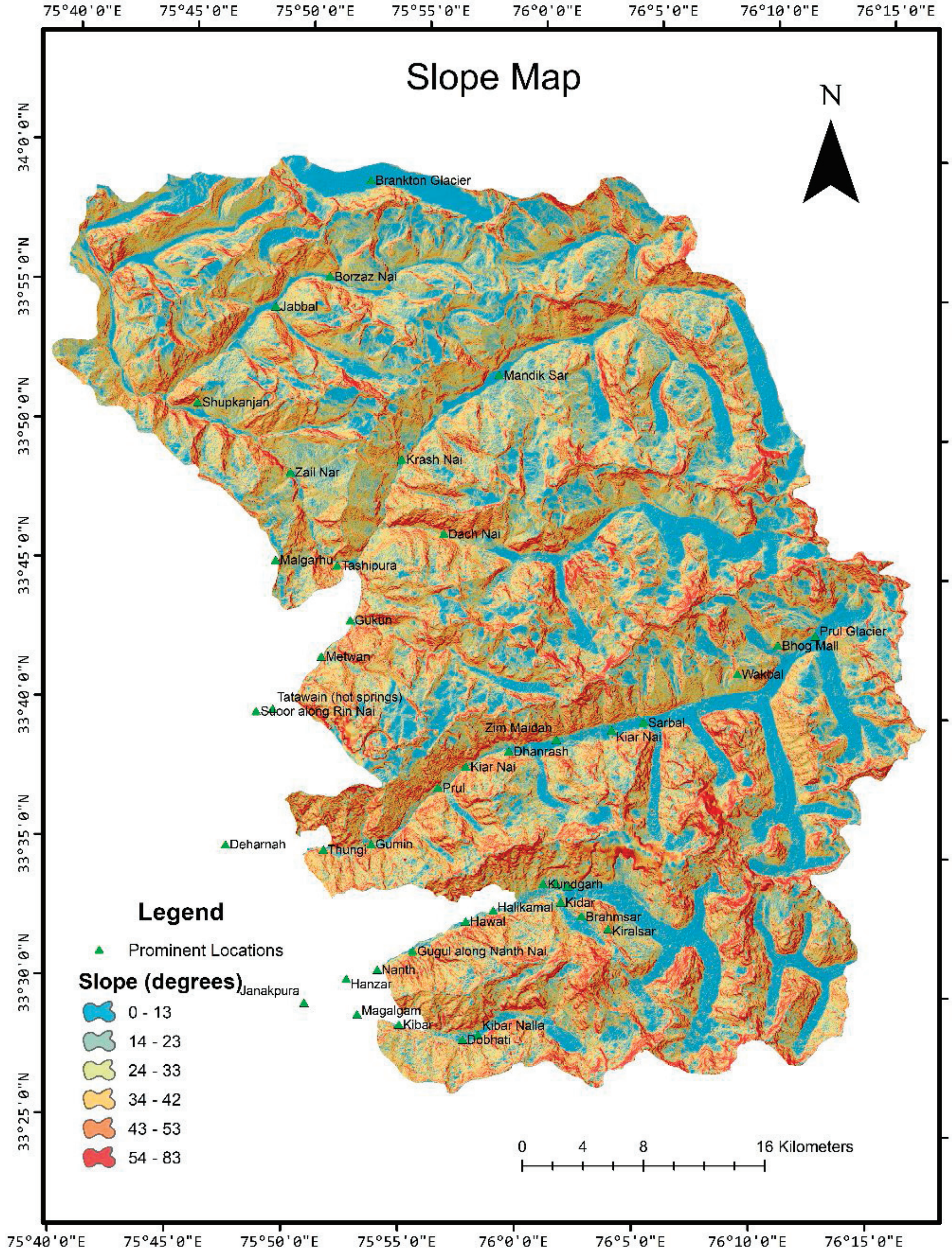


**Fig. 2.13** Spatial distribution of slope classes in the Kishtiwar High Altitude National Park

### 2.7. Aspect profile of KHANP

It has been found that KHANP comprises all the major aspect classes. The highest aspect found in the NP is of Northwest comprising of 331.03 sqkm (15.11%) followed by Southwest (304.96 sqkm, 13.92%), South (294.82 sqkm, 13.45%), West (280.33 sqkm, 12.79%), Northeast (247.41 sqkm, 11.29%), Southeast (229.47 sqkm, 10.47%), East (198.01 sqkm, 9.04%), North (152.78 sqkm, 6.97%), North (150.14 sqkm, 6.85%), and flat aspect was the least aspect class found (2.54 sqkm, 0.12%) (Table 2.7, Fig. 2.14 and 2.15)

**Table 2.7** Area under different aspect classes found in the Kishtiwar High Altitude National Park

| S No. | Aspect | Area in Sqkm | Percent Area |
|---|---|---|---|
| 1 | Flat | 2.54 | 0.12 |
| 2 | North | 152.78 | 6.97 |
| 3 | Northeast | 247.41 | 11.29 |
| 4 | East | 198.01 | 9.04 |
| 5 | Southeast | 229.47 | 10.47 |
| 6 | South | 294.82 | 13.45 |
| 7 | Southwest | 304.96 | 13.92 |
| 8 | West | 280.33 | 12.79 |
| 9 | Northwest | 331.03 | 15.11 |
| 10 | North | 150.14 | 6.85 |

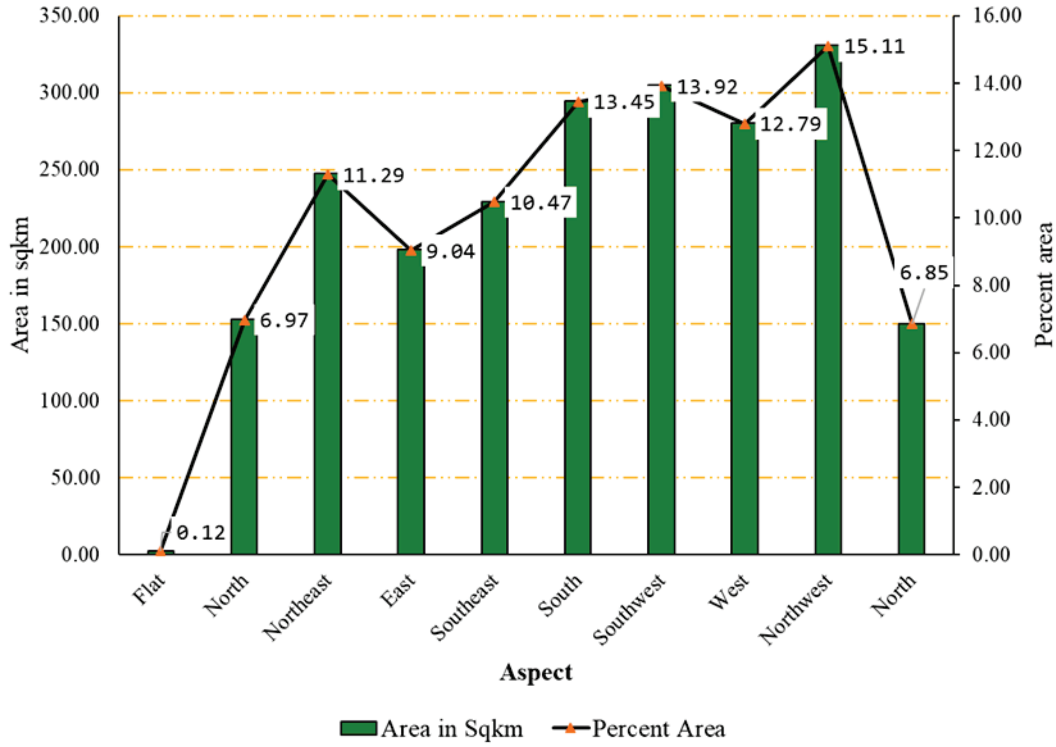


**Fig. 2.14** Column graph representing area (in sqkm and percent) of aspect classes in the Kishtiwar High Altitude National Park

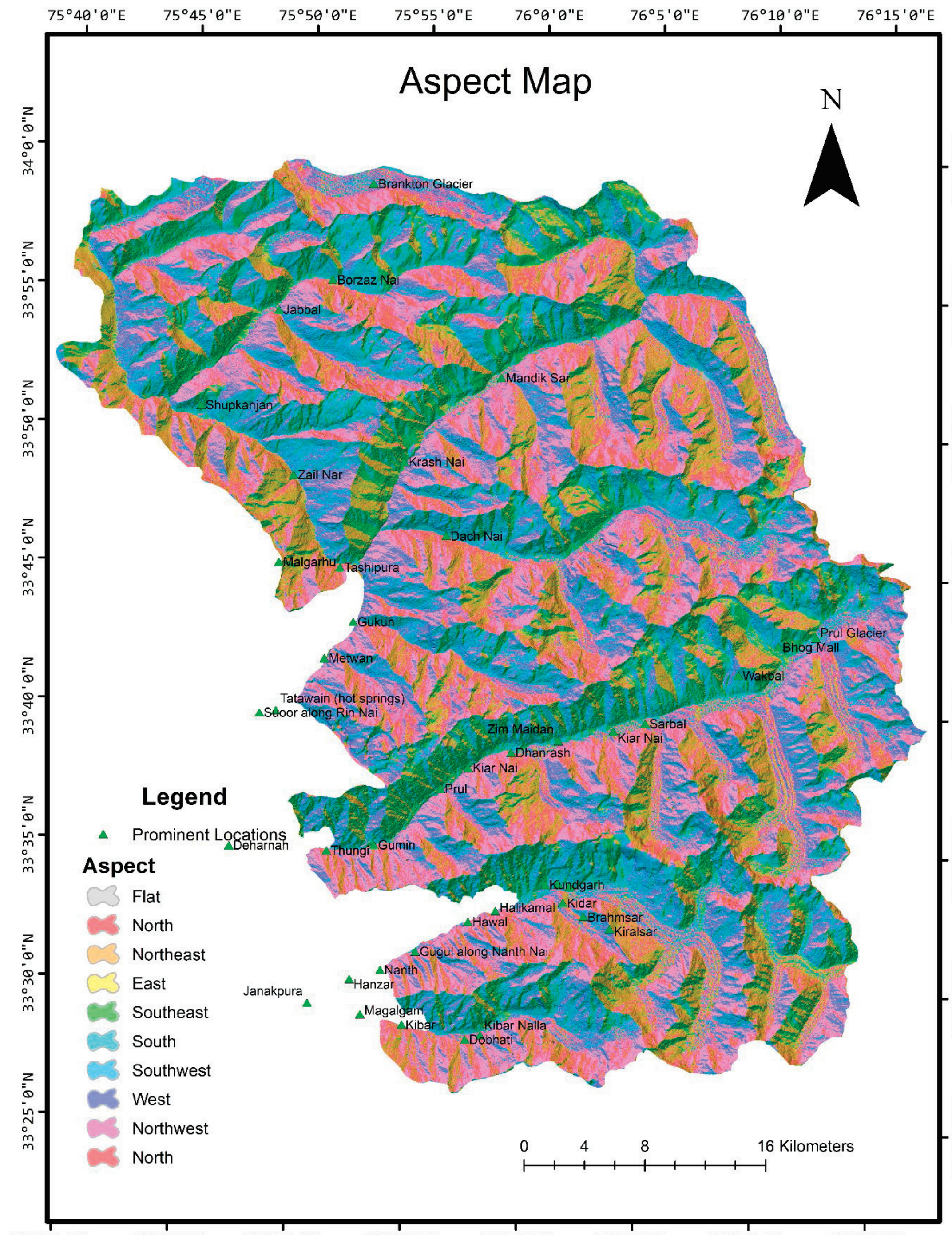


**Fig. 2.15** Spatial distribution of aspect classes in the Kishtiwar High Altitude National Park

### 2.8. Drainage profile of KHANP

There are numerous small streams that drain into Renai, Kiyar Nanth, and Kiber Nallah. All these nallahs independently drain into the river Marusudar. The river Marusudar joins river Chandrabhaga at Bhandarkot and merges into river Chenab. The National Park is located in the parts of the upper catchment of Renai, Kiyar, Nanth, Kiber nallah, of Chenab River (Fig. 2.16a, b).

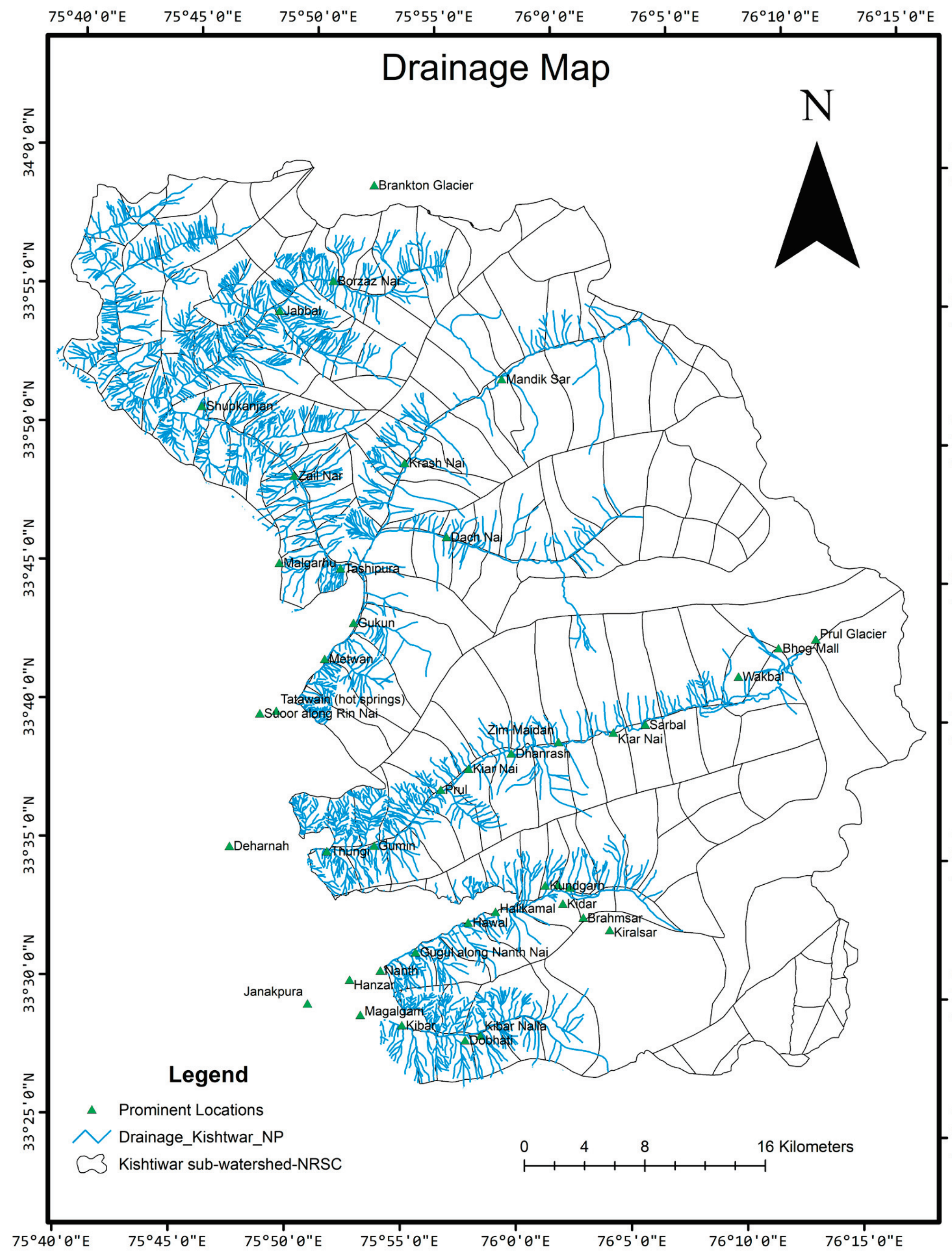


**Fig. 2.16a** Spatial distribution of drainage and watersheds as per NRSC, ISRO classification in the Kishtiwar High Altitude National Park

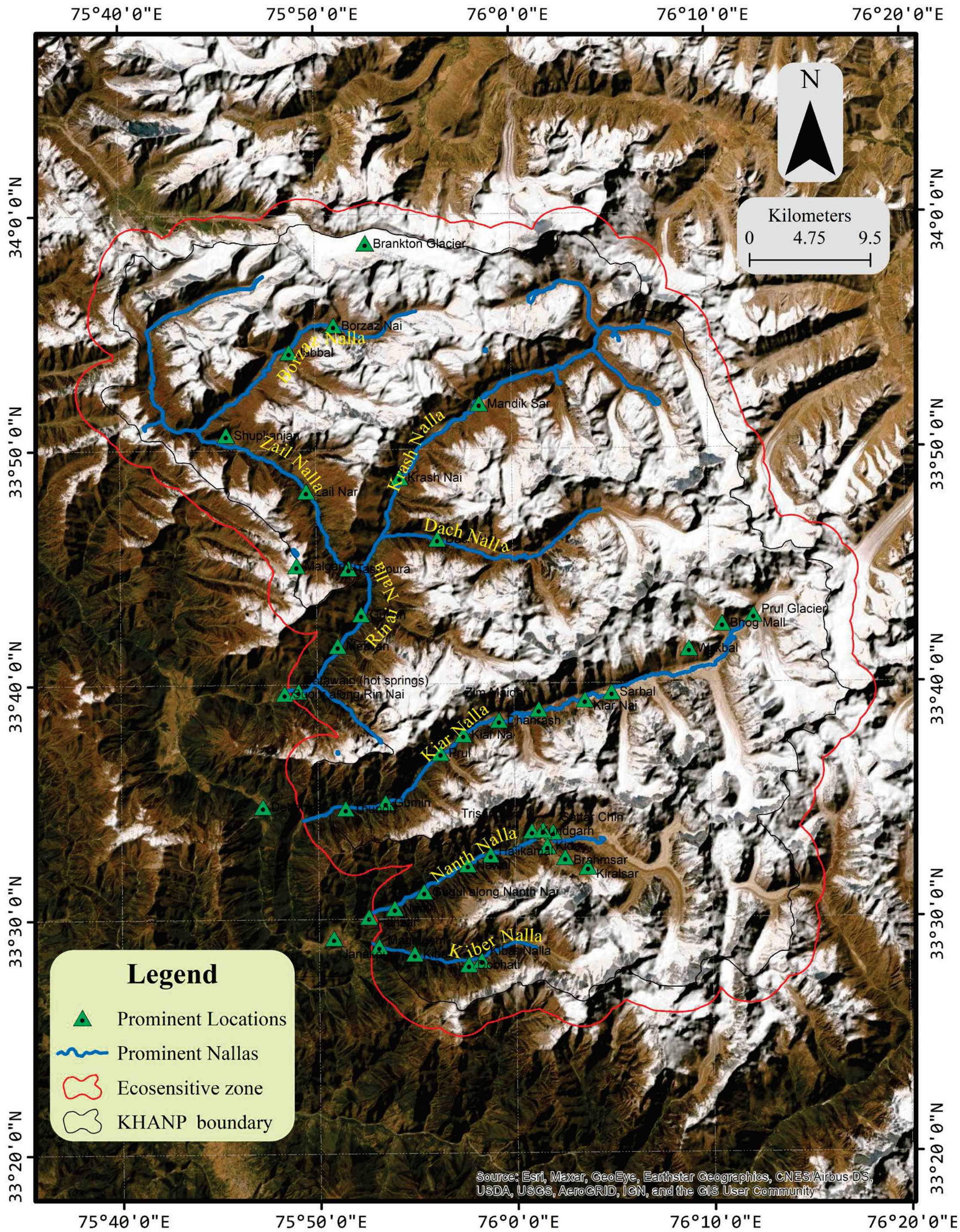


**Fig. 2.16b** Spatial distribution of prominent nallas in the Kishtiwar High Altitude National Park

### 2.9. Climate profile of KHANP

The upper reaches of the National Park is characterized by severe and prolonged winter and short summer season. The climate becomes temperate and milder in the valleys. Snowfall takes place mainly during December and January and sometimes even in the months of November, February and March. During winter, the whole area is blanketed with snow. In the upper reaches and unexposed aspects, the snow remains deposited for at least nine months which acts as the water source to the different nallahs during dry summer months. Most of the precipitation is received by the areas from December to April. The monsoon is often weak and reaches late. The main annual precipitation is about 920 mm (Fig. 2.17).

The terrain has high mountains marked with a series of ridges and narrow, deep valleys, which profoundly affect the climate. The salient features of the climate are severe winters. Considerable winter precipitation is due to westerly disturbances. Moderate Orographic rain is received during summer. Precipitation during winters is mostly in the form of snow, although at lower elevations, rain also occurs.

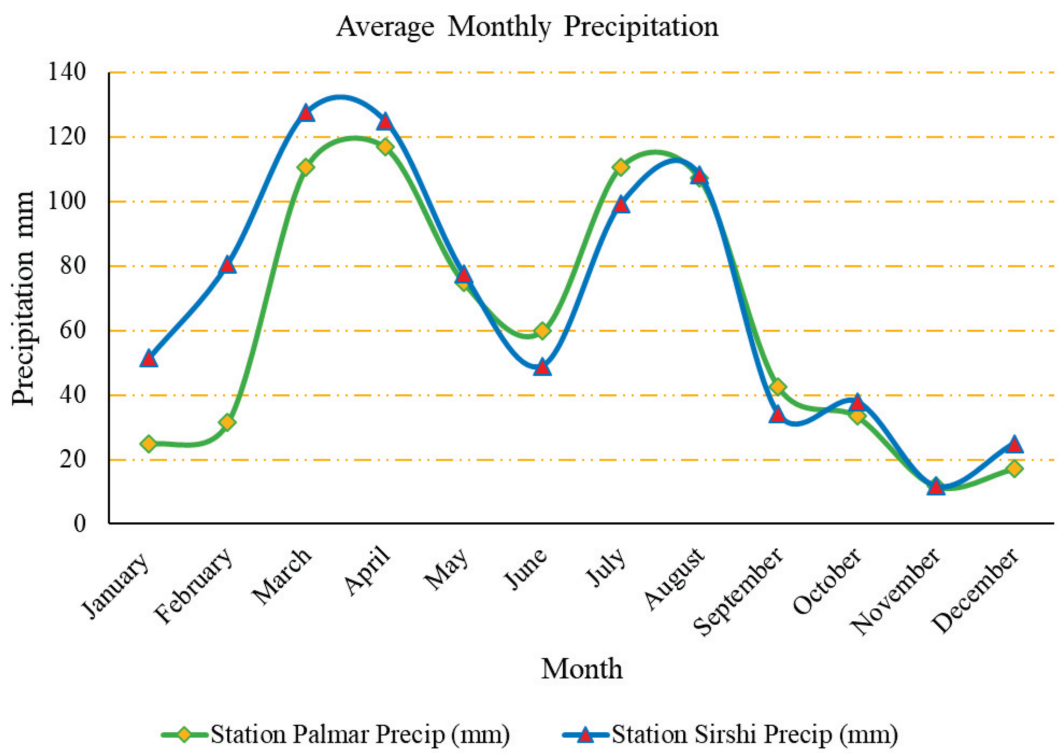


**Fig. 2.17** Graph representing the trend in average precipitation (rainfall/ snow) over a yearly cycle in the Kishtiwar High Altitude National Park

Winds are mostly light to moderate. The terrain also gives rise to various types of local winds. These become strong when blowing over fields and glaciers. Winds blowing through mountain ranges emerge out as strong currents.

The average month-wise precipitation data of Palmar and Sirshi meteorological stations are given. These two stations are located outside of the National Park but are a good representative of the area.

The mean maximum and minimum temperatures recorded during January at Sirshi station are 23°C and -7°C and during July are 35°C and 11°C, respectively. The meteorological data of these stations may not be representative of the whole area.

The climate of the National Park confirms the sub-Mediterranean type, and depending upon the duration and magnitude of precipitation and temperature, four seasons are recognized and distinguished spring, summer, autumn, and winter.

# CHAPTER-3

# CHAPTER – 3
## DESCRIPTION OF THE METHODS USED

Environmental monitoring needs, conservation goals, spatial planning implementation, and ecosystem-oriented natural resource management, to mention a few, all necessitate the development of operational systems that can extract useful information from remote sensing data sets. Landsat and SPOT satellites, as well as ASTER and MODIS, are produced by global satellite agencies such as NASA, JAXA, and ISRO for use in global and regional studies related to biodiversity, nature conservation, food security, deforestation impact, desertification monitoring, and a variety of other land surface applications. We used Landsat Legacy data to classify the land use and cover of the Kishtiwar high altitude national park in this study (KHANP).

Since 1972, Landsat has been monitoring the earth's surface. Every continent, season, and year are being examined. Landsat imagery provides a view of the Earth from space. Since the launch of the first Landsat satellite in 1972, the programme has collected data from all around the world, as well as data from our own planet's forest, metropolitan areas, barren land, ocean, and farmland. Landsat data from the USGS website may be used by urban planners and decision-makers all over the world to better comprehend environmental change, manage metropolitan areas, allocate precious water supplies, and monitor natural phenomena such as natural disasters, among other things.

The latest Landsat satellite series, include the Landsat 9, which was launched in 2021, continues the mission's heritage of monitoring critical natural and economic resources from space. The Operational Land Imager 2 (OLI-2) will collect images of Earth's landscapes in visible, near-infrared, and shortwave infrared light, and the Thermal Infrared Sensor 2 (TIRS-2) will measure the temperature of land surfaces. Landsat 9 will be managed by NASA's Goddard Space Flight Center in Greenbelt, Maryland. Landsat 9 is a collaborative mission of NASA and the US Geological Survey, just like its predecessors.

Both Landsat 7 and Landsat 8 are now orbiting the earth in a near-polar orbit. Every 16 days, each satellite repeats its orbital path, with two spacecraft offset so that the outcome of this procedure is that any location on the earth's surface measured by one of the other is covered every eight days. Each satellite's sensor captures scenes throughout a 195-kilometer-wide swath of the planet. Each image acquired by Landsat 7 and 8 has a pixel size of roughly 30 metres and a panchromatic band of about **15 metres**.

The most significant advancement in the Landsat satellite is that the sensors are now known as push-broom sensors rather than whiskbroom sensors. Thousands of detectors are used in push-broom sensors to scan the earth's surface when the satellite passes over it. The older Landsat satellites, Landsat 7 and Landsat 8, use whiskbroom technology, which uses a mechanical scanner to scan back and forth with a small number of detectors.

Our land usage are changing at an unparalleled rate in human history as a result of rising population. To manage and adapt with these changes, we need observations, information, and data that allow us to comprehend what is happening on the earth's surface, where the majority of us reside.

### 3.1. Data used

To assess the land use land cover changes in the Kishtiwar High Altitude National Park (KHANP) from 1990 to 2020, efforts were made to acquire Landsat data for 1990, 2000, 2010, and 2020. The primary data used in this work was acquired from four Landsat sensors. The details of the satellite along with their characteristics are shown in Table 3.1. A total of 4 number of images with least snow and cloud cover were obtained from the United States Geological Survey (USGS) and Global Visualization (GloVis) site. For change detection, various requirements of pre-processing, such as geometric registration, and radiometric and atmospheric corrections are the most important to avoid spurious. In this study, all downloaded images were level-1 products, which were rectified and geometrically and topographically corrected. Dark object subtraction (DOS) was used to correct atmospheric effects. Mosaic was applied on KHANP landsat image for two paths and rows. At the end, layer stacking as performed to combine various spectral bands of the Landsat images. All the image preprocessing steps were carried out using ENVY 5.4 and ERDAS Imagine software. The data source is summarized in the table 3.1 below.

**Table 3.1** Datasets used in the present study

| Data type | Date | Satellite /sensor | Band | Resolution | source |
|---|---|---|---|---|---|
| RS data | Aug 28, 1992 | Landsat 7 | 1-7 | 30m | https://www.usgs.gov |
| RS data | Sep 01, 2000 | Landsat 7 | 1-8 | 30m | https://www.usgs.gov |
| RS data | Aug 31, 2010 | Landsat 8 | 1-11 | 15m | https://www.usgs.gov |
| RS data | Sep, 04, 2020 (LATEST) | Landsat 8 OLI | 1-11 | 15m | https://www.usgs.gov |
| Toposheets | | | | 1:50,000 | Survey of India (SOI) |

## 3.2. Methods employed

This study aims to assess the change in land use and land cover in the KHANP national park using on-screen digitization or visual image interpretation technique as a method is estimate the changes using integrated field knowledge and remote sensing technique. The overall methodology adopted for the study has been shown in the Fig.3.1. The LULC change process has been studied using Landsat data for almost three decades (1992-2000; 2000-2010; 2010-2020).

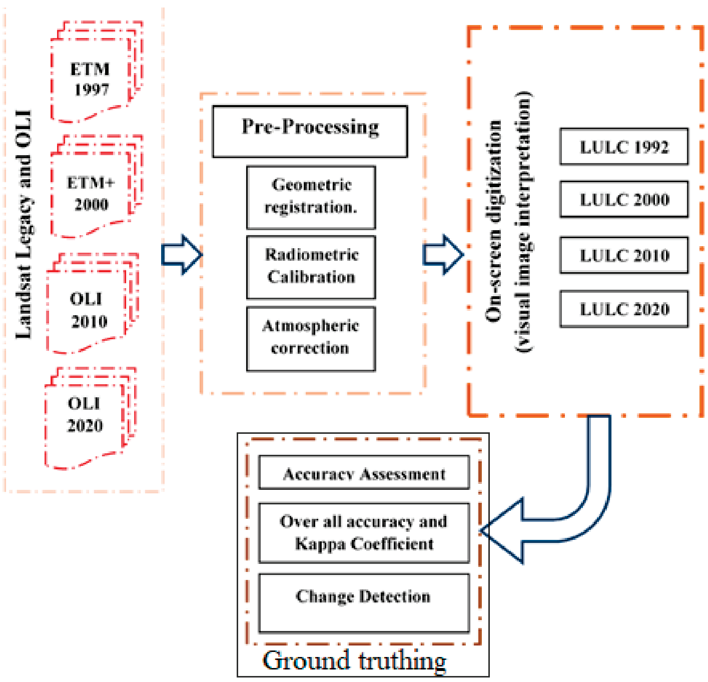


**Fig. 3.1** Methodology flowchart adopted for the study (ground truthing in accuracy assessment)

### *3.2.1. Data Preparation*

Image preprocessing is the most difficult part of the land cover change detection procedure, and it is often overlooked. To accurately and precisely identify land cover change between years with complete confidence, the atmosphere disturbance should be modelled so that it does not affect the digitization technique that works on the RGB concept of land cover change detection analysis using multi-date remote sensing images, which is dependent on accurate radiometric and geometric correction. Geometric and radiometric correction of multitemporal Landsat imageries are therefore the most critical.

### *3.2.2. Geometric correction*

Geometric correction is the process of georeferencing satellite images to the UTM map projection system for the zone of interest, correcting with uniformly distributed control points drawn from digitised topographic maps of the appropriate areas, and resampling to the nearest neighbourhood. Geometric correction include determining picture coordinates that are similar to their true places in ground coordinates, as well as a resampling process to select the digital values to place in the corrected output image's new pixel locations.

### *3.2.3. Radiometric correction*

In change detection analysis, radiometric correction of multi-date imageries is a critical stage. Geometric registration of multi-date picture data with high precision is a prerequisite for change detection. Sensor-measured reflectance values are not a pure depiction of the values reflected by earth surface features due to several external factors (sun angle, path radiance, and atmospheric condition). As a result, this effect should be minimised because it makes the task more difficult.

### *3.2.4. Image enhancement*

This technique is used on image data in order to more effectively display or record the information for later visual interpretation. Typically, the image enhancement process includes methods for improving visual differentiating between structures in a scene. The goal is to expand the visual interpretation of a picture by forming or creating new imageries from an original.

### *3.2.5. Visual image interpretation process/ On screen Digitization*

The process of extracting qualitative and quantitative information about things from satellite photos is known as interpretation. Except when working with aerial pictures, interpretation is commonly referred to as image interpretation. Visual and digital interpretation are two types of interpretation that can be classified based on the technique of interpretation. Visual interpretation is the process of analysing satellite photographs visually. Digital interpretation is when the interpretation is done with the assistance of computer software. Visual image interpretation is the process of an analyst/interpreter recognising elements on images and communicating information gathered from these images to others for the purpose of evaluating their relevance. This procedure, on the other hand, is not limited to deciding what objects should appear in photographs; it also entails determining their relative placements and extents. The amount of training and experience you have with image data processing affects your ability to comprehend visual images. Information derived from the interpretation process may be more authentic and dependable than information derived from digital procedures if the interpreter has an artistic and photographic sense. Visual interpretation of satellite pictures is used successfully in many sectors, including geology, geography, agriculture, water resources, and forestry, as you read previously. Digital interpretation entails the use of computers to analyse remote sensing data and extract information. In Block 4 of MGY-002, the steps involved in digital interpretation will be examined in detail. However, for completeness, the advantages and disadvantages of visual (human) and digital interpretation are compared below.

- <u>Comparison of merits and demerits of visual (human) and digital interpretation techniques</u>

*Visual (human) interpretation*

- ❖ Image analyst's experience and knowledge is available
- ❖ Very good for extraction of spatial information
- ❖ Time consuming
- ❖ Interpretation results may vary with time and person depending upon their experience and knowledge

*Digital interpretation*

- ❖ Time effective-requires much less time for interpretation
- ❖ Results can be exactly reproduced for any number of times
- ❖ Extraction of quantitative information is possible and easier
- ❖ Image analyst's experience and knowledge is not available

- ❖ Poor in extracting spatial information

- *<u>Image Interpretation Tasks</u>*

The image interpretation procedure is a complex task and requires several tasks to be conducted in a methodical manner which include:

- ❖ Classification
- ❖ Enumeration
- ❖ Mensuration, and
- ❖ Delineation

The assignment of objects, characteristics, or areas to classes based on their appearance on photographs is known as *classification*. Detection, recognition, and identification are the three levels of confidence and precision that are frequently distinguished. The presence or absence of a feature is determined by detection. A higher level of knowledge about a characteristic or an object is required for recognition so that the thing can be assigned an identity. And, by identification, we mean that an object's or feature's identity may be stated with enough certainty and precision to assign it to a certain class. The aim of *enumeration* is to list or count discrete things seen on an image. In many image interpretation difficulties, *mensuration* (or measurement) is a key function. The first type of measurement is the measurement of distance and height, as well as volumes and areas via extension. A quantitative assessment of image brightness is a second type of measurement. Finally, the interpreter must define or designate locations seen on remotely sensed images. The interpreter must be able to distinguish between diverse aerial units that have distinct tones and textures, as well as detect edges or boundaries. When studying an image, the image analyst may use many of these talents at the same time. As the interpreter studies an image, recognition, *delineation*, and mensuration may all be required.

- <u>Prerequisites for Image Interpretation</u>

Following are the requirements for image interpretation:

- ❖ Remote sensing system
- ❖ Knowledge of image and sensor characteristics
- ❖ Proficiency based on knowledge of the subject and
- ❖ Adequate familiarity of the geographic region and locality

- <u>Elements of Visual Image Interpretation</u>

The study of numerous basic properties of an item is required for visual interpretation of aerial images, as stated in the preceding section. Because there are usually several images recorded in different spectral regions of the electromagnetic spectrum, these features of objects are investigated with reference to a single or many spectral bands when interpreting satellite photographs. Tone, texture, form, size, pattern, shadow, position, and association are the basic elements, which are comparable to those utilised in aerial photo analysis. The following eight factors are combined in image interpretations:

1. Tone
2. Size
3. Shape
4. Texture
5. Association
6. Shadow
7. Site and
8. Pattern.

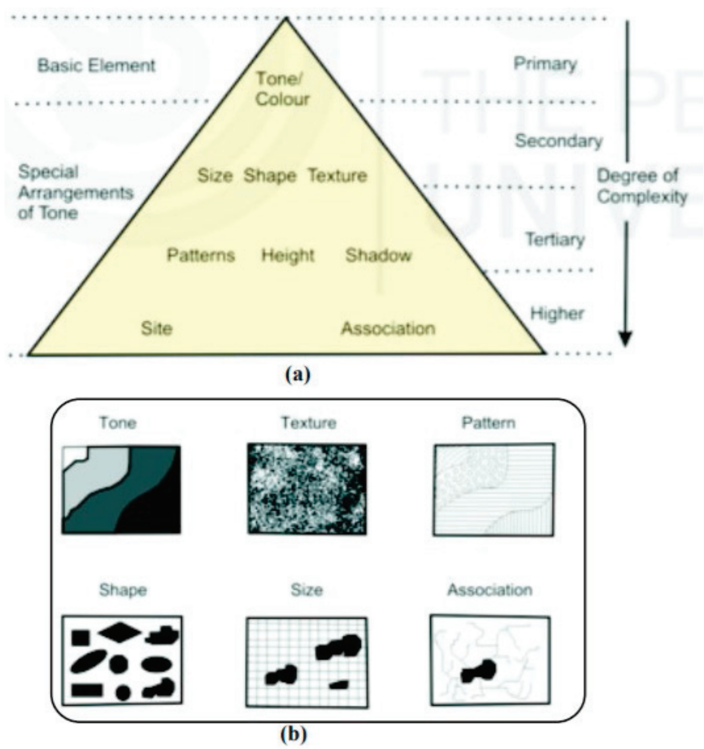


**Fig. 3.2** (a) Ternary plot showing the primary ordering of image elements that are fundamental to the image analysis process and (b) diagrammatic

representation of elements of visual image interpretation (source: http://rst.gsfc.nasa.gov)

Two essential aspects, picture elements and terrain elements, are commonly considered in a systematic study and visual interpretation of satellite images. The first seven elements stated above are picture elements, while the eighth element, pattern, is the terrain element, which includes drainage, landform, erosion, soil, vegetation, and land-use patterns. Fig. 3.2 depicts these aspects in order of their complexity.

Now we shall discuss the elements of image interpretation.

In a colour image, tone refers to the colour or relative brightness of an item, whereas in a black and white image, tone refers to the relative and quantitative shades of grey. As previously discussed, tonal fluctuation is caused by an object's reflection, transmission, or absorption characteristics. This may differ from one object to the next, as well as from one band to the next. Because it is impossible to distinguish other aspects without tonal distinctions, tone is one of the most fundamental factors. Smooth surfaces have a higher reflectivity than rougher surfaces, which have a lower reflectance. The light reflectivity of the object, the angle of reflected light, the geographic latitude, the type of photography and film sensitivity, light transmission of filters, and photographic processing all influence the tone of satellite pictures. On satellite images, strong tonal contrasts are always preferred for better image interpretation. Similarly, items at higher temperatures are recorded in a lighter tone than objects at lower temperatures, which appear in a medium to darker tone in thermal photography. Similarly, top soil has a darker tone than soil with quartz (silica) sand.

If the sizes of objects are not properly assessed, they can be misconstrued. The scale determines the size of items in an image. As a result, the scale of a photograph/image must be addressed while considering the size of items. Although the third dimension, which is the height of the items, is not easily quantifiable on satellite photos, the shadows of the objects might provide useful information. In two ways, the size of an object can be a useful tool for its identification. For starters, the size of an object or feature is proportional to the size of other objects on the image. This is the most direct and crucial function of size, as it gives the interpreter an intuitive sense of the image's scale and resolution even if no measurements or computations have been conducted.

This is accomplished by recognising common items such as houses, highways, and rivers. Second, absolute measurements can be just as useful as interpretive tools.

An individual object's shape refers to its overall form, structure, or outline. One of the most crucial single variables in recognising items from photographs is their shape. Human presence and use are frequently indicated by regular geometric shapes. In the same way, irregular shapes are typically associated with natural objects. Some objects can almost entirely be identified by their shapes. A railway line, for example, may usually be identified from a highway or an unmetalled road by its shape, which consists of long straight tangents and mild curves in contrast to a highway's shape. It's important to remember that an object's outline from above may differ significantly from its profile view. It is easy to calculate the areal dimensions using pictures for flat objects. Beaches, ponds, lakes, and rivers, for example, have distinct shapes that may be enough to identify them.

As shown in the images, texture is an indication of roughness or smoothness. It is the rate at which tonal values change (frequency of tonal changes). Texture refers to the frequency with which tones in an image vary and are arranged, and is created by a collection of unit features that are too small to be recognised separately on an image. Coarse, moderate, fine, extremely fine, smooth, rough, wavy, and speckled are all examples of texture. Visually, different texture classes are simpler to identify than in digitally oriented approaches. Texture is thus determined by the imagery's tone, form, size, pattern, and scale, and is created by a combination of components that are too small to discern individually. Grass and water, for example, appear'smooth,' whereas trees or a forest canopy can appear 'rough.'

The recurrence of traits in relation to their surroundings is known as association. A single feature may not always be distinguishable enough to allow identification. It describes the occurrence of specific items or characteristics in relation to a specific object or feature. Examining the linked features can help you identify a lot of features. A primary school and a high school, for example, may have comparable flat roofed building structures, but the high school may be distinguished by its proximity to a football field.

In the following approach, shadow is a very crucial indication in interpreting items. The outline or shape of a shadow provides a profile view of things, which aids in image interpretation; yet, items under shadow reflect little light and are difficult to distinguish on a Visual Image Interpretation image, which impairs interpretation. The shadows cast by taller features are greater than those cast by shorter features. Military picture interpreters are frequently focused on identifying specific pieces of equipment. Shadow is useful for detecting minor variations that would otherwise go undetected.

Sewage treatment facilities, for example, are located at low topographic sites along streams or rivers to collect waste flowing through the system from higher elevations. The interaction between a feature and its surroundings can reveal its identity. Consider the case of some tree species found in specific height zones. Landform identification can also aid in deciphering the underlying geology. Many rock types have particular topographic manifestations; for example, some sedimentary rocks are commonly exhibited as alternating ridge and valley topography.

The seven visual elements were addressed in detail above. The terrain element, which is important in image interpretation, is now examined. Drainage, topography/landform, soil, vegetation, and land use planning patterns are among the terrain factors. The spatial arrangement of items creates a pattern in an image. As a result, pattern can be described as an image's spatial arrangement of items. Because of their pattern, certain things can be quickly identified. A particular pattern may have a genetic link to multiple events that contributed to its emergence. The patterns generated by rows of houses or structures, for example, can easily distinguish urban and rural settlement zones.

Similarly, drainage patterns have a consistent relationship with the ground's underlying lithology, structure, soil texture, and hydrological properties, and hence convey information about them. Images of drainage patterns and texture are good indications of landform and bedrock type, as well as soil properties and drainage status. Dendritic drainage, for example, is the most prevalent drainage pattern found in nature, and it occurs in developed regions of homogeneous rocks. Long ridges and valleys, for example, correspond to resistant and non-resistant rocks, which combine to generate ridge and valley patterns. Soils have a particular pattern as well. Due to higher water content, fine grained, poorly drained soils are black in colour, whereas coarse textured, well drained soils are light in colour. Similarly, flora associated with specific rock types could aid in determining an area's lithology. The changes in land use planning and pattern that occur throughout time can be closely tracked, providing information on the land use pattern.

- Image Interpretation Keys

These are the requirements for identifying an object that has interpretation elements. The interpretation keys that an expert interpreter has created from prior knowledge and the analysis of current images are used to interpret images. To avoid variations between different interpreters, standardised keys must be defined. Graphic and/or textual image interpretation keys are available. They aid in the classification of thematic classes based on image feature characteristics. You will discover that designing and building a key to be used in a certain study is required at the start of a project. In general, there are two sorts of interpretation keys: selective and elimination keys. Selective keys include a variety of example images as well as supporting text. The translator chooses the example that most closely resembles the feature or circumstance that appears on the image under consideration. Elimination keys are made up of word descriptions that range from broad to particular characteristic discrimination levels. All features or conditions other than the one being identified are eliminated as the interpretation progresses from general to specific. A dichotomous key is a common type of elimination key. In dichotomous keys, the interpreter makes a sequence of decisions between two options until eliminating all but one option. As the analyst moves down the hierarchy, he or she makes decisions at branching description routes. Finally, the elimination procedure is used to identify items. The interpretation keys are defined in terms of the crown's shape, the crown's rim shape, tone, shadow, projected tree shape, pattern, texture, and other elements.

- Image Scale

Scale is required for interpretation because it affects the interpretation of picture features. The image's scale is carefully selected based on the observations to be made. The scale of the photograph/image should be such that items may be distinguished. We don't need to use particularly high-resolution data for regional mapping. For example, if you want to map the forest cover at the national or state level, you'll need data with a coarse to medium spatial resolution, such the WiFS or LISS III. Similarly, high spatial resolution data such as Cartosat PAN, IKONOS, and others are required for mapping at the local scale. It's important to remember that the optimal scale for a given application is determined by a number of factors, including the level of information sought, the technique of analysis to be utilised, and the geographic resolution of the data.

- Minimum Mapping Unit (MMU)

A minimal mapping unit is frequently used to depict maps obtained from remotely sensed data (MMU). The lowest size areal entity on the ground that can be identified in an image and mapped as a distinct and discrete entity is referred to as an MMU. A long narrow feature is displayed as a line and a small area is represented as a point for a specific map scale, the size or dimension below the MMU. Streams and rivers below the MMU, for example, will be depicted as lines, while a pond will be represented as a point. When creating a map from remotely sensed data, choosing the MMU to use is crucial since it dictates the level of detail provided by an interpreter in the map. When the information corresponding to the smallest patches is of little or no importance to the interpreter for the subject for which the map is being constructed, choosing an MMU permits decreasing the visual and spatial complexity of the information included in the map.

ENVY 5.3 and ArcGIS 10.7, as well as ERDAS Imagine 2015, were used to accomplish all processing and post-classification procedures. The images were sub-set depending on the polygon of the research region. The processing procedures included assigning a coordinate system, layer stacking of the different bands of the datasets, and layer stacking of the separate bands of the datasets. We perfomed the uniform at 1:15000 scale on all the satellite dates.

### 3.3. Land cover types classified in the present study

The classification scheme adopted for classifying the KHANP land followed the level-1 classification scheme described by the National Remote Sensing Centre (NRSC, Hyderabad). The seven land covers that were classified in the KHANP are dense forests, open forests, grasslands/ meadows, scrub land, water body, snow/ glaciers and rocky barren classes.

The interpretation key of these categories are:

1. **Dense forests** are the lands with tree cover of canopy density above 40% and 70% (FSI). We didn't classified forests as very dense forests (VDF, >70% canopy density according to FSI) in the KHANP as there was no clear distinction between VDF and DF on the satellite imagery.
2. **Open forest** are the lands with tree cover (Including mangrove cover) of canopy density between 10% and 40% (FSI)
3. **Grasslands/ pasture** are the areas of natural grass along with other vegetation, predominantly grass-like plants (Monocots) and non-grass-like herbs (except Lantana species which are to be classified as scrub). It includes natural/semi-natural grass/ grazing lands of Alpine/Sub-Alpine or temperate or sub- tropical or tropical zones, desertic areas and manmade grasslands (NRSC).
4. **Scrub land** (Shrubs) includes the forest lands with poor tree growth mainly of small or stunted trees having canopy density less than 10 percent (FSI)
5. **Water body** is any significant accumulation of water, generally on a planet's surface. The term most often refers to oceans, seas, and lakes, but it includes smaller pools of water such as ponds, swamp, wetlands, or more rarely, puddles. A body of water does not have to be still or contained; rivers, streams, canals, and other geographical features where water moves from one place to another are also considered bodies of water. In KHANP, perennial and alpine streams were categorized as the water bodies.
6. **Snow and glaciers** are the areas under snow cover confined to the Himalayan region. They are mostly located in mountain peaks and steep slopes/high relief areas. These are the areas which remain under snow either on temporary or permanent basis. These are the areas under perpetual snow cover throughout the year. They are the origins of most of Himalayan river systems.

7. **Rocky Barren** are those ecosystems in which less than one-third of the area has vegetation or other covers. In general, this category has thin soil, sand, or rocks. In the KHANP, the majority of the land of this category included the rock outcrops, the denuded land that usually is found near the snow and glacier fields.

### 3.4. Classification accuracy assessment/ cross-tabulation analysis

After classification is performed, it is to be evaluated so as to check the authenticity and reliability of the classified data. The method for testing the accuracy of the classification is the accuracy assessment. In this classification, the accuracy assessment method was used to for checking the authenticity of the classified LULC maps for 2020. Accuracy assessment is a general term for comparing the classification to the geographical data that are assumed to be true, in order to determine the accuracy of the classification process. Usually the assumed –true data are derived from ground truth data. It is not usually practical to ground truth. Therefore, a set of reference locations are used. Reference locations are points on the classified image for which actual data are (or will be) known. The reference locations where selected from ground field points which were taken with a GPS for Landsat 8 OLI derived Land cover map of 2020. While as reference locations for TM (1992), ETM (2000, 2010) were taken from historic Google Earth images. As there is no way to go back in time and check the reference locations of same date as of the images used. Points from different classes were taken in order to check the accuracy of all the classified categories. The number of reference locations is an important factor in determining the accuracy of the classification. In present study around 151 reference locations where used to estimate the overall accuracy. Locations points where taken from different locations during field verification in the months of September and October 2021.

A matrix or table that displays statistics for assessing image classification accuracy by showing the degree of misclassification among classes is called error matrix or cross-tabulation error estimation. The error matrix can be used to generate various statistics that characterize the accuracy of a classification technique. The error matrix compares the reference locations to the classified locations in a *n x n* matrix, where n is the no of classes. For example, the overall accuracy compares the number of locations correctly classified (those appearing on the diagonal of the matrix) to the total number of locations sampled. However, these statistics can be misleading since many correctly classified locations are expected to occur by chance alone.

The Cohen's Kappa statistics allows for chance and ranges from 0 in the case of the most confusing classification to 1 in the case of the most accurate classification. Other statistics that can be generated from the error matrix include errors of omission (producer's error) and errors of commission (user's error). These are based on individual classes, dividing the number of locations that are incorrectly classified by either the column or row totals, respectively.

Kappa coefficient was calculated using the below formula for the land use map (Meraj *et al*. 2015).

$$\{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r}(X_{+i}.X_{i+})\}/N^2 - \sum_{i=1}^{r}(X_{i+}.X_{+i})$$

Where N is the total no of observations considered for the matrix

Xii is the number of observations in row i and column i (elements on the main diagonal), X+i is the total of observations in column i and Xi+ is the total of the observations in row i; where r is the number of rows in error matrix.

### 3.5. Change detection of the Land use and Land cover

Change detection is a process that measures the attributes of a particular class that has changed between two or more time periods. In the present study four-date images where used for change detection i.e., TM (1992), ETM (2000), ETM (2010), and OLI (2020). The statistical analysis of the multi-temporal land cover maps of the KHANP was assessed to reveal the changes which have taken place from 1992 to 2020. The overall materials and methods followed in the present study is shown in Fig. 3.1

# CHAPTER-4

# CHAPTER – 4
# VEGETATION MAPPING AND CHANGE DETECTION IN THE KISHTIWAR HIGH ALTITUDE NATIONAL PARK

Kishtiwar High Altitude National Park is named after the well-known and historic town of Kishtiwar in the Jammu region. With Notification no. FST 20 of 1981, dated 04-02-1981, the Government of Jammu & Kashmir announced its intention to establish the National Park. The National Park is roughly 60 kilometers northeast of Kishtiwar town and lies between 33° 27' and 33° 59' N latitudes and 75° 40' to 76° 17' East longitudes. It is located in Jammu Province's District Kishtiwar. The National Park is accessible from the west by a route that leads to Dangduroo, some 40 kilometers from Kishtiwar town. Jammu, the nearest airport and railhead, is 230 kilometers distant. **Because the NP had been very early declared as the conservation priority region, it has been found the direct anthropogenic impacts (such as forest smuggling and poaching) on its flora and fauna have been minimal over the years.**

The Kishtiwar High Altitude National Park area is characterized by significant topographic, climate, and altitude change, resulting in diverse species of forest vegetation in the area, particularly on the northern and eastern sides. The four prominent nallas, Renai, Kiyar, Nanth, and Kiber, have lower catchment areas that support forest growth on favorable aspects with an increasing admixture of diverse species.

To assess the decadal change in the land use and land cover of the Kishtiwar High Altitude National Park, medium resolution Landsat imagery of 1992, 2000, 2010, and 2020 was carefully selected. We classified the national park into seven classes based on the level-1 classification of NRSC in concordance with the project's objectives. These seven classes include dense forests, open forests, grasslands/ meadows, scrubland, waterbody, snow/ glaciers, and rocky-barren classes.

In the following sections, first, the LULC of 2020 is discussed. Afterward, decadal change analysis is discussed.

### 4.1. Area estimates of different land covers in 2020

In the year 2020, the area estimates of various land cover classes of the National Park are discussed hereunder and summed in Table 4.1 and Fig. 4.1. Fig. 4.2 shows the spatial distribution of the various land cover classes in the KHANP.

4.1.1. **Dense Forest:** Presently, the dense forest cover spans about **107.75 sqkm** of the NP, constituting about **3.97 %** of its total area (Fig. 4.2).

4.1.2. **Open Forest:** Open forest cover spans about **253.14 sqkm** of the NP, constituting about **9.33 %** of its total area (Fig. 4.3).

The total forest cover of the NP, including dense and open, is about **360.89 sqkm,** accounting for **13.30 %** of its total area.

The forest vegetation types found in this 360.89 sqkm of the land of the NP are briefly discussed below:

Fir (*Abies pindrow*) Forests predominate over Deodar (*Cedrus deodara*) – Kail (*Pinus wallichiana*) Forests due to the high elevation and good moisture regime. The broad-leaved species are restricted to side nallas and cooler, damper locations. Patches of *Parrotiopsis jacquemontiana* can also be found. In the Dachhan Range, there is a sprinkling of *Pinus gerardiana* (Chilgoza pine). *Saussurea lappa* and other High Altitude plants can also be found at greater elevations. Fir can be found alone or in combination with Deodar and Kail, and it can even expand into the Deodar Kail zone on dumpy pockets.

**Table 4.1** Area estimates of the land under different land covers in **2020**

| S No. | Category | Area (sqkm) | Percentage |
|---|---|---|---|
| 1 | Dense Forest | 107.75 | 3.97 |
| 2 | Open Forest | 253.14 | 9.33 |
| 3 | Grasslands/Meadows | 138.20 | 5.09 |
| 4 | Scrub Land | 384.63 | 14.17 |
| 5 | Waterbody | 11.84 | 0.44 |
| 6 | Snow/Glacier | 798.20 | 29.41 |
| 7 | Rocky-barren | 1020.00 | 37.59 |
| | **Total** | **2713.76** | **100** |

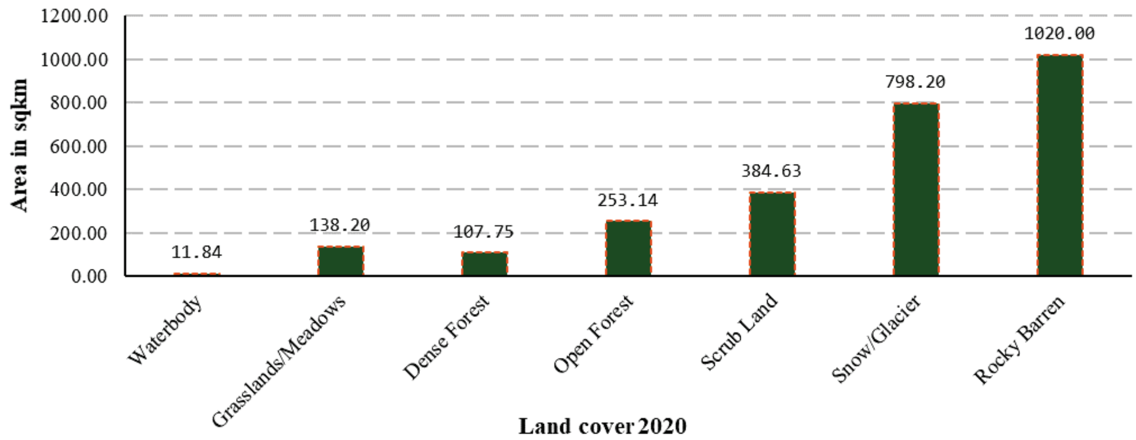


**Fig. 4.1** Graph of the area estimates of the land cover found in KHANP in the year 2020

The following forest types are found in the National Park, according to the revised Champion and Seth (1968) taxonomy of forest types.

- Moist Deodar Forest
- Western Mixed Coniferous Forest
- Moist Temperate Deciduous Forest
- Low-level Blue Pine Forest
- Himalayan temperate pastures
- West Himalayan High-level Dry Blue Pine Forest
- Birch / Fir Forest
- Birch / Rhododendron Scrub Forest
- Alpine Pastures

*a. Moist Deodar Forest*

The forest is normally fairly pure; however, blue pine and a small amount of spruce (*Picea smithiana*) are prevalent. The canopy is normally complete but not dense (especially in new crops) and reaches a height of around 30 m, but it is not truly climax. Pohu (*Parrotiopsis jacquemontiana*) produces dense undergrowth in areas where regeneration is difficult. This species is mostly found in the Dachhan Range. The forest type covers an altitude range of 1,700-2,500 meters and peaks to 3,000 meters on sunny ridges.

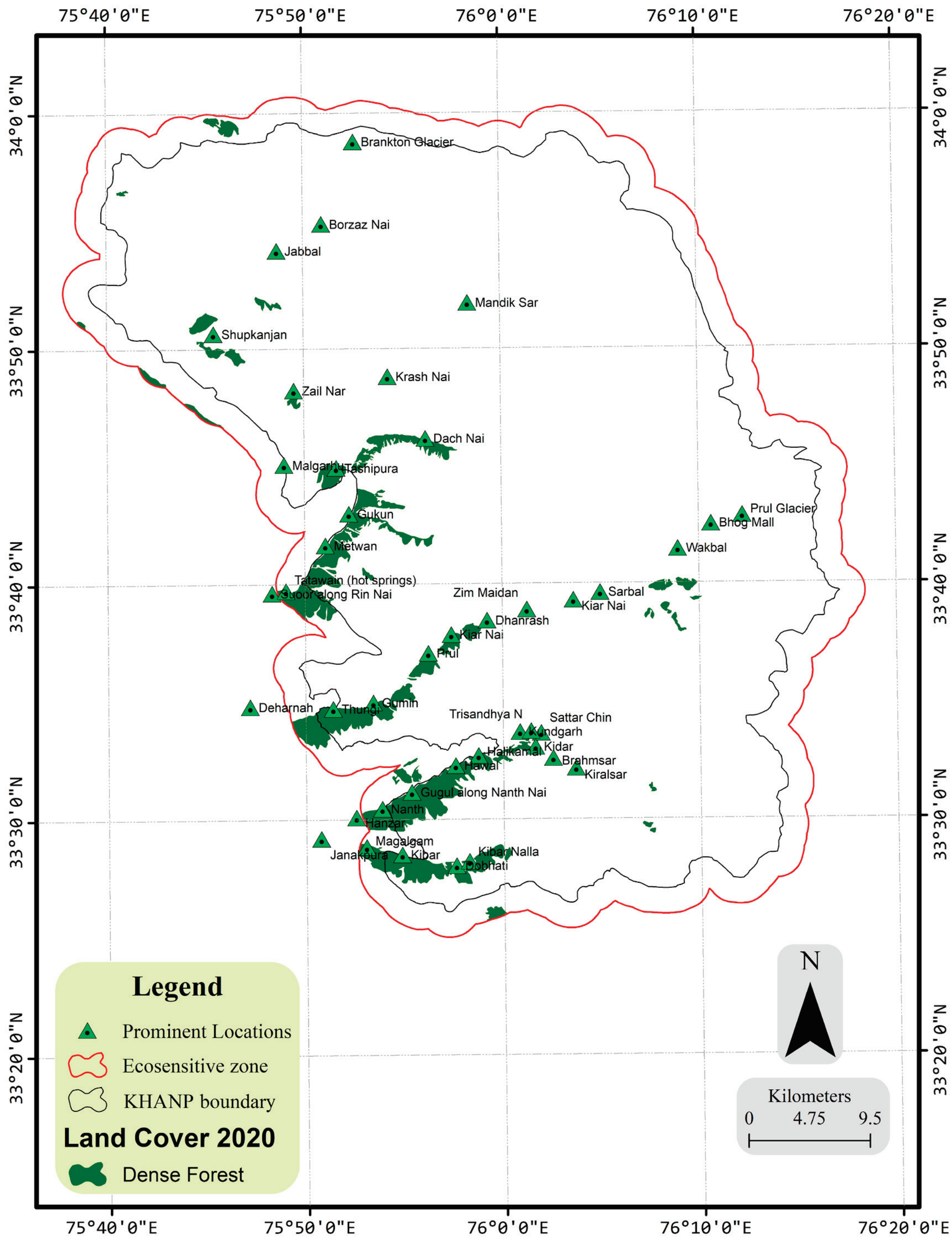


**Fig. 4.2** Current distribution of dense forest land cover class in the KHANP (year, 2020)

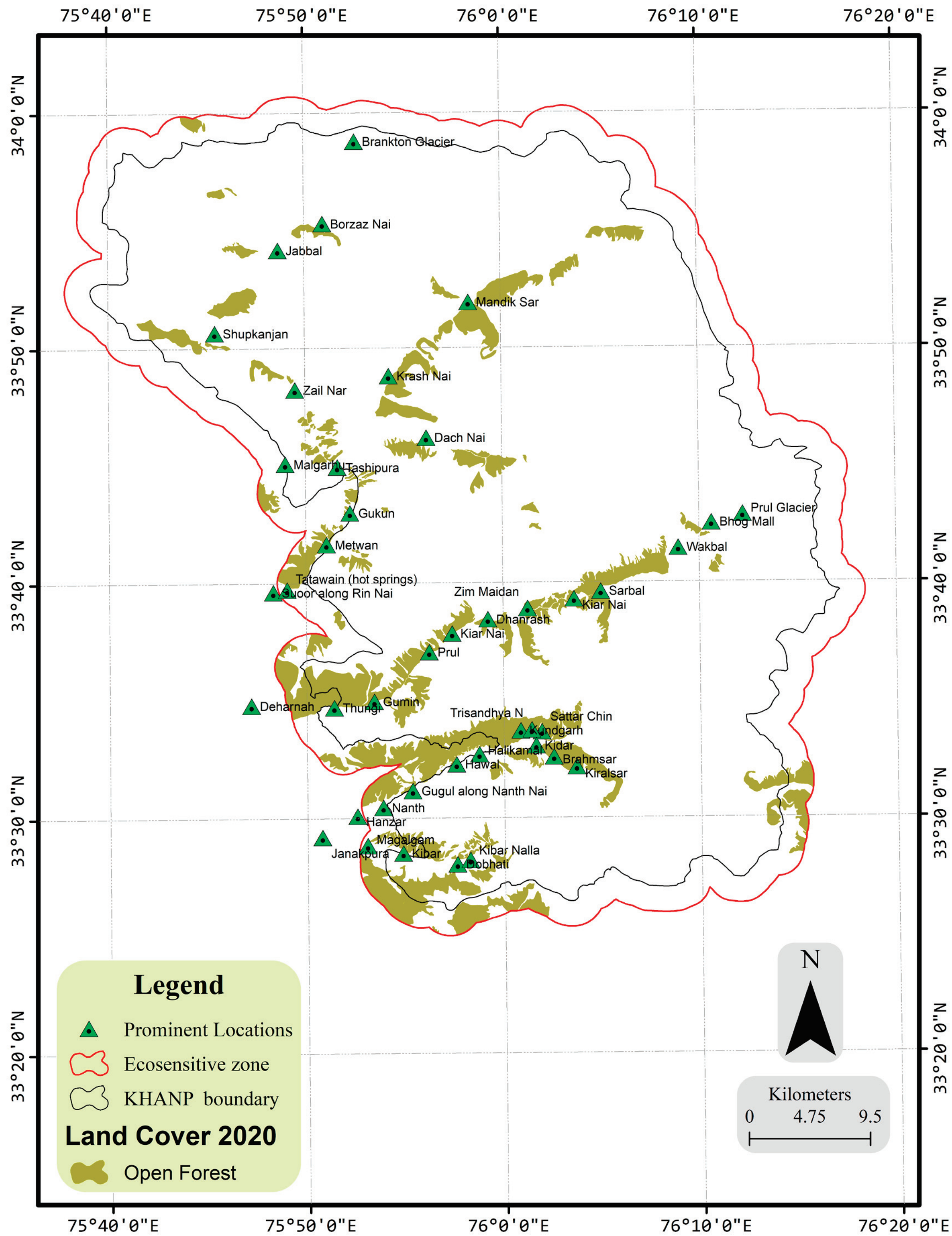


**Fig. 4.3** Current distribution of open forest land cover class in the KHANP (year, 2020)

Quercus ilex is found combined with deodar on all geological formations but avoids poorly drained soil. It's extremely usual for people to progress from Kail to Deodar. The following floral species have been discovered:

- *Cedrus deodara*, *Pinus griffithi*, *Picea smithiana*.
- *Quercus ilex*, *Fraxinus floribunda*, *Aesculus indica*, *Populus ciliata*, *Acer spp*., *Alnus nitida*, *Ulmus spp*., *Juglans regia*, *Celtis caucasica*
- *Parrotiopsis jacquemontana*, *Plectranthus regosus*, *Viburnum foetens*, *Indigo fera spp*., *Rosa spp*., *Lonicera spp*., *Desmodium spp*., *Saussurea lappa*, *Viola odorata*, *Podophyllum hexandrum*, *Rubus niveus*.

*b. Western Mixed Coniferous Forest*

The major community of Fir and spruce combined with deodar and Kail is referred to as this kind. This forest type may be found throughout the national park, with this type of forest accounting for the majority of the forest. This kind is well developed, with elevations ranging from 2,400 to 3,000 meters. Fir grows on the cooler parts of the mountain, Kail on the hotter spurs and ridges, and deodar grows on steep slopes and well-drained soils. Taxus wallichiana is a common companion, although *Betula utilis* takes over in the upper reaches. Spruce and Fir invariably mix, especially on slightly exposed areas.

This species thrives in the National Park's Marwah Range. Among the floral species discovered are:

- *Abies pindrow*, Picea *smithiana*, *Pinus wallichiana*, *Cedrus deodara*
- *Betula utilis*, *Acer spp*., *Padus cornuta*, *Aesculus indica*, *Corylus colurna*, *Populus ciliata*, *Juglans regia*, *Taxus wallichiana*, *Fraxinus floribunda*
- *Rosa spp*., *Lonicera spp*. *Viburnum spp*., *Sambucus spp*., *Salix spp*., *Polygonum spp*.,
- *Saussurea lappa*, *Podophyllum hexandrum*
- *Hedera* spp.

*c. Moist Temperate Deciduous Forest*

This variety can be found in wet hollows depressions and nallas at altitudes ranging from 1,200 to 2,750 meters. Deodar, Kail, and Mixed coniferous forests are all home to this species. These are commonly seen alone, but usually in the company of conifers. From the standpoint of wildlife, this type is critical. The following floral species have been discovered: *Aesculus indica*, *Juglans regia*, *Acer spp.*, *Populus ciliata*, *Coryl uscolurna*, *Padus cornuta*, *Fraxinus floribunda*, *Taxus wallichiana*

- *Viburnum foetens*, *Heterohylla gerardiana*

*d. Low-Level Blue Pine Forests*

Kail Forest occurs as a result of colonization on hotter aspects and hotter gaps, and is mostly pure. Kail is combined with Deodar and Spruce in some locations. Kail's regeneration is sufficient. Except in damp areas, the undergrowth is normally absent but present where the canopy is disturbed. Various forest types can be found throughout the National Park. This kind can be found at elevations ranging from 1,700 to 2,400 meters. There were a variety of floral species discovered.

- *Pinus griffithi*, *Cedrus deodara*, *Picea smithiana*, *Abies pindrow*
- *Quercus ilex*
- *Indigofera spp.*, *Desmodium spp.*, *Lonicera spp.*, *Berberis spp.*, *Viburnum spp*.

*e. West Himalayan High-Level Dry Blue Pines Forests*

This variety can be found in hotter areas as pure Kail woods. Arcnathodium is prevalent in this kind. This type of woodland covers only a small portion of the National Park. It can be found between 3,000 and 3,600 meters above sea level. The following floral species have been discovered:

- *Pinus griffithii*, *Abies pindrow*
- *Betula utilis*, *Rhododendron spp*.
- *Juniperus spp.*, Lonicera *spp*.

*f. West Himalayan Sub alpine Birch – Fir Forest*

The forest is frequently uneven, with changing amounts of three elements: Fir, birch, and rhododendron. This variety is found at elevations of 3,000 meters and higher, mainly on ridges and slopes where slips are uncommon.

Floristic species found include:

- *Abies pindrow*, *Betula utilis*, *Rhododendron spp*.

### 4.1.3. Grassland/ Meadows

We have dedicated a separate chapter regarding meadow resources of the KHANP as chapter 6.

### 4.1.4. Scrub land

Presently, the **scrub** class covers about **384.63 sqkm** of the NP, constituting about **14.17 %** of its total area (Fig. 4.4). Scrub woodlands with birch and rhododendron. This species is found in sheltered places, primarily on the northern and western sides, growing increasingly widespread eastward. This form of vegetation can be found in very small spots in the national park's upper elevations. The main feature is abundant snowfall, with the snow remaining until the day air temperature is rather warm. *Irises* are short and branchy, and the ground is covered with mosses and ferns and varied amounts of alpine shrubs and herbs.

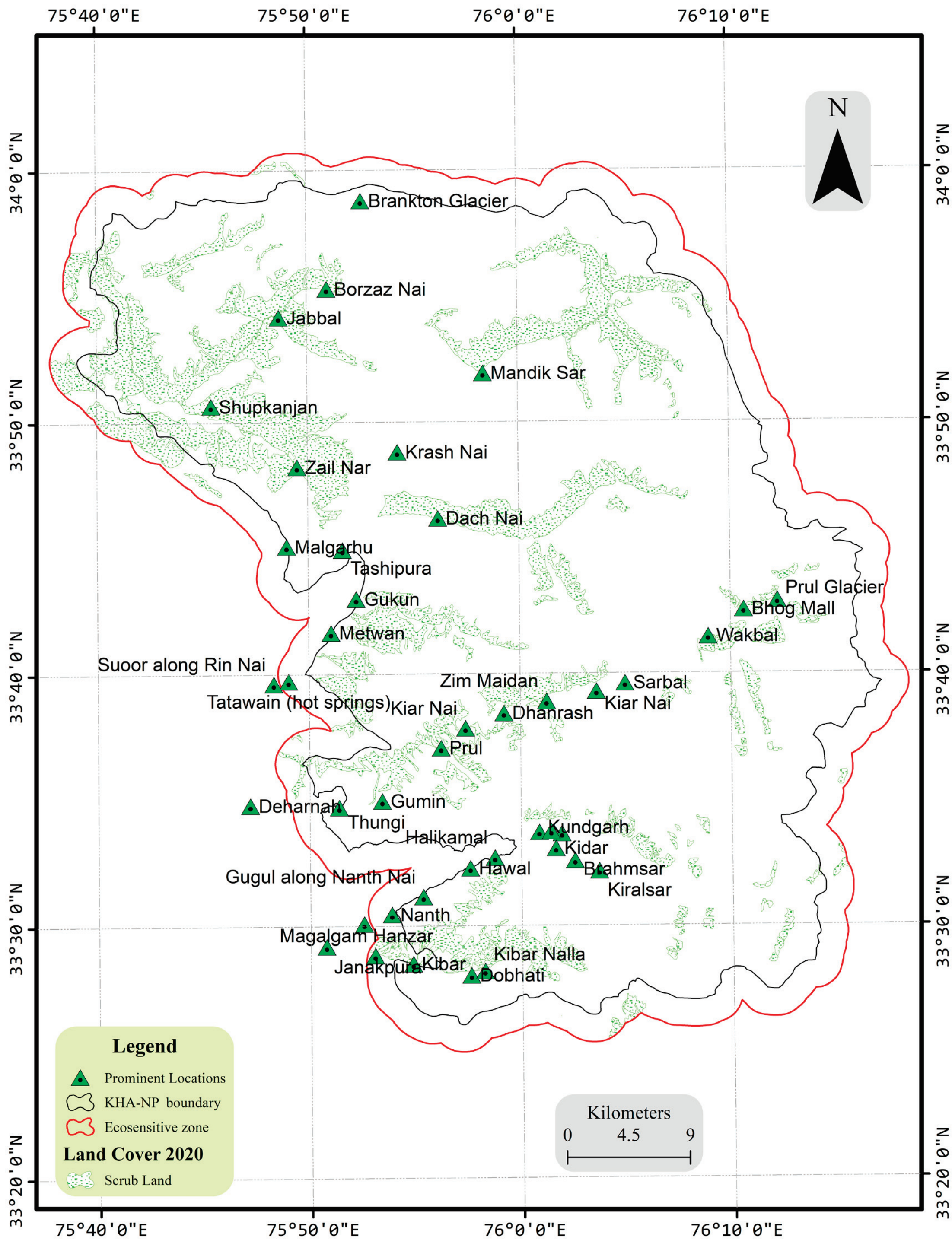


**Fig. 4.4** Current distribution of scrub land cover class in the KHANP (year, 2020)

### 4.1.5. Water body

Presently, the land under streams and alpine lakes in the National Park spans about **11.84 sqkm** constituting about **0.44 %** of its total area (Fig. 4.5).

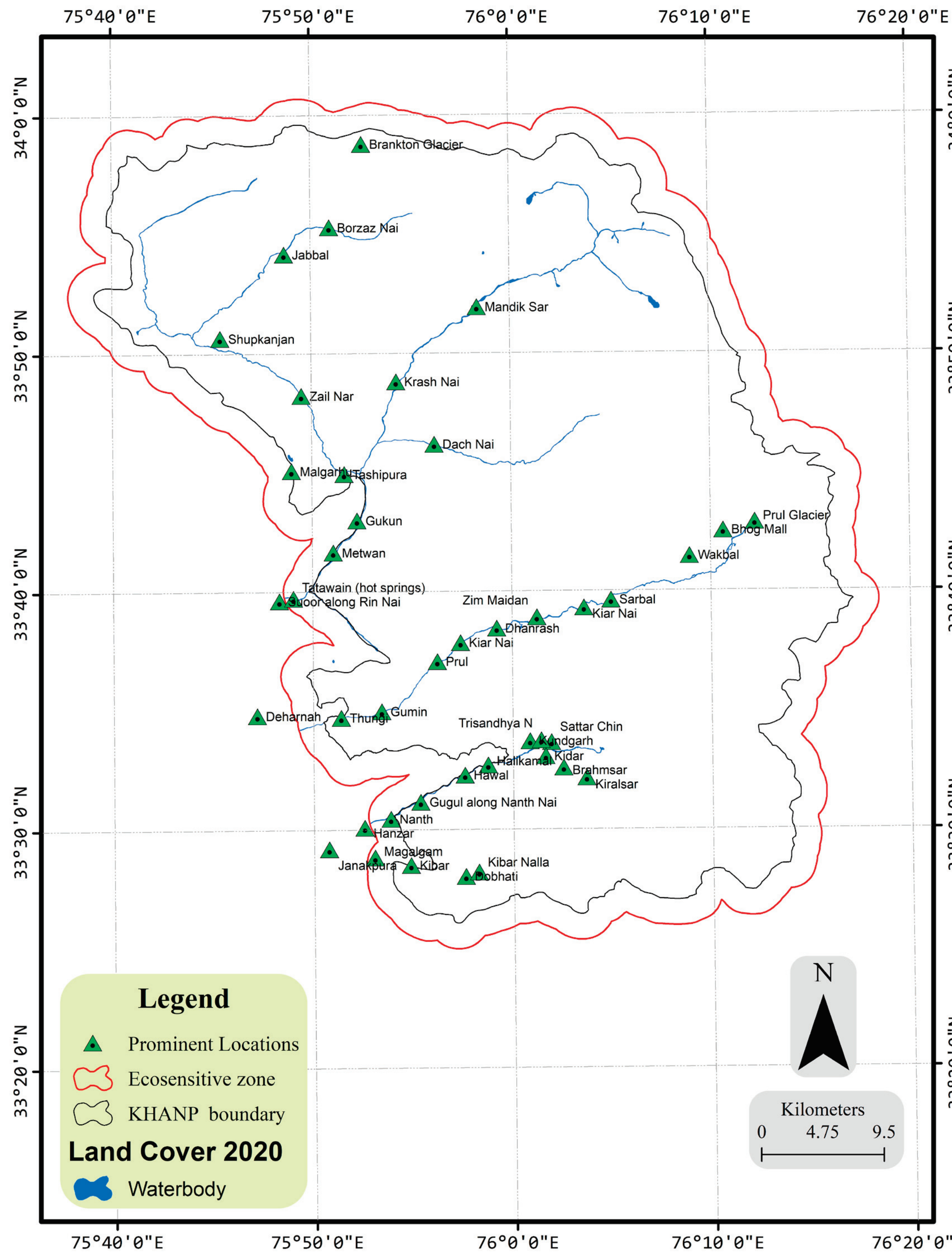


**Fig. 4.5** Current distribution of waterbody land cover class in the KHANP (year, 2020)

### 4.1.6. Snow/ glacier

In 2020, the area under snow/ glaciers spanned about **798.20 sqkm** of the NP, constituting approximately **29.41 %** of its total area (Fig. 4.6). It is the second-largest land cover category in the NP. A separate chapter has been dedicated to the water resources of the KHANP, wherein detailed investigation regarding changing snow and glaciers of the NP has been reported.

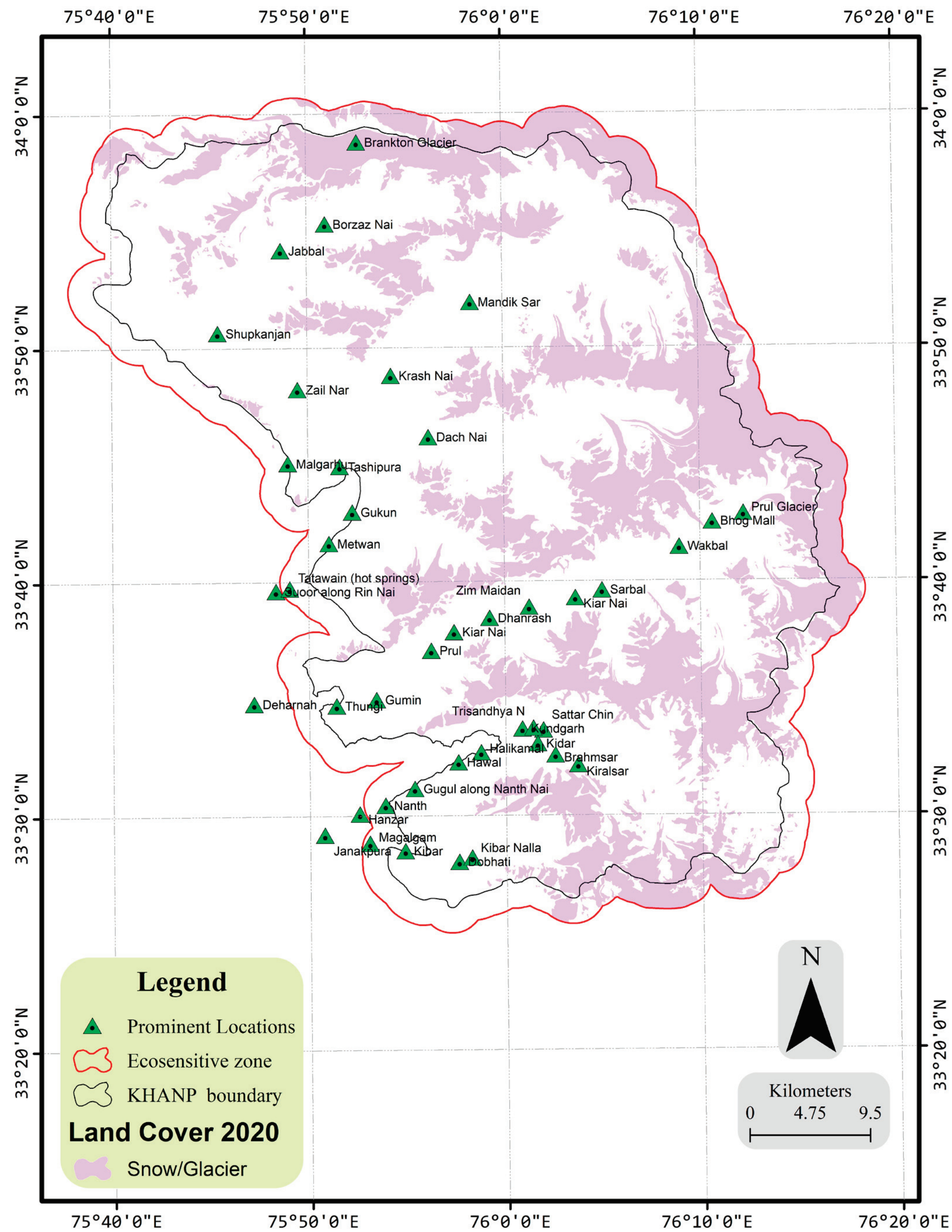


**Fig. 4.6** Current distribution of snow/ glacier land cover class in the KHANP (year, 2020)

### 4.1.7. Rocky-barren

In 2020, the land cover of the Kishtiwar High Altitude NP was dominated by the rocky-barren class, having about **1020.00 sqkm** of the national park under it and accounted for about **37 %** of its area (Fig. 4.7).

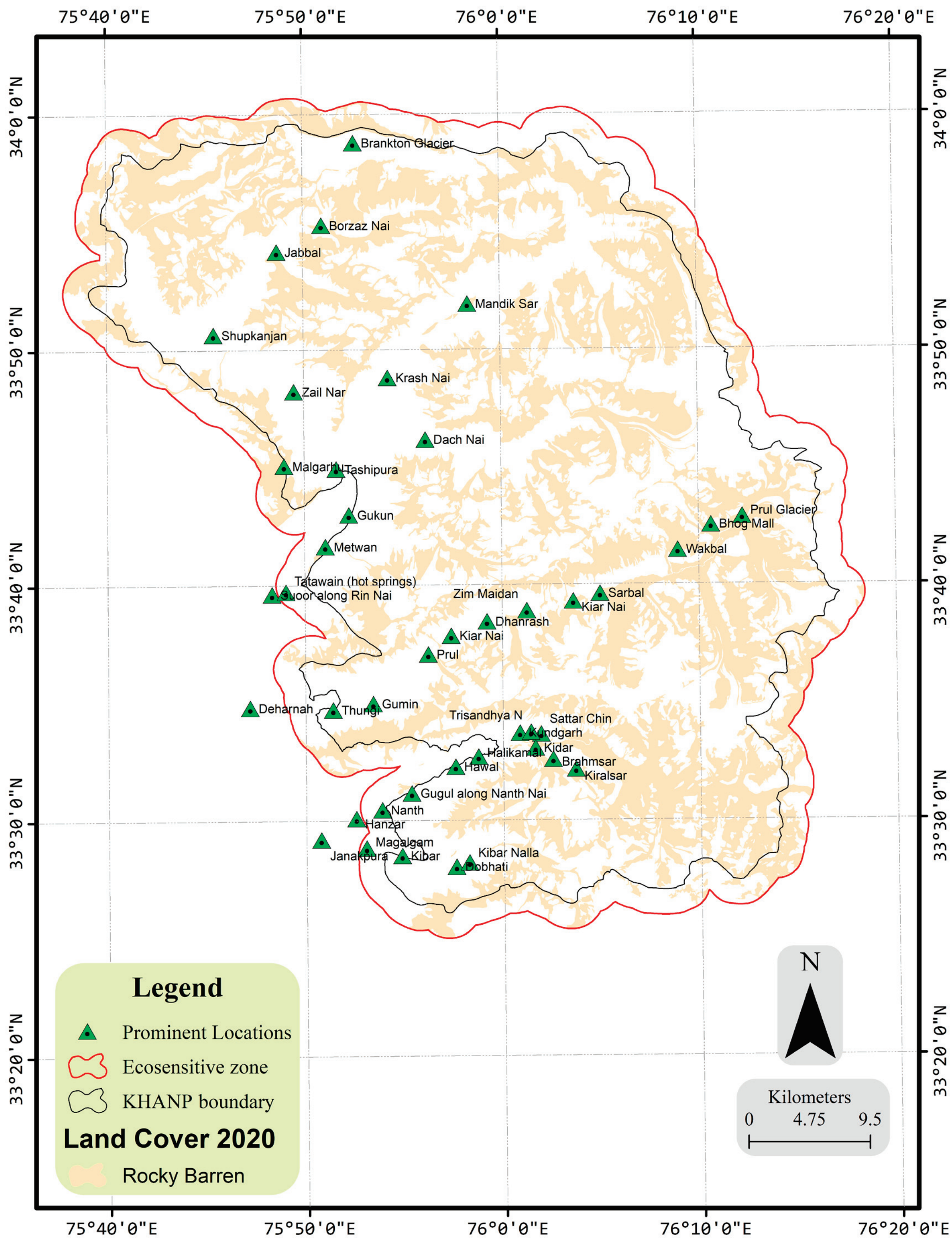


**Fig. 4.7** Current distribution of rocky-barren land cover class in the KHANP (year, 2020)

**Cross Tabulation for assessing the accuracy of the land cover of 2020**

We have carried extensive ground-truthing to correct the land cover classification using the visual image interpretation method for 2020 (Table 4.2). In total, 250 field samples were checked for validation of the classified map. The survey was conducted with high accuracy handheld GPS (Garmin GSMAP). The results shown above are the post-accuracy assessment after the corrections had been incorporated. The overall accuracy of the final classified map was 94.4%, and the kappa coefficient was equal to 0.91, implying that the LC classification is highly accurate.

**Table 4.2** Cross-tabulation or Error Matrix of land cover classification from LANDSAT OLI 2020

| | | ***Mapped LULC Classes*** | | | | | | | **Grand Total** | **User's Accuracy:** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *DF* | *OF* | *G/M* | *SC* | *W* | *SG* | *RB* | | |
| ***Mapped LC Classes*** | *DF* | **33** | | | | | | | 35 | 94.29% |
| | *OF* | | **31** | | 4 | | | | 35 | 88.57% |
| | *G/M* | | | **29** | | | | | 33 | 87.88% |
| | *SC* | | | | **38** | | | | 42 | 90.48% |
| | *W* | | | | | **35** | | | 35 | 100.00% |
| | *SG* | | | | | | **25** | | 25 | 100.00% |
| | *RB* | | | | | | | **45** | 45 | 100.00% |
| **Grand Total:** | | 33 | 31 | 29 | 42 | 35 | 25 | 45 | **250** | |
| **Producer's Accuracy:** | | 100% | 100% | 100% | 90% | 100% | 100% | 100% | | |

**Total Correct: 232** **Total Samples: 250** **Overall Accuracy: 94.4%** **Kappa Statistic: 0.91**

***Codes*** *DF, Dense forest (>40 % canopy cover); OF,Open forest (10% > 40 % canopy cover); G/M, Grassland/ meadows; SC, Scrub land (< 10% canopy cover forests); W, Water body; SG, Snow/ Glaciers; RB, Rocky-barren*

*Using the Accuracy Assessment or Cross Tabulation Table: The contingency table or error matrix is an array of numbers set out in rows and columns corresponding to a particular vegetation map unit relative to the actual vegetation type as verified on the ground. The column headings represent the vegetation classification as determined in the field and the row headings represent the vegetation classification taken from the vegetation map. The highlighted diagonal indicates the number of points assessed in the field that agree with the map label. Conversely, the inaccuracies of each map unit are described as both errors of inclusion (user's or commission errors) and errors of exclusion (producer's or omission errors). By reading across this table (i.e., rows) one can calculate the percent error of commission, or how many polygons for each map unit were incorrectly labeled according to the field ecologist. By reading down the table (i.e., columns) one can calculate the percent error of omission, or how many polygons for that type were left off the map. Numbers "on the diagonal" tell the user how well the map unit was interpreted and how confident they can be in using it. Numbers "off the diagonal" yield important information about the deficiencies of the map including which types were under- or over-represented.*

## 4.2. Decadal change assessment of different land covers in Kishtiwar High Altitude National Park

### 4.2.1. Analyzing the change in land covers between 1992-2000

For assessing the change in land cover between 1992 and 2000, we classified the Landsat images for these two years using visual image interpretation methodology. To reduce the errors in the change detection analysis, the scale of the digitization across all the dates (1992, 2000, 2010, and 2020) has been kept constant at the 1:15000 scale. Fig. 4.8 shows the spatial distribution of the land covers in 1992 at the KHANP. Table 4.3 shows the change between the years 1992 and 2000. Fig. 4.9 shows the land cover change in graphical representation.

It has been found that the most considerable change in this period was observed in the snow/ glacier class. Snow/ glaciers decreased from its areal extent of 1578.27 sqkm in 1992 to 978.97 sqkm in 2000, recording a decrease of 599.30 sqkm (-37.97%) of the area in this period. There has been a corresponding increase in the area under the rocky-barren class. Rocky-barren class increased from its areal extent of 304.83 sqkm to 813.68 sqkm, recording an increase of 508.85 sqkm (166.93%, i.e., more than doubled) of the area in this period. **It is to be noted that the increase of the area under rocky-barren class corresponded to the 84% decrease of the area under snow/ glaciers class, indicating that the decreased area of the snow/glaciers got converted to rocky-barren. It must be noted that these two classes interchange throughout the year. Hence their decrease or increase is not significant unless there are significant changes in the snow cover climatologically. This has been addressed in the chapter on water resources, wherein it has been found that in the last 20 years, there has been not significant change in the snow precipitation in the study area.**

The area under dense forests class has increased from 69.49 sqkm in 1992 to 95.71 sqkm in 2000, recording an increase of 26.22 sqkm (37.74%) of the area in this period. The area under open forests class has also increased from its areal extent of 96.90 sqkm in 1992 to 139.89 sqkm in 2000, recording an increase of 42.99 sqkm (44.36 %) of the area in this period. The area under grassland/meadows has decreased from its areal extent of 152.72 sqkm in 1992 to 100.56 sqkm in 2000, recording a decrease of 52.15 sqkm (-34.15%)

in this period. **It was observed that the open forests got converted to dense forests, and the decrease of land under grassland/ meadows class corresponded to the conversion into the open forest class category, along the transition zones between grassland/ meadow class and the open forest class.**

The area under the scrubland class has increased from its areal extent of 500.31 sqkm in 1992 to 573.56 sqkm in 2000, recording an increase of 73.26 sqkm (14.64%) of the area in this period. The area under the waterbody class has almost remained the same.

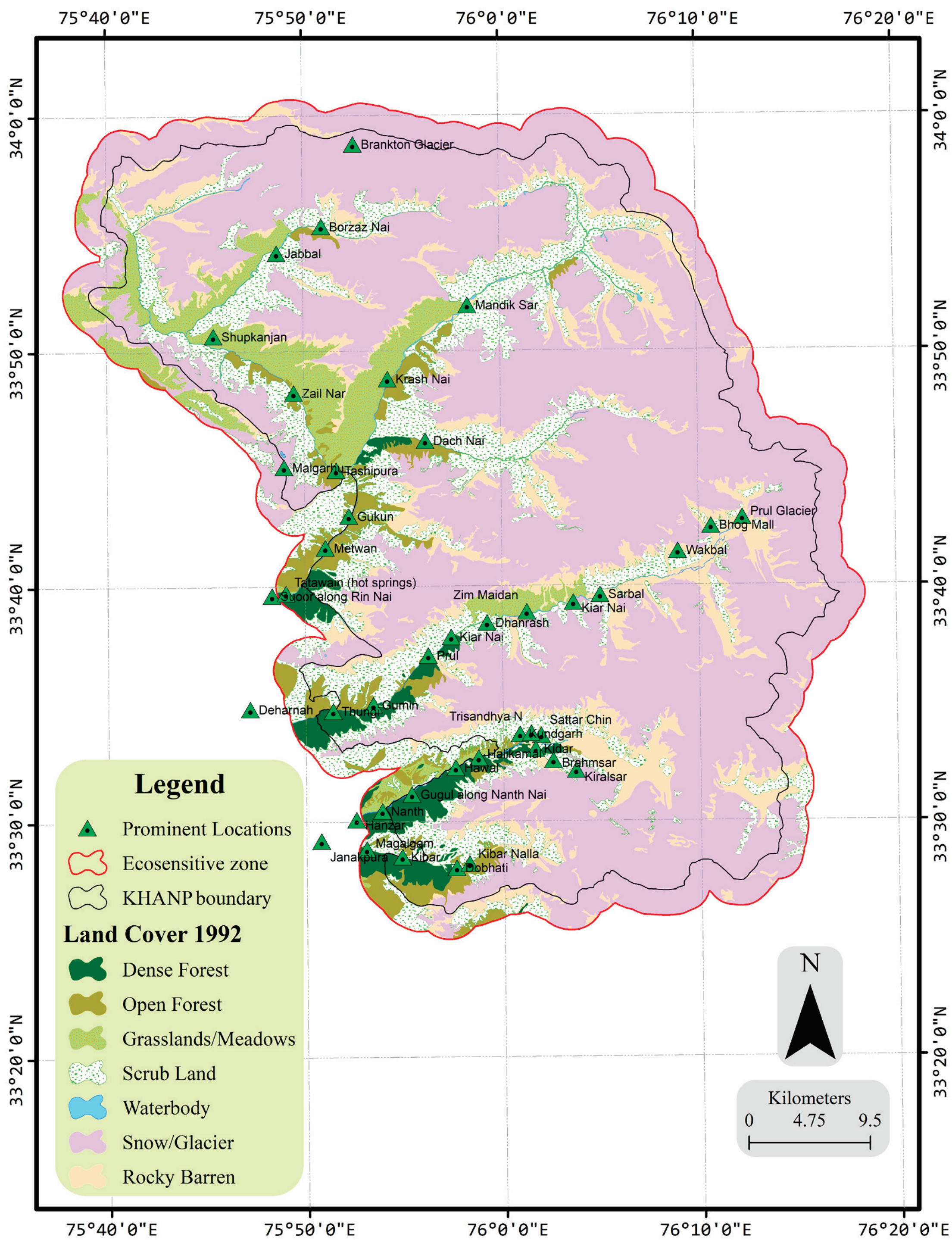


**Fig. 4.8** Spatial distribution of different land covers in the KHANP in the year 1992

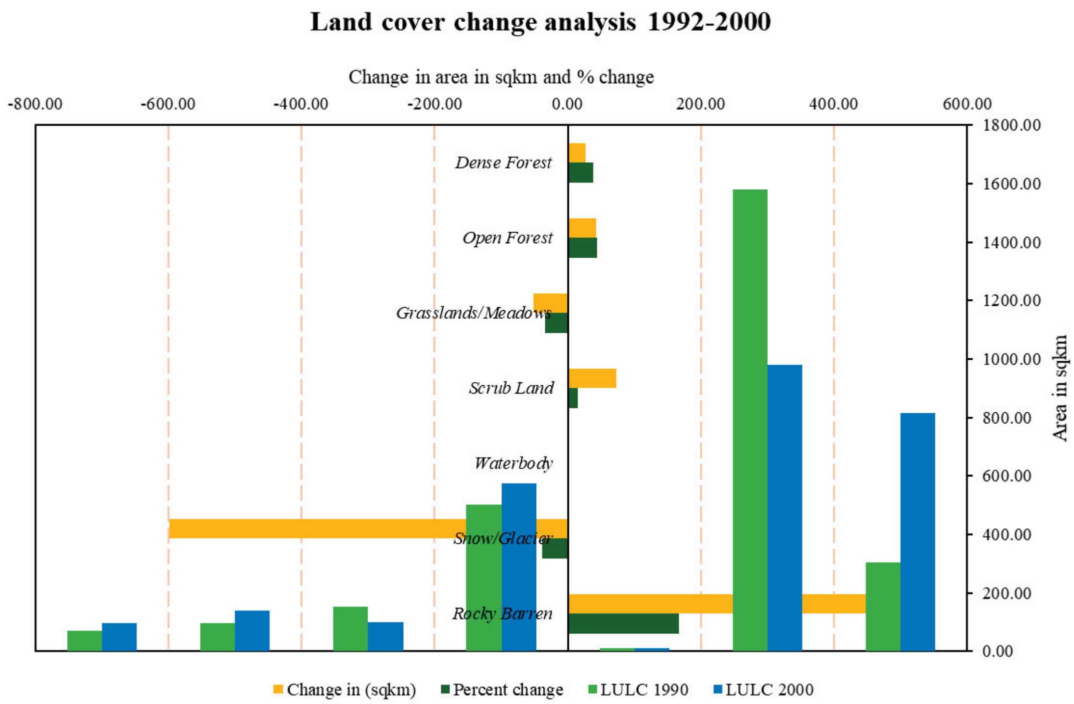


**Fig. 4.9** Column graphs elucidating the land cover change analysis between the years 1992 and 2000

**Table 4.3** Estimations of the land cover change between the years 1992 and 2000

| S No. | Categories | LULC 1990 | LULC 2000 | Change in (sqkm) | Percent change |
|---|---|---|---|---|---|
| 1 | Dense Forest | 69.49 | 95.71 | 26.22 | 37.74 |
| 2 | Open Forest | 96.90 | 139.89 | 42.99 | 44.36 |
| 3 | Grasslands/ Meadows | 152.72 | 100.56 | -52.15 | -34.15 |
| 4 | Scrub Land | 500.31 | 573.56 | 73.26 | 14.64 |
| 5 | Waterbody | 11.25 | 11.39 | 0.13 | 1.17 |
| 6 | Snow/Glacier | 1578.27 | 978.97 | -599.30 | -37.97 |
| 7 | Rocky-barren | 304.83 | 813.68 | 508.85 | 166.93 |

### 4.2.2. Analyzing the change in land covers between 2000-2010

For assessing the change in land cover between 2000 and 2010, we classified the Landsat images for these two years using visual image interpretation methodology. Fig. 4.10 shows the spatial distribution of the land covers in 2000 at the KHANP. Table 4.4 shows the land cover change between the years 2000 and 2010. Fig. 4.11 shows the land cover change in graphical representation.

It has been found that the largest change in this period was observed in the snow/ glacier class, however lesser than the previous decade. Snow/ glaciers decreased from its areal extent of 978.97 sqkm in 2000 to 923.12 sqkm in 2010, recording a decrease of 55.85 sqkm (-5.71%) of the area in this period. There has been a corresponding increase in the area under the rocky-barren class. Rocky-barren class increased from its areal extent of 813.68 sqkm in 2000 to 832.35 sqkm, recording an increase of 48.67 sqkm (5.98%) of the area in this period. **It is to be noted that the increase of the area under rocky-barren class corresponds to the decrease of the area under snow/ glaciers class, indicating that the decreased area of the snow/glaciers got converted to rocky-barren.**

The area under the dense forests class has increased from its areal extent of 95.71 sqkm in 2000 to 105.93 sqkm in 2010, recording an increase of 10.22 sqkm (10.68%) of the area in this period. There has been a slight decrease of the area under the open forests class from its areal extent of 139.89 sqkm in 2000 to 128.33 sqkm in 2010, recording a decrease of 11.57 sqkm (-8.27%) of the area in this period. The area under grassland/meadows has decreased from its areal extent of 100.56 sqkm in 2010 to 91.84 sqkm in 2010, recording a decrease of 8.72 sqkm (-8.67%) in this period. **It was observed that the open forests got converted to dense forests, and the decrease of land under grassland/ meadows class corresponded to the conversion into scrubland class category, along the transition zones between grassland/ meadow class and the scrub class.**

The area under the scrubland class has increased from its areal extent of 573.56 sqkm in 2000 to 590.81 sqkm in 2010, recording an increase of 17.24 sqkm (3.01%) of the area in this period. The area under the waterbody class has almost remained the same.

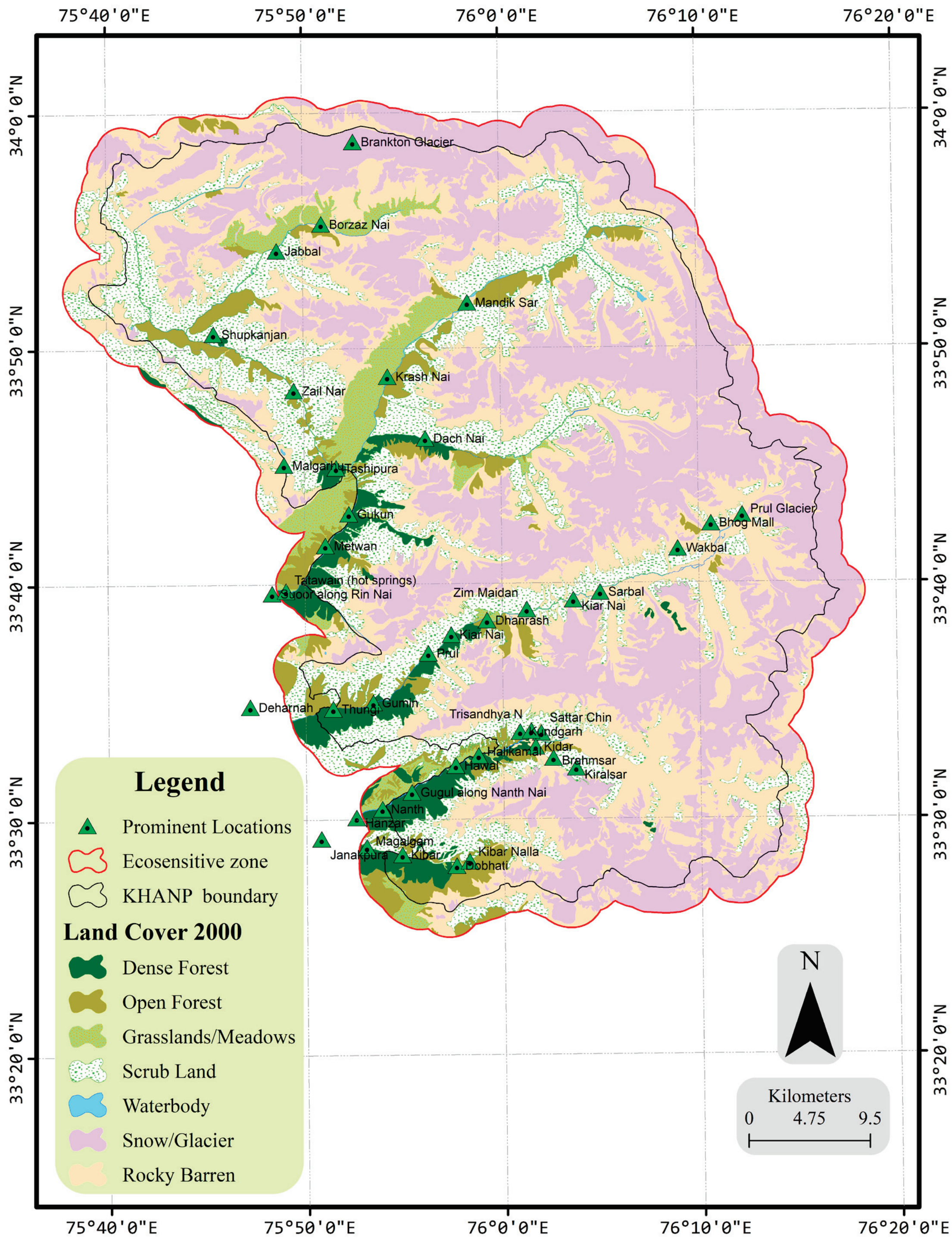


**Fig. 4.10.** Spatial distribution of different land covers in the KHANP in the year 2000

**Table 4.4** Estimations of the land cover change between the year 2000 and 2010

| S No. | Categories | LULC 2000 | LULC 2010 | Change in (sqkm) | Percent change |
|---|---|---|---|---|---|
| 1 | Dense Forest | 95.71 | 105.93 | 10.22 | 10.68 |
| 2 | Open Forest | 139.89 | 128.33 | -11.57 | -8.27 |
| 3 | Grasslands/ Meadows | 100.56 | 91.84 | -8.72 | -8.67 |
| 4 | Scrub Land | 573.56 | 590.81 | 17.24 | 3.01 |
| 5 | Waterbody | 11.39 | 11.39 | 0.00 | 0.02 |
| 6 | Snow/Glacier | 978.97 | 923.12 | -55.85 | -5.71 |
| 7 | Rocky-barren | 813.68 | 862.35 | 48.67 | 5.98 |

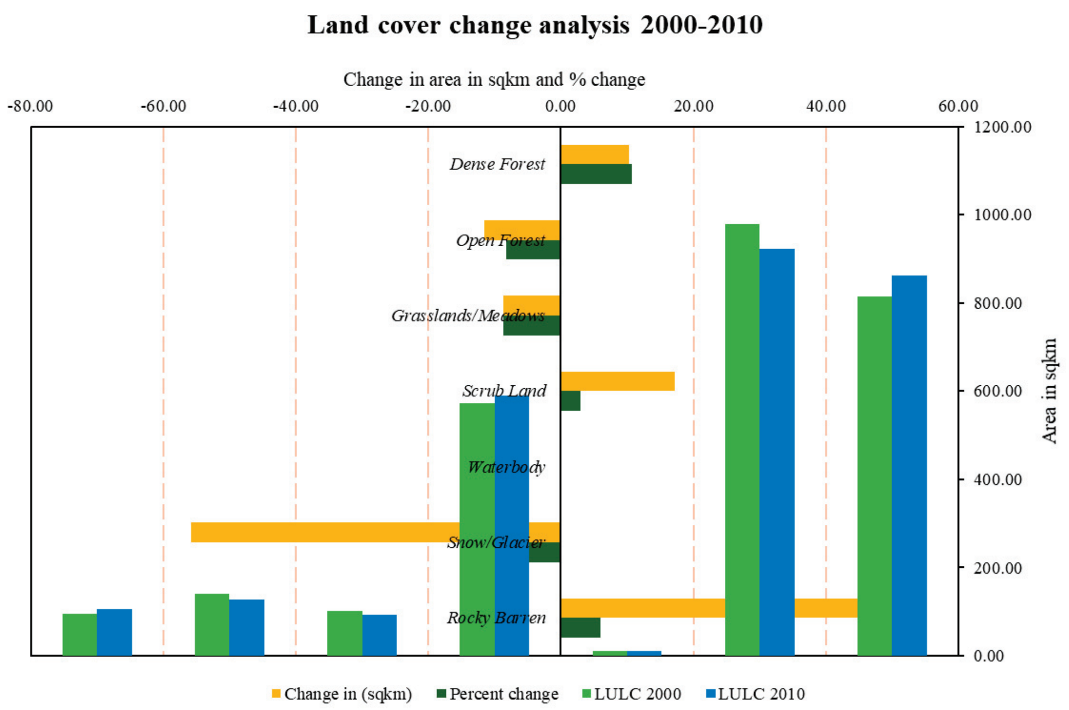


**Fig. 4.11** Column graphs illucidating the land cover change analysis between the years 2000 and 2010

### 4.2.3. Analyzing the change in land covers between 2010-2020

For assessing the change in land cover between 2010 and 2020, we classified the Landsat images for these two years using visual image interpretation methodology. Fig. 4.12 and Fig. 4.13 show the spatial distribution of the land covers in 2010 and 2020 at the KHANP. Table 4.5 shows the land cover change between the years 2010 and 2020. Fig. 4.14 shows the land cover change between 2010 to 2020 in graphical representation.

Snow/ glaciers decreased from their areal extent of 923.12 sqkm in 2010 to 798.20 sqkm in 2020, recording a decrease of 124.32 sqkm (13.53% decrease since 2010) of the area in this period. There has been a corresponding increase in the area under the rocky-barren class. Rocky-barren class increased from its areal extent of 832.35 sqkm in 2010 to 1020 sqkm in 2020, recording an increase of 157.65 sqkm (18.28% increase since 2010) of the area in this period. **It is to be noted that the increase of the area under the rocky-barren class corresponds well with the decrease of the area under snow/ glaciers class, indicating that the decreased area of the snow/glaciers got converted to rocky-barren.**

The area under the dense forests class has slightly increased from its areal extent of 105.93 sqkm in 2010 to 107.75 sqkm in 2020, recording an increase of 1.82 sqkm (1.72% increase since 2010) of the area in this period. However, the open forest class has almost doubled in the area, its areal extent of 128.33 sqkm in 2010 to 253.14 sqkm in 2020, recording an increase of 124.81 sqkm (97.26% increase since 2010) of the area in this period. The area under the scrubland class has decreased from its areal extent of 590.81 sqkm in 2010 to 384.63 sqkm in 2020, recording a decrease of 206.18 sqkm (-65.10 % decrease since 2010) of the area in this period. **It is to be noted that the decrease of the area under scrubland class corresponds well with the increase of the area under open forest class, indicating that the decreased area of the scrubland got converted to open forest.**

The area under grassland/meadows has increased from its areal extent of 91.84 sqkm in 2010 to 138.20 sqkm in 2020, recording an increase of 46.36 sqkm (49.52 % since 2010) in this period. As with the previous decade, the area under the water body class has almost remained the same.

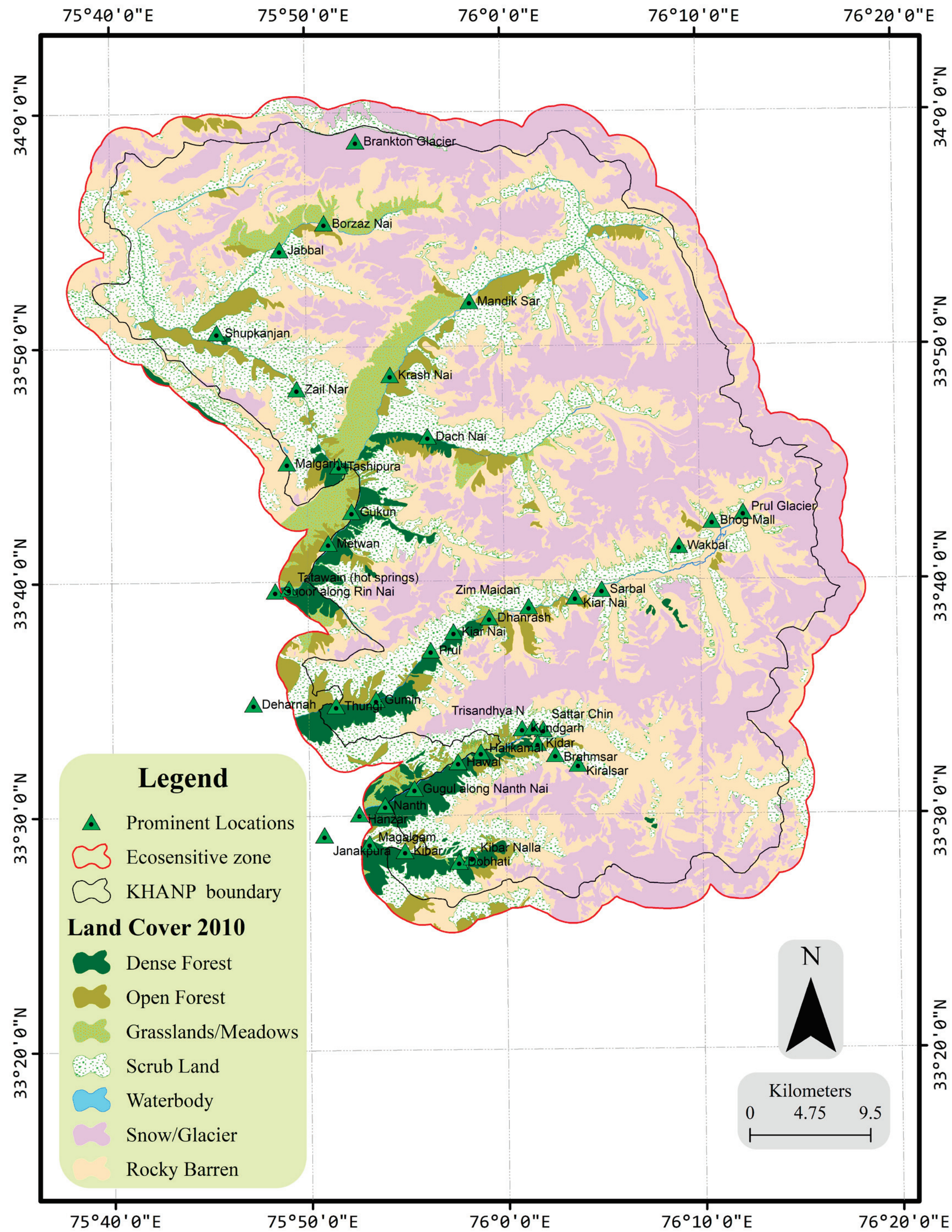


**Fig. 4.12** Spatial distribution of different land covers in the KHANP in the year 2010

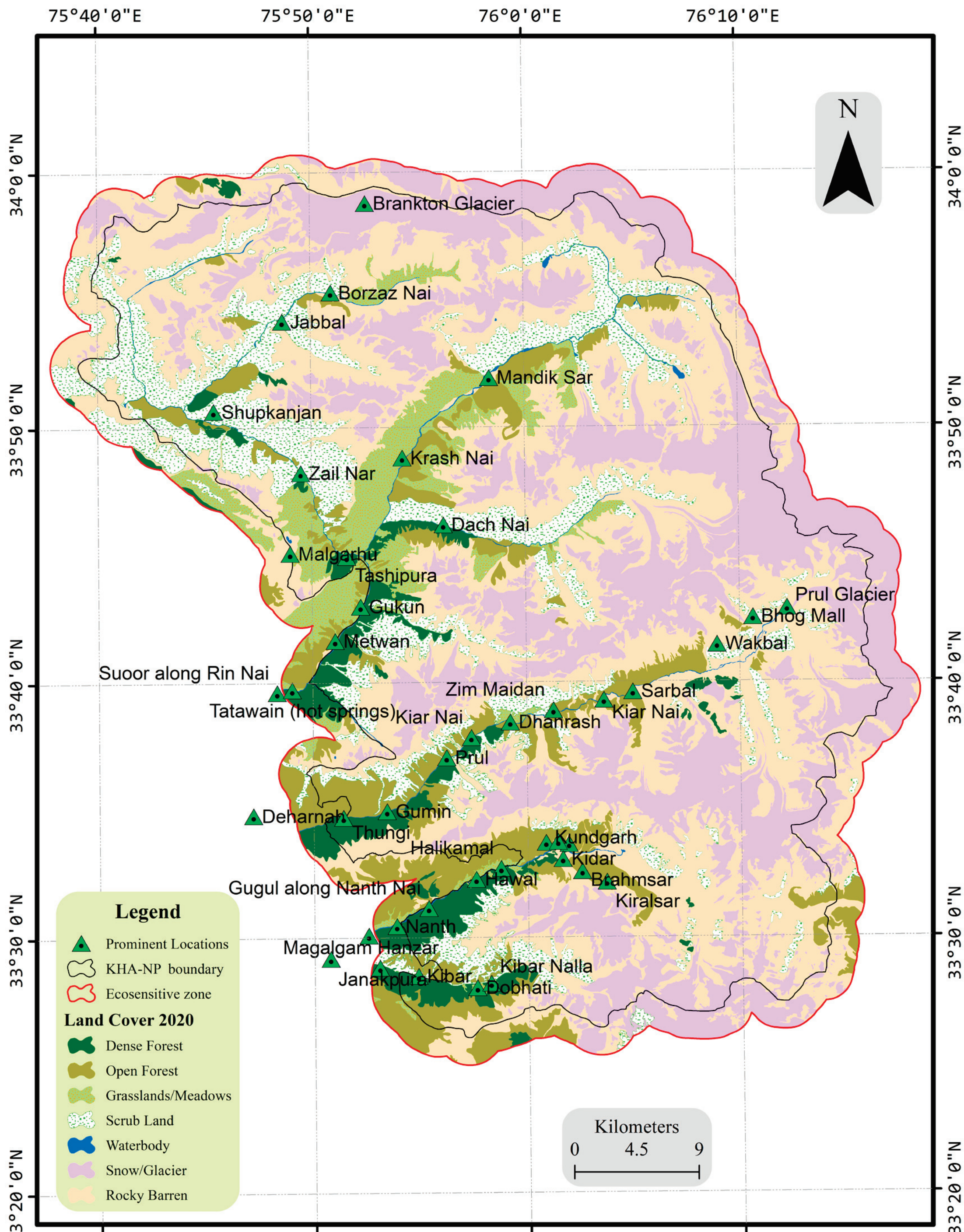


**Fig. 4.13** Spatial distribution of different land covers in the KHANP in the year 2020

**Table 4.5** Estimations of the land cover change between the year 2010 and 2020

| S No. | Categories | LULC 2010 | LULC 2020 | Change in (sqkm) | Percent change |
|---|---|---|---|---|---|
| 1 | Dense Forest | 105.93 | 107.75 | 1.82 | 1.72 |
| 2 | Open Forest | 128.33 | 253.14 | 124.81 | 97.26 |
| 3 | Grasslands/ Meadows | 91.84 | 138.20 | 46.36 | 49.52 |
| 4 | Scrub Land | 590.81 | 384.63 | -206.18 | -65.10 |
| 5 | Waterbody | 11.39 | 11.84 | 0.46 | 4.01 |
| 6 | Snow/Glacier | 923.12 | 798.20 | -124.92 | -13.53 |
| 7 | Rocky-barren | 862.35 | 1020.00 | 157.65 | 18.28 |

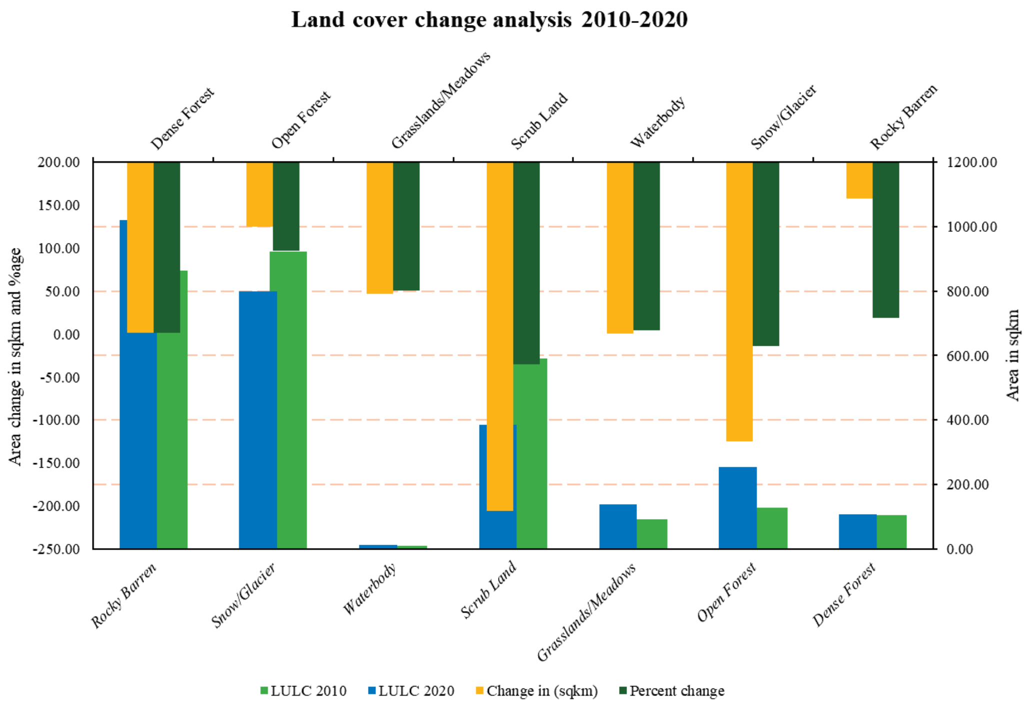


**Fig. 4.14** Column graphs illucidating the land cover change analysis between the years 2010 and 2020

### 4.2.4. Overall change in land covers between from 1992 till 2020

Table 4.6 shows the land cover change between the years 1992 and 2020. Fig. 4.15 shows the land cover change between 1992 to 2020 in the graphical representation.

Snow/ glaciers have decreased almost half of their areal extent in 1992. It decreased from 1578.27 sqkm in 1992 to 798.20 sqkm in 2020, recording a decrease of 780.07 sqkm (-49.43% decrease since 1992) of the area in this period. There has been a corresponding increase in the area under the rocky-barren class. Rocky-barren class increased from its areal extent of 304.83 sqkm in 1992 to 1020 sqkm in 2020, recording an increase of 715.17 sqkm (234.61% increase since 1992, nearly five times increase since 1992) of the area in this period. **Overall It is concluded that the increase of the area under rocky-barren class corresponds well with the decrease of the area under snow/ glaciers class, indicating that the decreased area of the snow/glaciers got converted to rocky-barren.**

The area under the dense forests class has increased from its areal extent of 69.49 sqkm in 1992 to 107.75 sqkm in 2020, recording an increase of 38.27 sqkm (55.07 % since 1992) of the area in this period. The open forest class has similarly increased in area with its areal extent increasing from 96.90 sqkm in 1992 to 253.14 sqkm in 2020, recording an overall increase of 156.24 sqkm (161.23% increase since 1992) of the area in this period. The area under the scrubland class has overall decreased from its areal extent of 500.31 sqkm in 1992 to 384.63 sqkm in 2020, recording an overall decrease of 115.68 sqkm (-23.12% decrease since 1992) of the area in this period. The area under grassland/meadows has also decreased from its areal extent of 152.72 sqkm in 1992 to 138.20 sqkm in 2020, recording an overall decrease of 14.52 sqkm (-9.51% since 1992) in this period.

It is to be noted that the decrease of the area under scrubland and grassland/meadows class corresponds well with the increase of the area under open forest class, indicating that the decreased area of these classes got converted to open forest. Overall there has been no significant change in the waterbody class since 1992.

**Table 4.6** Estimations of the land cover change between the year 1992 and 2020

| S No. | Categories | LULC 1992 | LULC 2020 | Change in (sqkm) | Percent change |
|---|---|---|---|---|---|
| 1 | Dense Forest | 69.49 | 107.75 | 38.27 | 55.07 |
| 2 | Open Forest | 96.90 | 253.14 | 156.24 | 161.23 |
| 3 | Grasslands/ Meadows | 152.72 | 138.20 | -14.52 | -9.51 |
| 4 | Scrub Land | 500.31 | 384.63 | -115.68 | -23.12 |
| 5 | Waterbody | 11.25 | 11.84 | 0.59 | 5.25 |
| 6 | Snow/Glacier | 1578.27 | 798.20 | -780.07 | -49.43 |
| 7 | Rocky-barren | 304.83 | 1020.00 | 715.17 | 234.61 |

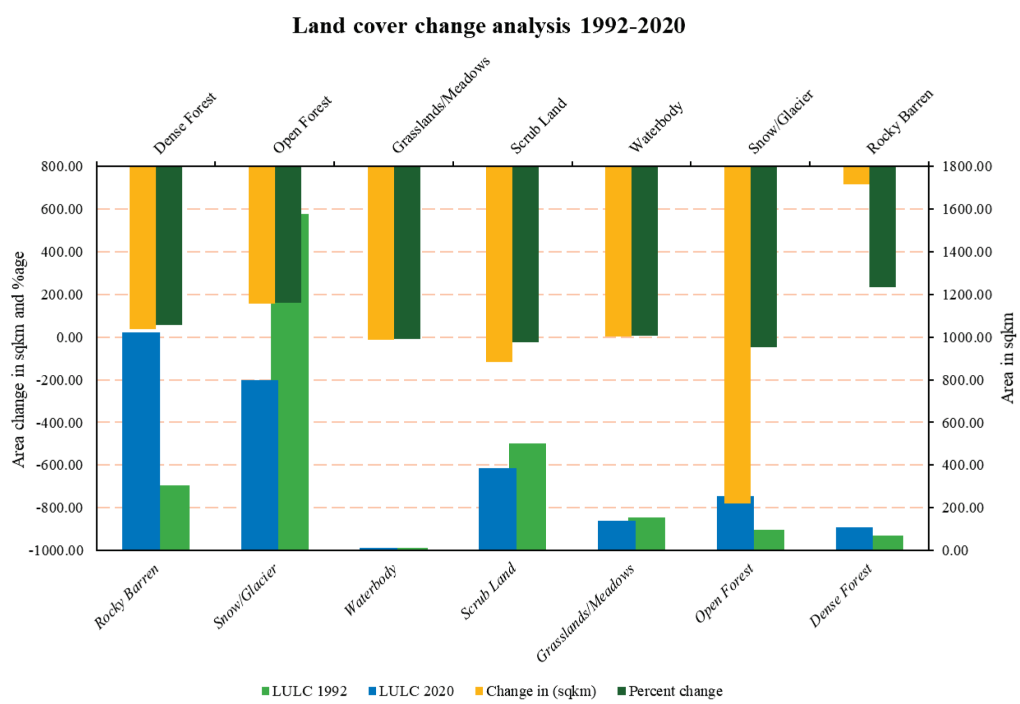


**Fig. 4.15** Column graphs elucidating the land cover change analysis between the years 1992 and 2020

### 4.2.5. Comparative decadal change analysis in land covers from 1992 till 2020

**Tables 4.7 and 4.8** show the decadal land cover change for each decade from the year 1992 till 2020 in sqkm and percent changes, respectively. Fig. 4.16 and Fig. 4.17 show the decadal land cover change for each decade in the graphical representation.

*I.* The cover of the dense forest has increased since 1992. However, the decade-wise dense forest has seen a maximum increase in the area between 1992 and 2000, accounting for an increase of 26.22 sqkm with a percent increase of 37.74.

*II.* The overall cover of the open forest has increased since 1992. However, it witnessed a decrease in its cover between 2000 and 2010, accounting for 11.57 sqkm (-8.67% decrease). Between 2010 and 2020, it witnessed a massive increase in its cover, amounting to 124.81 sqkm (97.26% increase).

*III.* The grassland/meadow class showed a decrease in the first two decades (1992-2000, -52.15 sqkm and 2000-2010, -8.72 sqkm) and witnessed an increase between 2010 and 2020 amounting to 46.36 sq km (49.52 % increase).

*IV.* The scrubland class showed an increase in the first two decades (1992-2000, -73.26 sqkm and 2000-2010, 17.24 sqkm) but witnessed a decrease between 2010 and 2020, amounting to 206.18sq km (-65.10% decrease).

*V.* The waterbody class showed no significant change in any decade of the analysis.

*VI.* The cover of snow/glaciers has decreased since 1992. However, decade-wise, it has seen a maximum decrease in the area between 1992 and 2000, accounting for a decrease of 599.30 sqkm with a percent decrease of 37.97.

*VII.* The cover of rocky barren has increased since 1992. This increase could be due to small variations in the seasonal snowfall events. Since the snowfall events vary during the year, therefore it cannot be concluded that snowfall has decreased as the same has not been captured by MODIS snow cover data analysis, described in the next chapter. Moreover, decade-wise, it has seen a maximum increase in the area between 1992 and 2000, accounting for an increase of 508.85 sqkm with a percent increase of 166.93.

**Table 4.7** Area estimations of the decadal land cover change between the year 1992 and 2020 **(sqkm)**

| S No. | Category | Change 1992-2000 | Change 2000-2010 | Change 2010-2020 |
|---|---|---|---|---|
| 1 | Dense Forest | 26.22 | 10.22 | 1.82 |
| 2 | Open Forest | 42.99 | -11.57 | 124.81 |
| 3 | Grasslands/ Meadows | -52.15 | -8.72 | 46.36 |
| 4 | Scrub Land | 73.26 | 17.24 | -206.18 |
| 5 | Waterbody | 0.13 | 0.00 | 0.46 |
| 6 | Snow/Glacier | -599.30 | -55.85 | -124.92 |
| 7 | Rocky-barren | 508.85 | 48.67 | 157.65 |

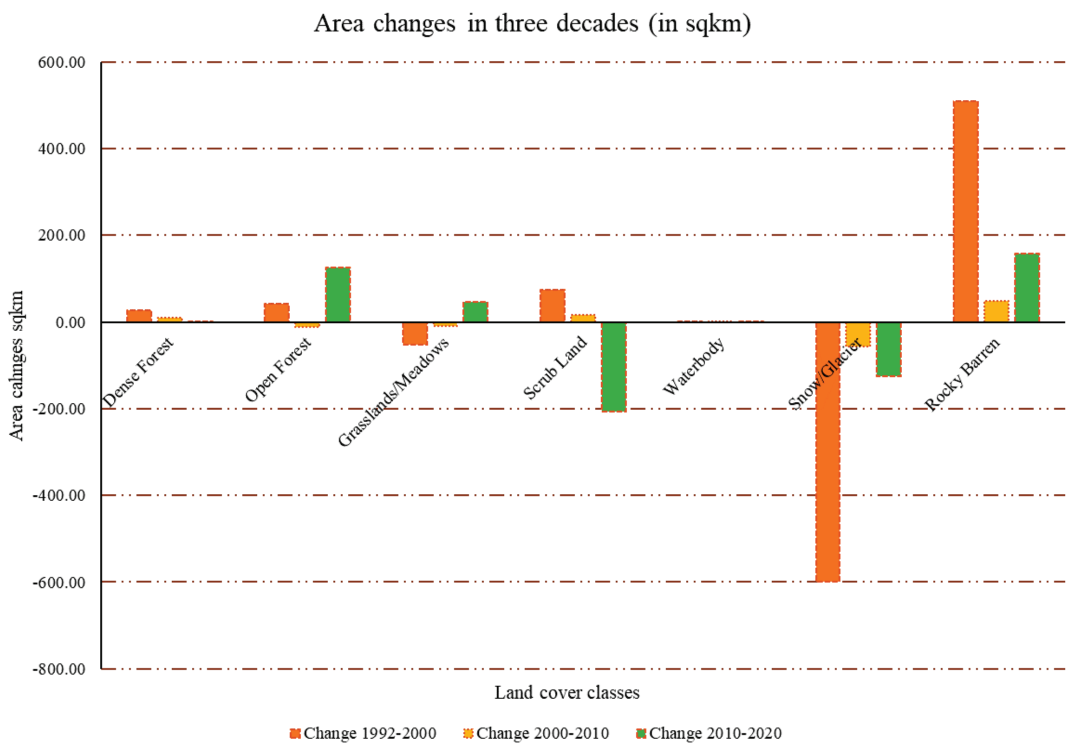


**Fig. 4.16** Decadal land cover change (sqkm) for each decade in the graphical representation

**Table 4.8** Percent estimations of the decadal land cover changes between the 1992 and 2020

| S No. | Category | Percent change 1992-2000 | Percent change 2000-2010 | Percent change 2010-2020 |
|---|---|---|---|---|
| 1 | Dense Forest | 37.74 | 10.68 | 1.72 |
| 2 | Open Forest | 44.36 | -8.27 | 97.26 |
| 3 | Grasslands/Meadows | -34.15 | -8.67 | 49.52 |
| 4 | Scrub Land | 14.64 | 3.01 | -65.10 |
| 5 | Waterbody | 1.17 | 0.02 | 4.01 |
| 6 | Snow/Glacier | -37.97 | -5.71 | -13.53 |
| 7 | Rocky-barren | 166.93 | 5.98 | 18.28 |

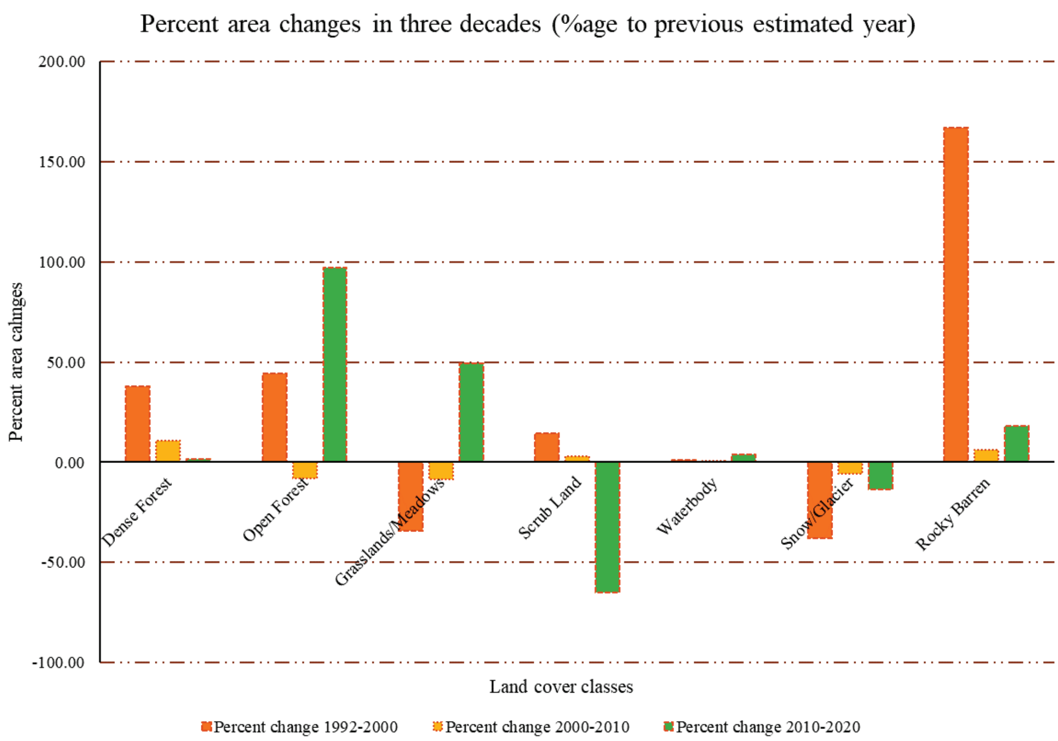


**Fig. 4.17** Decadal land cover change (percent changes) for each decade in the graphical representation

# CHAPTER-5

# CHAPTER – 5
# INVENTORIZING THE WATER RESOURCES OF THE KISHTIWAR HIGH ALTITUDE NATIONAL PARK

Kishtiwar High Altitude National Park has huge resources of snow and glaciers. Almost 29.41% of the area is annually covered by perennial snow and glaciers. In this section, we inventoried the snow and glacier resources separately. In the previous chapter, snow and glaciers were considered as one class. However, snow and glaciers are two different components of the land system and have entirely different physical properties that ascribe different water storage capabilities to them. This chapter inventoried the current number and areal extents of the glacier found in the KHANP. We have also analyzed the decadal change in the areal extents of the glaciers found in the KHANP. Volumes of some selected large glaciers of the NP have also been calculated. The change in the NP's perennial snow resources over the last two decades has also been analyzed. Overall the chapter provides an interesting understanding of the presents water resources of the NP and how they have changed in the last few decades. We start with a brief introduction to perennial snow and glacier characteristics followed by the materials and methods used to analyze the current and past trends of the glacier and snow resources of the NP and how the volume of the glaciers has been calculated.

## 5.1. Data used for this analysis

Due to the remoteness of glaciers, challenging terrains, hostile meteorological conditions, and logistic constraints, field observation of snow and glacier cover changes is extremely difficult. Furthermore, the lack of frequent back-in-time data on snow and glacier resources makes any conclusions regarding the recession pattern impossible. However, advances in satellite data have made regular monitoring and scientific assessment of snow cover and glacier extension possible. Several studies have used satellite data to monitor and measure changes in snow and glacier cover efficiently.

Because of their low cost and ortho-rectified format, Landsat pictures have largely replaced other data sources in glaciological studies. The world's longest acquired data series is this intermediate resolution space-based remote sensing data source. With the launch of Landsat 1, the United States Geological Survey (USGS) and NASA began a high-quality data collecting project for land surveillance in 1972. From July 1972 through January 1999, the Landsat 1 featured a Multispectral Scanner System (MSS) on board, which produced data with an 80m spatial resolution. Landsat 4 was launched on July 16, 1982, with the Thematic Mapper (TM) sensor onboard, which produced data with higher spectral and spatial resolution than the MSS. Furthermore, the TM sensor contained a blue channel that provided true-color composites at 30 m resolution, as well as short-wave infrared (SWIR) bands that distinguished snow from clouds. Landsat 5 was launched on March 1, 1984, in response to Landsat 4's power system concerns. This mission used the same MSS and TM sensors as Landsat 4 and had similar characteristics. After more than 29 years of service and 2.5 million photos, the system has been retired. On June 5, 2013, it was decommissioned. The Enhanced Thematic Mapper Plus (ETM+) earth observing sensor was launched with the Landsat 7 on April 15, 1999. The ETM+ has all of the capabilities of the TM, but it also has additional features such as a panchromatic band with 15m spatial resolution, full aperture, 5% absolute radiometric calibration, a thermal Infrared (TIR) channel with 60m spatial resolution, and an on-board data recorder, making it ideal for mapping land features. On February 11, 2013, the Landsat 8 satellite was launched with technologically improved equipment. The Operational Land Imager (OLI) and the Thermal Infrared Sensor are two instruments onboard the Landsat 8. (TIRS). These two sensors have a spatial resolution of 30m in visible, NIR, and SWIR wavelengths, 100m in the thermal band, and 15m in panchromatic bands.

- *ASTER GDEM version 2*

The Global Digital Elevation Model Version 2 (GDEM v2) of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) was jointly developed by Japan's Ministry of Economy, Trade, and Industry (METI) and

NASA, and was formally released and made freely available to the public on October 17, 2011. In comparison to the previous version, the GDEM v2 uses an additional 260,000 stereo-pairs, which provides improved coverage and reduces the occurrence of artefacts in the data. Furthermore, the data quality was improved by the modified production algorithm, which provided higher spatial resolution, better vertical and horizontal accuracy, and increased the coverage and detection of water bodies. The ASTER GDEM v2 is in GeoTIFF format, with 30-meter posts and 1 degree tiles, just like its predecessor (v1). Several studies have used ASTER GDEM to map glacier extent and conduct other cryospheric research.

- *MODIS Snow Cover Images*

Moderate Resolution Imaging Spectro-radiometer (MODIS) is a land, ocean, and lower atmosphere observation instrument installed on the Terra (EOS AM) and Aqua (EOS PM) satellites by Santa Barbara Remote Sensing. The Terra satellite, launched on December 18, 1999, crosses the equator from north to south in the morning, while the Aqua satellite, launched on May 4, 2002, crosses the equator from south to north in the afternoon. Terra and Aqua satellites, which orbit at a height of 705 kilometres above the Earth, collect data in 36 spectral bands and cover the entire planet every 1 to 2 days. Visible light, near infrared, short, mid, and long waves with wavelengths ranging from 0.4 to 14.4 m are among the 36 spectral bands. Two bands 1-2 have a nominal resolution of 250 m at nadir, five bands (3-7) have a resolution of 500 m, and the remaining 29 bands have a resolution of 1 km. MODIS provides data with sufficient spatial and temporal resolution for snow mapping. In particular, the usage of MODIS snow cover products in climatic and hydrological studies is increasing.

- *MODIS/Terra Snow Cover 8-Day L3 Global 500m Grid, Version 6*

MODIS/Terra Snow Cover 8-Day L3 Global 500m Grid (MOD10A2) data is the greatest snow cover extent retrieved using the snow mapping method (NDSI) over an eight-day compositing period. It also includes the sequenced observations of snow occurrences in compressed Hierarchical Data Format-

Earth Observing System (HDF-EOS) format and metadata. MOD10A2 is a 500 m resolution sinusoidal map projection with 1200 km by 1200 km tiles. To extract the 8-day snow cover, the snow-cover product was re-projected to UTM WGS 1984 ZONE 43.

## 5.2. Glacier Mapping

One of the most important aspects of estimating glacial retreat is identifying and mapping glacier boundaries and termini. Because of the significant variation in spectral reflectance, it is feasible to identify snow, ice, and rocks in satellite photos if glaciers are not covered by debris. Furthermore, in the spectral band between visible and SWIR, the reflectance of ice differs significantly from that of rock. The terminus can be identified using a variety of geomorphological markers. Downstream of the glacier terminal, moraine-dammed lakes frequently occur. On satellite pictures, these lakes are easily identifiable. A steep ice wall can sometimes be found at a glacial terminal. It can generate a shadow downstream depending on the relative locations of the sun and the wall, which can be utilised as a marker for terminus delineation. The temporal variations in the glacier area of the Kishtiwar National Park were mapped using multi-temporal satellite data from the Landsat-5 Thematic Mapper (1991), Landsat-7 Enhanced Thematic Mapper ETM+ (2000), Landsat-5 Thematic Mapper 2009, and Landsat-8 Operational Land Imager OLI (2020). All of the sensors mentioned above provide images with a spatial resolution of 30 metres. Furthermore, the glacier boundaries were mapped using photos collected near the end of the ablation phase, preferably cloud- and snow-free satellite views. In a Geographical Information System (GIS) context, glacier outlines were manually digitised at 1:25000 scale. The Digital Elevation Model (DEM v.2) of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) was also utilised to create topographic details of the glaciers, such as the location of frontal and lateral moraines and Ice Divides. These topography characteristics aid in the understanding of glacier margins on satellite pictures. The characteristics of the satellite data sets used in this study are listed in Table 5.1.

Table 5.1 Satellite data used in the assessment of water resources of the KHANP

| **Sensor** | **Resolution** | **Acquisition Date** | **Source** |
|---|---|---|---|
| Landsat Thematic Mapper TM | 30m | 20-09-1992, 07-10-2010 | http://earthexplorer.usgs.gov/ |
| Landsat Enhanced Thematic Mapper ETM+ | 30m | 22-8-2000 | http://earthexplorer.usgs.gov/ |
| Landsat OLI | 15 m | 29-08-2020 | http://earthexplorer.usgs.gov/ |
| ASTER GDEM v.2 | 30m | | http://gdem.ersdac.jspacesystems.or.jp/ |
| MODIS Snow Cover Product | 500m | 2000 to 2020 | http://earthexplorer.usgs.gov/ |

### 5.3. Glacier Volume Estimations

Volume of the glaciers was estimated using slope dependent thickness approach. Surface slope of the glacier is the prime factor that governs the thickness of glacier ice, which means that steeper glaciers tend to have thinner ice and vice versa (Linsbauer *et al.* 2009). However, it also depends on various other factors such as plasticity of the glacier, basal sliding and horizontal to vertical extent ratio of the glaciers. Therefore, simplifications are added to the force equations in the slope-dependent method for the estimation of the glacier volume as has been discussed in details by Linsbauer *et al.* (2012) and Frey *et al.* (2014). Subsequently, the thickness d (m) of a glacier is calculated by using the following equation.

$$h_f = \frac{\tau}{\rho g f sin(\alpha)}$$

where $\rho$ is the density of glacier ice (900 kg/m3), g is acceleration due to gravity (9.81 m/s2) and $f$ is the shape factor (0.8) constant for valley glaciers. The shape factor $f$ is basically related to the friction of a glacier body with its valley walls and is the ratio between cross-sectional area of a glacier and its perimeter (Paul and Linsbauer 2012),$\alpha$ is the mean slope of a glacier.

In combination with a DEM, mean slope can also be directly derived for each glacier without knowing its length. However, mean surface slope derived from $\Delta$H and l (αL) is different generally smaller – from mean surface slope averaged over all DEM cells of a glacier (αDEM). In order to determine a correction factor for αDEM, glacier length has been manually determined for 50 glaciers of the study region, including the 10 largest glaciers. Resulting αL values have then been compared to the αDEM values. Differences between αDEM and αL appear to be nearly constant for different glacier size classes. Based on this comparison, the correction factors to be applied to αDEM have been determined as $-10^o$, $-5^o$, and $-2.5^o$ for glaciers with an area > 20 sqkm, 5–20 sqkm, < 5 sqkm, respectively.

The basal shear stress (Pa) is a function of elevation range and is calculated by the Equation below (Haeberli and Hoelzle 1995), ∆h is elevation range in kilometers (km) and the maximum value for $\tau$ is 1.5 bars for ∆h equal to or larger than 1.6 km.

$$\tau = \begin{cases} 0.5 + 159.8\Delta h - 43.5(\Delta h)^2 : if \Delta h \leq 1.6km \\ 150 : if \Delta h > 1.6km \end{cases}$$

For the extrapolation of the mean ice-thickness along the central flowline (hf ) to the mean ice-thickness of the entire glacier (hF)(Paterson, 1994), in accordance with the assumptions of a semi-elliptic cross sectional the mean ice thickness hf is multiplied by π/4.

$$h_F = h_f \left(\frac{\pi}{4}\right)$$

## 5.4. Inventorizing the present Glacier resources of the KHANP

### 5.4.1. Number of Glaciers in the KHANP

In 2020, the total number of glaciers found in the KHANP was **177**. From 1991, it is observed the number of glaciers has increased (Table 5.2, Fig. 5.1). However, at this point, it must be noted that there have been no new glaciers formed in the study area. The increase in the numbers is due to the fragmentation of already existing glaciers. This is also a manifestation of the current anthropogenic climate change and a cause of concern for water resource management and conservation under future climate change.

Table 5.2 Change in the number of glaciers between **1992** and **2020**

| Year | No. of Glaciers |
|---|---|
| 1991 | 166 |
| 2000 | 169 |
| 2009 | 171 |
| 2020 | 177 |

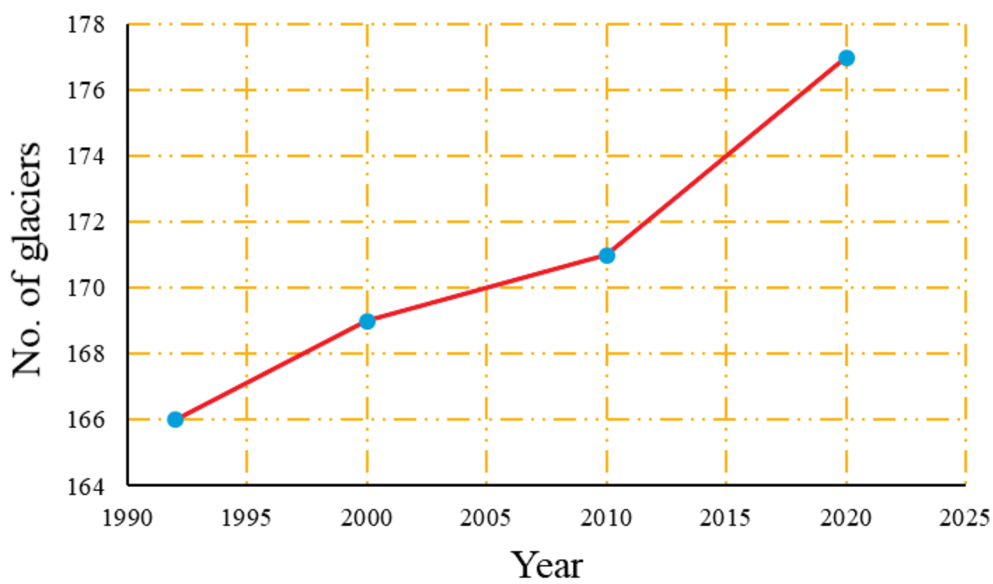


Fig. 5.1 Line graph depicting the change in the number of glaciers between 1992 and 2020

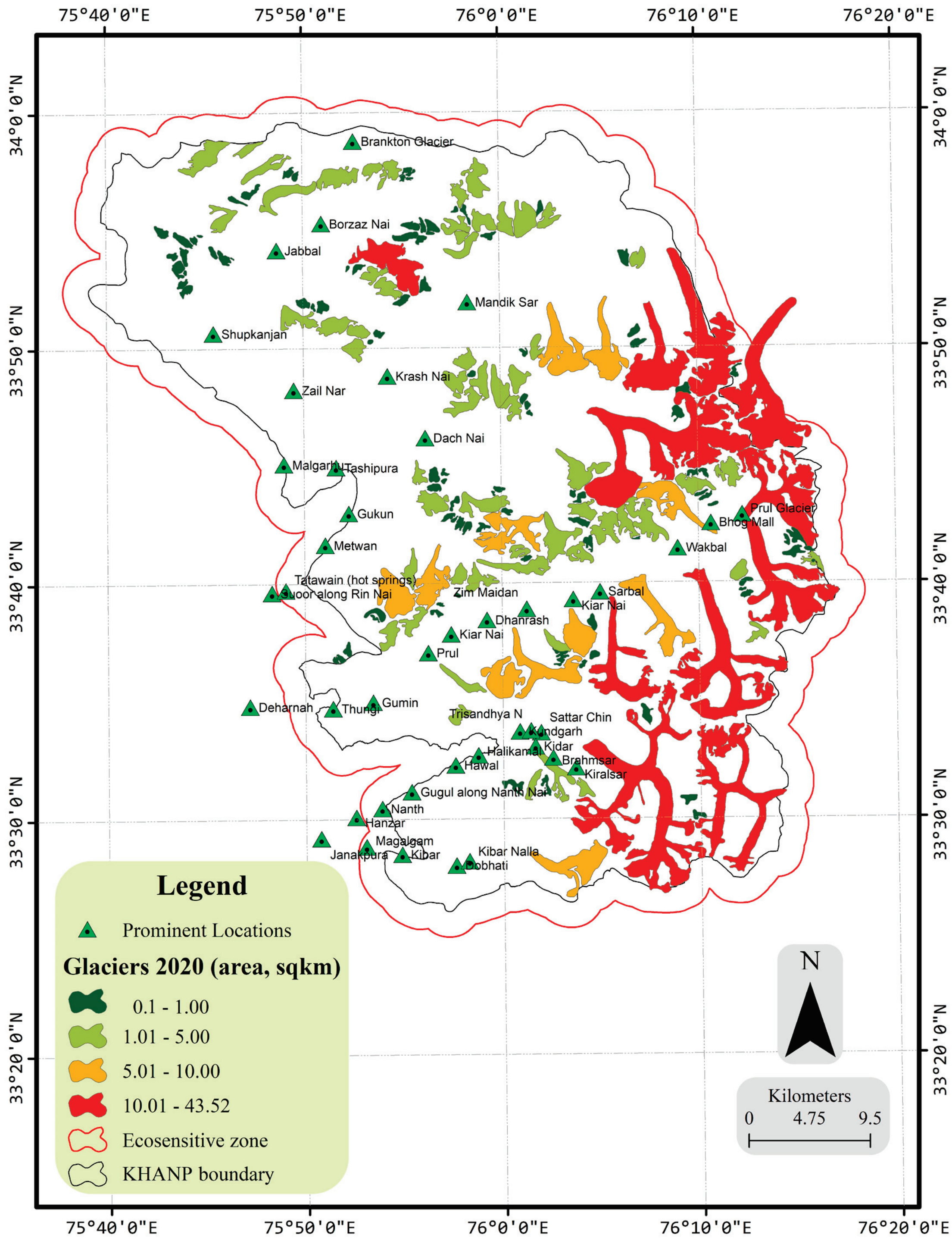


Fig. 5.2 Area-wise categories of glaciers for the year 2020

5.4.2. Area and volume of Glaciers in KHANP in 2020

- *Areal Extent of Glaciers (in sqkm)*

In the year 2020, the total area under glaciers in the KHANP is 532.97 sqkm. It accounts for 23.90% of the total area of the NP. This is a huge area and stock of water resources for the downstream populations (Table 5.3, Fig. 5.2).

Table 5.3 Total area under glaciers in the KHANP in 2020

| Year | Glacier Area (sqkm) | Glacier Area (%) |
|---|---|---|
| 2020 | 523.97 | 23.90 |

- *Volume of Glaciers (cukm)*

In 2020, the total volume of glaciers covered by 532.97 sqkm of area constituted about 36.16 cubic kilometers of ice volume or approximately **36160 mega tonnes** of water. This is an enormous stockpile of water present in the KHANP in the form of glaciers. This water sustains the downstream villages during dry seasons, and protecting and conserving it must be the priority of the decision-makers.

Table 5.4 Categorise volume of glaciers found in the KHANP in **2020**

| *Glacier Size Category | Glacier Volume (cukm) | No. of Glaciers |
|---|---|---|
| Large (Size > 10.01 sqkm) | 20.72 | 11 |
| Medium (5.01 – 10 sqkm) | 5.87 | 11 |
| Small (Size 1 – 5 sqkm) | 7.67 | 59 |
| Very Small (0.1<1 sqkm) | 1.90 | 96 |
| Total | 36.16 | 177 |

*The lowest size of the glacier is 0.01 as per United State Geological Survey; https://www.usgs.gov/

Table 5.4 shows the size-wise distribution of the glaciers and their corresponding volumes. Nearly 88 % (155 No.) of these glaciers are categorized as very small (0.1<1 sqkm) and small (1 - 10 sqkm). Since small glaciers are sensitive to minor temperature changes, these are the first to get affected by global warming and regional climate change (Table 5.4, Fig. 5.3).

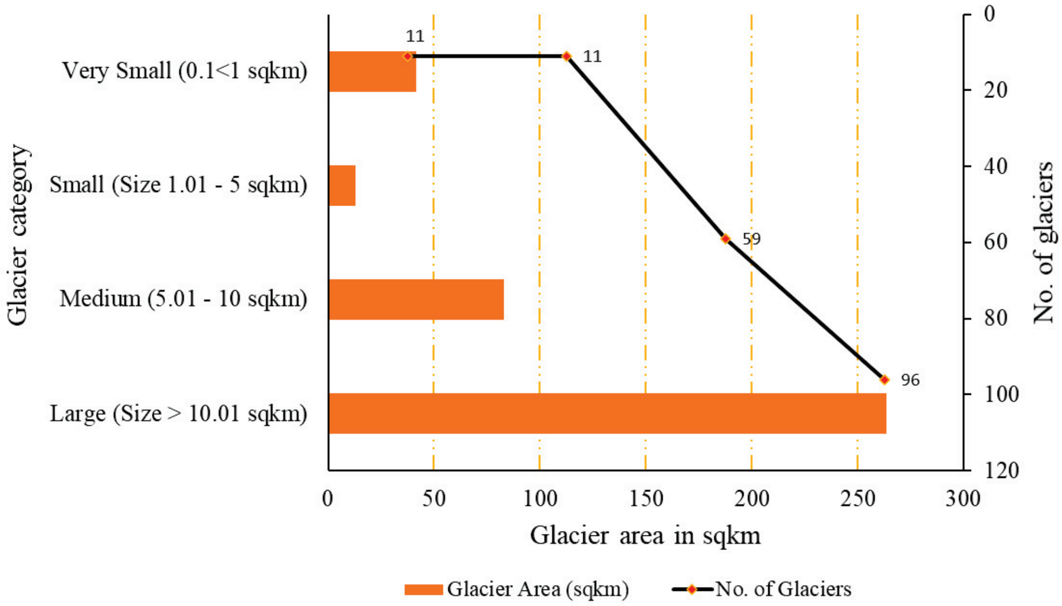


**Fig. 5.3** Category wise volume of glaciers found in the KHANP in **2020**

5.4.3. Analyzing the changes in areal extents in the Glaciers of KHANP

The areal extents of glaciers have decreased since 1992. In the year 1991, the total area under glaciers was 609.27 sqkm. Subsequently, in the year 2000, it got to 573.84 sqkm. In the year 2010, it further got reduced to 558.96, and finally, in 2020, it equaled 523.97 sqkm (Table 5.5, Fig. 5.4-5.7).

Table 5.5 Change in the areal extent of glaciers between **1992** and **2020** (in sqkm and percent changes)

| Year | Glacier Area (sqkm) | Glacier Area (%) |
|---|---|---|
| 1990 | 609.27 | 27.80 |
| 2000 | 573.84 | 26.18 |
| 2010 | 558.96 | 25.50 |
| 2020 | 523.97 | 23.90 |

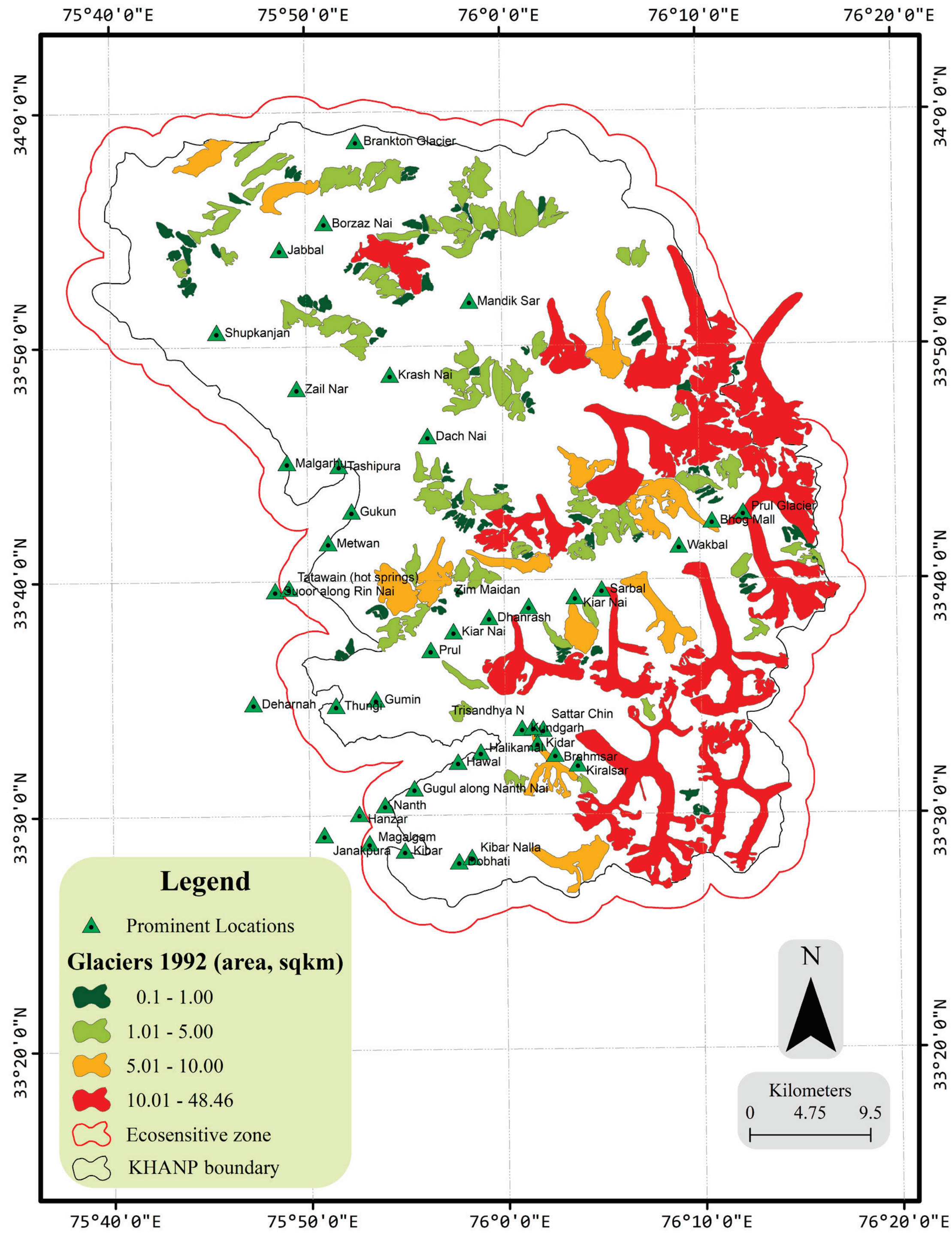


**Fig. 5.4** Area-wise categories of glaciers for the year 1992

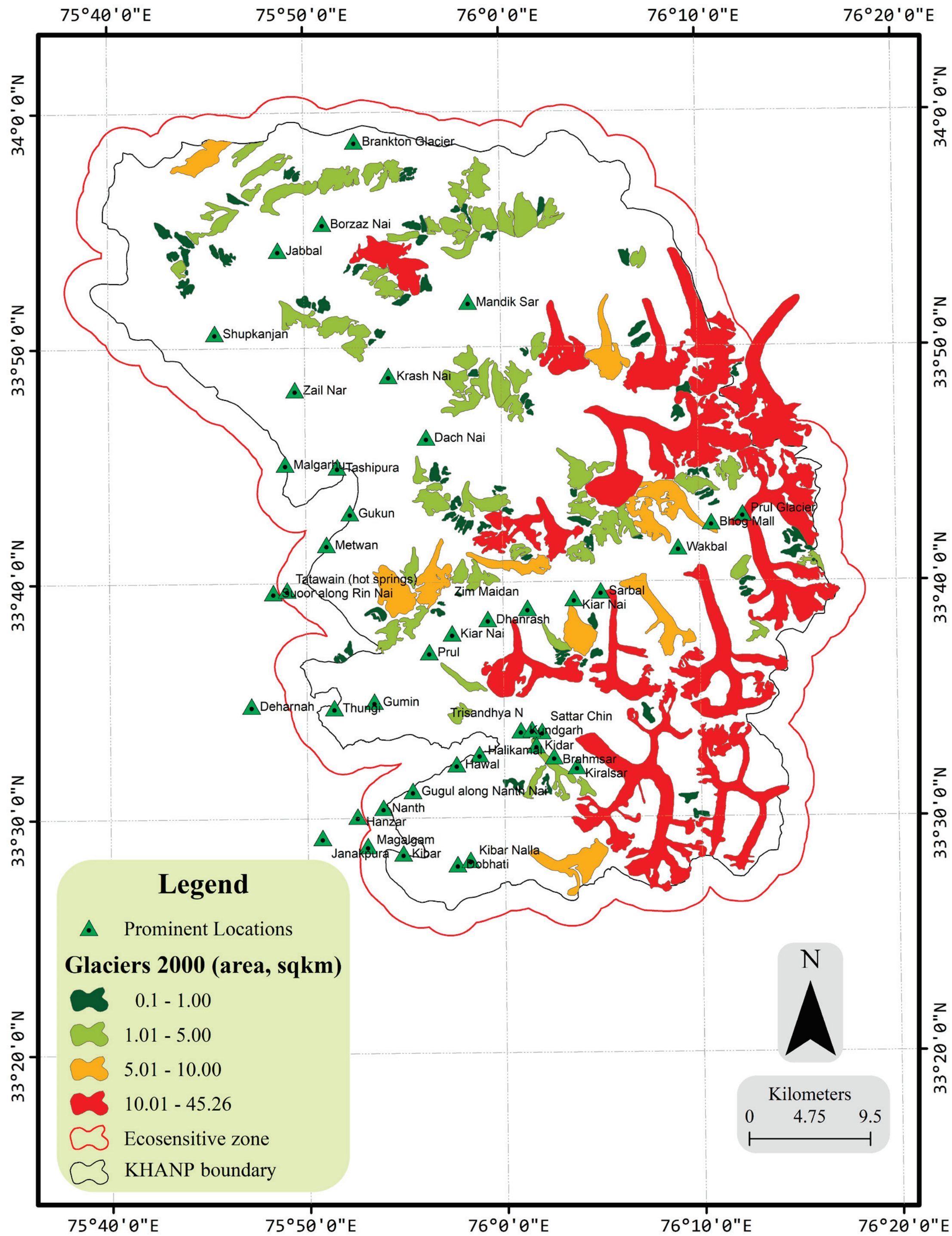


Fig. 5.5 Area-wise categories of glaciers for the year 2000

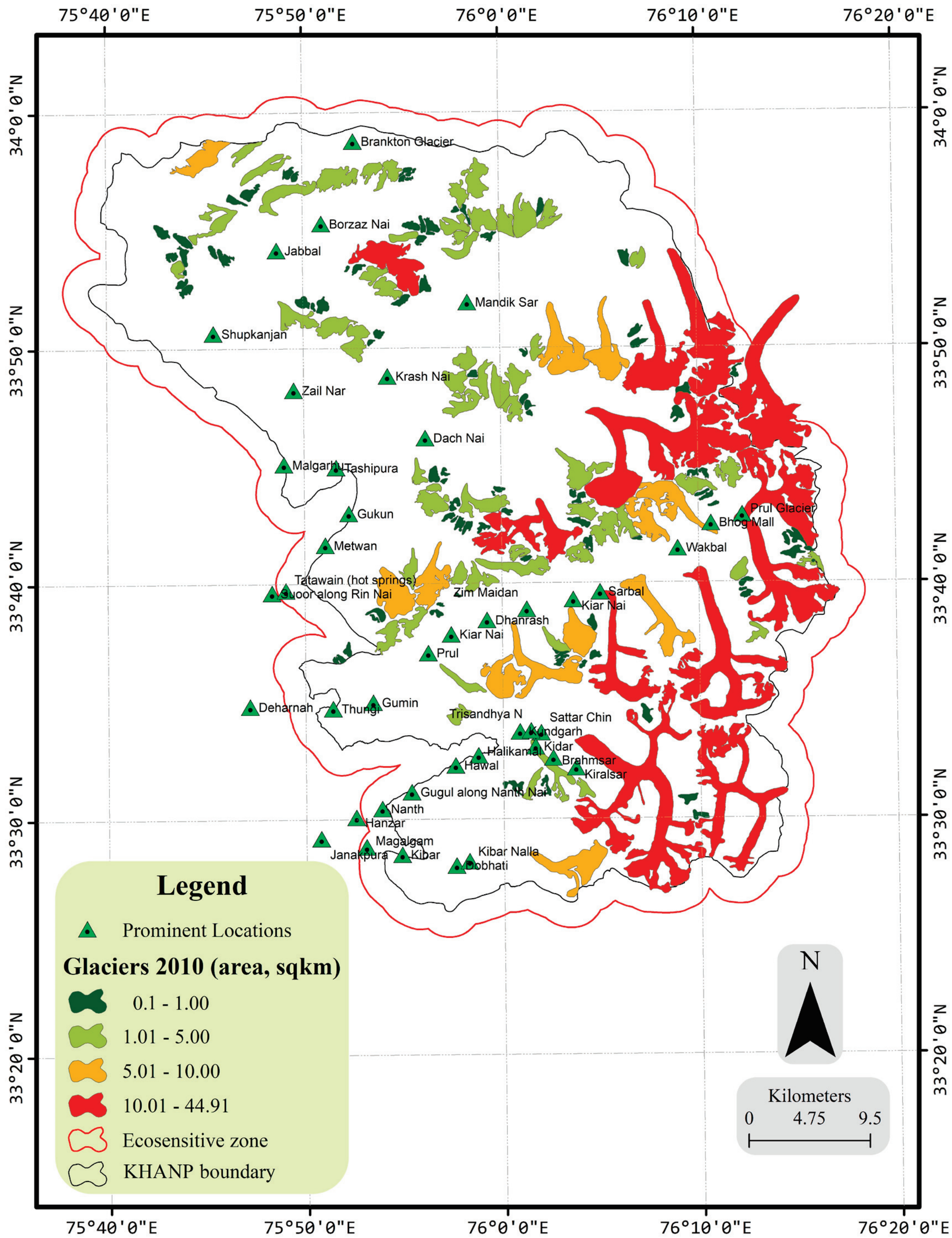


Fig. 5.6 Area-wise categories of glacier outlines for the year 2010

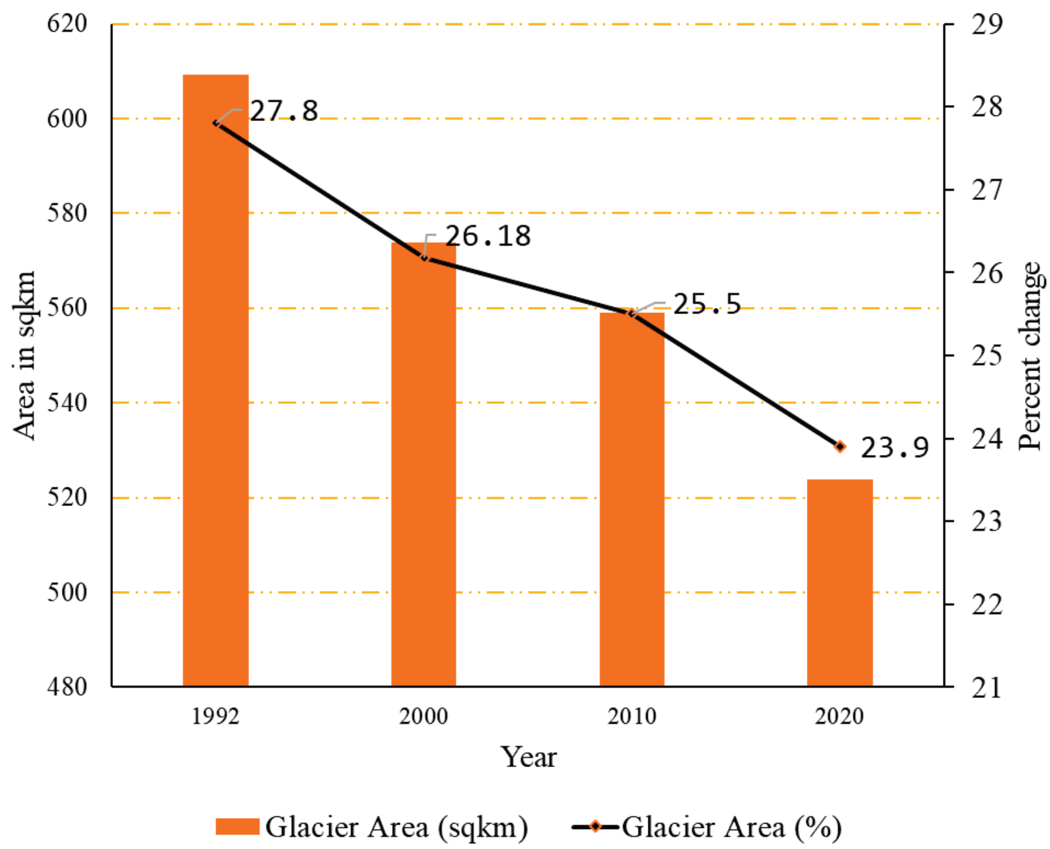


**Fig. 5.7** Change in the areal extent of glaciers between **1992** and **2020** (in sqkm and percent changes)

Table 5.6 Decadal change in the areal extent of glaciers between **1992** and **2020** (in sqkm and percent changes)

| Period | Area Change (Sqkm) | Area Change (%) |
|---|---|---|
| 1991-2000 | 35.42 | -5.81 |
| 2000-2010 | 14.87 | -2.59 |
| 2010-2020 | 34.99 | -6.26 |

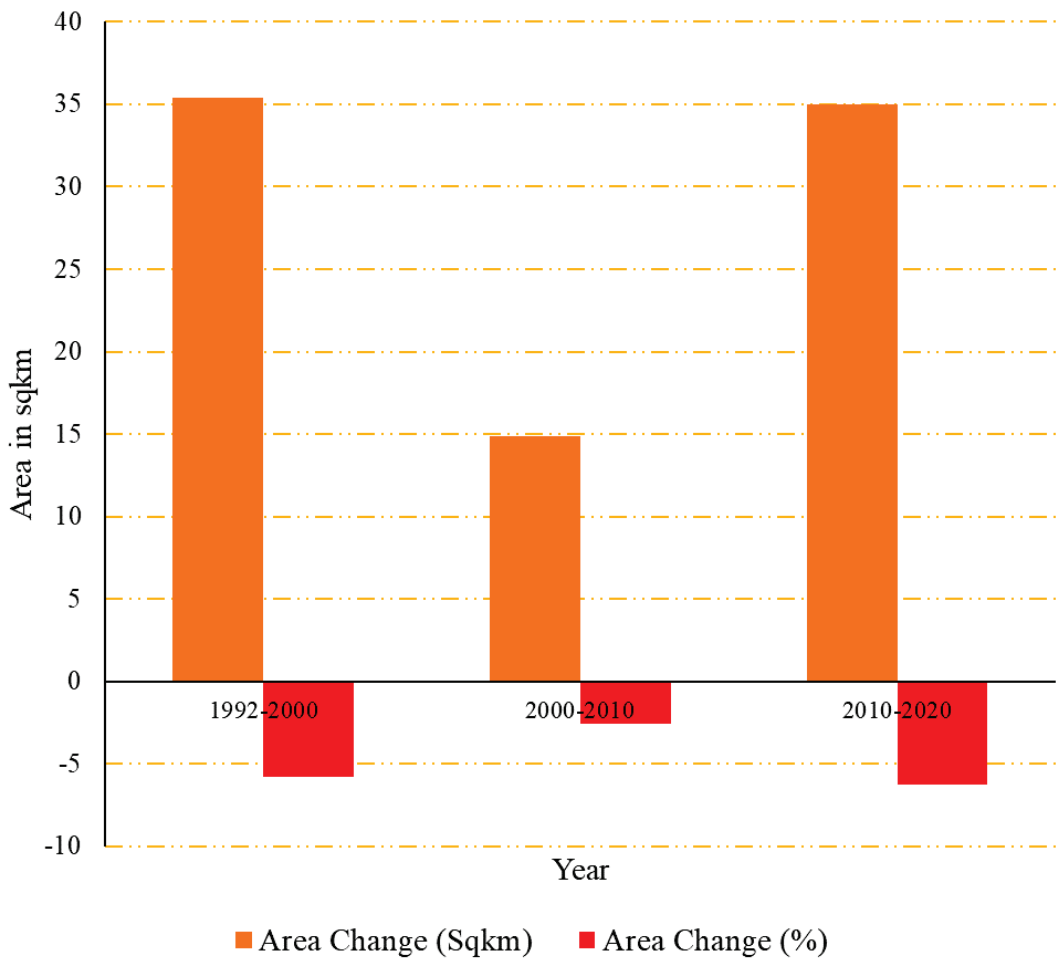


Fig. 5.8 Decadal change in the areal extent of glaciers between **1992** and **2020** (in sqkm and percent changes)

From Table 5.6 and Fig. 5.8, it is observed that glaciers were comparably stable during the 2000-2010 decade corresponding to the least changes in their areal extents observed in this period equalling 14.87 sqkm, accounting for a percent decrease of -2.59 %. In contrast, the decades 1991-2000 and 2010-2020 have witnessed very high recessional rates of the glaciers in the KHANP, corresponding to -5.81% (35.42 sqkm lost) and 6.26% (34.99 sqkm lost), respectively. The causal factors related to this ambiguity shall be further explored during the remaining project period and will be included in the final DPR.

Table 5.7 Category wise area and number of glaciers found in KHANP in **1992**

| Glacier Size Category | Glacier Area (sqkm) | No. of Glaciers |
|---|---|---|
| Large (Size >10.01 sqkm) | 329.94 | 13 |
| Medium (5.01 - 10 sqkm) | 90.12 | 13 |
| Small (Size 1 - 5 sqkm) | 148.87 | 62 |
| Very Small (0.1<1 sqkm) | 40.32 | 78 |

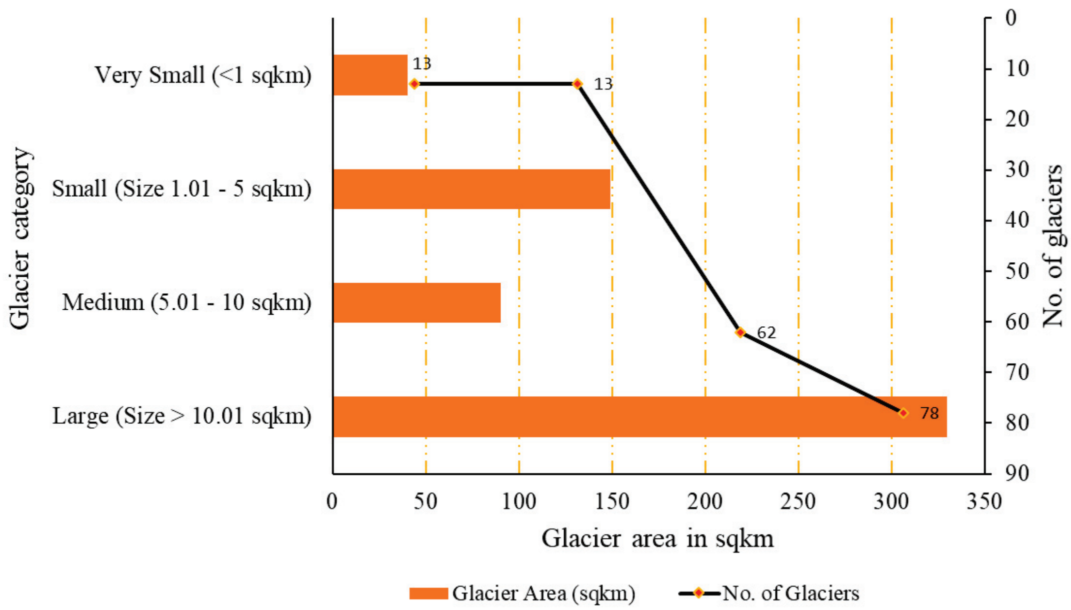


Fig. 5.9 Category wise area and number of glaciers in KHANP in **1992**

Table 5.8 Category wise change in area of glaciers found in KHANP between 1992 and 2020 (in sqkm and percent change)

| Glacier Size Category | Area (1992) | Area (2020) | Change in % |
|---|---|---|---|
| Large (Size >10.01 sqkm) | 329.94 | 300.004 | -9.07% |
| Medium (5.01 - 10 sqkm) | 90.12 | 77.92 | -13.54% |
| Small (Size 1 - 5 sqkm) | 148.87 | 116.47 | -21.76% |
| Very Small (0.1<1 sqkm) | 40.32 | 29.57 | -26.65% |

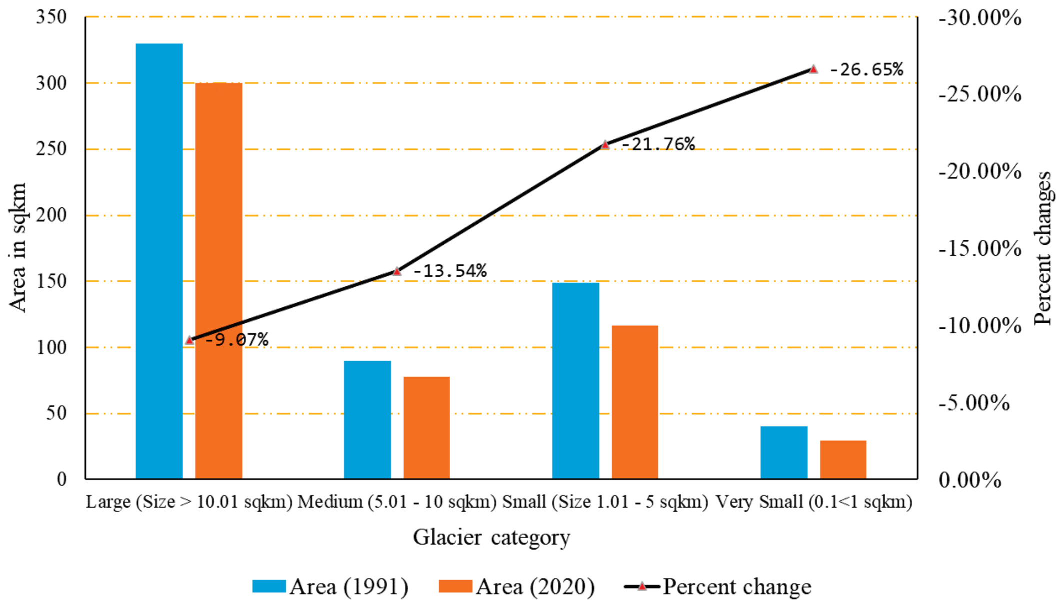


Fig. 5.10 Category wise change in the area of glaciers found in KHANP between 1992 and 2020 (in sqkm and percent change)

The total areal extents of glacier categories based on their sizes are shown in Tables 5.7, 5.8 and Fig. 5.9, 5.10. It has been observed that since 1992, the area of very small and small glaciers has reduced 26.65% and 21.76%, respectively. As seen in the case of volumes, smaller glaciers are very vulnerable to minute climate variations in the region (Fig. 5.11-5.13). Some of the causal factors behind their recession are uneven western disturbances and summer monsoonal snowfall, biomass burning, and the associated black carbon, increased variability in the weather parameters such as temperature and precipitation, all contributing to the process of glacier recession. However, which parameter plays the major role is the question that needs to be researched out.

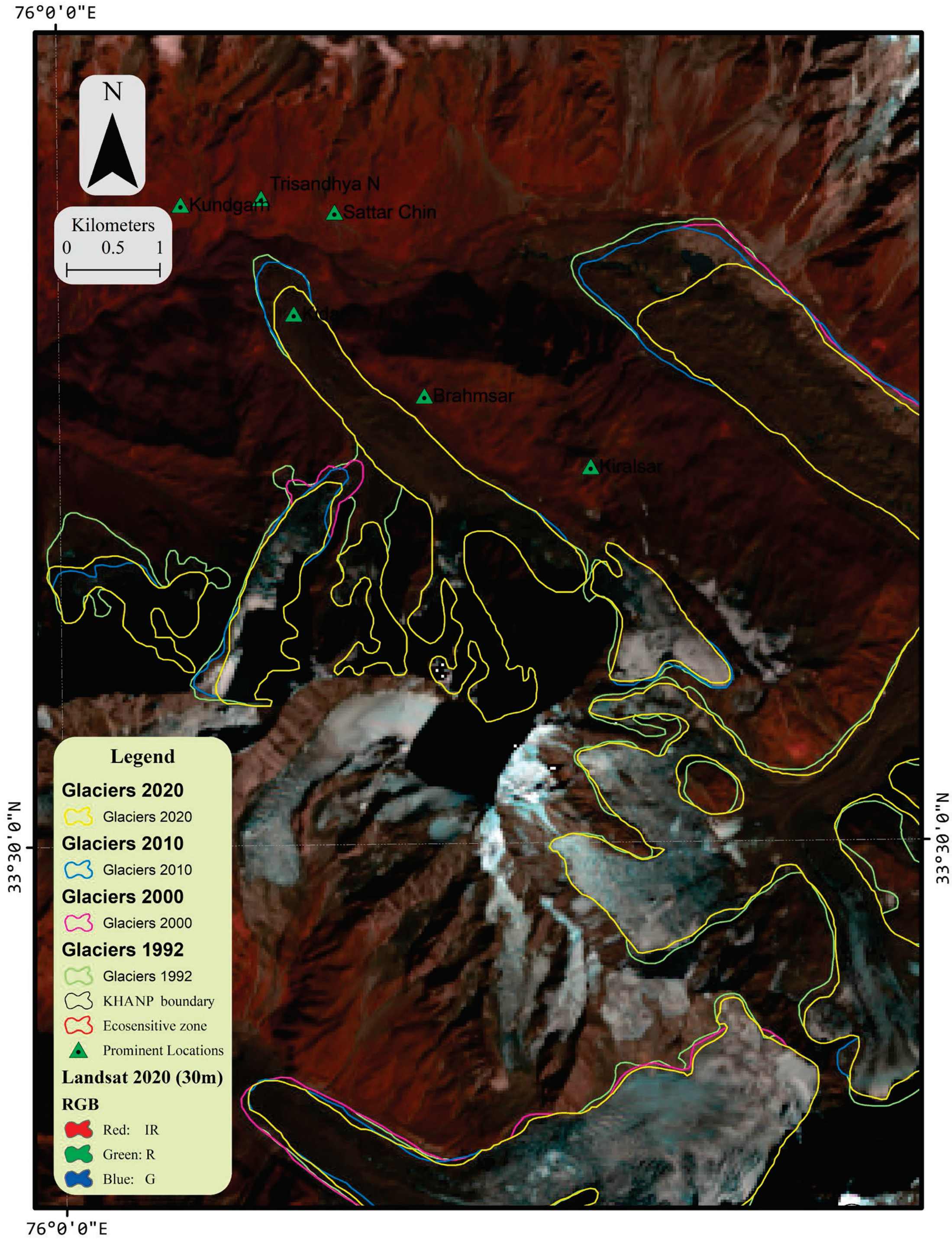


Fig. 5.11 Zoomed in view of the glacier extent change for 1992, 2000, 2010, and 2020 in and around Brahmsar glacier chain

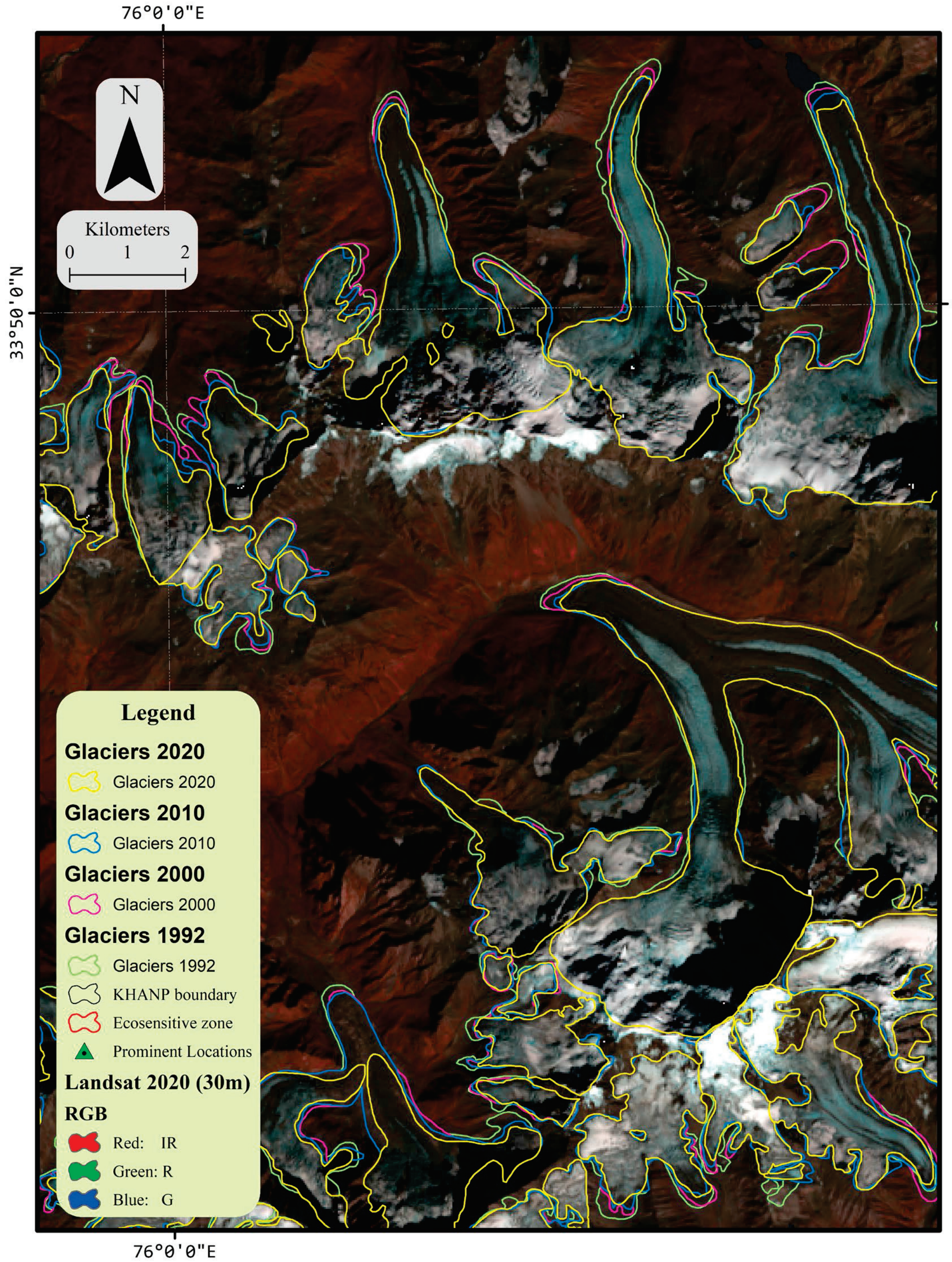


Fig. 5.12 Zoomed in view of the glacier extent change for 1992, 2000, 2010, and 2020

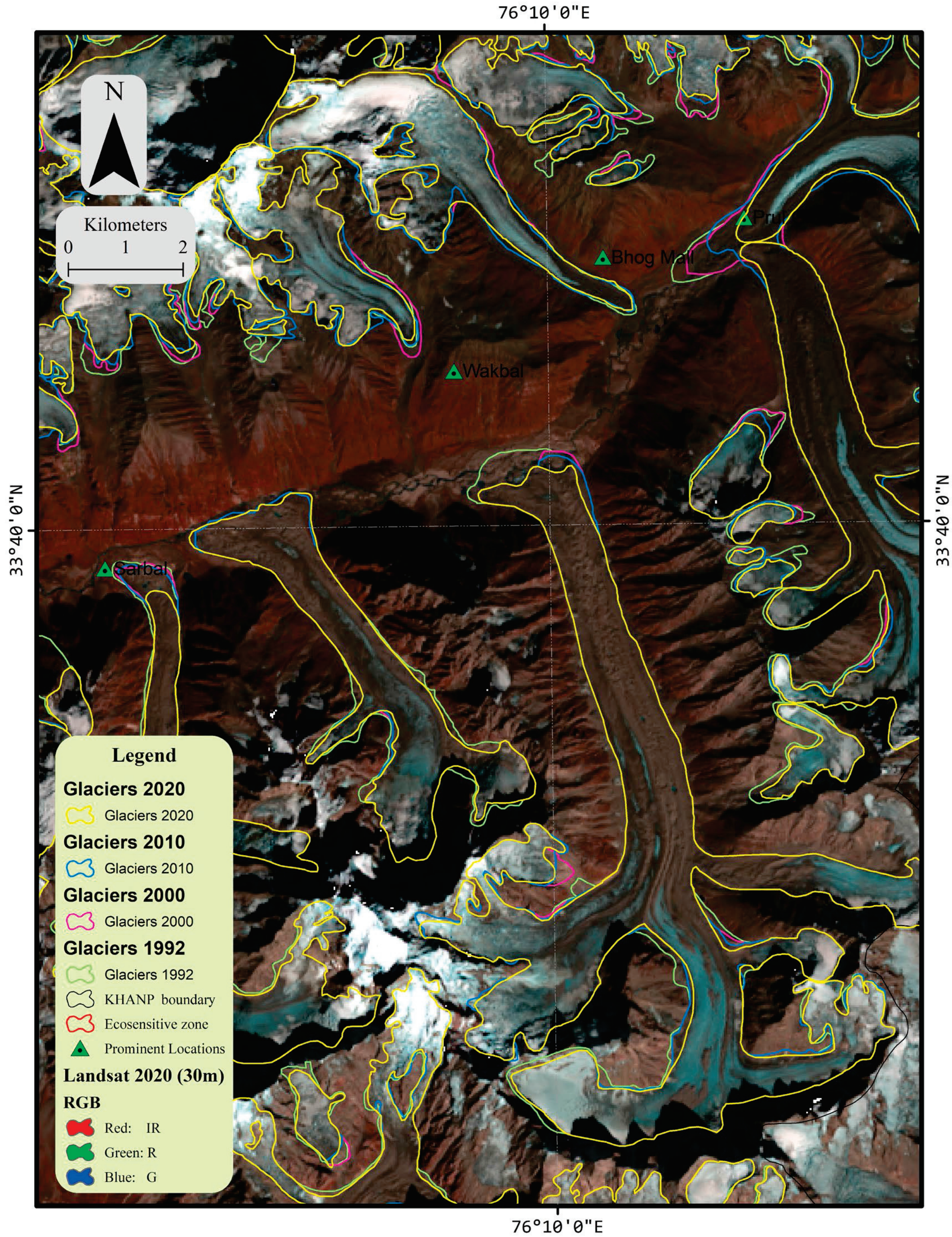


Fig. 5.13 Zoomed in view of the glacier extent change for 1992, 2000, 2010, and 2020 in and around Sarbal glacier chain

## 5.5. Snow Resources of the KHANP

The snow distribution in the KHANP keeps on changing throughout the year. The hydrological cycle of the Himalayan watersheds usually starts in October. Before this date, whatever proportion of the previous year's snow is present will generally stop melting now. The new snow that falls after this date adds the water to the following year's supply in the watershed's drainage system. The average percent snow cover for each month from 2000 to 2020 (Fig. 5.15).

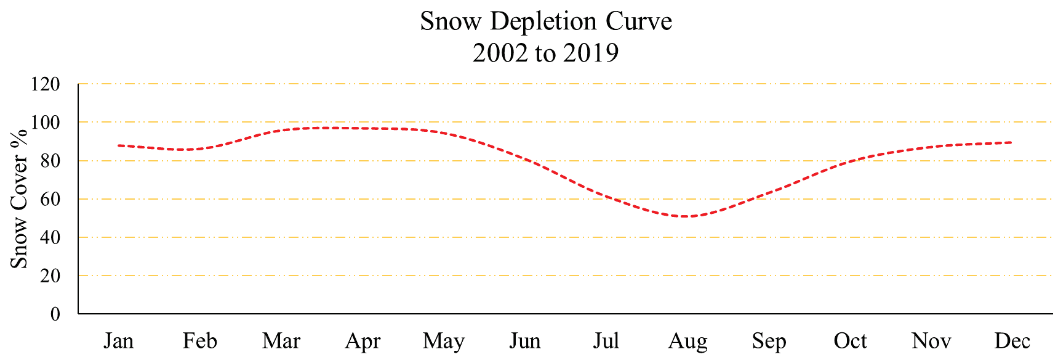


Fig. 5.14 Snow depletion curve of the snow cover over a yearly cycle in the KHANP analyzed using MODIS data

The snow depletion curve of the KHANP indicates that from August, the snow cover starts building again (Fig. 5.14). This means that the water storage for the next season gets building up from September.

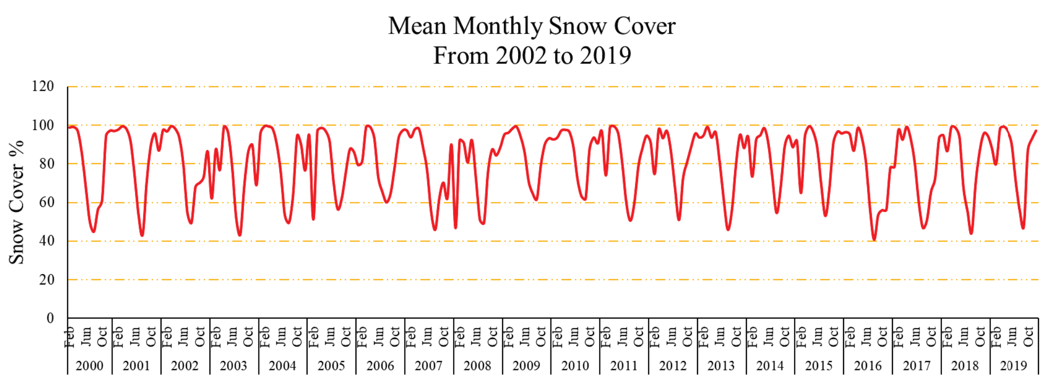


Fig. 5.15 Changes in the mean monthly snow cover in the KHANP between 2000 and 2020 analysed using MODIS data

It is observed that in the last 20 years, there has been no significant change in average snow cover in the KHANP. This points out that no precipitation factor is involved in the depletion of glaciers in the KHANP (Fig. 5.15).

Below are the mean monthly percent snow cover graphs from 2002 to 2019

**The month average SDC of the KHANP reveal that:**

- The year 2003 and 2008 witnessed decreased snow covers in January compared to other January years from 2002 till 2020 (Fig. 16).
- The month of February shows undulating percent snow covers over the years. This could be owing to the fluctuations in the mean monthly temperatures over the years (Fig. 17).
- The month of March shows almost the same percent snow cover throughout the time series 2000-2020 (Fig. 5.18)
- The year 2008 witnessed decreased snow cover in April compared to other April years from 2000 till 2020. Overall, the percent snow covers have remained constant over the years, approximated at 100 percent cover (Fig. 5.19)
- The month of May shows undulating percent snow covers over the years. From 2000 till 2020, however it has been observed there is an increasing trend percent in the snow in May (Fig. 5.20).
- The month of June shows almost the same percent snow cover throughout the time series 2000-2020 (Fig. 5.21).
- The month of July shows undulating percent snow covers over the years. From 2000 till 2020, however, it has been observed there is increasing trend percent snow in the month of July (Fig. 5.22).
- The month of August shows undulating percent snow covers over the years. From 2000 till 2020, however, it has been observed there is constant trend percent snow in the month of August (Fig. 5.23).
- The month of September shows undulating percent snow covers over the years. From 2000 till 2020, however, it has been observed there is constant trend percent snow in the month of September (Fig. 5.24).

❖ The month of October shows undulating percent snow covers over the years. From 2000 till 2020, however, it has been observed there is constant trend percent snow as witnessed in previous years (Fig. 5.25).

❖ The month of November shows undulating percent snow covers over the years. The year 2002, 2007, and 2016 has witnessed comparatively lower snow covers than other years of the time series (Fig. 5.26).

❖ The month of December shows undulating percent snow covers over the years. The year 2003 and 2016 has witnessed comparatively lower snow covers as compared to other years of the time series (Fig. 5.27).

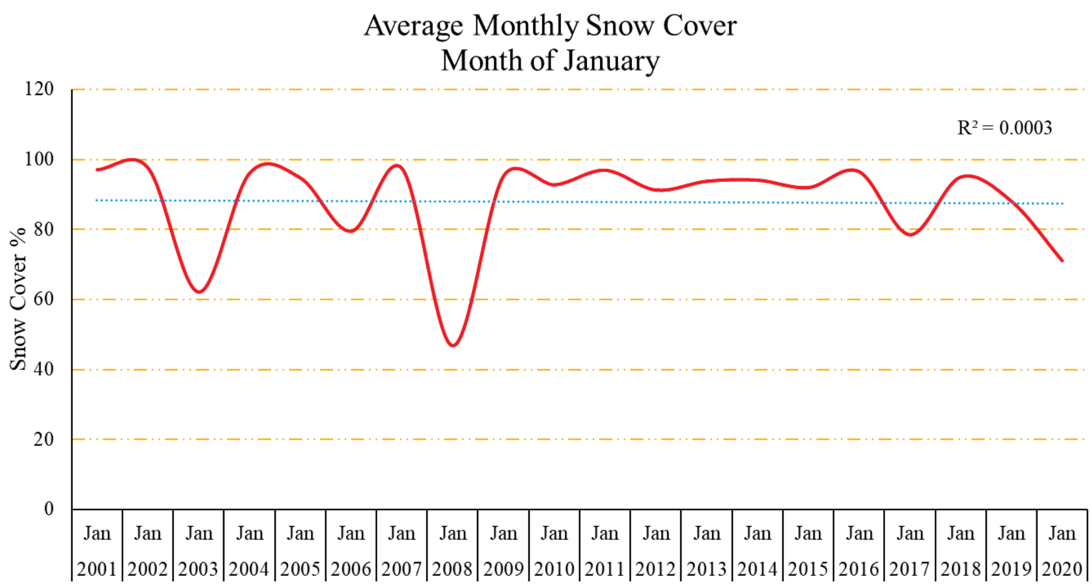


Fig. 5.16 Changes in the snow cover for the month of January in the KHANP between 2000 and 2020 analysed using MODIS data

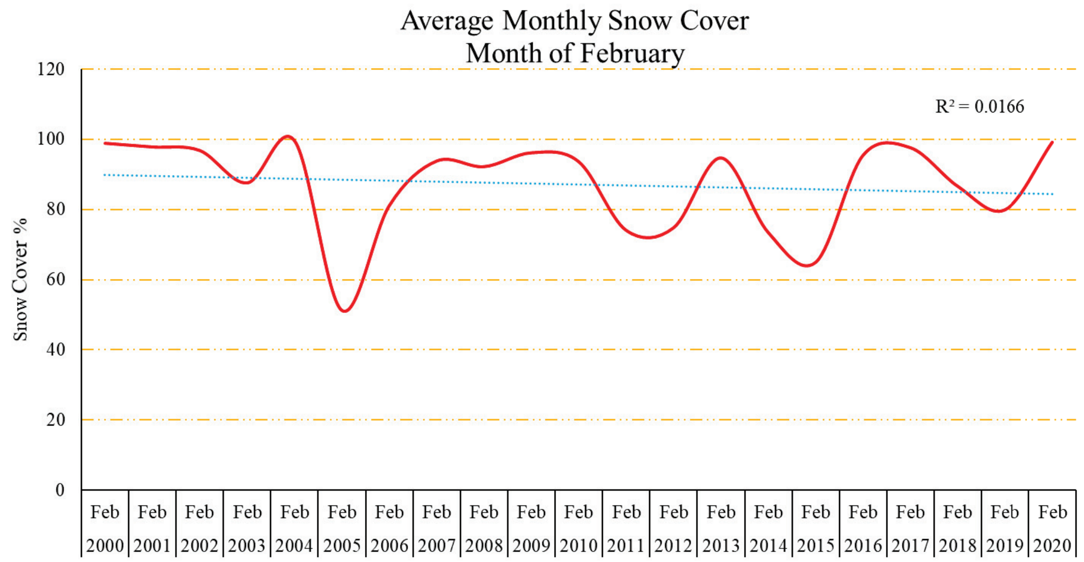


Fig. 5.17 Changes in the snow cover for the month of February in the KHANP between 2000 and 2020 analysed using MODIS data

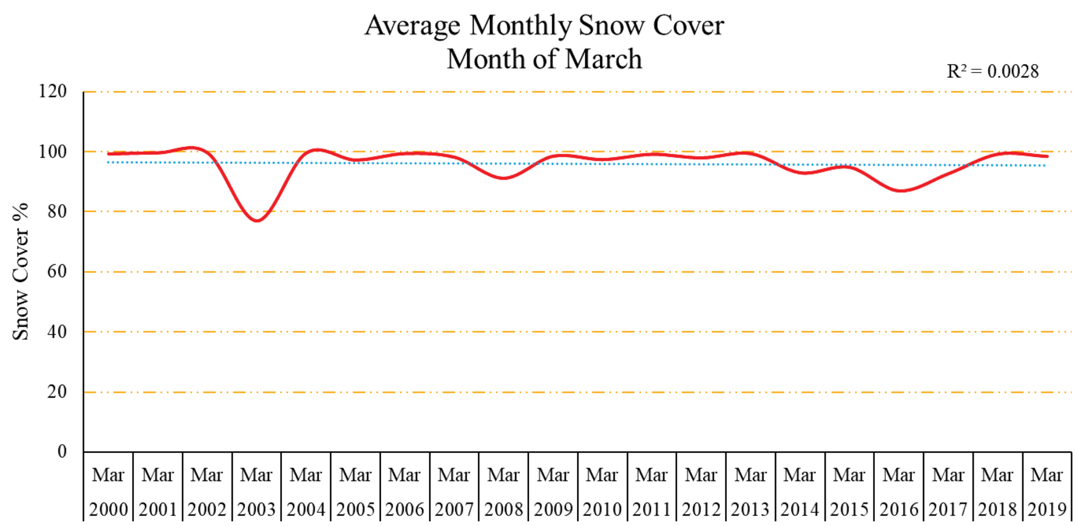


Fig. 5.18 Changes in the snow cover for the month of March in the KHANP between 2000 and 2020 analysed using MODIS data

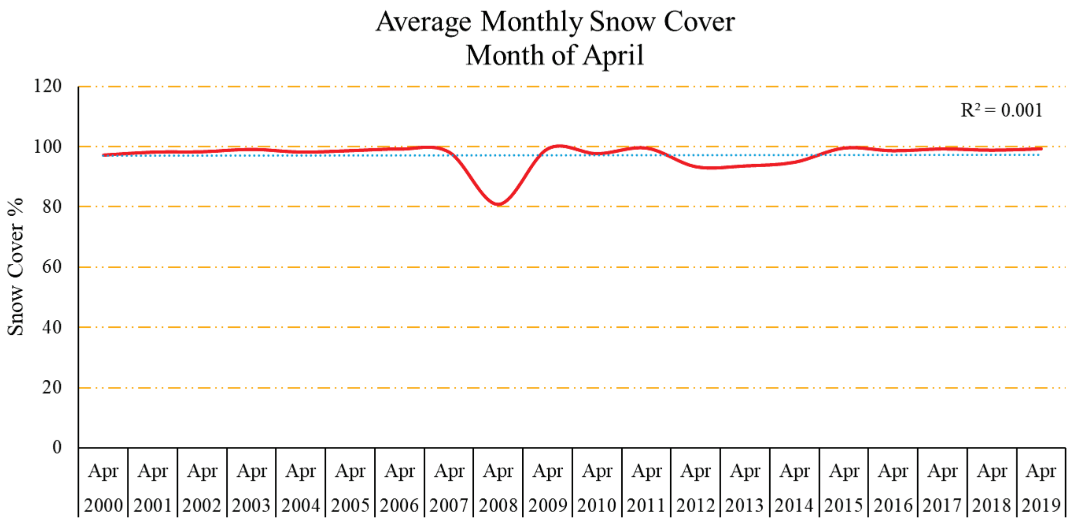


Fig. 5.19 Changes in the snow cover for the month of April in the KHANP between 2000 and 2020 analysed using MODIS data

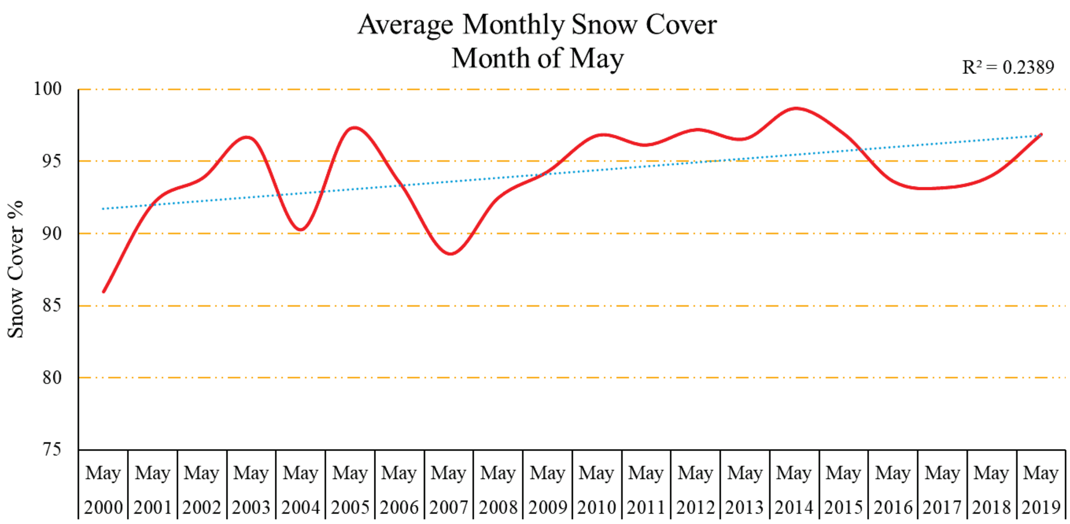


Fig. 5.20 Changes in the snow cover for the month of May in the KHANP between 2000 and 2020 analysed using MODIS data

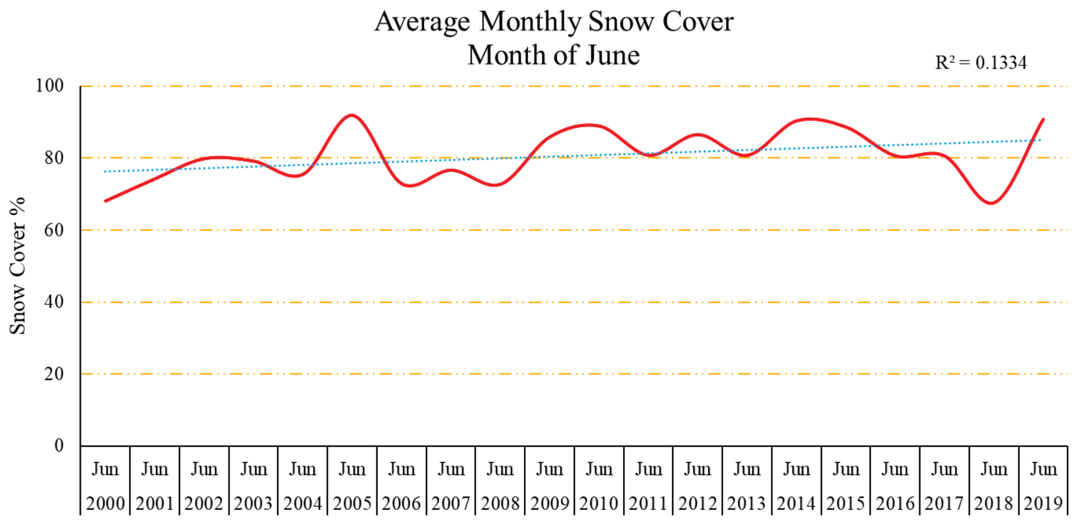


Fig. 5.21 Changes in the snow cover for the month of June in the KHANP between 2000 and 2020 analysed using MODIS data

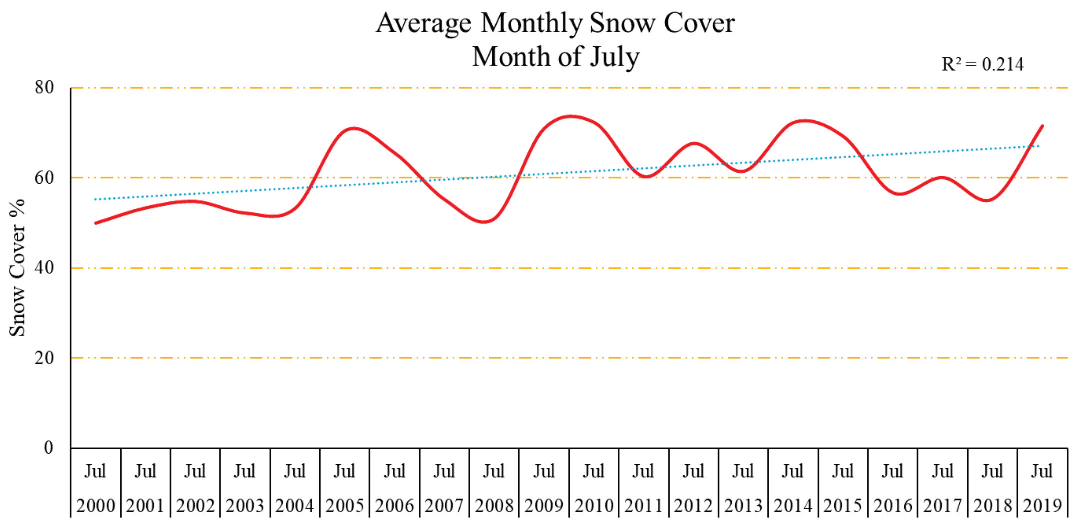


Fig. 5.22 Changes in the snow cover for the month of July in the KHANP between 2000 and 2020 analysed using MODIS data (trend)

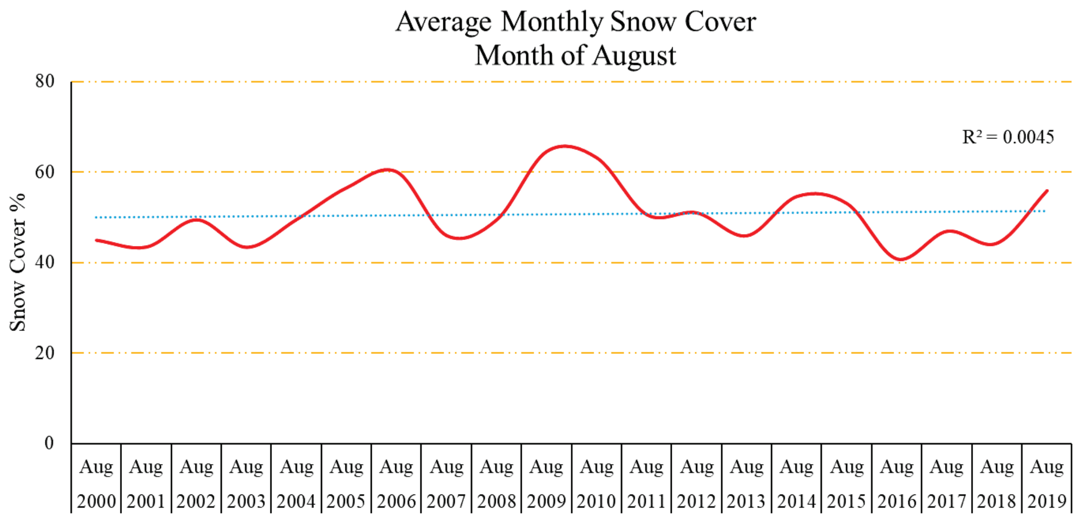


Fig. 5.23 Changes in the snow cover for the month of August in the KHANP between 2000 and 2020 analysed using MODIS data

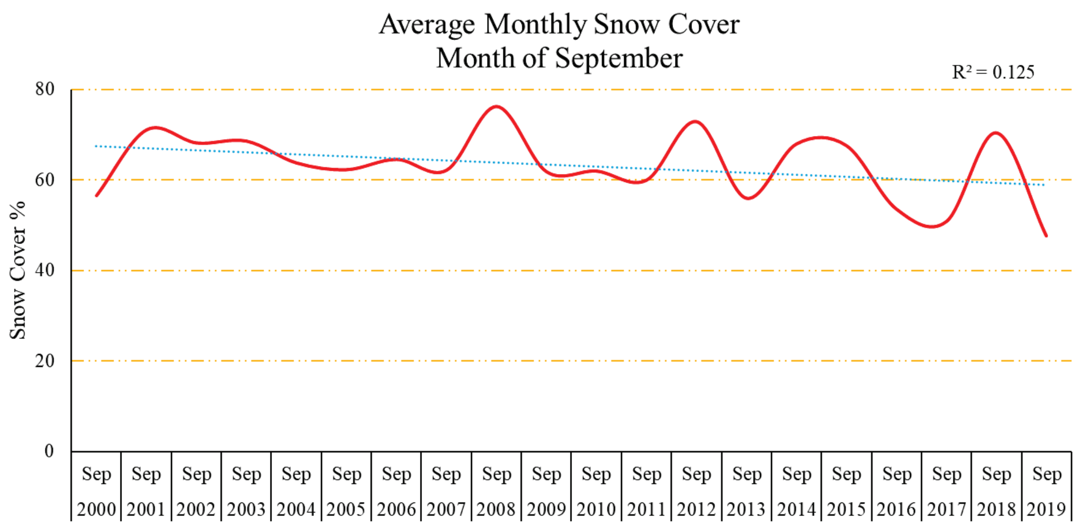


Fig. 5.24 Changes in the snow cover for the month of September in the KHANP between 2000 and 2020 analysed using MODIS data

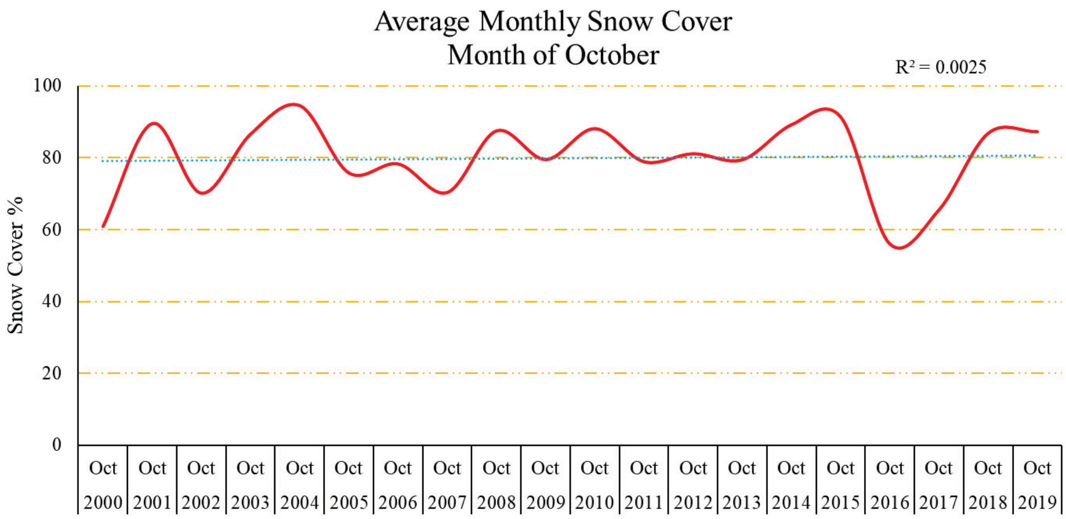


Fig. 5.25 Changes in the snow cover for the month of October in the KHANP between 2000 and 2020 analysed using MODIS data

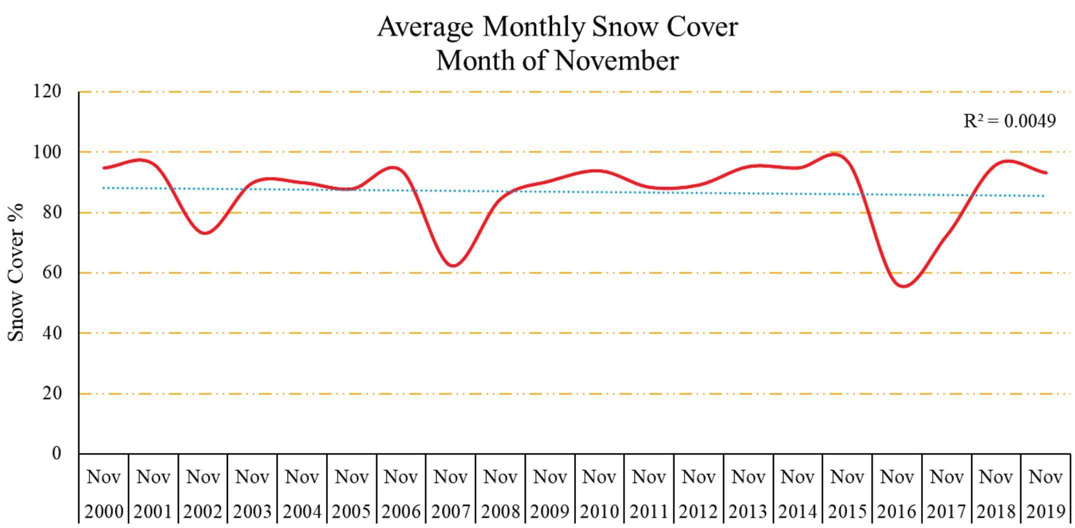


Fig. 5.26 Changes in the snow cover for the month of November in the KHANP between 2000 and 2020 analysed using MODIS data

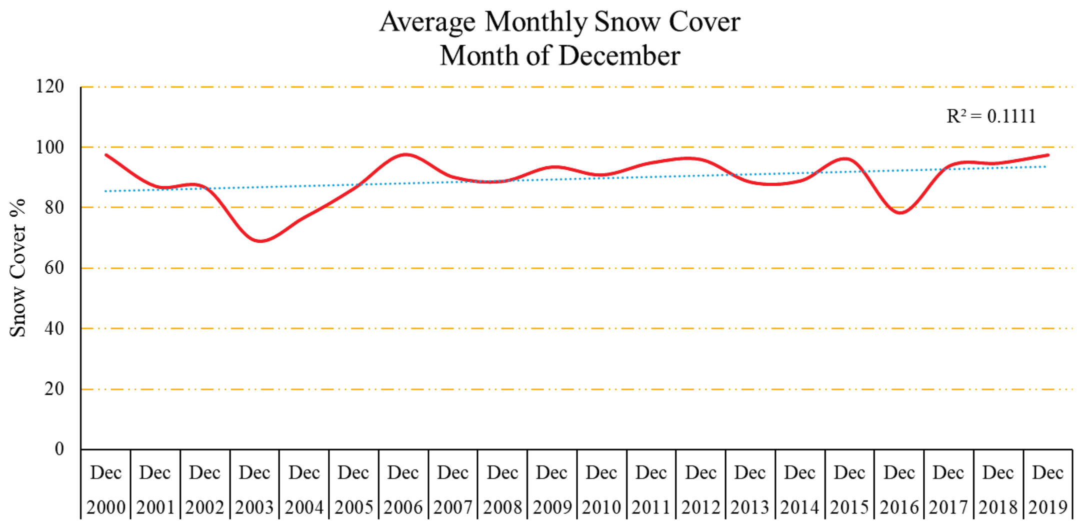


Fig. 5.27 Changes in the snow cover for the month of December in the KHANP between 2000 and 2020 analysed using MODIS data

## 5.6. Main concepts related to Glaciers and Snow and Discussion regarding recession of glaciers and snow

Snow, a solid form of water that crystallizes in the atmosphere and falls to Earth, covers around 23% of the Earth's surface permanently or intermittently. Snow falls at sea level poleward of latitudes 35° N and 35° S, but only at higher latitudes on the west coasts of continents. Snowfall occurs only in mountainous areas near the equator, at heights of around 4,900 metres (16,000 feet) or above.

The amount of snow on the ground has a big impact on the climate, as well as plant, animal, and human life. It creates a cold climate by enhancing solar radiation reflection and interfering with heat conduction from the earth. Small plants are protected from the impacts of the coldest winter temperatures by the low heat conduction; yet, the late departure of snow in the spring slows plant growth. When the snow melts in the spring, the runoff feeds rivers and provides water for irrigation and other human uses. In varied temperate climates, heavy snowfalls might obstruct mobility but also provides a firm surface for travel in remote Arctic, Antarctic, and hilly places using traditional dogsleds, snowshoes, or modern snowmobiles.

The texture and density of falling snow change all the time. Snow on the ground tends to become denser over time, and when it survives years of melting in the spring and summer, it can convert to ice and form a glacier. Gravity and viscosity may overcome friction on hillsides when temperature changes impair the coherence of snow particles in the snow cover, creating snow slides and avalanches.

Glaciers are enormous masses of perennial ice that grow on land as a result of the recrystallization of snow or other forms of solid precipitation and show traces of previous or current flow. A little snow area that lasts more than one season is hydrologically indistinguishable from a genuine glacier, except in size. All enduring snow and ice masses greater than 0.1 square kilometre (approximately 0.04 square mile) should be considered as glaciers, according to one international body (USGS). The repeated expansion and contraction of the world's ice cover has been a fascinating part of recent geological time (about 30 million years ago to the present). The evolution and development of early humans were influenced by glacial oscillations, which influenced geological, climatological, and biological conditions.

Glacier ice now holds nearly three-quarters of the world's fresh water. Glacier ice covers around 11% of the world's surface area, and if all of it melted, the world's sea level would increase by about 90 metres (300 feet). Glaciers can be found in practically every corner of the earth and in almost every latitude. Glaciers can be found at or near the Equator in Ecuador, Kenya, Uganda, and Irian Jaya (New Guinea), albeit at great heights (www.nsidc.org/cryosphere/glaciers/quickfacts.html)

The source of the world's glacier cover variability is yet unknown. On long time scales, periodic shifts in the heat received from the Sun, induced by variations in the Earth's orbit, are known to correspond with substantial swings in ice sheet advance and retreat. Large ice sheets, on the other hand, contain various "instability mechanisms" that may have contributed to global climate change. The high albedo, or reflectivity of dry snow to solar radiation, is one of these causes. No other widely distributed material on the planet even comes close to snow's albedo. As a result, as an ice sheet expands, a greater proportion of the Sun's radiation is reflected back into space, less is absorbed on Earth, and the global climate cools. The fact that the thicker and more broad an ice sheet is, the more snowfall it will get in the form of orographic precipitation, suggests another instability mechanism (precipitation resulting from the higher altitude of its surface and attendant lower temperature). Studies of the West Antarctic Ice Sheet have suggested a third instability mechanism. Ice streams are sections of an ice sheet that move rapidly outward on a regular basis, possibly due to the accumulation of a thick layer of moist, malleable material beneath the ice. Despite the fact that the exact origins of ice ages are unknown, experts agree that the world's ice cover and temperature are in a fragile equilibrium.

Only the greatest ice masses have a direct impact on global climate, although all ice sheets and glaciers respond to local climate changes, particularly variations in air temperature and precipitation. The previous changes of these glaciers can be deduced from the features they left on the landscape. Researchers can deduce earlier climatic variations by researching these characteristics.

- *Transformation of snow to ice*

Glacier ice is a collection of unevenly formed, interconnecting crystals ranging in size from a few millimetres to several tens of centimetres in diameter. The conversion of snowpacks to glacier ice involves a number of processes, each of which moves at a different rate depending on moisture and temperature. In the atmosphere, snow crystals take the form of small hexagonal plates, needles, stars, and other complicated formations. These complicated forms are typically unstable in a deposited snowpack, and molecules tend to evaporate from the sharp (high curvature) tips of crystals and condense into hollows in the ice grains. This causes the microscopic ice grains to round off, allowing them to fit closer together. Furthermore, the delicate crystal points may be broken off by the wind, causing them to pack more densely. Individual small grains may spin to fit more securely together, or the evaporation and condensation process may continue: contacting grains may produce necks of ice that connect them (sintering) and grow at the expense of other regions of the ice grain. These processes occur more quickly at the melting threshold and more slowly at lower temperatures, but they all result in the snowpack becoming denser. If a high temperature differential exists, however, water molecules may migrate from grain to grain, resulting in a variety of complicated crystal forms (known as depth hoar) with a reduced density. Because of the melting of ice from grain extremities with refreezing elsewhere, the compacting force of surface tension, refreezing after pressure melting (regulation), and the freezing of water between grains, the rate of change is many times faster if liquid water is present.

After reaching a density of 500–600 kilogrammes per cubic metre, the snow densifies more slowly, and many of the mechanisms outlined above become less and less effective. Recrystallization occurs as a result of stress induced by the weight of the underlying snow, and grains change in size and form to reduce the stress on them. Large or favourably orientated grains typically grow at the expense of others as a result of this transformation. Further recrystallization may occur as a result of stresses caused by glacier flow. As a result of these processes, the density of the mass and the average grain size increase.

The air spaces between grains are sealed off when the aggregate density reaches about 830 to 840 kilogrammes per cubic metre, and the material becomes impermeable to fluids. When it comes to retrieving climate-history information from ice cores, the time it takes for pores to seal is crucial. The density of the ice crystal lattices rises with time and stress due to the compression of air bubbles. At great depths, the air is absorbed into the ice crystal lattices, and the ice becomes clear. Although the density of mountain glaciers rarely exceeds 900 kilogrammes per cubic metre, the density of ice sheets at extreme depths can approach that of pure ice (917 kilogrammes per cubic metre at 0 °C and atmospheric pressure).

The refreezing of water at the glacier's base can also help it accumulate mass. Previously, it was considered that water at the foot of a glacier served as a lubricating layer that aided the glacier's movement across the ground, and that refrozen water only happened in subglacial lakes. Refrozen water, on the other hand, has been shown to expand the size of a glacier by adding bulk to its base. Furthermore, the refreezing process tends to lift and change the glacier's upper layers. Several Antarctic ice fields have seen this lifting phenomenon, including the huge Dome A plateau at the top of the East Antarctic ice sheet.

- *Mass balance*

Glaciers are largely fed by snowfall, and they deteriorate primarily due to melting and runoff, as well as the breaking off of icebergs (calving). A glacier's size must be maintained by striking a balance between income (accumulation) and outgo (expenditure) (ablation). The glacier will grow if the mass balance is positive (more gain than loss); if it is negative, the glacier will shrink.

All processes that contribute bulk to a glacier are referred to as accumulation. Hoarfrost (direct condensation of ice from water vapour), rime (freezing of supercooled water droplets on reaching a surface), hail, the freezing of rain or meltwater, or avalanching of snow from adjacent slopes are also possible contributors. All processes that remove mass from a glacier are referred to as ablation. Melting at the surface usually takes precedence in temperate zones. The amount of melting near the base is usually negligible (1 centimetre [0.4 inch] per year or less). Calving is frequently the most essential process on huge polar glaciers, as well as certain temperate glaciers. In some particular settings, evaporation and ice avalanches are crucial; floating ice can lose mass by melting from below.

Because the processes of accumulation, ablation, and change of snow to ice differ so greatly depending on temperature and the presence or absence of liquid water, glaciers are commonly classified by their thermal condition. A polar glacier has ice below freezing temperature throughout its mass for the entire year; a subpolar (or polythermal) glacier has ice below freezing temperature throughout its mass except for surface melting in the summer and a basal layer of temperate ice; and a temperate glacier has ice below freezing temperature throughout its mass except for surface freezing in the winter. A polar or subpolar glacier may be frozen to its bed (cold-based) or melting at its bed temperature (warm-based).

Glacial ice has two characteristics: (a) a density of 830 to 920 kg $m^{-3}$ (83 to 92 percent water content) and (b) trapped air in bubbles within the ice that is no longer in contact with the atmosphere. When snow falls on a surface, it has a density of 50 to 70 kg $m^{-3}$ at first, but within a few days, it has a density of 100 to 300 kg $m^{-3}$ (10 to 30 percent water content). The density of the snowpack steadily rises over time due to compaction of overlying snow and metamorphic processes. Snow that does not melt is carried over to the following season and may be buried by successive snowfall. "Firn" or "névé" refers to snow that is older than a year but not yet glacial ice. Over time, the density of firn increases, and the air trapped in pockets or bubbles finally loses contact with the atmosphere. Firn has turned into glacial ice. The rate at which seasonal snow transforms into glacial ice is determined by the local climate (cf. Cuffey and Paterson, 2010).

Internal deformation produced by shear tension applied by overlying ice and snow, as well as basal sliding on a layer of liquid or quasi-liquid water, are all factors that cause glaciers to move. Because of the pressure created by overlying snow and ice, ice masses can flow down slopes or across flat land. A glacier is defined as a mass of ice that flows as a solid. Glaciers are ice and snow patches that do not flow.

The principles of glacial activity can be easily comprehended by knowing that glaciers have both an accumulation zone and an ablation zone, in which the volume of the glacier grows and is lost. A glacier gains bulk during the accumulation season (summer in the eastern HKH and winter in the western HKH). Some or all of that buildup is lost during the melt season (summer in both the eastern and western HKH). As a result, the size of a glacier may rise, shrink, or remain constant over the course of a year. This is decided by whether accumulation or ablation takes precedence, or if both are equally important. The accumulation zone is the upper elevation zone where annual net mass gain occurs, while the ablation zone is the lower elevation zone where annual net mass loss occurs. The elevation where the accumulation and ablation zones meet and the annual net mass balance is zero is known as the equilibrium-line altitude (ELA). The net difference between accumulation and ablation is the annual mass balance (cf. Cuffey and Paterson, 2010).

Snowfall, condensation, refreezing of rainfall, avalanche transport onto the glacier, and blowing snow transfer onto the glacier are all examples of processes that increase glacier snow and ice mass. Snowmelt, icemelt, sublimation, blowing snow transport off the glacier, calving, and avalanche removal are all mechanisms that cause glaciers to lose snow and ice mass (cf. Cuffey and Paterson, 2010).

Glaciers are similar to lakes in terms of water delivery networks. The overall amount of water held in glaciers is comparable to the total amount of water stored in a lake. Water intake to a lake is equivalent to glacial accumulation, which comprises precipitation and water brought into the lake by streams, rivers, and groundwater channels. Glacial ablation is similar to lake water withdrawal, which includes evaporation, water carried out of the lake by streams, rivers, and groundwater channels, and human extraction. The lake is in a steady state when water intake sources equal water output sources, and the lake level does not change. When accumulation equals ablation in glaciers, the volume of water held in the glacier remains constant, and the ELA remains constant. When ablation surpasses accumulation over an extended period of time, the ELA rises, and the glacier in question eventually vanishes. This is similar to a lake with a self-terminating persistent overdraft, in which water extractions surpass water input.

This dialogue has resulted in a number of key principles. First, whether the net change is positive or negative is determined by the change in the volume of the glacier, not by the change in its downward extent or area. However, physically measuring the volume of a glacier is challenging, hence measurements of glacial volumes are rare around the world. Second, if the entire glacier is below the equilibrium line, no buildup will occur, and the glacier will eventually disintegrate. Third, knowledge on glacial mass balance will help to establish a relationship between changes in glacier volume and climatic change (Meier, 1962). Understanding what happens to glaciers throughout time requires a basic understanding of glacial mass balance.

Glaciers respond to climatic change by reaching a steady state, or a state in which the mass balance or ELA does not change over time. A positive mass balance occurs when a glacier advances due to cooler temperatures or increased snowfall. A negative mass balance and glacial retreat arise from rising temperatures or reduced snowfall. When a glacier is out of balance due to a warmer environment, it will retreat until equilibrium is restored or the glacier disappears.

Most years, the ablation zones of glaciers in the world's mid-latitude mountain ranges, including those in the HKH region, melt. Glacial ice melting is a common phenomenon. Most, if not all, mid-latitude glaciers release meltwater into streams and rivers. Glacial meltwater contributes to the discharge of mountain streams and rivers even when the glacier mass balance is positive. A steady-state situation occurs when climate conditions are such that glacial melt equals accumulation and the mass balance remains constant across time. The contribution of glaciers to streamflow can be considered in terms of the hydrological cycle, as proposed by Comeau et al (2009). They used the water equivalent to describe "glacial melt" and "glacial wastage" in their study of glacier hydrology in the Canadian Rockies. They simplified the annual glacial mass balance by ignoring sublimation and assuming no avalanche, snowdrifting, or blowing snow inputs or outputs, as well as no ice losses from calving. Sublimation is an important glaciological term in analysing the mass balance of the glacier at the high elevations of the HKH, as well as in central and northern Tibet, where it is extremely cold and dry. As a result, while discussing the relationship between glacier meltwater and streamflow, the Committee has taken the approach of Comeau *et al.* (2009) and used the words "glacial melt" and "glacial wastage." Because there are variances in meaning suggested between glacial melt and glacial wastage for different fields, the Committee has remained consistent with the wording used in the original reference when publishing results from other sources.

The annual glacial mass balance, according to Comeau *et al.* (2009), is equal to the annual snowfall minus the annual glacial snowmelt and minus the annual glacial icemelt. The glacial icemelt term is defined as the icemelt volume that is equal to or less than the water equivalent of snow that accumulates into the glacier system in a hydrological year if the glacier is in equilibrium or has a positive mass balance. Glacial waste is defined as the volume of icemelt that exceeds the water equivalent of the annual volume of snow accumulation into the glacier system, resulting in an annual net loss of glacier volume if the glacial mass balance is negative. To summarise, glacial melt does not indicate a negative mass balance or wastage on its own. According to these criteria, the presence of a glacier in a basin influences overall streamflow volume only through wastage contributions on a yearly basis. Glacial melt is a storage term, and it has no effect on overall annual streamflow. Glaciers and groundwater are both storage reservoirs in the hydrological cycle. Snowfall on glaciers is equivalent to groundwater recharge, glacial melt is analogous to groundwater extraction (or outflow from artesian aquifers), and glacial wasting is analogous to groundwater overdraft, according to Comeau *et al.* (2009). Both persistent glacial wastage and persistent overdraft are self-destructive.

Glacial melt has the potential to alter overall streamflow on a seasonal basis, and its importance is evident in its timing, since water is held as snow accumulation in the glacier system, and the water equivalent runoff is postponed until icemelt in the otherwise low streamflow months of late summer. As a result, glacial melt's relevance in terms of percentage contribution to streamflow is essentially seasonal.

The reaction of glaciers to climate change necessitates an understanding of ice dynamics (Armstrong, 2010). The advance of the terminus will increase the overall glacier area if climate and ice dynamics result in a glacier extending farther downslope with time. A temporal lag of decades or more exists between climate change and glacial advance or retreat, and year-to-year glacier terminal variations are most likely a response to climatic events that occurred decades or more ago. The bulk of glaciers in the HKH region have reaction times ranging from decades to hundreds of years (Humphrey and Raymond, 1994;

Johannesson *et al.*, 1989). The area and volume of a glacier, the precipitation regime, debris cover, and topography shielding or shadowing all influence response time (Kargel *et al.*, 2011). All of these variables are variable. Glaciers are being measured.

The location of the endpoint is the easiest glacial characteristic to quantify. The terminal of a glacier can be found simply by trekking uphill to the glacier's beginning. The year's endpoint location can be marked in a variety of ways, including with a simple pile of rocks. Some glaciers have precise endpoint position records dating back a hundred years or more. However, over short durations of a decade or so, this basic assessment may provide inaccurate information regarding a glacier's retreat and rate of retreat. The retreat of a glacier's terminal over several decades indicates that the glacier is retreating.

The "glaciological" method of calculating glacier mass balance uses a network of stakes and pits on the glacier surface to measure the change in surface level between two preset dates (year mass balance) or at the conclusion of the ablation and accumulation seasons (seasonal mass balance) (Racoviteanu *et al.*, 2008). This is the most accurate method and gives the most information regarding spatial variance (Kaser *et al.*, 2003). However, there are no long-term glaciological mass balance data for the HKH region, and there are few glacial mass balance measurements at all (Kaser *et al.*, 2006).

The "geodetic approach" can be used to calculate mass balance. The elevation variations of the glacial surface over time are measured using multiple digital elevation models created over the entire glacier surface in this indirect manner (Racoviteanu *et al.*, 2008). The geodetic approach can only be used to evaluate glacier changes at decadal or longer durations due to substantial uncertainty (Kaser *et al.*, 2003; Racoviteanu *et al.*, 2008).

Because of the logistical challenges posed by the region's steep topography and remote position of glaciers, remote sensing techniques are of special interest. Glacier extent, length, surface elevation, surface flow fields, accumulation/ablation rates, albedo, ELA, accumulation area ratio, and mass balance gradient can all be monitored via remote sensing.

# CHAPTER-6

# CHAPTER – 6
# INVENTORIZING THE GRASSLAND RESOURCES OF THE KISHTIWAR HIGH ALTITUDE NATIONAL PARK

## 6.1. Grassland status of Kishtiwar High Altitude National Park

Presently, Grasslands or meadows cover about 138.20 sqkm of the NP, constituting approximately 5.09% of its total area. There are two classes of grasslands found in this NP, sub-alpine pastures and alpine pastures (Fig. 6.1). A brief description of both is provided below:

*a.* *Sub-alpine* Pastures

This category mainly covers pasture areas and meadows between the elevations of 2,900 and 3,500 meters. There are no trees in the area, but alpine grasses and therapeutic herbs are plentiful. Snow is a common occurrence, with depths of up to 3 meters. Primula spp. are among the flowers that bloom in the spring. *Brachypodium spp*., *Bromus spp*., *Danthonia spp*., and other grasses predominate in these pastures.

*b. Alpine Pastures*

The only distinction between sub-alpine and alpine pastures is that the latter has a shorter snow-free time and more floral features. The perennial mesophytic herbs dominate these meadows, with only a few grasses. *Primula spp*., *Anemone spp*., *Fritillaria imperialis*, *Iris spp*., *Gentiana spp*., and several *Ranunculaceae*, *Cruciferae*, *Compositae*, and *Caryophyllaceae* species are prominent among the herbs. Beyond this type, rocky outcroppings and bare boulders begin. This class also includes *Juniperus recurva*.

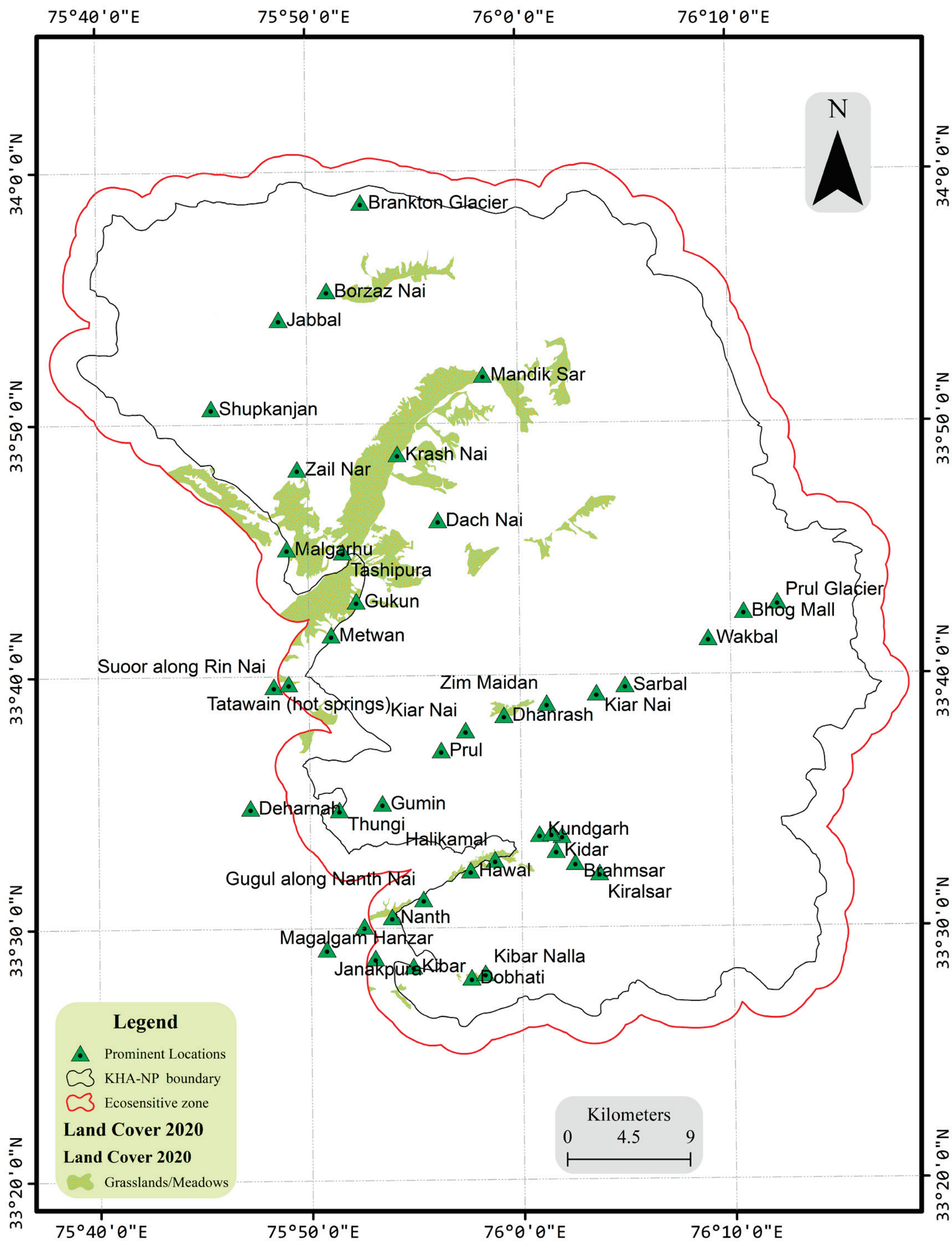


**Fig. 6.1** Current distribution of grasslands/ meadows land cover class in the KHANP (year, 2020)

### 6.2. A brief discussion of the Grasslands of KHANP

Geospatial analysis has been widely applied in ecology, biodiversity conservation, vegetation mapping, and other earth system processes such as biogeochemical cycling and land surface process characterization. Geoinformatics has opened up new frontiers in understanding the biodiversity richness, distribution patterns, disturbances regimes, impact of causative factors, including anthropogenic, for the loss of biodiversity and ultimately integrating all of this information for developing conservation strategies.

Vegetation type information has been used in conjunction with climate and topography in the GIS environment in Indian Himalayas to categorize the habitats as *a priori* and then determine the relationship between remotely sensed habitat categories and species distribution patterns. Such type of geospatial analysis is used to identify biodiversity hotspots utilizing a combination of the spatial distribution of drivers of vegetation change.

Spatial databases on vegetation types (such as grasslands) and status have been used in a GIS environment for landscape and habitat analysis. As seen in chapter 4, that forest class forms the dominant vegetation cover type in KHANP. However, the pastures of the alpine zones have particular significance. Apart from serving as grazing lands, they are essential for their role in traditional medicine, slope stabilization, and sediment retention. Hence these alpine pastures are an excellent repository of medicinal plants, some even endemic to the Western Himalayas. The area's climate is sub-humid temperate, experiencing rainfall from March to May and snowfall from December to February hence ideal for the proliferation of lush green alpine pastures. The lower elevations of the district are very fertile, suitable for agriculture.

Moist alpine pastures are found at elevations more significant than 3,200 m in various prominent places of Kishtiwar, such as Wadwan valley, Margan Pass and Sinthan Pass. Most of the herbs have tremendous medicinal and economic values associated with them, as local tribal communities use them. But over the past few decades, reckless exploitation of medicinal plants has rendered them vulnerable to extinction, as is the case with Saussurea *costus*, Gentiana *kurroo*, Podophyllum *hexandrum,* and many other plant species.

Over-grazing is one of the fundamental threats to alpine pastures. Large herds of herbivores of nomads occupy the alpine meadows during the summer months. The Bakerwals, the local grazers, take their livestock up to upper reaches during the summer months. Grazing continues to be a limiting factor for the habitats of many wild grazing animals in the national park.

The local inhabitants use about thirteen important medicinal herbs to cure some common ailments and diseases mainly found in the KHANP. Following are the important herbs found exclusively in the grasslands of KHANP

1. Adiantum *capillus-veneris* L. Family: Adiantaceae, Common names: Southern maidenhair, Venus maidenhair, Venus' hair fern, Local Name: Geutheer, Life form: Herb, Part used: Fronds The dried powdered fronds are mixed with milk and given as a remedy for fever to infants.
2. *Ajuga bracteosa* Wall. ex Benth. Family: Lamiaceae, Local name: Gutti, Life form: Herb, Flowering: June-September, Part used: Leaves, Roots Dried leaves and roots of this herb mixed in mustard oil are applied on the scalp to enhance the hair growth.
3. *Artemisia maritima* L. Family: Asteraceae, Common Name: Sea wormwood, Local name: Moin, Life form: Herb, Flowering: July September, Part used: Aerial parts. The aerial parts of the plant are given with gur (raw sugar) to get rid of the intestinal worms in infants. Also given in severe Stomach pain.
4. *Asplenium dalhousiae* Hook. Family: Aspleniaceae, Local name: Sunashud, Life form: Herb, Part used: Leaves. Powdered dried leaves of this fern are given with milk to the infants in high fever, soar throat, cough and cold.
5. *Caltha palustris* L. Family: Ranunculaceae, Common Name: Cowflock, cowslip, kingcup, marsh-marigold, meadow-bright, Local name: Bidgove, Life form: Herb, Flowering: May July, Part used: Aerial parts. Fresh aerial parts of the herb are given orally to infants suffering from acute constipation.
6. *Cannabis sativa* L. Family: Cannabaceae, Local name: Bhang, Life form: Herb, Flowering: June September, Part used: Leaves. The leaves of the plant are crushed and the juice is applied on the insect bite, it reduces the swelling and relieves the pain. Capsella *bursa-pastoris* (L.) Medik. Family: Brassicaceae, Common Name: Shepherd's purse, Local name: Kathkram,

Life form: Herb, Flowering: April-October, Part used: Leaves Crushed leaves of this herb are given to infants in dysentery.

7. *Cydonia oblonga* Mill. Family: Rosaceae, Common Name: Quince, Life form: Tree, Flowering: June July, Local name: Bhi, Part used: Fruit, seeds. Crushed seeds mixed in milk are given to infants as a remedy for sore throat. Family: Poaceae, Common Name: Bermuda grass, Local name: Dhrub, Life form: Herb, Flowering: May November, Part used: Aerial parts. The extract of the plant is used against nasal bleeding.
8. *Fragaria nubicola* (Hook. f.) Lindl. ex Lacaita Family: Rosaceae, Local name: Ing dach, Life form: Herb, Flowering: April June, Part used: Leaves. The leaves of the plant are given orally to infants in high fever.
9. *Jurinea dolomiaea Boiss*. Family: Asteraceae, Local name: Dhupa, Life form: Herb, Flowering: August-October, Part used: Roots. Root ash is rubbed against skin as remedy for irritation and skin rashes. Oxalis corniculata L. Family: Oxalidaceae, Common Name: creeping lady'ssorrel, creeping oxalis, creeping wood-sorrel, Local name: Dang chuch, Life form: Herb, Flowering: April July, Part used: Leaves, flowers. The fresh leaves are crushed and given orally in cases of stomach troubles like stomach pain, dysentery and other intestinal infections.
10. *Plantago lanceolata* L. Family: Plantaginaceae, Common Name: Local name: Life form: Herb, Flowering: May-June, Part used: Seeds Seeds of this herb are used against constipation.
11. *Prunella vulgaris* L. Family: Lamiaceae, Common Name: heal-all, self-heal, Local name: Kalvouth, Life form: Herb, Flowering: June September, Part used: Seeds The plant is used for fever and cough.
12. *Solanum nigrum* L. Family: Solanaceae, Common Name: black nightshade, common nightshade Local name: Life form: Herb, Flowering: July-August, Part used: Whole Plant Juice of whole plant used against sore throat.
13. *Viola indica* W. Becker Family: Violaceae, Local name: Sontar posh, Life form: Herb, Flowering: April-August, Part used: Flowers. Dried flowers mixed with milk and are given to infants for curing cough and chest infections.

These herb species used for curing illnesses in infants are all dicots. Only old and knowledgeable persons can identify them. The plant parts used for medicinal preparations are leaf, root, flower, fruit, rhizome, tuber, and seeds. In some cases, the whole herb is utilized. The herbal preparations are used to treat respiratory tract infections (cold, cough, fever,) gastrointestinal problems (cholera, gastritis, intestinal pain, stomachache, etc.), and dermatological problems. The preparation methods include decoction, juice, oil, paste, powder, extract, smoke, and even raw (unprocessed). In a nutshell, the grasslands of this national park are rich repositories of enormous biodiversity and medicinal plants besides serving as fodder grounds for nomads' livestock.

# CHAPTER-7

# CHAPTER – 7
# MAIN FINDINGS FOR FUTURE DECISION MAKING

## 7.1. Main Findings of this report

1. It has been found that KHANP comprises of six geological classes. The highest geological class found in the NP is of Denudational Hill comprising of 1304.21sqkm (59.51%) followed by Glacial Plain (794.48 sqkm, 36.25%), Piedmont Zone (31.84 sqkm, 1.45%), Structural Hills (31.79 sqkm, 1.45%), Eolian Plain (20.73 sqkm, 0.95%) and the least area found under Waterbody class (8.45 sqkm, 0.39%). The area's geology determines the soil characteristics and, in turn, the erosional rates. The higher percentages of Denudational Hill and Glacial Plains reflect the very less area available for vegetation in the KHANP.

2. It has been found that KHANP comprises of 17 geomorphological classes, although only 15 have significant areal extents. The highest geomorphological class found in the NP is of massive type denudational hills (small) comprising of 1087.31 sqkm (49.61%) followed by glacial valley (702.80 sqkm, 32.07%), ridge type denudational hills (114.59 sqkm, 5.23%), dome type denudational hills (small) (69.00 sqkm, 3.15%), moraineous plains (47.65 sqkm, 2.17%), dome type denudational hills (large) (39.25 sqkm, 1.79%), ridge type structural hills (large) (30.28 sqkm, 1.38%), terminal moraine (29.74 sqkm, 1.36%), talus cones (21.15 sqkm, 0.97%), bazada (16.59 sqkm, 0.76%), lateral moraine (15.00 sqkm, 0.68%), lower piedmont slope (13.00 sqkm, 0.59%), alluvial fan (3.12 sqkm, 0.14%), intermountain valley/structural valley (1.73 sqkm, 0.08%), and the least area was found under upper piedmont alluvium – deep (0.19 sqkm, 0.01%). Geomorphology is the outcome of the interaction of geology, topography, and the area's climate. It also determines how well the areas with a specific geomorphological setting can sustain vegetation. It is the result of the geomorphology that the KHANP comparatively has lesser vegetation to total area ratio.

3. It has been found that KHANP comprises of five lithological classes. The highest lithological class found in the NP is of Shists with Gneiss Mixed covering of 2125.41 sqkm (96.98%), followed by Gravel Sand Silt (46.42

sqkm, 2.12%), Waterbody (8.42 sqkm, 0.38%), Bedded Limestone (5.66 sqkm, 0.26%), and the least area was found under Sand Silt with Clay (5.60 sqkm, 0.26%).

4. It has been found that KHANP comprises of six soil types. The highest class found in the NP is of Glacial Area covering 978.2 sqkm (44.6%), followed by Fine Loamy Soil (367.7 sqkm, 16.8%), Rock Outcrop (343.9 sqkm, 15.7%), Loamy Soil (291.4 sqkm, 13.3%), Coarse Loamy Soil (185.6 sqkm, 8.5%), and the least area was found under Sandy Soils (24.6 sqkm, 1.1%). The loamy and Coarse Loamy Soils are very fertile and good for alpine vegetation.

5. The elevation ranges from 2148 meters to 6504 meters in the KHANP. For ease of analysis, we divided the elevation into ten classes. It was found that is of 4576m-4822m class comprising of 366.51 sqkm (16.72%) followed by 4327m-4575m class (356.82 sqkm, 16.28%), 4061m-4326m class (317.71 sqkm, 14.50%), 4823m-5098m class (308.41 sqkm, 14.07%), 3768m-4060m class (263.00 sqkm, 12.00%), 3435m-3767m class (190.65 sqkm, 8.70%), 5099m-5459m class (182.46 sqkm, 8.33%), 3026m-3434m class (96.58 sqkm, 4.41%), 5460m-6504m class (64.16 sqkm, 2.93%), and was the least 2148m-3025m elevation class found (45.15 sqkm, 2.06%).The elevation of the KHANP is the determining factor behind the sustenance of a large number of glaciers present there. The majority of the Glaciers of KHANP are found above 4500 m.

6. The slope ranges from 0 degrees to 83 degrees in the KHANP. For ease of analysis, we divided the slope into six classes. It was found that maximum area was found under the slope class $24^o$ -$33^o$ covering 547.51 sqkm (24.98%) followed by $34^o$-$42^o$ class (434.46 sqkm, 19.82%), $14^o$-$23^o$ class (422.15 sqkm, 19.26%), 0-$13^o$ class (361.43 sqkm, 16.49 %), $43^o$-$53^o$ class (306.28 sqkm, 13.98 %), and the least area was found under $54^o$-$83^o$ class (119.67 sqkm, 5.46 %). The steeper slopes are usually devoid of vegetation and vice-versa.

7. It has been found that KHANP comprises of all the major aspect classes. The highest aspect found in the NP is of Northwest comprising of 331.03 sqkm (15.11%) followed by Southwest (304.96 sqkm, 13.92%), South (294.82 sqkm, 13.45%), West (280.33 sqkm, 12.79%), Northeast (247.41 sqkm, 11.29%), Southeast (229.47 sqkm, 10.47%), East (198.01 sqkm,

9.04%), North (152.78 sqkm, 6.97%), North (150.14 sqkm, 6.85%), and flat aspect was the least aspect class found (2.54 sqkm, 0.12%). The aspect has a huge role in determining vegetation's type, density, composition, and biodiversity. The southern aspects have relatively higher vegetation than the northern aspects.

8. Since KHANP had been declared as the conservation priority region, it has been found that the direct anthropogenic impacts (such as forest smuggling and poaching) on its flora and fauna have been minimal over the years.

9. The dense forest cover spans about 107.75 sqkm of the NP, constituting approximately 3.97 % of its total area (Fig. 4.2).

10. The open forest cover spans about 253.14 sqkm of the NP, constituting approximately 9.33 % of its total area (Fig. 4.3).

11. The total forest cover of the NP, including dense and open, is about 360.89 sqkm, accounting for 13.30 % of its total area.

12. Presently, the scrub class covers about 384.63 sqkm of the NP, constituting approximately 14.17 % of its total area.

13. Presently, the Grasslands/Meadows covers about 138.20 sqkm of the NP, constituting approximately 5.09 % of its total area.

14. Presently, the land under streams and alpine lakes in the National Park spans about 11.84 sqkm constituting approximately 0.44 % of its total area (including the ESZ)

15. In 2020, the area under snow/ glaciers spanned about 798.20 sqkm of the NP, constituting approximately 29.41 % of its total area.

16. In 2020, the land cover of the Kishtiwar High Altitude NP was dominated by the rocky-barren class, having about 1020.00 sqkm of the national park under it and accounting for about 37 % of its area

17. Snow/ glaciers have decreased almost half of their areal extent in 1992. It decreased from 1578.27 sqkm in 1992 to 798.20 sqkm in 2020, recording a decrease of 780.07 sqkm (-49.43% decrease since 1992) of the area in this period. There has been a corresponding increase in the area under the rocky-barren class. Rocky-barren class increased from its areal extent of 304.83 sqkm in 1992 to 1020 sqkm in 2020, recording an increase of 715.17 sqkm (234.61% increase since 1992, nearly five times increase since 1992) of

area in this period. Overall It is concluded that the increase of the area under rocky-barren class corresponds well with the decrease of the area under snow/ glaciers class, indicating that the decreased area of the snow/glaciers got converted to rocky-barren.

18. The area under the dense forests class has increased from its areal extent of 69.49 sqkm in 1992 to 107.75 sqkm in 2020, recording an increase of 38.27 sqkm (55.07 % since 1992) of the area in this period. The open forest class has similarly increased in area with its areal extent increasing from 96.90 sqkm in 1992 to 253.14 sqkm in 2020, recording an overall increase of 156.24 sqkm (161.23% increase since 1992) of the area in this period. The area under the scrubland class has overall decreased from its areal extent of 500.31 sqkm in 1992 to 420.21 sqkm in 2020, recording an overall decrease of 80.29 sqkm (-16.01% decrease since 1992) of the area in this period. The area under grassland/meadows has also decreased from its areal extent of 152.72 sqkm in 1992 to 138.20 sqkm in 2020, recording an overall decrease of 14.52 sqkm (-9.51% since 1992) in this period.

19. It is to be noted that the decrease of the area under scrubland and grassland/meadows class corresponds well with the increase of the area under open forest class, indicating that the decreased area of these classes got converted to open forest. Overall there has been no significant change in the waterbody class since 1992.

20. The cover of the dense forest has increased since 1992. However, the decade-wise dense forest has seen a maximum increase in the area between 1992 and 2000, accounting for an increase of 26.22 sqkm with a percent increase of 37.74.

21. The overall cover of the open forest has increased since 1992. However, it witnessed a decrease in its cover between 2000 and 2010, accounting for 11.57 sqkm (-8.67% decrease). Between 2010 and 2020, it witnessed a massive increase in its cover, amounting to 124.81 sqkm (97.26% increase).

22. The grassland/meadow class showed a decrease in the first two decades (1992-2000, -52.15 sqkm and 2000-2010, -8.72 sqkm) and witnessed an increase between 2010 and 2020 amounting to 46.36 sq km (49.52% increase).

23. The scrubland class increased in the first two decades (1992-2000, -73.26 sqkm and 2000-2010, 17.24 sqkm) but witnessed a decrease between 2010 and 2020, amounting to 206.18 sq km (-65.10% decrease).

24. The waterbody class showed no significant change in any decade of the analysis.

25. The cover of snow/glaciers has decreased since 1992. However, decade-wise, it has seen a maximum decrease in the area between 1992 and 2000, accounting for a decrease of 599.30 sqkm with a percent decrease of 37.97.

26. The cover of rocky barren has increased since 1992. However, decade-wise, it has seen a maximum increase in the area between 1992 and 2000, accounting for an increase of 508.85 sqkm with a percent increase of 166.93.

27. In 2020, the total number of glaciers found in the KHANP was 177.

28. No new glaciers have formed in the study area. The increase in the numbers is due to the fragmentation of already existing glaciers. This is also a manifestation of the current anthropogenic climate change and a cause of concern for water resource management and conservation under future climate change.

29. In 2020, the total area under glaciers in the KHANP is 532.97 sqkm. It accounts for 23.90% of the total area of the NP.

30. In 2020, the total volume of glaciers covered by 532.97 sqkm of area constituted about 36.16 cubic kilometers of ice volume or approximately 36160 Mega tones of water.

31. The areal extents of glaciers have decreased since 1992. In the year 1991, the total area under glaciers was 609.27 sqkm. Subsequently, in the year 2000, it got to 573.84 sqkm. In the year 2010, it further got reduced to 558.96, and finally, in 2020, it equaled 523.97 sqkm

32. It has been observed that glaciers were comparably stable during the 2000-2010 decade corresponding to the least changes in their areal extents observed in this period equalling 14.87 sqkm, accounting for a percent decrease of -2.59 %. In contrast, the decades 1991-2000 and 2010-2020 have witnessed very high recessional rates of the glaciers in the KHANP,

corresponding to -5.81% (35.42 sqkm lost) and 6.26% (34.99 sqkm lost), respectively.

33. It has been observed that since 1992, the area of very small and small glaciers has reduced 26.65% and 21.76%, respectively

34. The snow distribution in the KHANP keeps on changing throughout the year. The hydrological cycle of the Himalayan watersheds usually starts from October month of every year. Before this date, whatever proportion of the previous year's snow is present will generally stop melting now. The new snow that falls after this date adds the water to the following year's supply in the watershed's drainage system.

35. In the last 20 years, there has been no significant change in average snow cover in the KHANP.

36. The year 2003 and 2008 witnessed decreased snow covers in January compared to other January years from 2002 till 2020.

37. The month of February shows undulating percent snow covers over the years, which could be due to the mean monthly temperatures over the years.

38. The month of March shows almost the same percent snow cover throughout the time series 2000-2020.

39. The year 2008 witnessed decreased snow cover in April compared to other April years from 2000 till 2020. Overall the percent snow covers have remained constant over the years, approximated at 100 percent cover.

40. The month of May shows undulating percent snow covers over the years. From 2000 till 2020, however, it has been observed there is an increasing trend percent in the snow in May.

41. The month of June shows almost the same percent snow cover throughout the time series 2000-2020.

42. The month of July shows undulating percent snow covers over the years. From 2000 till 2020, however, it has been observed there is increasing trend percent snow in July.

43. The month of August shows undulating percent snow covers over the years. From 2000 till 2020, however, it has been observed there is constant trend percent snow in August.

44. The month of September shows undulating percent snow covers over the years. From 2000 till 2020, however, it has been observed there is constant trend percent snow in September.

45. The month of October shows undulating percent snow covers over the years. From 2000 till 2020, however, it has been observed there is constant trend percent snow as witnessed in previous years.

46. The month of November shows undulating percent snow covers over the years. The years 2002, 2007, and 2016 have witnessed comparatively lower snow covers than other years of the time series.

47. The month of December shows undulating percent snow covers over the years. The year 2003 and 2016 has witnessed comparatively lower snow covers compared to other years of the time series.

48. Presently, Grasslands or meadows cover about 102.62 sqkm of the NP, constituting approximately 3.78 % of its total area (including the ESZ). There are two classes of grasslands found in this NP, sub-alpine pastures and alpine pastures.

49. Moist alpine pastures are found at elevations more significant than 3,200 m in various prominent places of Kishtiwar, such as Wadwan valley, Margan Pass and Sinthan Pass. Most of the herbs have tremendous medicinal and economic values associated with them, as local tribal communities use them. But over the past few decades, reckless exploitation of medicinal plants has rendered them vulnerable to extinction, as is the case with Saussurea *costus*, Gentiana *kurroo*, Podophyllum *hexandrum*, and many other plant species.

50. Overgrazing is one of the fundamental threats to alpine pastures. Large herds of herbivores of nomads occupy the alpine meadows during the summer months. The Bakerwals, the local grazers, take their livestock up to upper reaches during the summer months. Grazing continues to be a limiting factor for the habitats of many wild grazing animals in the national park.

51. The local inhabitants use about thirteen essential medicinal herbs to cure some common ailments and diseases in infants in the KHANP.

## 7.2. Future Scope of the Work - Resource Allocation

Global environmental problems include biodiversity loss, emerging infectious diseases, and climate change. There are insufficient resources to eliminate this broad range of environmental issues, and hence it is necessary to prioritize. These problems have a standard structure that seeks to optimize an outcome subject to constraints. Recent developments have moved from ground-breaking work that ranks threats to determining efficient strategies for reducing hazards.

Decision theory provides the tools to identify these efficient strategies. Fundamental aspects of decision theory include an objective function that defines the goal of management and a method to determine the combination of management strategies that optimizes the objective function. Examples of decision theory in conservation include allocating conservation resources among the region, designing nature reserves, allocating funding to species conservation programs, designing biodiversity surveys and monitoring programs, managing threatened, migratory or invasive species, and investing in greenhouse gas mitigation schemes.

Furthermore, uncertainty is prevalent in environmental management and needs to be considered to manage risks. Ignoring uncertainty is risky, can lead to over-confidence in the chosen management strategy, and exposes managers to unexpected failure. The particular structure of this simplification allows these approaches to incorporate uncertainty about the state of the world and the management response is what conservationists need to ask themselves before allocating resources.

Biodiversity hotspots support many endemic species but face high levels of threat. Allocating finite conservation resources among biodiversity hotspots can minimize the expected number of endemic plant species becoming extinct. In addition to threat (a function of the level of protection and the rate of vegetation clearance) and endemism, the cost of acquiring land is a critical variable driving the optimal allocation of resources among areas. There are expert judgment based models available such as the analytical hierarchy process (AHP) that could be used for determining the priorities for conservation using various factors that govern it, such as the attitude of the community in land conservation, the issue of costs, value of the goods that people yield from nature and similar others. It is necessary to consider such variables to arrive at an effective conservation policy for the biodiversity hotspot area.

Stochastic dynamic programming is used to find the optimal resource allocation schedule for small problems but is intractable for significant problems due to the "curse of dimensionality." Conservation organizations allocate resources to areas that have been identified as priorities for conservation investment. These priority regions are determined using the information on relative biodiversity values, past or present threats to these values, and current levels of protection. Species richness, or endemic species richness, is typically used to estimate the biodiversity value.

One of the most pressing issues facing the global conservation community is distributing limited resources between regions identified as priorities for biodiversity conservation. International organizations use biodiversity hotspots, endemic bird areas, and ecoregions to prioritize conservation efforts globally. Although identifying priority regions is essential in solving this problem, it does not indicate how limited regions should allocate resources. To allocate conservation resources optimally between regions identified as priorities for conservation - the 'conservation resource allocation problem' is what needs to be defined at the very onset.

The relative cost of conservation in different regions is ignored in identifying priority regions despite evidence that its inclusion improves the cost-effectiveness of conservation prioritization. Some international organizations rank these regions in terms of their priority for funding, but the approaches used to derive these rankings are not solutions to an adequately formulated problem. Suppose the objective is to maximize the total number of species conserved. This objective is unlikely to be achieved if regions are prioritized only based on species richness. This is because highly threatened regions but marginally less species-rich may lose many species before considering conservation investment. Likewise, suppose the relative cost of investing in different regions is not considered. In that case, resources may be directed to the expensive areas when the same amount of resources might have conserved more species if invested in regions with lower land acquisition and management costs.

The efficient resource allocation for prioritized conservation of different parks can only be achieved if the strategy is based on biodiversity, threat, cost, and many other essential factors. Above all, the planning must be rigorously formulated. Allocation of conservation resources, like any problem in decision theory, requires a broad goal, a specific objective, a set of constraints, a set of possible actions that form a strategy, and an understanding of the system dynamics provided by equations that link the efforts and limitations to the objective.

Further, given that surrounding land use affects the function of protected areas, it is essential to understand drivers of change and threats and opportunities that those changes may pose to the maintenance of biodiversity. Furthermore, understanding future land use around protected areas is crucial to mitigate the potential effects of climate change effectively. Many climate change adaptation strategies call for the establishment of corridors to allow for species migration as suitable habitat and environmental conditions shift location.

Understanding land use and land cover change around protected areas at different spatial scales are essential to understand human pressures on protected areas better. It is also crucial because species relate to the landscape in different ways. Species differ in their home range size requirements, movement and dispersal capabilities, and perception of the environment. Therefore, it is vital to understand land use change at different scales that correspond to the range of scales at which species relate to landscapes.

Land use change very broadly follows a trajectory from natural land cover to frontier clearing, subsistence agriculture, and ending in intensive land use where the majority of land has been converted for agricultural and urban use. Different regions of the World are at different points along this trajectory. The time required to pass through the different stages varies widely, with some remaining in the frontier and subsistence stage. Many areas of the World have progressed through the stages, beginning with agricultural production, followed by growth of population centers, and finally urbanization and has established regional land use patterns. Because these patterns are predictable to some degree, future land use can be simulated. Regional patterns may vary considerably, and changes in land use are affected by regional economic, demographic, and ecological forces, which, when modeled, allow us to fine-tune simulations of future land use. Past land use changes provide information that can be exploited to quantify the likely effects of different economic policies and scenarios on future land use patterns. In Jammu and Kashmir, past land use trends suggest that land use is likely to continue to intensify rapidly, with urban use growing faster than other land use classes. This means that the protected area network of the state may be at risk from the effects of land use intensification surrounding protected areas.

The main goal of the PAN conservation is to maintain such areas' biological integrity, yet this goal may be compromised by intensifying land use in the surroundings. Furthermore, given concerns that climate change will likely exacerbate current land use effects on wildlife and the buffer system, it is of great interest to the PAN conservationists to assess future land use change as a major step in determining what climate change adaptation measures are indicated. Predictive models of future land use change can help managers explore plausible outcomes of different policy or economic scenarios and are thus an important tool for maintaining biological integrity. Future scenarios generated from such models can provide land managers with a better understanding of the full range of potential futures and the possible effects of alternate futures on biodiversity and other ecological resources. Managers may be able to use the scenario outcomes to identify important pre-emptive actions for lands outside protected area boundaries which, if managed appropriately, can be important for the maintenance of biodiversity. It is proposed that such a predictive model shall be used for the LULC future modeling for KHANP, and the results shall be included in the final DPR.

**In protected areas such as Kishtiwar High Altitude National Park in India, the decision-makers need to start developing baseline information to pave the way for the comprehensive resource allocation strategy. For conservation measures, the central government funds national parks massively, but allocating the required funding for prioritized conservation efforts has to be determined scientifically. Whether more stress has to be laid on watershed management that eventually affects the sediment retention services or the focus needs to be on conserving biodiversity. This scientific question can only be resolved once an understanding of the primary function of the land system processes operating in the NP is developed. This report has assessed vegetation change, water resource mapping, and its change over the years and forms some of the initial baseline data required for the successful resource allocation for**

**conservation. It is proposed to initialize further research by evaluating the sediment retention and water yield services provided by the natural vegetation of the NP. By doing so, we can almost cover 85% of the science behind a successful resource allocation strategy for the KHANP.**

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# ANNEXURES

**Department of Wildlife Protection**
**Office of the Regional Wildlife Warden Jammu**
**Manda Hills Jammu Near Hotel Ashok Phone : 0191-2544575 Fax: 2520948**
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**Subject:** **Minutes of the meeting of Standing Committee on first interim report of deliverables titled "GIS- Based Land Use and Ecosystem Resource Mapping of Kishtwar High Altitude National Park".**

To discuss the draft interim deliverable namely "GIS- Based Land Use and Ecosystem Resource Mapping of Kishtwar High Altitude National Park", meeting of the Standing Committee constituted vide Order No. 13 of 2020 dated: 28-01-2020 was held on 1st of January, 2022 at 3.00 PM under the chairmanship of Pr.CCF/Chief Wildlife Warden J&K Govt. Jammu.

List of Standing Committee members and special invitees' who took part in the meeting is listed in ANNEXURE "A" to this MoM.

After detailed deliberations following observations were made for incorporation.

**(A) Land use/Land capability Characterizations:**

i) *Qualitative assessment of decadal Land Use Land Cover (LULC)* change analysis of ecosystem resources in addition to quantitative assessment as has been done in the instant draft deliverables.

ii) *Biodiversity characterization at landscape level based on ground truthing and qualitative and quantitative analysis* for vegetation cover (meadows both alpine and sub alpine, scrub land and open forest) for period between 2010 to 2020. Preferably, qualitative assessment *inter-alia* to reflect change in species composition of grass, herb, shrub with a specific input with regards to species composition indicating, palatable and non-palatable composition from the perspective of herbivore.

iii) *Assessment of change analysis* of major vegetation cover (meadows both alpine and sub alpine, scrub land and open forest) *viz-a-viz* anthropogenic pressure and their inter relationship for period between 2010 to 2020.

iv) *Assessment and characterization of drivers of change*, implications thereof (for park bio-diversity, zonation and sustainable management) and identification- of possible vulnerable (zone of influence) and buffer zones for priority management interventions.

v) Identification and mapping of potential biodiversity hotspots harboring key floral and faunal communities of conservation importance.

vi) To map the alpine grasslands/ pastures for different vegetation classes (native, mixed and invasive alien species) based on high resolution data/ NDVI/ Google Earth Engine cloud computing coupled with ground-truthing.

vii) To delineate the montane, timberline and tree line vegetation (Betula utilis, Quercus semecarpifolia, Abies pindrow) and alpine scrub

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(Rhododendron-Juniper communities) and generate baseline maps of the same for long term ecological monitoring.

viii) Vulnerability/ risk assessment and mapping of disaster-prone zones with respect to landslide, GLOFs, LLOFs, floods, forest fires, etc.

ix) Creation of biological richness map depicting ecological (service) flow, biodiversity hotspots and endemism.

x) Assessment and characterization of potential flash points or conflict zone within meadows (alpine and sub-alpine), scrub lands and open forest due to nomadism, overlap of cattle grazing.

**(B) Methodology, resolution, data source information:**

i) For biodiversity characterization at landscape level and biomass/yields assessment of grassland (alpine, sub-alpine), open forest and scrub land, the agency to explore the use of the latest available high resolution imagery (resource sat/land sat/ LISS-IV) and GIS model.

ii) To define glaciers in terms of size and minimum period of permanent ice or snow cover, and accordingly to characterize and analyze the glaciers for various study parameters.

**(C) Other General observations:**

i) Land use/land cover assessment to be compared with existing management plan details for data verification and for change deduction, if any, and substantiation thereof by ground truthing.

ii) Mapping of existing infrastructure and potential area for infrastructure creation after taking into account accessibility, logistics, resource availability, necessity and other limitations for construction of rescue center, staff accommodation, veterinary hospital, biodiversity park, possible species revival of relocation infrastructure etc.

iii) To comment on need and possible locations for having meteorological observatory within KHANP for long term recording of location specific climatic data and future reference.

iv) For more appropriateness, use the word "precipitation" instead of "rainfall" wherever required, and also use the word "transition zone/area" instead of "fringe zone" within national park area may be considered.

v) Also to see and incorporate appropriateness of the word "ecosystem services" instead of "ecosystem resources" wherever required, as the former being more holistic than the later which covers only the tangible resources.

vi) Aims and objectives of the work also to include (a) mapping of potential herbivore habitat *viz-a-viz* grazing area and threat assessment based on decadal change analysis between 2010 to 2020 at landscape level and (b) Mapping and characterization of existing infrastructure and future requirement, disaster prone area and mitigation measures thereof based on current and future needs/challenges.

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vii) To carryout typographical/spell check of scientific names and other corrections as made out in the proof read document.

(D) Committee after having discussed the interim deliverable "GIS- Based Land Use and Ecosystem Resource Mapping of Kishtwar High Altitude National Park" approved the instant deliverable with above observations. Accordingly, the agency (NDF) to submit its revised report in 15 days time for those observations which can be incorporated immediately. With respect to rest of the observations requiring further field exercise and research work, same shall be taken up by the NDF in due course of time and re-revised report incorporating these observations shall be made part of the DPR/final outcome submission after the culmination of EoI study. Progress in this behalf shall however, be reviewed periodically.

Issued with the approval of Chief Wildlife Warden J&K Govt. Jammu.

11/01/22

**(Dr. Kumar, MK) IFS**
**Regional Wildlife Warden**
**Jammu**

**No: RWLWJ/2022/**5023-30 **Dated:** 11 **-01-2022**

1. Copy submitted to Chairman Standing Committee (Pr.CCF/CWLW) for his kind information.
2. Copy to all Committee members and special invitees for information.

**RESPONSES TO COMMENTS SUGGESTED DURING THE MEETING OF STANDING COMMITTEE ON FIRST INTERIM REPORT OF DELIVERABLES TITLED, "GIS-BASED LAND USE AND ECOSYSTEM RESOURCE MAPPING OF KHANP HELD ON 1ST OF JANUARY, 2022 AT 3.00 PM UNDER THE CHAIRMANSHIP OF PR.CCF/ CHIEF WILDLIFE WARDEN J&K GOVT. JAMMU**

## A. Land use/Land capability Characterizations:

| S No | Suggestions | Remarks |
|---|---|---|
| 1. | Qualitative assessment of decadal Land Use Land Cover (LULC) change analysis of ecosystem resources in addition to quantitative assessment as has been done in the instant draft deliverables. | Partially done. As discussed during the review meeting, this work requires more data being collected during the project period and will be part of the final DPR of the project. |
| 2. | Biodiversity characterization at landscape level based on ground truthing and qualitative and quantitative analysis | It would be the outcome of the (1). We have chalked out methodology for it, and would be done in the next season. |
| 3. | Assessment of change analysis of major vegetation cover (meadows both alpine and sub alpine, scrub land and open forest) | Although meadows have been mapped in the present report. However, alpine and sub-alpine level mapping will be done along with the task (6). |
| 4. | Assessment and characterization of drivers of change | Once the new information is generated, it will get updated |
| 5. | Identification and mapping of potential biodiversity hotspots harboring key floral and faunal communities of conservation importance. | As discussed during the review meeting, this work requires more data being collected during the project period and will be part of the final DPR of the project. **It would be the outcome of the (1, 2).** |
| 6. | To map the alpine grasslands/ pastures for different vegetation classes (native, mixed and invasive alien species) based on high resolution data/ NDVI/ Google Earth Engine cloud computing coupled with ground-truthing. | It is the outcome of the (2) |
| 7. | To delineate the montane, timberline and tree line vegetation (Betula utilis, Quercus semecarpifolia, Abies pindrow) and alpine scrub (Rhododendron-Juniper communities) and generate baseline maps of the same for long term ecological monitoring. | It would be the outcome of the (2) |
| 8. | Vulnerability/ risk assessment and mapping of disaster-prone zones with respect to landslide, GLOFs, LLOFs, floods, forest fires, etc. | It would be done in the next six months as it requires a lot of new datasets alongwith extensive field survey. |
| 9. | Creation of biological richness map depicting ecological (service) flow, biodiversity hotspots and endemism. | It is the outcome of the (2). |
| 10. | Assessment and characterization of potential flash points or conflict zone within meadows (alpine and sub-alpine), scrub lands and open forest due to nomadism, overlap of cattle grazing. | It is the outcome of the (2). |

## (B) Methodology, resolution, data source information:

| S No | Suggestions | Remarks |
|---|---|---|
| 1. | For biodiversity characterization at landscape level and biomass/yields assessment of grassland (alpine, sub-alpine), open forest and scrub land, the agency to explore the use of the latest available high resolution imagery (resource sat/land sat/ LISS-IV) and GIS model. | As discussed during the review meeting, this work requires more data being collected during the project period and will be part of the final DPR of the project. |
| 2. | To define glaciers in terms of size and minimum period of permanent ice or snow cover, and accordingly to characterize and analyze the glaciers for various study parameters. | **Yes, it has been revised** |

## Other General observations:

| S No | Suggestions | Remarks |
|---|---|---|
| 1. | Land use/land cover assessment to be compared with existing management plan details for data verification and for change deduction, if any, and substantiation thereof by ground truthing. | Ground truthing of LULC has been performed. However, comparison with existing management plan details for data verification requires substantial ground-truthing and will be completed in the next six months |
| 2. | Mapping of existing infrastructure and potential area for infrastructure creation after taking into account accessibility, logistics, resource availability, necessity and other limitations for construction of rescue center, staff accommodation, veterinary hospital, biodiversity park, possible species revival of relocation infrastructure etc. | Requires extensive fieldwork, will be updated during future work. |
| 3. | To comment on need and possible locations for having meteorological observatory within KHANP for long term recording of location specific climatic data and future reference. | It will be done in consultation with the IMD |
| 4. | For more appropriateness, use the word “precipitation” instead of “rainfall” wherever required, and also use the word “transition zone/area” instead of “fringe zone” within national park area may be considered. | **Yes, it has been revised** |
| 5. | Also to see and incorporate appropriateness of the word “ecosystem services” instead of “ecosystem resources” wherever required, as the former being more holistic than the later which covers only the tangible resources. | **Yes, it has been revised** |
| 6. | Aims and objectives of the work also to include (a) mapping of potential herbivore habitat viz-a-viz grazing area and threat assessment based on decadal change analysis between 2010 to 2020 at landscape level and (b) Mapping and characterization of existing infrastructure and future requirement, disaster prone area and mitigation measures thereof based on current and future needs/challenges. | As discussed during the review meeting, this work requires more data being collected during the project period and will be part of the final DPR of the project. |
| 7. | To carryout typographical/spell check of scientific names and other corrections as made out in the proof read document. | **Yes, it has been revised** |