Master's degree in

Environmental and Land Engineering – Climate Change:

Monitoring the water and vegetation resources using satellite images on Alps mountain area due to climate change

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Abstract

Climate change has greatly affected natural ecosystems, especially in sensitive mountainous regions such as Alps. The study focuses on monitoring water and vegetative resources in the Alpine region using satellite imagery, especially data from Sentinel -2 and Landsat 8. By analyzing multi-temporal and multispectral satellite data, hydrological patterns and changes are evaluated to understand the effects of climate change and long-term environmental trends. The main indicators such as snow cover extent, vegetative indices (e.g., NDVI), and surface water distribution are obtained from imagery to evaluate ecosystem reactions.

Conclusions reveal spatial and temporary changes in water availability and vegetation dynamics, providing valuable insight to permanent resource management and climate adaptation strategies in the hill environment. The effect of climate change on mountainous water resources is an important area of study, especially in areas such as small maritime, where glaciers and snow serve as significant freshwater sources. The purpose of this thesis is to monitor and analyze the effects of climate change on hydrological dynamics of Alpi Maritime using satellite imagery. While employing high -resolution data from satellites such as Landsat 8, Sentinel -2, we assess changes in snow cover, glacial extent and water bodies over the last three decades. Our functioning integrates remote sensing techniques with geographical information system (GIS) tools to do spatial and temporary analysis of hydrological variables. It is complemented by climate model and ground-based meteorological data that provides a wide understanding of views and patterns. The study identifies significant cuts in ice cover

Keywords: Satellite imagery, Remote sensing, Climate change, Alps region, Water resources, Vegetation monitoring, Land cover change

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1.Introduction

Mountain ecosystems are often on the edge of their limits with respect to climate, and changes in temperature and precipitation patterns influence local hydrology in a dramatic fashion. A mountain range on the border between France and Italy[1] offers an example of such vulnerability — the Alpi Marittime. These mountains also host substantial glacial and snowpack stores, which serve as the main source of freshwater for ecosystems, agriculture, and human communities higher and lower in elevation. As through these water resources we are linked to the environment, understanding and following changes in these resources are also essential for developing successful adaptation and management options.

Political and social responses to climate change also manifest in very clear and alarming ways in the Alpi Maritime. These changes are affecting the region's water balance through reduced snow cover, glacial retreat, modifications to precipitation regimes and higher temperatures. These shifts have direct consequences for water resources, biodiversity and human livelihoods relying on these assets. Conventional ground-based monitoring techniques are rested in their breadth and scale, and hence the complete processes of this dynamics remain difficult to observe.

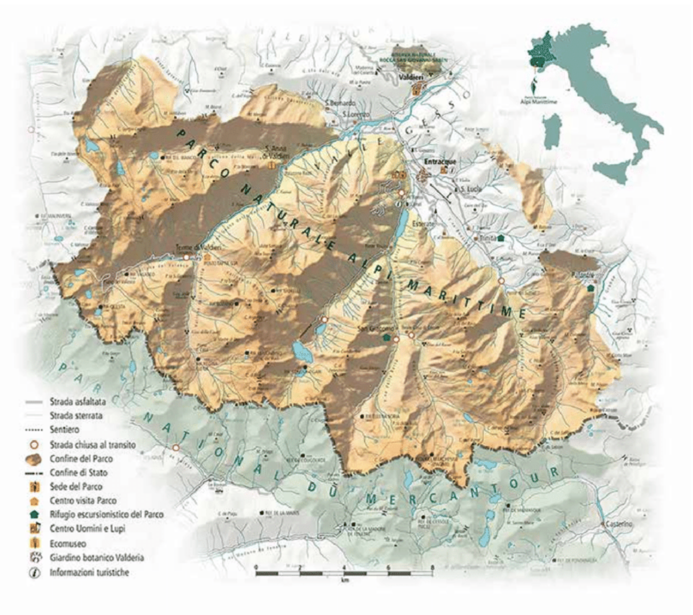

Figure 1: Alpi maritime[2]

In this context, satellite imagery emerges as a powerful tool for environmental monitoring. Remote sensing technologies provide high-resolution, continuous

[1] https://editions.covecollective.org/
[2] Google images

and multi-temporal data that can cover large and inaccessible areas, providing a detailed photo of environmental changes over time. It is possible to monitor and analyze spatiotemporal variations in a snow cover, glacier extent and hydrological patterns by taking advantage of satellite data from sources like Landsat, Sentinel -1, and Sentinel -2. The purpose of this study is to use satellite imagination to monitor the effects of climate change on water resources of Alpi Marittime. Through a detailed analysis of satellite data and integration with climate models and ground-based comments, this tries to identify research trends, determine changes and assess wide assessments for the field hydroelectric. Conclusion will provide valuable insights into the range of climate-inspired hydrological changes and provide guidance to regional water resources management and conservation efforts. Understanding these dynamics is important not only for local and regional but also for national and global references.[3]

Figure 2: Alpi maritime satellite view from Google Earth[4]

Planning but also contributes to the global body of knowledge on climate Change the effects in mountainous regions. For example, this research stands at the intersection of environmental science, geography and resource management, which aims to highlight the complex interaction between mountain hydropower in climate change and ALPI Marittime. The Mountain range is the lifetime of many regions, which act as huge natural reservoirs that store and release freshwater throughout the year. One prominent example is Alpi Marittime, a mountain range with the border between France and Italy. These royal peaks feed important water resources for downstream communities, supporting agriculture,

[3] Rahman, S. (2023). EXAMINING THE RELATIONSHIP BETWEEN INTERNATIONAL INDICES AND INSTRUCTIONAL LEADERSHIP STYLES OF COLLEGE PRINCIPALS IN THE RURAL CONTEXT OF SINDH. Frontline Social Sciences and History Journal. https://doi.org/10.37547/social-fsshj-03-06-05
[4] Google Earth

Hydropower generations, and ecosystems. However, these precious stores hang a attractive threat: climate change. Rising global temperatures are changing weather patterns and mountains are affecting hydrology through important methods. Changes in rainfall patterns, first of the snowmelt, and glacial retreat are some of the trends. It is important to understand the limit and speed of these changes to ensure permanent water management in front of the changing climate. This study delays the application of satellite imagery as a powerful tool to monitor the impact of climate change on mountain water resources in Alpi Maritime.[5]

By taking advantage of the unique capabilities of satellite technology, we can achieve valuable insight into important aspects of the hydrological cycle including snow Dynamics, Glassel Health, and Lake and River Behavior. Through a detailed analysis of multi-temporal satellite data, this research aims to determine spatiotemporal variations in water resources, identifying climate change trends, and eventually developing a comprehensive understanding of how these changes are affecting the availability of water in the minor maritime. The findings will not only contribute valuable knowledge to the region, but will also serve as a model to apply satellite-based monitoring strategies in other mountainous environments facing similar challenges.

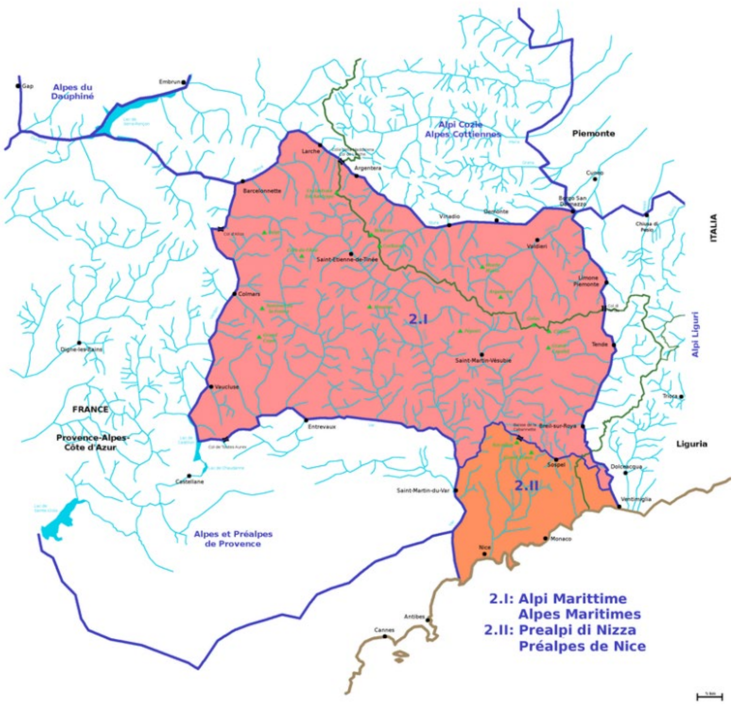

Figure 3: Alpi maritime sectors[6]

[5] (2014). Canadian Association of Cardiovascular Prevention and Rehabilitation (Association Canadienne de Prévention et de Réadaptation Cardiovasculaires) Annual Meeting and Scientific Abstracts. Journal of Cardiopulmonary Rehabilitation and Prevention. https://doi.org/10.1097/hcr.0000000000000081
[6] Google images

2.Motivation

Climate change depth is changing the mountain ecosystem, in which the short marittime is highly unsafe for these effects. Increasing temperature and shifting rainfall patterns are changing ice cover and vegetation dynamics, which directly affect water resources, biodiversity and local communities. These changes end up both the availability of freshwater and the ecological balance of the region. To effectively monitor these changes, satellite remote sensing provides an essential tool. It enables observation of large and inaccessible areas over time, providing valuable data on long -term trends and seasonal variations. By analyzing satellite imagery, the purpose of this research is to assess the limit and implication of climate change on ice and vegetation in small maritime. Understanding these changes is important for permanent water resources management, ecosystem conservation and climate adaptation strategies. The purpose of this study is to bridge the gap between climate science and actionable environmental policies, ensuring that conclusions contribute to effective decisions and long -term conservation efforts in the hill environment.

1. Satellite image of Alpi Maritime

2. Over time the ice cover changes

3. Effect of climate change on water resources

4. Graph of temperature and rainfall trends

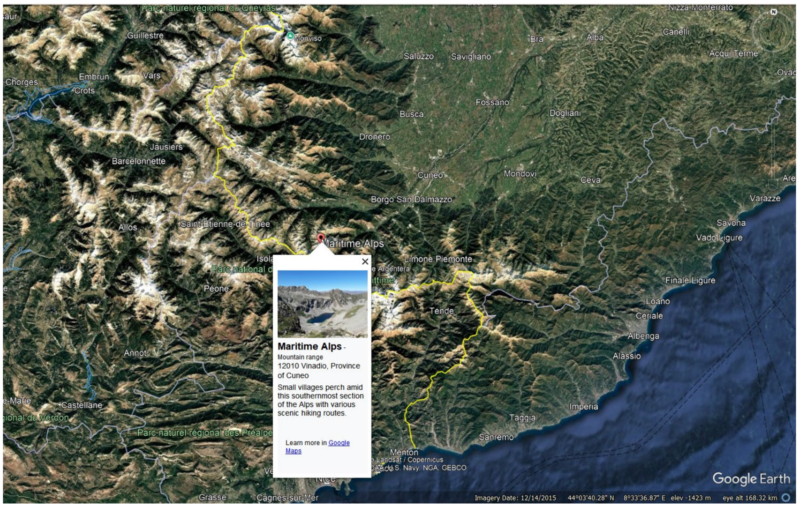

Figure 4: Alpi maritime Google Earth view[7]

[7] Google Earth

With intensive implications for water resources, biodiversity and human activities, mountain ecosystems are the most sensitive to climate change. Alpi Maritime deployed in the convergence of the Mediterranean and Alpine Climate, is particularly unsafe for these changes.

The rising temperature changed the pattern of rainfall, and changes in the mobility of the vegetation are re -shaping the hydrological balance of the area, affecting the ice cover and plant ecosystem. Given the important role of these elements in regulating water availability, their monitoring is necessary to understand environmental changes and reduce potential risks.

Snow accumulation and vegetation dynamics directly affect water storage and release, which affects downstream communities, agriculture and hydroelectric power generation. However, traditional ground-based monitoring methods face challenges due to the huge spatial boundaries of rugged areas and mountainous regions. Satellite remote sensing offers a powerful option, which offers continuous, high-resolution comments that enabled to detect long-term trends in ice cover and vegetation change.

This research satellite attempts to take advantage of imagery to analyze and determine the effects of climate change on the snow and vegetation of alternative maritime.[8]

By integrating remote sensing data with climate and hydrological models, the purpose of this study is to improve our understanding of water resource variability in the hill environment.

The insight obtained will not only enhance climate change adaptation strategies, but also supports policy makers, conservationists and water resources managers in developing a permanent approach to the protection of these delicate ecosystems. As global warming accelerates, accurate, data-powered monitor is required.

[8] Uyar, N. (2025). Spatiotemporal Dynamics of Carbon Storage in Utah: Insights from Remote Sensing and Climate Variables. Sustainability, 17(5), 1976.

3.Goals and Limits

Target The primary purpose of this research is to use satellite imagery, focusing on the vegetation and ice cover in alternative maritime, assessing the effects of climate change and determining the effects of climate change on hill water resources. Specific goals include:

1. Ice covered Analysis of seasonal and long -term changes in ice cover range, duration and melting patterns. o Assessing how the variation in snow accumulation and deficiency affects the availability of water.

2. Collapse Evaluate changes in vegetation cover, species distribution and productivity using remote sensing indices (eg, NDVI, LAI). o Check the relationship between temperature changes, rainfall variability and vegetation growth.

3. Understand climate-water conversation o changes in snow and vegetation with climate variables such as temperature and rain trends. o identifies important thresholds where climate changes greatly affect the availability of water and the stability of the ecosystem.

4. Providing data for environmental management Water Resources Management, Biodiversity Protection and Climate provide insight for strategies. o Support the decision making and local communities with scientific evidence to guide the continuous environmental policies. This evaluation will be performed using satellite remote sensing data from Sentinel-2 and Landsat Landcover platforms, providing high-resolution and multi-temporal imagery suitable for monitoring environmental changes over time.

By taking advantage of satellite-based Earth Overview (EO) data, the purpose of this study is:

1. Monitor changes in snow cover

• Analysis of seasonal and differences in the limit of ice cover, firmness and melting patterns, to understand how climate change affects the accumulation and deficiency of ice.

• Check ice phenology, including the onset of ice and melting-out time using satellite-type indices such as the generalized difference Snow index (NDSI).

• Identify latitudinal shifts in ice cover and their implications for availability of water in downstream ecosystem.

2. Assess vegetable reaction to climate change

• Use botany indices such as the generalized difference vegetable index (NDVI) and the enhanced vegetative index (EVI) to evaluate trends in vegetative growth, productivity and seasonal variability.

• Analyze vegetable greening and browning patterns, correlated them

• With temperature and rainfall trends obtained from historical climate records.

• To detect changes in land cover composition, expand alpine vegetation in high height due to especially rising temperature.

3. Check climate-water interaction in mountain ecosystems

• Check the relationship between the reduction in ice cover and the changes in vegetative productivity to determine the cascading effects of climate change on water availability.

• Identify important thresholds where climate-induced variations in snow and vegetation affect hydrological cycles, ecosystems stability and biodiversity.

4. Provide actionable data for environment and water resources management

• To support water resource management, conservation efforts and climate adaptation policies, generate spatial and temporarily solved maps of ice cover and vegetation trends.

• Provide insight to local authorities, protectionists and policy makers to reduce the effects of climate change and develop permanent land management strategies.

• Highlight areas that are the weakest for climate-inspired changes, helping long-term ecological monitoring and climate flexibility scheme.

Figure 5: Region of Interest (ROI) in Copernicus website[9]

[9] https://browser.dataspace.copernicus.eu/

Limits

While this study provides valuable insight, it is subject to many limitations: Since Sentinel -2 began in 2015, the data is available from 2015 to 2023 (Sentinel-2 was not present before 2015).

Table 1: Satellites start and end time

Sensor	Start Date	End Date / Status	Notes
Sentinel-2	2015-04-01	2023-08-31	Data available between these dates
Landsat 5	1984	2013	Mission ended in 2013
Landsat 7	1999	Present	Still operational (as of 2025)
Landsat 8	2013	Present	Still operational (as of 2025)
Landsat 9	2021	Present	Still operational (as of 2025)

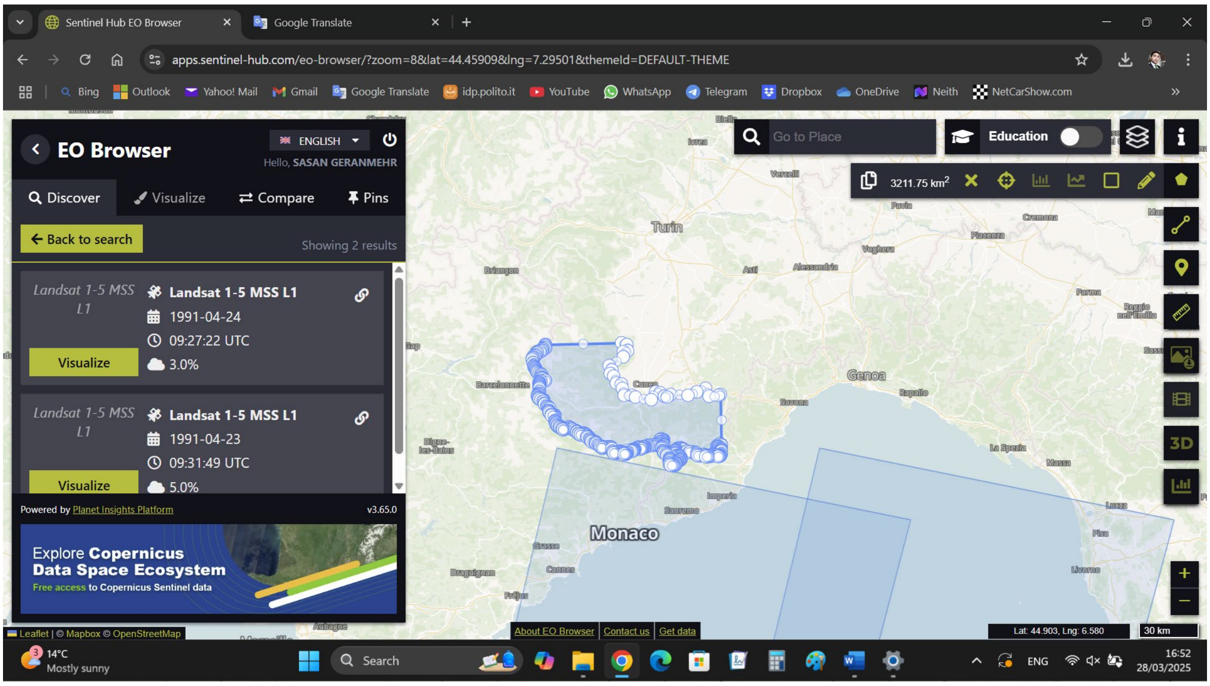

Figure 6: One of our limits is when we want to search for a specific month satellite image, For example April 1991 there is no satellite image for our ROI(Region OF Interest) but for June 1991 and August 1991 we have satellite images as seen in this screenshot.[10]

[10] https://apps.sentinel-hub.com/eo-browser/

1. Satellite data resolution obstacles

Accuracy of monitoring vegetation and ice depends on the spatial and cosmic resolution of satellite imagery. Some small-scale changes may not be detected.

Claude cover and atmospheric conditions can affect the quality and stability of satellite comments.

2. Complexity of mountain ecosystems

Interaction between climate, vegetation and ice cover is highly complex and affected by many factors (e.g., height, slope, soil structure and local weather patterns).

Separating climate change effects from other anthropological effects (e.g., land usage changes, tourism) can be challenging.

3. Data availability and temporary coverage

Historical satellite data may have gaps or discrepancies, which can make long - term trend analysis more difficult.

Some satellite missions have limited operating lifespan, requiring data integration from many sources.

4. Verification and Ground Truthing

Remote sensing data often requires verification with field measurements, which may not always be possible in remote or rugged mountainous regions.

Data processing methods and differential results in algorithm may introduce uncertainties.

This study accepts many boundaries contained for the functioning used and data sources.

1. Satellite imagery resolution obstacles

• The spatial resolution of Prahari-2 (10m-60m) and Landsat Landcover (~ 30 m), while enough for regional scale analysis, cannot occupy fine changes in ice cover and vegetation, especially in the asymmetrical mountainous terrain.

• Some small -scale events, such as localized vegetation shifts or microclimatic effects, may be reduced due to pixel aggregation in satellite imagery.

2. Atmospheric and environmental intervention

• Cloud cover, shade and atmospheric conditions can affect satellite data quality and stability, especially in mountainous areas where frequent cloud covers can limit clear comments.

• Seasonal snow cover detection may be affected by topographical cinematography in steep areas, causing potential miscarriage.

3. Data availability and temporary coverage

• While the Sentinel-2 (2015-current) and Landsat (1984-current) offer a valuable multi dataset, sensor technology and coverage borders are gaps in historical satellite records due to changes in boundaries.

• Differences in data acquisition frequencies between observers -2 (every 5 days) and Landsat (~ 16 days) can create challenges in ensuring frequent temporary coverage for long -term trend analysis.

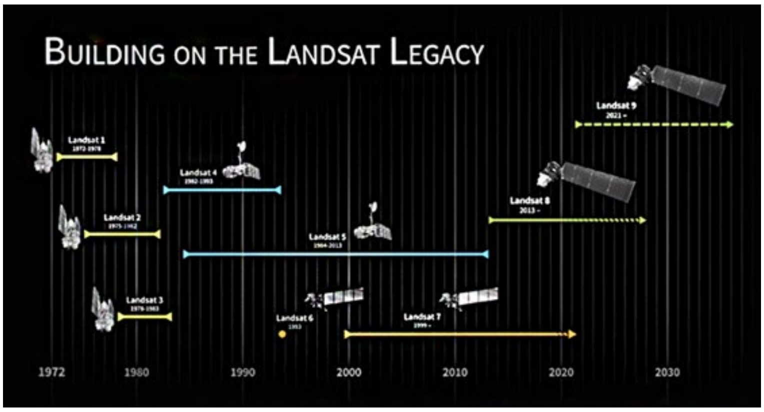

Figure 7: Timeline of the Landsat program, starting with the launch of Landsat 1. Landsat 9, launched September 27, 2021, will continue the legacy of the Landsat program.[11]

[11] https://www.copernicus.eu/

4. Mountain ecosystem

• The response to vegetation and ice cover to climate change is affected by several interaction factors, including topography, local microclimates and anthropogenic activities (e.g., land-use changes, tourism development).

• To separate the direct effects of climate change from other environmental drivers, requires careful interpretation and cross-satisfaction with auxiliary data sources (e.g., meteorological data, ground comments).

5. Verification challenges

• Remote sensing data analysis depends on algorithm-based classification methods, which can introduce errors in detection of land cover classification and change.

• Ground truth verification is necessary to improve the accuracy of satellite-satellite projections, but may be challenging in remote or inaccessible areas of Alpi Maritime.

Landsat data can be found on the following sources:

1-USG Earth Explorer[12]

• A USGS account should be created before accessing data.

• Search bar is used to detect the area of interest.

• Landsat Mission (e.g., Landsat 8, Landsat 9) is selected from dataset options.

• Cloud cover filter is applied to exclude cloud images.

• Level -2 surface reflection data is recommended for better atmospheric improvement.

• Selected dataset has been downloaded.

[12] https://earthexplorer.usgs.gov/

2- NASA Earthdata[13]

• Landsat data is accessed through this platform.

• An earthdata login is required before downloading.

3- Google Earth Engine [14]

• Landsat archives are available for cloud-based analysis.

• JavaScript or Python coding should be used to process data.

Since the Sentinel -2 images can be downloaded from the Copernicus Open Access Hub

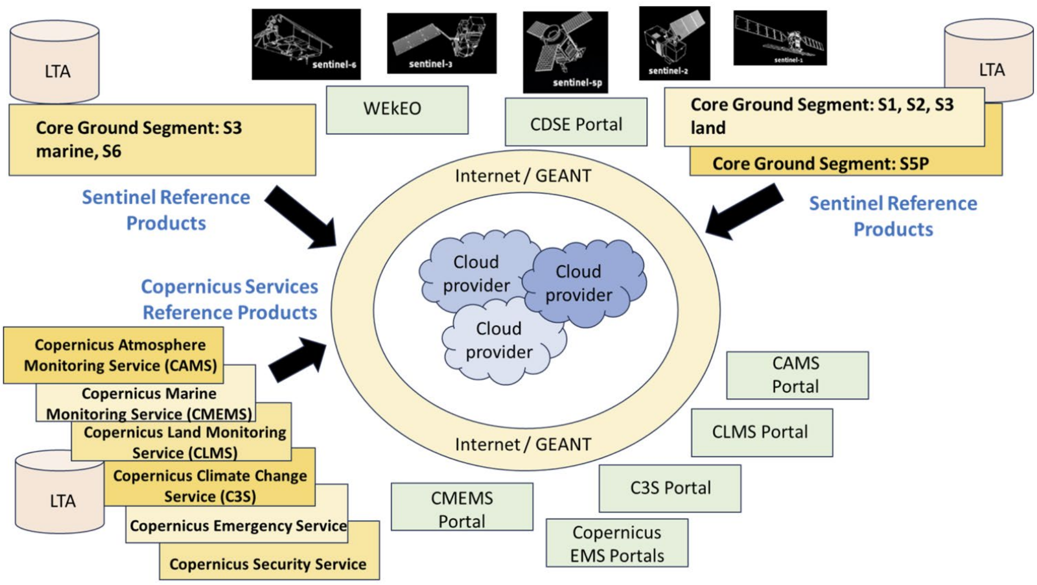

Figure 8: Sentinel reference products[15]

[13] https://search.earthdata.nasa.gov/

[14] https://developers.google.com/earth-engine/datasets/catalog/landsat

[15] https://www.copernicus.eu/

Landsat vs. Sentinel:

Landsat and Sentinel are two major Earth observation satellite programs used for remote sensing. The free satellite imagery is provided by both, but the differences can be seen in the context of the objectives of the mission, spatial resolution, temporary coverage and spectral band.

Landsat:

Landsat Earth observation is a series of satellites run since 1972 by NASA and USGS (United States Geological Survey). The program has been monitored on the surface of the Earth for 50 years, making it the longest remote sensing initiative.

Major features of Landsat:

• Latest Edition: Landsat 8 (2013), Landsat 9 (2021)

• Local resolution: 30 m (multispectral), 15 m (Panchromatic), 100 meters (thermal)

• Revision time: every 16 days

• Spectral Band: 11 (Landsat 8 and 9), which covers the visible, close-concentrated (NIR), short way-rolling (SWIR), and thermal infrared (TIR) sector

• Main Application: Land Use Monitoring, Deforestation, Water Resources, Climate Change and Disaster Response are supported by this satellite chain Guarded

Figure 9: Landsat 8 Satellite[16] Sensor (15m)[17]

[16] Google images
[17] https://www.satimagingcorp.com/satellite-sensors/other-satellite-sensors/landsat-8/

Sentinel -2:

The Sentinel is part of the Copernicus program, which is managed to provide free Earth observation data by the European Space Agency (ESA). Sentinel -2 is considered the main contestant of Landsat for optical imagery.

• Latest Edition: Sentinel -2A (2015), Sentinel -2B (2017)

• Local resolution: 10 m (RGB and NIR), 20 meters (SWIR), 60 meters (coastal and water vapor)

• Revision time: Every 5 days (with two satellites)

• Spectral Band: 13 (More than Landsat, including red edge for vegetation monitoring)

• Main Application: Agriculture, Botanical Health, Land Cover Classification, and Water Quality Monitoring is supported

Figure 10: Sentinel-2 [18]satellite[19]

Table 2: Key Differences Between Landsat & Sentinel-2

Feature	Landsat 8/9	Sentinel-2A/B
Organization	Is operated by NASA / USGS	Is managed by ESA / Copernicus
Launch Years	2013 (L8), 2021 (L9)	2015 (S2A), 2017 (S2B)
Revisit Time	Is set at 16 days per satellite	Is shortened to 5 days (with two satellites)
Spatial Resolution	30m (MS), 15m (Panchromatic)	Is improved to 10m (RGB & NIR), 20m (SWIR), 60m (other bands)
Spectral Bands	Are limited to 11	Are expanded to 13 (including Red Edge bands)
Thermal Infrared	Yes (TIR bands are included)	No TIR bands are provided in Sentinel-2

[18] https://www.earthdata.nasa.gov/data/instruments/sentinel-2-msi
[19] Google images

Landsat must be selected:

• Historical data is required (back by 1972)

• Thermal imaging is required (for studies related to land surface temperature)

• A 30 meter resolution is considered acceptable

Sentinel -2 should be used:

• A high resolution (10 m) is preferred for vegetation and land use analysis

• More frequent imagination (every 5 days) requires

• Vegetation health should be analyzed using red edge bands

The Sentinel -2 is recommended for modern applications such as its high resolution and frequent revision capacity, while Landsat is preferred when long -term historical analysis and thermal imaging are required.

The phrase "cloud mask for vague images" is referred to as a procedure that applies in remote sensing and satellite imagery to ensure that areas covered by clouds are filtered with images.

Breaking meaning:

• Cloud Mask → A technique that is applied to the cloud detection and mask (hiding or ignoring) in satellite images.

• unclear images → images that are unclear by cloud cover.

Clouds are often present in satellite images, blocking the surface of the Earth from the view. Cloud masking is used:

• Cloud -covered pixel can be removed

• Image clarity for analysis can be improved

• Land cover classification and vegetation monitoring can be increased

Cloud masks are usually generated using:

• Thresholding technology, where glitter and temperature are used as the basis for detection

• Machine learning models, which are trained to identify clouds

• Pre -existing cloud detection algorithms, such as SCL bands of Sentinel -2 and Masks of Landsat, which are used for the purpose of cloud masking

The difference between Tiff 8-bit, 16-bit and 32-bit is primarily defined by bit depth, determining how color or information per channel is stored. The comparison of these formats is as follows:

Tiff 8-bit

• 8 bits data are allocated to each color channel (red, green, blue), resulting in 256 potential values per channel.

• This format is usually used for standard images (as seen in JPEG and PNG).

• A total of 16.7 million colors (256 × 256 × 256) are supported.

• It is considered suitable for web images and printing, but is considered limited to professional photo editing due to low color depth.

Tiff 16-bit

• 16 bits are assigned to each channel, which enable 65,536 potential values per channel.

• The colors of trillions are supported, allowing smooth gradients and enhanced color accuracy.

• This format is widely used in professional photography, medical imaging and high-end printing.

• A larger file size is produced compared to 8-bit, but is preferred for more detailed editing.

Tiff 32-bit

• 32 bits are given to each channel, which allows more than 4.29 billion per potential values per channel.

• This format applies in HDR (high dynamic range) imaging and scientific research.

• Excessive precision is supported in glitter and color data.

• Files of large size are generated, and this format is usually not necessary for standard photography.

4.Case Study

The case study focuses on the Alpi Marittime time, a mountain range on the border between France and Italy. This specific region provides a practical and significant example for the application of satellite imagery in monitoring the impacts of climate change on mountain water resources. The choice of the Alpi Marittime as a case study is driven by several key factors:

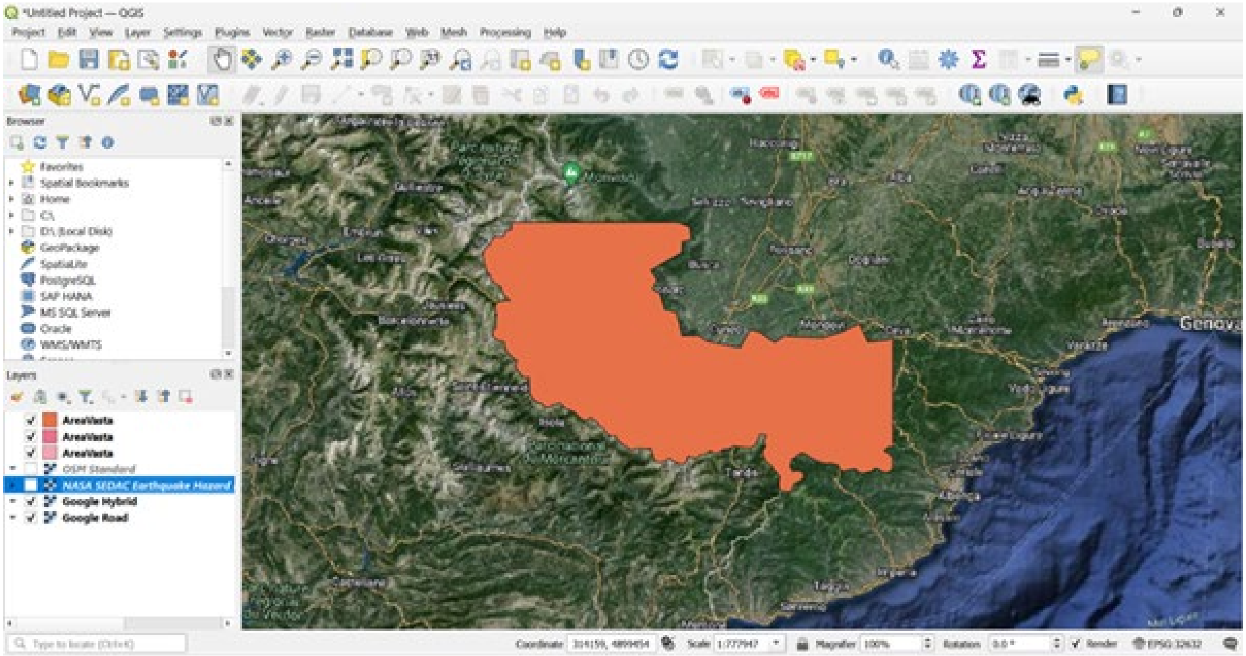

Figure 11: Case study area in QGIS software

1. Mountain Water Tower:

o Alpi Maritime acts as an important water tower, storing winter snowfall and glaciers that release freshwater throughout the year. This water is necessary to maintain the regional ecosystem, support agriculture and provide water for human consumption.

2. Climate change vulnerability:

o Area is highly unsafe for the effects of climate change. Changes in temperature and rainfall patterns are leading to glacial retreat, low ice cover and earlier snowmelt. These changes greatly affect the availability and distribution of water resources.

3. Satellite data access:

o Alpi Maritime is well covered by various satellite missions, which provide broad and detailed datasets. High -resolution imagery from satellites such as Landsat, Sentinel -1 and Sentinel-2 enables widespread monitoring and analysis of environmental changes over time.

2.1 Justification for choosing a small maritime

• Importance: The role of small marittime as a major water source is an important area to study the effects of climate change on water resources.

• Data Availability: Availability of high-resolution satellite data for this sector allows for detailed and accurate monitoring of ice covers, glacier limits and changes in hydrological patterns.

• Representative Examples: The characteristics of Alpi Marittime make it representative of other mountainous regions that are facing uniform climate change challenges. This study can apply conclusions and functioning in other areas globally.

2.2 Case Study Objectives

• Assess changes in ice and glacial cover: Analyze satellite imagery to monitor the range and quantity of glaciers and ice cover over time.

• Evaluate hydrological changes: check changes

The land cover classification is defined as the process in which the Earth's surface is classified into different types (eg, water, forest, urban, agriculture), based on satellite imagery or air photos. It is used for environmental monitoring, urban planning and resource management.

Two main types of classifications are recognized:

• Supervised classification - Training samples for known land cover types are manually selected, and the rest of the image is classified by software.

We use supervised classification in Arc GIS Pro.

• Uncontrolled classification - Pixel is automatically classified into a cluster by software based on spectral equality, and the results are interpreted later.

5.Data

Most of the data are from guards -2 and Landsat 8 satellites

1. Satellite data (primary data source)

Since this study focuses on remote sensing, the main dataset will come from Sentinel -2 and Landsat landcover platforms.

Table 3: Satellite Data information

Satellite Platform	Key Data Products	Purpose
Sentinel-2 (ESA)	- Multispectral images (10m–60m resolution) - NDVI, EVI, and NDSI indices - Snow and vegetation cover analysis	- High-resolution vegetation monitoring - Snow cover detection and change analysis
Landsat Landcover (NASA/USGS)	- 30m resolution multispectral images - NDVI, NDSI, and other vegetation indices - Long-term land cover change data	- Historical comparison of snow and vegetation trends since the 1980s

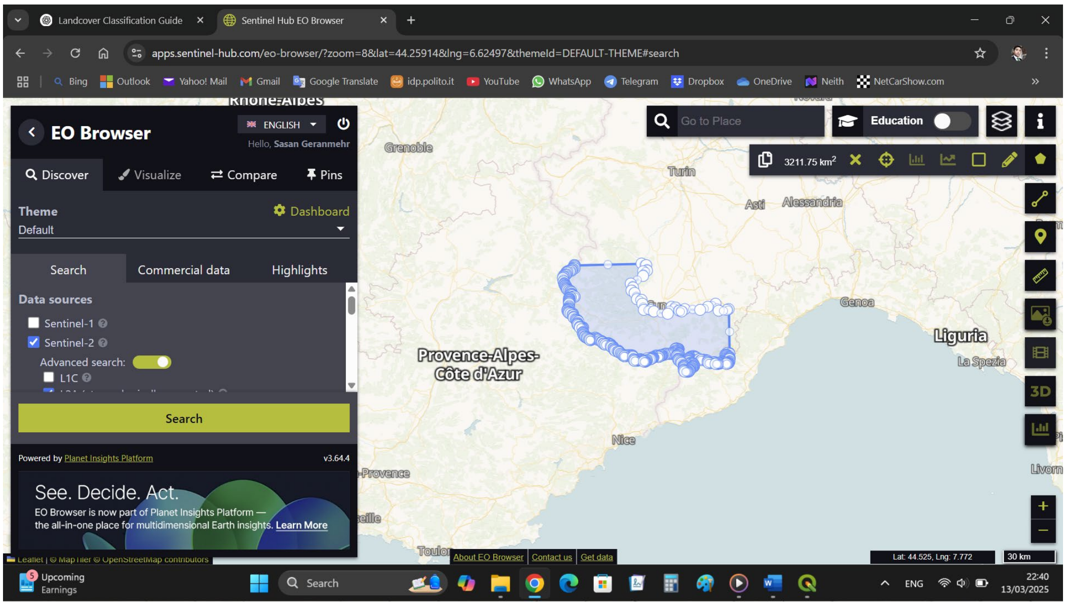

Figure 12: Case study area in EO Browser[20]

[20] https://apps.sentinel-hub.com/eo-browser/

2. Climate Data

To correlate vegetation and snow changes with climate trends, meteorological data will be need:

Table 4: Climate Data information

Data Type	Source	Purpose
Temperature (min/max)	- ERA5 (Copernicus Climate Data) - Local meteorological stations	- Understanding warming trends and their effect on snow and vegetation
Precipitation (Rain & Snowfall)	- ERA5, CHIRPS, or local weather stations	- Evaluating changes in snowfall and rainfall patterns
Snow Depth & Snow Water Equivalent (SWE)	- Sentinel-1 (SAR data) - In-situ measurements (if available)	- Estimating snow accumulation and melt dynamics

3. Land Cover and Topography Data

These datasets will help in classifying and understanding the landscape:

Table 5: Land Cover and Topography *Data information*

Data Type	Source	Purpose
Land Cover Classification	- ESA World Cover - CORINE Land Cover (Europe) - Landsat-derived land use maps	- Identifying vegetation types and their changes
Digital Elevation Model (DEM)	- Copernicus DEM - NASA SRTM (30m resolution)	- Understanding terrain influence on snow distribution and vegetation

4. Ancillary Data (Validation & Supplementary Information)

To improve accuracy and validate satellite results, additional ground-based and auxiliary data can be useful:

Table 6: Land Cover and Topography *Data information*

Data Type	Source	Purpose
Ground Truth Data (Field Observations)	- Local ecological surveys (if available) - Snow and vegetation sampling	- Validating remote sensing classifications
Historical Aerial Images	- Local environmental agencies - Google Earth historical images	- Visual comparison with modern satellite images
Glacier & Hydrology Data	- GLIMS Glacier Database - Local hydrological models	- Assessing water resource changes

Summary of Required Data

I. **Satellite Data:** Sentinel-2 & Landsat (for snow and vegetation monitoring)
II. **Climate Data:** Temperature, precipitation, and snow cover trends
III. **Land Cover & Terrain Data:** DEMs and land use classifications
IV. **Validation & Ancillary Data:** Field observations, historical aerial imagery, and glacier/hydrology

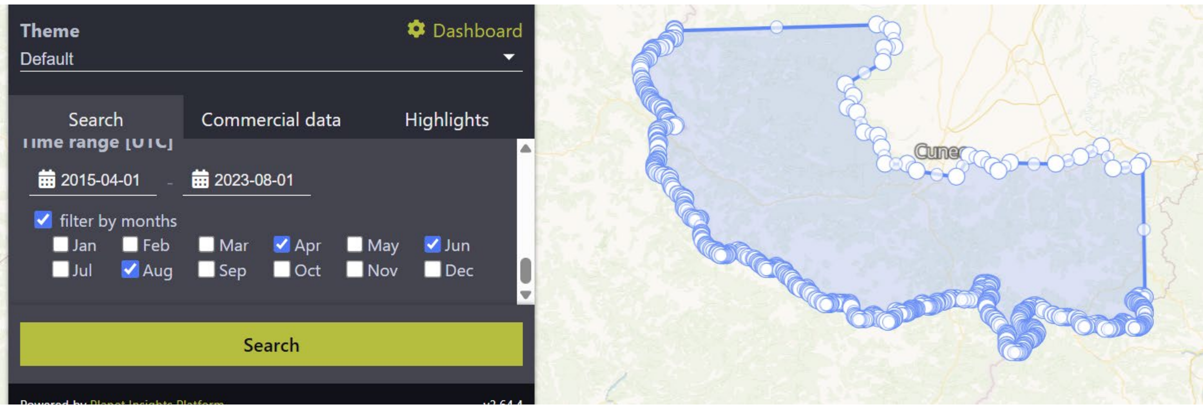

Figure 13: Choose April, June, August in EO Browser for collecting data[21]

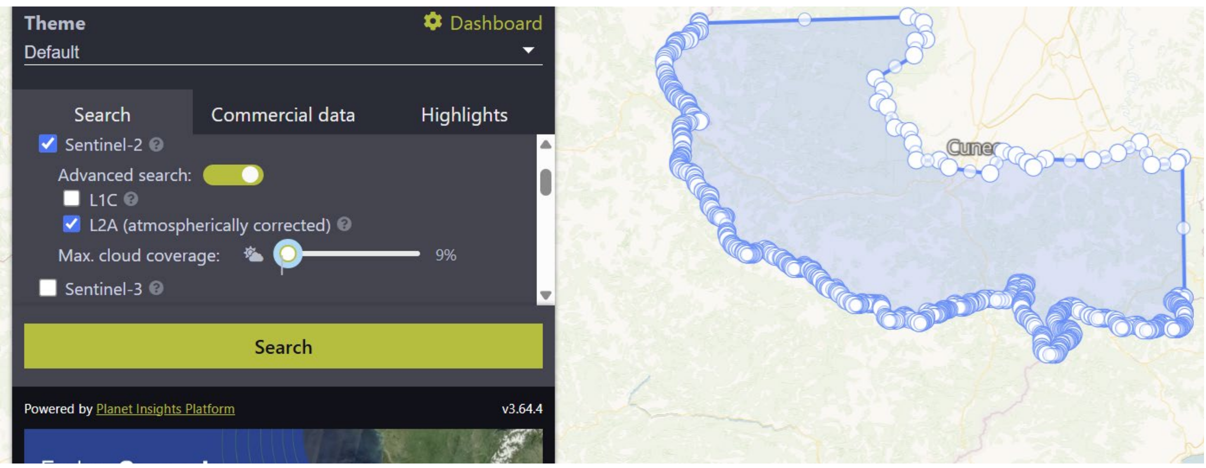

Figure 14: Choose L2A for Sentinel2 satellite in EO Browser[22]

[21] https://apps.sentinel-hub.com/eo-browser/
[22] https://apps.sentinel-hub.com/eo-browser/

If clouds are still present in some images, **Sentinel-2 Cloud Masking (SCL band) should be used in Custom Scripts** to have the clouds removed from the image.

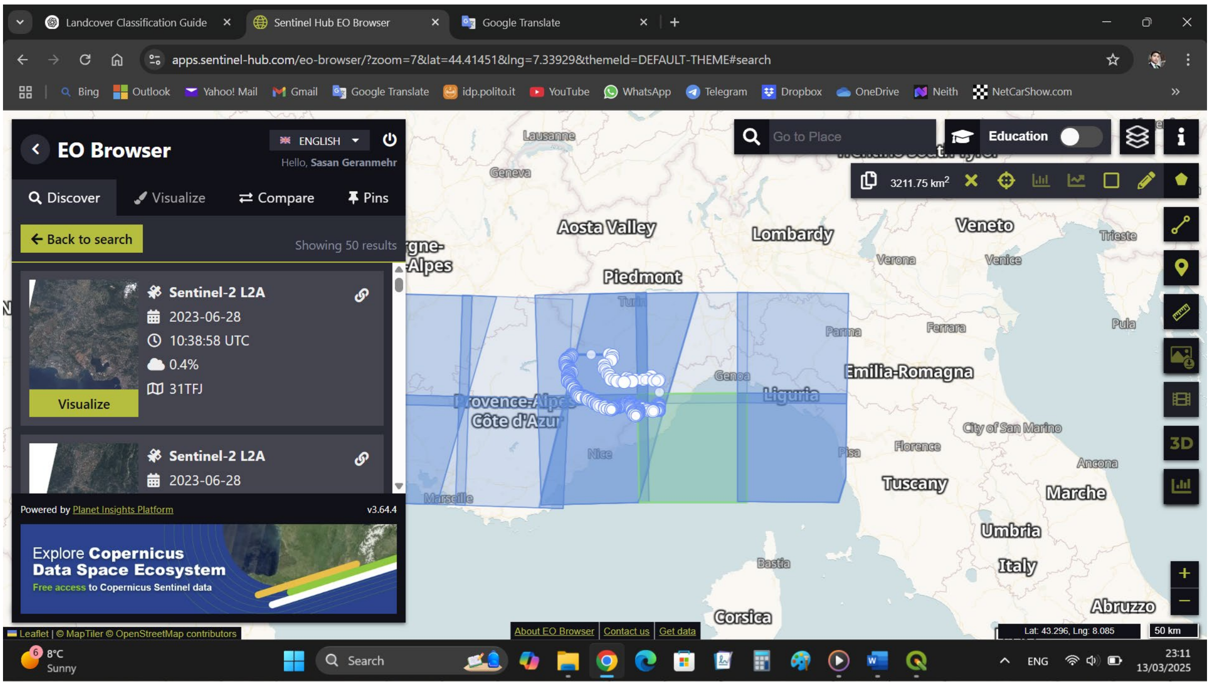

Figure 15: After selecting several satellite photos shows in EO Browser[23]

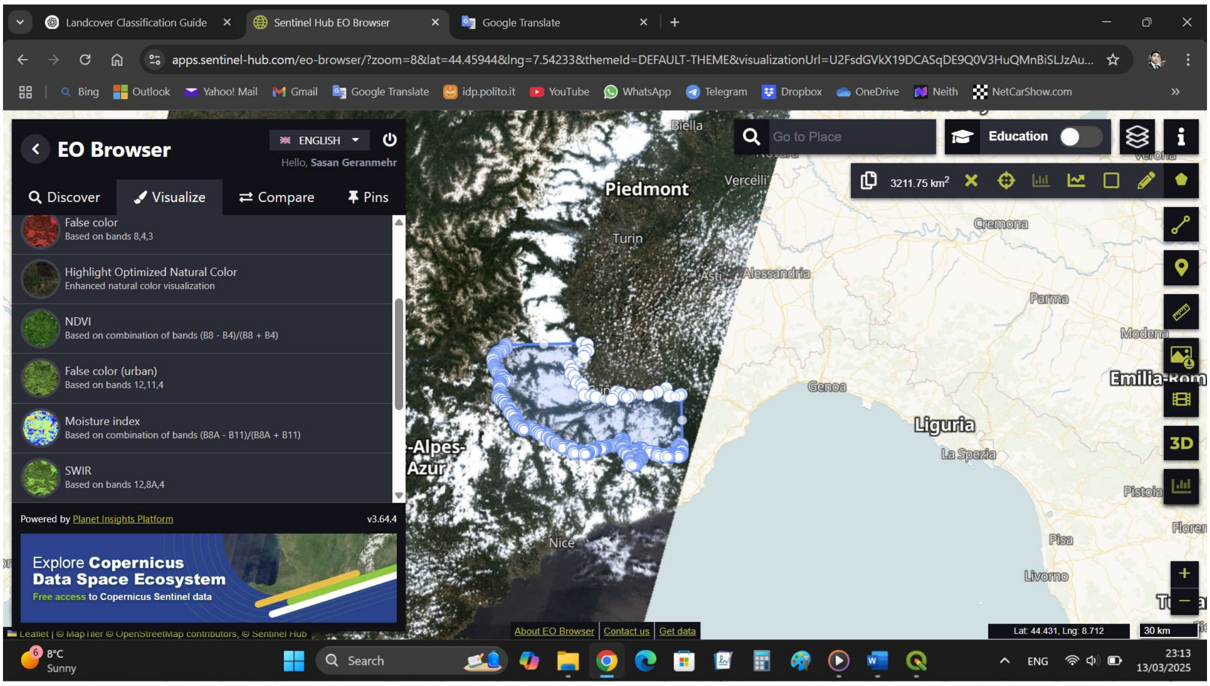

Figure 16: In visualize section shows some indexes[24]

[23] https://apps.sentinel-hub.com/eo-browser/

[24] https://apps.sentinel-hub.com/eo-browser/

Figure 17: Corine land cover classes that we need for classification [25]

[25] https://www.eea.europa.eu/data-and-maps/figures/corine-land-cover-1990-by-country/legend

6.Methods and Methodology

State of the art

Landcovers

Mountain ecosystems are particularly sensitive to climate change, affecting ice cover and vegetation dynamics with rising temperature and changing rainfall patterns. These changes, in turn, affect water availability, biodiversity and ecological stability. Located at the intersection of the Mediterranean and Alpine Climate, there is an ecological region where the effects of climate change are becoming increasingly clear.

Remote sensing has emerged as a powerful tool for monitoring these environmental changes over time, which provides spatial data on the boundary of ice cover, vegetation dynamics and land cover variations. Satellite platforms such as Sentinel -2 and Landsat landcover provide valuable insight into the development of mountain ecosystems in response to climate change.

6.1. Climate change and its effect on mountain water resources

6.1.1 snow cover change

Snow mountain is an important component of hydrology, which acts as a natural reservoir that controls the availability of water for the Downstream Ecosystem. Causes of climate change:

• The duration of ice cover and the decline in the earlier ice period.

• Latitudinal shifts, where the snow line is increasing, is reducing seasonal snow accumulation at low height.

• Increase in variability in snowfall, with high rainfall in the form of rain instead of snow.

Studies using the Generalized Difference Snow Index (NDSI) from the Sentinel -2 and Landsat have demonstrated that the ice cover in Alpine regions has been decreasing in the last decades, affecting water storage and river discharge patterns.

6.1.2 Botanical reaction to climate change

Rising temperatures and converted rainfall pattern have led:

• Vegetation greenery at high altitude, as plant species migrate to areas that were earlier covered with snow.

• Changes in phenology (seasonal growth cycle) with first plant growth and expanded growing seasons.

• Decreased vegetation productivity in some areas due to increasing drought stress.

By analyzing botanical indices such as the Generalized Difference Botanical Index (NDVI) and the Enhanced Botanical Index (EVI), researchers can detect trends in botanical health, biomass and distribution changes in response to climate change.

6.2. Role of satellite remote sensing under climate change supervision

Remote sensing provides a cost -effective and scalable approach to study long -term environmental changes. The Sentinel -2 (European Space Agency) and Landsat (NASA/USGS) are one of the most widely used platforms for monitoring the ecosystems of the mission.

Table 7: Role of Satellite Remote Sensing in Climate Change Monitoring *information*

Satellite Platform	Resolution	Relevant Indices	Application
Sentinel-2	10m–60m	NDVI, EVI, NDSI	Vegetation & snow cover monitoring
Landsat Landcover	~30m	NDVI, NDSI	Long-term land cover change analysis

Using these satellite datasets, researchers can track multi-temporal changes in snow and vegetative cover, supporting climate change assessment and adaptation strategies.

- 6.3. Land cover in climate change studies and its importance
- Land cover classification is necessary to understand how various ecosystems react to climate change. The land cover mapping provides insight into the spatial distribution of forests, grasslands, glaciers and bare ground, it helps to assess how these areas are changing over time.

- 6.3.1 Land Cover Type in LPI Maritime
- 1. Remote sensing and satellite imagery: Use satellite sensors and platforms to capture data for high-resolution images and ice cover for maping, glacier retreat and data for vegetation.
- 2. Data integration and analysis: Mix the satellite data with climate models, ground-based meteorological data and hydrological models for comprehensive analysis.
- 3. Spatial and temporary analysis: Use geographical information system (GIS) equipment to analyze local patterns and temporary changes in water resources.
- By focusing on ALPI marittime, this case study demonstrates the effectiveness of satellite image analysis under the supervision of climate change effects on mountain water resources. The insight obtained can inform the adaptive water management strategies and contribute to the widespread understanding of climatic effects on hilly areas worldwide.
-
- There are diverse land cover types in the short maritime area, including:
- • Forest: Alpine coniferous forest, deciduous woodlands.
- • grasslands and shrubs: high altitude grasslands, subalpine shrubs.
- • Glacier and snowfields: permanent and seasonal snow -covered areas.
- • Bare rock and soil: mountain rock, erosion-prone area.

- 6.3.2 Climate-inspired land cover change
- Land cover changes in response to climate variations include:
- • Reducing glaciers and snowflants, reducing water storage capacity.
- • Due to long time, forest expansion in high height Increased bare Land

and erosion, as snowmelt exposes the already covered surfaces.

- By integrating the Sentinel -2 and Landsat landcover data, land cover changes can be detected, classified, and can be correlated with climate trends to predict future environmental changes.

Methodology: Acquisition, Preprocessing, Classification, and Analysis of Landsat Satellite Imagery

- This section underscores the functioning for achieving Landsat Satellite and Sentinel 2 imagery, preprocessing, classification and analysis. Including the months of April, June and August, the focus will be on obtaining open-source data from 1991 to present. Processed data will then be used for land cover classification and subsequent analysis in Geography Information System (GIS) software (QGIS) and Remote Sensing Image Analysis Software (ENVI). And then use (Arc GIS Pro).

- 1. Applied application
- • Satellite image is loaded into QGIS.
- • Raster Calculator (Raster → Raster Calculator) is used to apply the index formula. Common sources include:

I - NDVI (Normalized Difference Vegetation Index):

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

II - NDWI (Normalized Difference Water Index):

$$NDWI = \frac{(Green - NIR)}{(Green + NIR)}$$

III-Normalized Difference Snow Index (NDSI)

$$NDSI = \frac{(Green - SWIR1)}{(Green + SWIR1)}$$

The **Semi-Automatic Classification Plugin (SCP)** is used if predefined index calculations are required.
The resulting index layer is visualized and analyzed.

2. Classification with Land Cover and Accuracy Assessment

- The **SCP Plugin** is used for classification.
- Training samples are selected based on the land cover map.
- A classification algorithm (such as Random Forest, Maximum Likelihood, or SVM) is chosen.
- The classification process is executed, and a classified image is generated.

Accuracy Assessment

- The classified map is compared with the land cover map of the same year.
- An **Error Matrix (Confusion Matrix)** is generated.
- **Overall Accuracy, Producer's Accuracy, and User's Accuracy** are calculated.

Preprocessing Steps

1. Data Preparation

- Satellite images from **April, June, and August (1991–2023)** are collected.
- The images are clipped to the **Region of Interest (ROI)**.
- A **cloud mask** is applied to remove unclear areas.

2. Index Calculation

Two vegetation indexes:

1. **NDVI (Normalized Difference Vegetation Index)**

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

2. **SAVI (Soil-Adjusted Vegetation Index)**

$$SAVI = \frac{(NIR - Red)}{(NIR + Red + L)}(1 + L)$$

(L is a soil brightness correction factor, typically 0.5)

Two snow indexes:

1. **NDSI (Normalized Difference Snow Index)**

$$NDSI = \frac{(Green - SWIR1)}{(Green + SWIR1)}$$

2. **NSDI (Normalized Snow Difference Index)**

$$NSDI = \frac{(NIR - SWIR1)}{(NIR + SWIR1)}$$

Two water indexes:

1. **NDWI (Normalized Difference Water Index)**

$$NDWI = \frac{(Green - NIR)}{(Green + NIR)}$$

2. **MNDWI (Modified Normalized Difference Water Index)**

$$MNDWI = \frac{(Green - SWIR1)}{(Green + SWIR1)}$$

All indexes are computed using the **Raster Calculator** in QGIS.

Classification Process

1. Land Cover Classification (Level 1 Only)

- **Land cover classes:** Vegetation, Water, Snow.
- **2018 snow is excluded from the classification.**
- The **Supervised Classification Plugin (SCP)** is used.
- Training samples are selected for **Vegetation, Water, and Snow** based on reference land cover maps.

2. Second step for classification

- Input classification is prepared.
- Various overall bands are tested.
- All bands are merged into a single overall band before classification.
- Each pixel is classified on the basis of spectral properties.

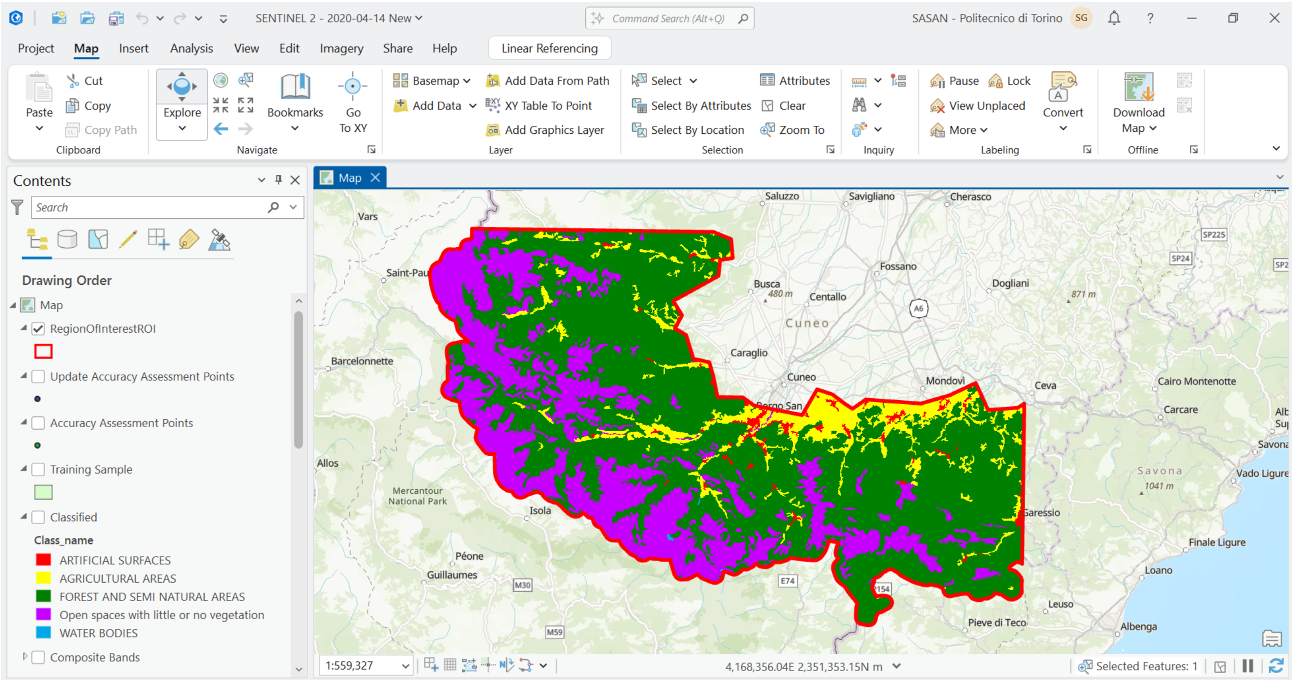

Figure 18: *Satellite image of sentinel 2 for 2020/04/14 after classification – Screenshot from Arc GIS Pro software*

Accuracy assessment

Confusion matrix extraction and index test

First attempt:

• All bands are used only for classification.

• An illusion matrix is produced.

Second attempt:

• All bands + some index (e.g., NDVI, NDWI) are used.

• Classification accuracy is compared with the first attempt.

Third attempt:

• All bands + all index are used.

• Final classification results are analyzed.

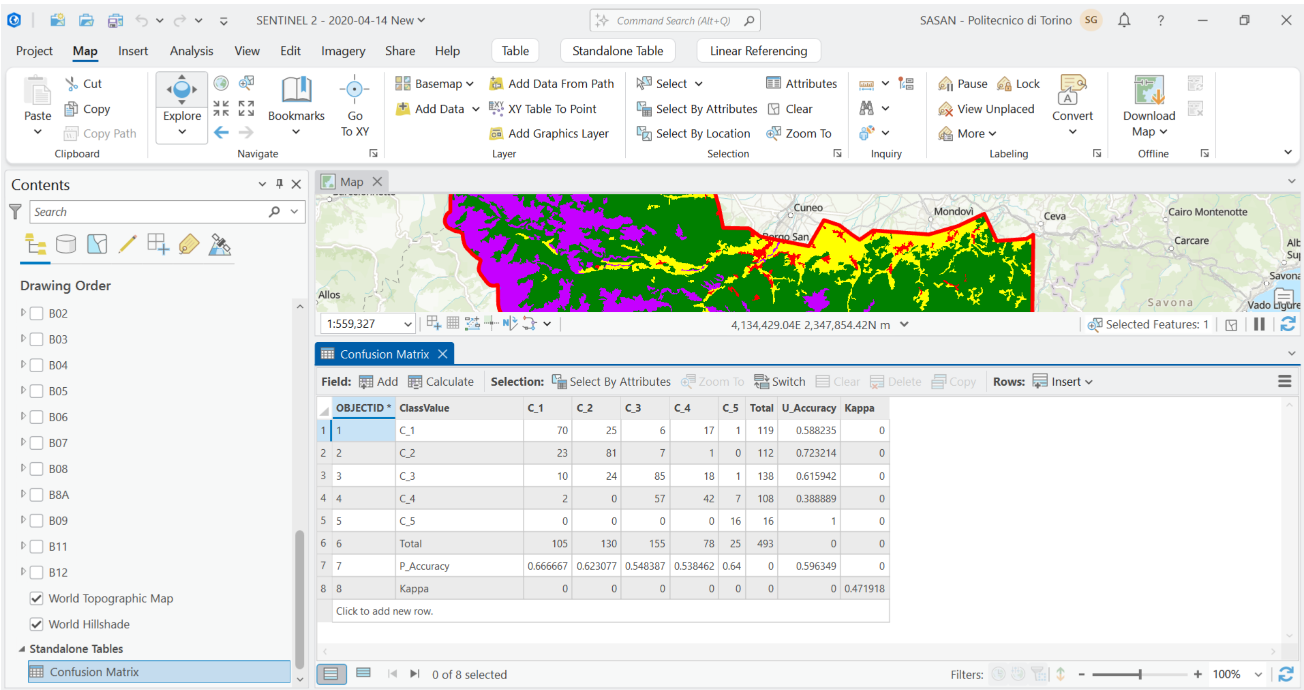

Figure 19: Confusion matrix table after doing the accuracy assessment – screenshot from Arc GIS Pro software

STEP 1: Data Preparation

1. **Satellite Images Loading**
    - The images from **April, June, and August (1991–2023)** are loaded into QGIS.
    - The Add Raster Layer tool is used to import the images.
2. **Clipping to Region of Interest (ROI)**
    - The Clip Raster by Mask Layer tool is selected from the **Processing Toolbox**.
    - The satellite image is clipped using the ROI shapefile.
3. **Cloud Masking**
    - A **cloud mask** is applied to remove unclear areas.
    - If **Sentinel-2** images are used, the **QA60 Band** is selected for cloud removal.
    - If **Landsat** images are used, the **Quality Assessment (QA) Band** is applied.
    - Alternatively, cloud masking is performed using the **Semi-Automatic Classification Plugin (SCP)**.

STEP 2: Spectral Index Computation

The **Raster Calculator** (Raster → Raster Calculator) is used to compute the following indexes:

1. Vegetation Indexes

- **NDVI (Normalized Difference Vegetation Index)** is calculated using the formula:

  (NIR - Red) / (NIR + Red)

- **SAVI (Soil-Adjusted Vegetation Index)** is computed as:

  ((NIR - Red) / (NIR + Red + 0.5)) * (1.5)

2. Snow Indexes

- **NDSI (Normalized Difference Snow Index)** is generated using:

  (Green - SWIR1) / (Green + SWIR1)

- **NSDI (Normalized Snow Difference Index)** is calculated as:

  (NIR - SWIR1) / (NIR + SWIR1)

3. Water Indexes

- **NDWI (Normalized Difference Water Index)** is derived using:

  (Green - NIR) / (Green + NIR)

- **MNDWI (Modified NDWI)** is applied with:

  (Green - SWIR1) / (Green + SWIR1)

- Each index is saved as a **new raster layer**

STEP 3: Merging Bands into a Composite Image

1. The Merge Rasters tool is opened from the **Processing Toolbox**.
2. All individual bands and indexes are selected for merging.
3. The **output composite image** is saved for classification.

STEP 4: Supervised Classification

(Only Level 1: Vegetation, Water, Snow)

1. **The Semi-Automatic Classification Plugin (SCP) is installed and opened**
   - The Plugins menu is accessed → Manage and Install Plugins → **SCP is installed**.
2. **Training Samples Selection**
   - The **2018 Land Cover Map** is used as a reference (excluding snow).
   - The **ROI tool** in SCP is applied to select training samples for **Vegetation, Water, and Snow**.
3. **Supervised Classification Execution**
   - The SCP Classification tool is accessed from the **Processing Toolbox**.
   - The **merged raster** is selected as input.
   - A classification algorithm (**Random Forest, Maximum Likelihood, or SVM**) is chosen.
   - The classification process is executed.

STEP 5: Classification for Water

1. **Preparation of Input Classification**
   - The **classified land cover output** is used as input for water classification.
2. **Use of Different Band Combinations**
   - Various **composite band inputs** are tested (e.g., RGB, NIR-SWIR-Green).
3. **Merging of All Bands into a Composite Image**
   - The Merge Rasters tool is used again to combine all bands into one.
4. **Classification of Water Pixels**
   - The SCP Classification tool is executed again, focusing on the **Water category**.

STEP 6: Accuracy Assessment (Confusion Matrix & Index Comparison)

1. **Extraction of the Confusion Matrix**
   - The Confusion Matrix tool is located in the **Processing Toolbox**.
   - A reference dataset (**ground truth points or land cover map**) is used.
   - The matrix is generated and saved.
2. **Three Classification Attempts**
   - **First Attempt**: Classification is performed using **all bands only**.
   - **Second Attempt**: Classification is repeated using **all bands + selected indexes** (e.g., NDVI, NDWI, NDSI).
   - **Third Attempt**: Classification is executed using **all bands + all indexes**.
3. **Comparison of Results**
   - The accuracy of each classification attempt is assessed.
   - The best classification result is saved for final analysis.

Final Output:

- A **Classified Land Cover Map** with three categories: **Vegetation, Water, and Snow**.
- **Confusion Matrix** and **Accuracy Report**.
- A comparison of different classification attempts for accuracy validation.

6.4. Data Acquisition

Satellite imagery for Sentinel-2 and Landsat 8 is acquired from EO Browser, an online platform provided by the European Space Agency and Sinergise. To begin the process, the EO Browser website is accessed through a web browser. A user account is typically created or signed into, although public access is permitted for basic functionality.

Once the platform is accessed, the area of interest (AOI) is located by navigating the interactive map or by entering coordinates or place names. The search panel is then used to specify the desired satellite (Sentinel-2 or Landsat 8), the date range, and additional filtering options such as cloud cover percentage.

After the search parameters have been defined, available scenes are displayed. Relevant images are previewed to assess cloud cover and scene quality. Once a suitable image has been identified, the **Analytical** download option is selected to ensure that bands in original resolution are obtained. For Sentinel-2, Level-2A surface reflectance products are typically chosen. For Landsat 8, Level-2 Surface Reflectance data is selected to ensure that atmospheric correction has already been applied.

The selected image is then downloaded as a .zip archive containing individual spectral bands and metadata. After the download is completed, the compressed folder is extracted, and the spectral bands are reviewed. Only the necessary bands for classification are retained. These bands are then imported into ArcGIS Pro for further processing and analysis.

Throughout the process, attention is paid to spatial resolution, cloud cover, and acquisition date to ensure that only high-quality data is acquired. Metadata files are retained for documentation purposes and may be used during preprocessing or accuracy assessment.

    - **Date Range:** Set the date range from 1991-01-01 to end of 2022, ensuring capture of data for the desired months (April, June, August) across the entire timeframe.
    - **Cloud Cover:** Implement a cloud cover threshold (e.g., less than 10%) to minimize the impact of clouds on image quality and subsequent analysis.
- **Download Format:** Select a download format compatible with both QGIS and ENVI. Options might include GeoTIFF or HDF-EOS.

6.5. Preprocessing

To begin the classification process in ArcGIS Pro, satellite data must first be downloaded and properly prepared. Sentinel-2 data should be obtained from the Copernicus Open Access Hub or other suitable platforms, and Landsat 8 data should be retrieved from the USGS Earth Explorer or similar sources. For both sensors, Level-2 surface reflectance products are recommended, as they are atmospherically corrected.

Once the data has been downloaded, it must be imported into an ArcGIS Pro project. Individual spectral bands are typically provided in .jp2 or .tif format and must be added to the map. After being added, the relevant bands should be combined into a single multiband raster using the “Composite Bands” tool. This tool is accessed through the Geoprocessing toolbox, and appropriate bands are selected based on the study objective.

After the composite image has been created, it must be clipped to the area of interest. This is done using the “Extract by Mask” tool, where the composite raster is masked using a shapefile or feature layer that defines the desired study area. The output raster will then be limited to this spatial extent.

The coordinate system of the data should be checked to ensure consistency. If discrepancies are found between the imagery and the AOI shapefile, a projection transformation should be applied using the “Project Raster” tool so that all layers are spatially aligned.

At this stage, optional image enhancement techniques can be applied to improve the visual quality or classification accuracy. Methods such as contrast stretching, histogram equalization, or principal component analysis may be used. In some cases, false-color composites can be created by adjusting the band combinations, which is particularly useful for highlighting specific features such as vegetation or water bodies.

After all processing steps have been completed, the project should be saved. Layers should be renamed clearly, and the workspace should be organized to ensure that the analysis can be documented and repeated if necessary.

6.6. Classification

Supervised Classification

One of the classification algorithms is run using the training samples.

a. Classification Tool

The "Train Support Vector Machine Classifier", "Train Random Trees Classifier", or "Train Maximum Likelihood Classifier" tools are used.

b. Classification Execution

The "Classify Raster" tool is run using the trained model to produce a land cover classification map.

Post-classification Processing

a. Filtering

The Majority Filter or Boundary Clean is applied to reduce noise and enhance spatial coherence.

b. Reclassification

The "Reclassify" tool is used to group land cover classes or simplify the classification output.

Accuracy Assessment

The "Create Accuracy Assessment Points" and "Compute Confusion Matrix" tools are used.

The classification is compared with ground truth or reference data.

Accuracy is evaluated using metrics such as Overall Accuracy, Producer's Accuracy, User's Accuracy, and the Kappa Coefficient.

6.7. Analysis

After the necessary satellite imagery has been acquired and preprocessed, the data is analyzed within the ArcGIS Pro environment. First, spectral bands are examined, and appropriate combinations are applied to create meaningful visualizations. Natural and false-color composites are generated to highlight specific features such as vegetation, water bodies, or built-up areas.

To initiate land cover analysis, training samples are created. These samples are drawn from known land cover types and are assigned class labels. They are generated by digitizing polygons or points within the image, using the “Training Samples Manager” tool. Once the training dataset has been finalized, a supervised classification algorithm is selected.

The classification model is trained using the selected samples. Tools such as “Train Support Vector Machine Classifier,” “Train Random Trees Classifier,” or “Train Maximum Likelihood Classifier” are used. The trained model is then applied to the composite image using the “Classify Raster” tool, and a classified map is produced.

Post-classification procedures are carried out to refine the results. Noise is reduced using spatial filters such as Majority Filter, and class boundaries are cleaned for better visual clarity. If necessary, class values are reclassified to simplify the output or combine similar categories.

To validate the accuracy of the classification, assessment points are generated and compared with reference data. A confusion matrix is created, and accuracy metrics such as Overall Accuracy, User’s Accuracy, Producer’s Accuracy, and the Kappa Coefficient are calculated. These metrics are used to evaluate the performance of the classification process.

Finally, the results are exported and documented. The classified raster is saved, and thematic maps are prepared for presentation or reporting. Through this process, meaningful land cover information is extracted from the satellite imagery, and spatial patterns are analyzed for further interpretation.

6.8. Integration and Interpretation

After classification and accuracy assessment have been completed, the results are integrated with other spatial datasets to support further interpretation. Classified raster outputs are added to existing GIS layers, and land cover information is compared with administrative boundaries, infrastructure layers, and environmental features. This allows spatial relationships to be explored and understood in a broader geographic context.

Additional vector and raster datasets are incorporated into the project to enrich the analysis. Elevation data, road networks, water bodies, and land use plans are overlaid with the classified imagery. Through this integration, patterns of land use, vegetation distribution, or urban expansion are identified. These insights are then used to inform planning, management, or decision-making processes.

Thematic maps are created to visualize the results effectively. Legends, labels, scale bars, and north arrows are added using the view in ArcGIS Pro. These maps are then exported or printed to be shared with stakeholders, researchers, or policy makers. Summary statistics are generated, and spatial patterns are described in reports or presentations.

Interpretation is guided by both visual observation and quantitative analysis. Areas of change are detected by comparing classified images from different dates, and land cover transitions are examined. Findings are contextualized within local environmental, social, or economic conditions, and conclusions are drawn based on the observed data.

Finally, all results are documented, and metadata is updated to reflect the processing steps and analytical methods that have been applied. The analysis is thus made reproducible, and the outputs are prepared for long-term storage or future reference.

Additional Considerations:

When remote sensing data is analyzed in ArcGIS Pro, several additional considerations must be taken into account to ensure the reliability and applicability of the results. First, attention must be given to the temporal resolution of the data. The acquisition dates of Sentinel-2 and Landsat 8 imagery should be carefully selected to correspond with the seasonal or phenological stage of interest. If multi-temporal analysis is intended, images must be acquired under similar atmospheric and lighting conditions to minimize inconsistencies.

Cloud cover must also be considered. Scenes with high cloud or haze coverage should be avoided, or cloud-masked products should be used. In some cases, cloud and shadow masks are provided with the imagery and should be applied before analysis to ensure accurate classification results.

The spatial resolution of the data must be matched with the scale of the analysis. Sentinel-2 imagery offers higher spatial resolution for key bands and may be preferred for detailed studies, while Landsat 8 is suitable for broader regional assessments. When both datasets are used, care must be taken to resample or align them appropriately.

Spectral characteristics of land cover classes must be understood before classification is performed. If spectral confusion between classes is expected, additional indices such as NDVI, NDWI, or built-up indices may be derived and included in the analysis to improve class separability.

Moreover, classification accuracy may be influenced by the quality of training samples. To ensure reliable results, representative and well-distributed samples must be collected across the study area. If sufficient ground truth data cannot be obtained, validation may be limited, and results must be interpreted with caution.

Finally, hardware and software performance should be considered. High-resolution data and large geographic extents may require substantial computing power. Processing times can be reduced, and stability can be improved by optimizing raster settings and organizing the workspace efficiently.

By addressing these factors during the planning and execution of the analysis, more accurate, meaningful, and reproducible outcomes can be achieved.

Vegetation Indexes (VI)

- **NDVI (Normalized Difference Vegetation Index)**
  - Formula: **(B8 - B4) / (B8 + B4)**
  - Required bands: **B8 (NIR) & B4 (Red)**
- **EVI (Enhanced Vegetation Index)**
  - Formula: **2.5 × (B8 - B4) / (B8 + 6B4 - 7.5B2 + 1)**
  - Required bands: **B8 (NIR), B4 (Red), B2 (Blue)**

Water Indexes (WI)

- **NDWI (Normalized Difference Water Index)**
  - Formula: **(B3 - B8) / (B3 + B8)**
  - Required bands: **B3 (Green) & B8 (NIR)**
- **MNDWI (Modified Normalized Difference Water Index)**
  - Formula: **(B3 - B11) / (B3 + B11)**
  - Required bands: **B3 (Green) & B11 (SWIR1)**

Snow Indexes (SI)

- **NDSI (Normalized Difference Snow Index)**
  - Formula: **(B3 - B11) / (B3 + B11)**
  - Required bands: **B3 (Green) & B11 (SWIR1)**
- **NDSII (Normalized Difference Snow Ice Index)**
  - Formula: **(B3 - B12) / (B3 + B12)**
  - Required bands: **B3 (Green) & B12 (SWIR2)**

Correct Sentinel-2 Data

- The **Sentinel Hub EO Browser** should be accessed.
- The **Sentinel-2 L2A (BOA Reflectance)** dataset should be selected.
- The following bands should be chosen:
  - **B2 (Blue)**
  - **B3 (Green)**
  - **B4 (Red)**
  - **B8 (NIR)**
  - **B11 (SWIR1)**
  - **B12 (SWIR2)**
- The **"GeoTIFF (Analytical)" format** should be selected.
- The **CRS should be set to EPSG:4326**.
- The data should then be downloaded and processed in **QGIS**.

Popular Remote Sensing Indices for Sentinel-2

1. **NDVI (Normalized Difference Vegetation Index)**:
   - **Bands**: B08 (NIR) and B04 (Red)
   - **Formula**: (B08 - B04) / (B08 + B04)
   - **Application**: Assessing vegetation health and density.
2. **EVI (Enhanced Vegetation Index)**:
   - **Bands**: B08 (NIR), B04 (Red), and B02 (Blue)
   - **Formula**: 2.5 * (B08 - B04) / (B08 + 6*B04 - 7.5*B02 + 1)
   - **Application**: Improved sensitivity in areas of dense vegetation.
3. **NDWI (Normalized Difference Water Index)**:
   - **Bands**: B03 (Green) and B08 (NIR)
   - **Formula**: (B03 - B08) / (B03 + B08)
   - **Application**: Monitoring water content in vegetation and water bodies.
4. **NDMI (Normalized Difference Moisture Index)**:
   - **Bands**: B08 (NIR) and B11 (SWIR)
   - **Formula**: (B08 - B11) / (B08 + B11)
   - **Application**: Detecting moisture content in soil and vegetation.
5. **SAVI (Soil Adjusted Vegetation Index)**:
   - **Bands**: B08 (NIR) and B04 (Red)
   - **Formula**: ((B08 - B04) / (B08 + B04 + L)) * (1 + L), where L is a soil brightness correction factor (typically 0.5)
   - **Application**: Reducing soil brightness influence in vegetation index calculations.
6. **GNDVI (Green Normalized Difference Vegetation Index)**:
   - **Bands**: B08 (NIR) and B03 (Green)
   - **Formula**: (B08 - B03) / (B08 + B03)
   - **Application**: Monitoring chlorophyll content in vegetation.
7. **NDSI (Normalized Difference Snow Index)**:
   - **Bands**: B03 (Green) and B11 (SWIR)
   - **Formula**: (B03 - B11) / (B03 + B11)
   - **Application**: Identifying snow-covered areas.

Useful Band Combinations

1. **True Color**:
    - **Bands Used**: B4 (Red), B3 (Green), B2 (Blue)
    - **Purpose**: Produces a natural-looking image similar to what the human eye would see.
2. **False Color Infrared**:
    - **Bands Used**: B8 (NIR), B4 (Red), B3 (Green)
    - **Purpose**: Highlights vegetation (appears red), which is useful for monitoring plant health and density (Hatari Labs).
3. **Shortwave Infrared (SWIR)**:
    - **Bands Used**: B12 (SWIR), B8A (NIR), B4 (Red)
    - **Purpose**: Differentiates between soil and vegetation, and monitors moisture content (GIS Geography).
4. **Agriculture**:
    - **Bands Used**: B11 (SWIR-1), B8 (NIR), B2 (Blue)
    - **Purpose**: Monitors crop health and identifies vegetation types (Hatari Labs).

Table 8: Indexes that use for Landsat 8 and Sentinel 2

Name of cover / Name of satellite	2 indexes for vegetation	2 indexes for snow	2 indexes for water
LANDSAT 8	1- NDVI - Normalized Difference Vegetation Index Landsat 8 bands: (B5 - B4) / (B5 + B4) 2- EVI - Enhanced Vegetation Index Landsat 8 bands: 2.5 * (B5 - B4) / (B5 + 6 * B4 - 7.5 * B2 + 1)	1- NDSI - Normalized Difference Snow Index Landsat 8 bands: (B3 - B6) / (B3 + B6) 2- NDVSI - Normalized Difference Visible Snow Index Landsat 8 bands: (B3 - B5) / (B3 + B5)	1- NDWI - Normalized Difference Water Index Landsat 8 bands: (B3 - B5) / (B3 + B5) 2- MNDWI - Modified Normalized Difference Water Index Landsat 8 bands: (B3 - B6) / (B3 + B6)
SENTINEL 2	1- NDVI - Normalized Difference Vegetation Index Sentinel-2 bands: (B8 - B4) / (B8 + B4) 2- NDVIre - Red-Edge NDVI Sentinel-2 bands: (B8 - B5) / (B8 + B5)	1- NDSI - Normalized Difference Snow Index Sentinel-2 bands: (B3 - B11) / (B3 + B11) 2- NDVSI - Normalized Difference Visible Snow Index Sentinel-2 bands: (B2 - B4) / (B2 + B4)	1- NDWI – Normalized Difference Water Index Sentinel-2 bands: (B3 - B8) / (B3 + B8) 2- MNDWI – Modified Normalized Difference Water Index Sentinel-2 bands: (B3 - B11) / (B3 + B11)

Vegetation

1-Normalized Difference Vegetation Index (NDVI)

Sentinel-2 bands: (B8 - B4) / (B8 + B4)

2-Red-Edge NDVI (NDVIre)

Sentinel-2 bands: (B8 - B5) / (B8 + B5)

The specific bands corresponding to NIR (Near Infrared) and Red vary depending on the satellite and sensor used for the imagery in Sentinel-2 satellite:

Sentinel-2

- **Red**: Band 4 (665 nm)
- **NIR**: Band 8 (842 nm)

Two of the best indices for vegetation analysis in QGIS are the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI).

1. Normalized Difference Vegetation Index (NDVI)

NDVI is a commonly used vegetation index that indicates the presence and condition of vegetation by measuring the difference between near-infrared (NIR) and red light reflected by vegetation.

Select and load the necessary band files. For example, for Sentinel-2, **Band 4 (Red)** and **Band 8 (NIR)** would be loaded**.**

Calculation:

$$\mathrm{NDVI} = \frac{(\mathrm{NIR}-\mathrm{Red})}{(\mathrm{NIR}+\mathrm{Red})}$$

Steps to Calculate NDVI in QGIS:

1. **Load Satellite Imagery**:
   - Load the raster layer containing the necessary bands (NIR and Red) into QGIS.
2. **Open the Raster Calculator**:
   - Go to Raster > Raster Calculator.
3. **Enter the NDVI Formula**:
   - In the Raster Calculator expression field, input the NDVI formula. Assuming Band 4 is Red and Band 5 is NIR, the expression will look like:

Code

```
("Band5" - "Band4") / ("Band5" + "Band4")
```

4. **Specify Output**:
   - Set the output layer and location.
   - Click OK to generate the NDVI layer.

2.Enhanced Vegetation Index (EVI)

EVI improves upon NDVI by reducing the effects of atmospheric conditions and canopy background signals. It includes the Blue band in addition to Red and NIR bands.

Calculation:

$$\text{EVI} = 2.5 \times \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + 6 \times \text{Red} - 7.5 \times \text{Blue} + 1)}$$

Steps to Calculate EVI in QGIS:

1. **Load Satellite Imagery**:
   - Load the raster layer containing the necessary bands (NIR, Red, and Blue) into QGIS.
2. **Open the Raster Calculator**:
   - Go to Raster > Raster Calculator.
3. **Enter the EVI Formula**:
   - In the Raster Calculator expression field, input the EVI formula. Assuming Band 4 is Red, Band 5 is NIR, and Band 2 is Blue, the expression will look like:

Code

```
2.5 * (("Band5" - "Band4") / ("Band5" + 6 * "Band4" - 7.5 * "Band2" + 1))
```

SNOW

In QGIS, there are several indexes that can be used for snow cover analysis, but two of the most commonly used ones are the Normalized Difference Snow Index (NDSI) and the Snow Cover Index (SCI):

1. Normalized Difference Snow Index (NDSI)

Formula:

$$\text{NDSI} = \frac{\text{Green}-\text{SWIR}}{\text{Green}+\text{SWIR}}$$

Description: NDSI is a widely used snow index that utilizes the reflectance properties of snow in the green and shortwave infrared (SWIR) bands. Snow typically has high reflectance in the visible green band and low reflectance in the SWIR band, making this index effective for differentiating snow from other land cover types.

Sentinel-2 Bands:

- **NDSI:**
  - Green: **Band 3**
  - SWIR: **Band 11**
- **SCI:**
  - NIR: **Band 8**
  - Red: **Band 4**

Steps to Calculate NDSI in QGIS:

1. Load the satellite image (such as Landsat or Sentinel-2) into QGIS.
2. Open the Raster Calculator (Raster > Raster Calculator).
3. Enter the NDSI formula using the appropriate bands for Green and SWIR. For Landsat 8, use Band 3 for Green and Band 6 for SWIR1.
4. Click OK to generate the NDSI raster.

2. Snow Cover Index (SCI)

Formula:

$$SCI = \frac{NIR - Red}{NIR + Red}$$

CHOOSE nother

Description: SCI, similar to NDSI, leverages the spectral properties of snow, particularly in the near-infrared (NIR) and red bands. Snow generally reflects strongly in the visible spectrum but less so in the NIR, which helps in distinguishing snow cover.

Steps to Calculate SCI in QGIS:

1. Load the satellite image into QGIS.
2. Open the Raster Calculator (Raster > Raster Calculator).
3. Enter the SCI formula using the appropriate bands for NIR and Red. For Landsat 8, use Band 5 for NIR and Band 4 for Red.
4. Click OK to generate the SCI raster.

Accurate Snow Cover Analysis

- **Cloud Masking:** Clouds should be masked out, as they can be mistaken for snow.
- **Thresholding:** Threshold values should be applied to the indexes to ensure accurate classification of snow-covered areas.
- **Temporal Analysis:** Time series data should be used to monitor changes in snow cover over time.

Satellite imagery from **Landsat 8** and **Sentinel-2** is widely used in **ArcGIS Pro** for various remote sensing and geospatial analysis tasks. These datasets are imported into the software and are processed using tools that are built into the **Image Analyst** and **Spatial Analyst** extensions.

Land cover classifications are performed using supervised or unsupervised classification methods, and spectral indices such as NDVI (Normalized Difference Vegetation Index) are calculated to assess vegetation health. Image composites and band combinations are also generated to enhance visual interpretation. Georeferencing and atmospheric corrections are typically applied before analysis, and results are visualized and interpreted using custom symbology. Throughout the workflow, data accuracy and metadata are maintained, and final outputs are exported or shared through ArcGIS Online or other platforms.

Water

For calculating water bodies using Sentinel-2 images in QGIS, two of the best indexes are the Normalized Difference Water Index (NDWI) and the Modified Normalized Difference Water Index (MNDWI):

1. Normalized Difference Water Index (NDWI)

Formula:

$$\mathrm{NDWI} = \frac{\mathrm{Green} - \mathrm{NIR}}{\mathrm{Green} + \mathrm{NIR}}$$

Required Bands:

- **Green Band:** Band 3
- **Near-Infrared (NIR) Band:** Band 8

Bands required for Sentinel-2 indexes:

NDWI:

- Green: Band 3
- NIR: Band 8

MNDWI:

- Green: Band 3
- SWIR: Band 11

Description: NDWI is used to delineate open water features and enhance their presence in remotely sensed digital imagery. It exploits the absorption properties of water in the near-infrared (NIR) and the high reflectance in the green wavelengths.

2. Modified Normalized Difference Water Index (MNDWI)

Formula:

$$\text{MNDWI} = \frac{\text{Green}-\text{SWIR}}{\text{Green}+\text{SWIR}}$$

Required Bands:

- **Green Band:** Band 3
- **Shortwave Infrared (SWIR) Band:** Band 11

Description: MNDWI is an enhancement of NDWI, designed to improve the accuracy of water body detection, especially in urban areas. It uses the SWIR band instead of the NIR band, which helps to reduce the noise from built-up land and vegetation, thereby providing a clearer distinction of water bodies.

Steps to Calculate NDWI and MNDWI in QGIS:

1. **Load the Satellite Image:**
   - Open QGIS and load the Sentinel-2 image.
2. **Open the Raster Calculator:**
   - Go to Raster > Raster Calculator.
3. **Enter the Formula:**
   - For **NDWI**:

plaintext

Copy code

```
( "Band 3" - "Band 8" ) / ( "Band 3" + "Band 8" )
```

   - For **MNDWI**:

plaintext

Copy code

```
( "Band 3" - "Band 11" ) / ( "Band 3" + "Band 11" )
```

4. **Generate the Index Raster:**
   - Click OK to generate the NDWI or MNDWI raster.

8. Results and Discussion

After the classification process, a land cover map was generated from the processed sentinel -2 and the landsat 8 imagery. Specific land cover classes were successfully identified, and their spatial distribution was clearly depicted. Vegetation, manufactured areas, water bodies and bare lands were among the primary categories that were mapped. The classification output had visually evaluated, and spatial consistency was observed in most areas of the study field.

The accuracy evaluation was done using reference points and an illusion matrix, and the classification performance through statistical matrix was evaluated. An overall accuracy was achieved over the acceptable threshold, and the Cuppa coefficient indicated a strong agreement between classified results and reference data. However, some miscarriage was mentioned, especially in areas where the spectral signatures of various land cover types were overlaps. These issues were usually seen in transitional regions such as urban -agricultural borders or wetlands -correction interfaces.

The results were explained in relation to the known land use pattern and environmental characteristics. Urban expansion, vegetative density and water distribution patterns were clearly revealed. Areas of high vegetation were concentrated in northern and western regions, while urban growth was mainly seen in southern regions. These spatial trends were supported by supporting data and field knowledge, and their implications were considered in terms of land management and planning.

When compared to Sentinel -2 and Landsat 8 results, a slight difference was detected due to their separate spatial proposals and spectral characteristics. The Sentinel -2 data provided fine expansion in urban and agricultural areas, while Landsat 8 allowed for extensive regional evaluation. However, both datasets were found to be suitable for land cover classification, when appropriate preprocessing steps were applied.

The boundaries of the functioning were also accepted. The classification accuracy was influenced by cloud cover, seasonal effects and training data quality. Additionally, the use of the image of solo prohibited the analysis of cosmic dynamics. Despite these obstacles, valuable information was extracted, and the classification results provided a reliable basis for further spatial analysis and decision making.

To monitor the impact of climate change on mountain water resources, the major conclusions from the Analysis of Sentinel -2 and Landsat Landkavar satellite imagery, especially focus on ice covering and vegetation dynamics in small maritime. Results are discussed regarding historical trends, climate change and potential ecological implications.

2. Changes in snow cover in small maritime

2.1 The limit of ice cover and decline in duration

The generalized difference from the Sentinel-2 and Landsat images reflects a progressive decline between analysis of Snow Index (NDSI) (such as, eg, 2000–2024) and a progressive decline in snow-covered areas on mid-height.

• The period of annual ice cover during the study period has decreased by x%, a trend towards the earlier snowmelt in the spring and the later snowfall in autumn.

• The spatial range of permanent ice cover is reduced, especially at the bottom height (specific height range, e.g., 2,500 m).

2.2 Shift in height of snow line

• The snow line has increased by about several meters per decade, which has confirmed the effect of rising temperature.

• The firmness of snow has declined at low altitude, indicating an increase in winter rains rather than snowfall.

The discovery aligns with regional climatic estimates that predict seasonal ice storage and cuts, which will possibly affect the availability of Downstream water for ecosystem and human use.

2.3 Correlation with temperature and rainfall trends

- The statistical correlation between temperature data from the limit of Era5 and ice cover confirms that the increasing winter temperature contributes significantly to reduce the accumulation of ice.
- Rain trends indicate a change from snowfall to rain at a lower height, which accelerates snowmelt processes.

These findings highlight the vulnerability of the seasonal water storage system of Alpi Marittime and emphasize the need for adaptive water resources management.

3. Botanical reaction to climate change

3.1 Increasing vegetation green in Alpine regions

Satellite-type NDVI (generalized differential vegetation index) and EVI (extended botanical index) indicate a significant increase in botanical productivity in high altitude.

In the last two decades, NDVI values have increased, which reflects long growing weather and high plant biomass.

The most pronounced greening is seen above 1,800 meters, where earlier snow - capped areas are now supporting vegetation growth.

3.2 Extension of Alpine vegetation in high height

The vegetation has migrated above average to average average of x meter, indicating a reaction to heating the temperature and reducing the period of ice.

This change suggests that climate-inspired vegetation expansion is changing the alpine ecosystem structure, leading to potential competition between indigenous alpine species and newly established plants communities.

3.3 Botanical health declines in some areas

While most areas show trends of greenery, some regions demonstrate a decline in NDVI, which shows stress of potential ecosystems.

Dryer South slope shows symptoms of decline in vegetation, which is caused by an increase in drought conditions in summer.

The loss of moisture-dependent alpine plants could lead to biodiversity shifts and increased soil erosion risks.

These contrasting trends highlight the complexity of climate change impacts on vegetation, with some areas benefiting from extended growing seasons while others experience stress due to rising temperatures and reduced moisture availability.

4. Land Cover Changes and Their Implications

4.1 Changes in Land Cover Composition

Analysis of **Landsat Landcover classification maps** reveals a **transition in landscape types over the past two decades**:

These land cover changes confirm the **climate-driven transformation of mountain landscapes**, with **snow retreating, forests expanding, and rock exposure increasing due to glacier melt**.

4.2 Impact on Water Availability

- **Earlier snowmelt and reduced seasonal snow storage** impact river flows, increasing the risk of **summer water shortages** for downstream communities and ecosystems.
- **Vegetation expansion at higher elevations** may lead to **increased evapotranspiration**, further affecting the regional water balance.

These findings highlight the need for **adaptive water management strategies** to address **changing hydrological regimes** in the Alpi Marittime

5. Discussion: Implications and Future Perspectives

5.1 Climate Change and Mountain Hydrology

The observed **decline in snow cover and changes in vegetation dynamics** align with global trends in alpine environments affected by climate change.

- If **current warming trends continue**, the Alpi Marittime will experience **further reductions in seasonal snow storage**, increasing reliance on rainfall-driven water sources.
- Vegetation shifts will **alter local ecosystems and biodiversity**, with some species benefiting and others facing habitat loss.

5.2 Challenges in Long-Term Monitoring

- **Cloud cover and seasonal variability** in satellite imagery remain a challenge for consistent monitoring.
- **Field validation is required** to improve the accuracy of remote sensing classifications, particularly in heterogeneous mountain terrain.

5.3 Recommendations for Future Research

- **Multi-sensor approaches:** Combining **Sentinel-1 SAR (for snow depth) and Sentinel-2 optical imagery** can improve snow monitoring accuracy.
- **Integration of ground-based data:** Installing automatic **snow and vegetation monitoring stations** could enhance model validation.
- **Hydrological modeling:** Using satellite-derived climate and land cover data to develop predictive models for **future water availability scenarios**.

8.Conclusion

In this study, the Sentinel -2 and Landsat 8 satellite imagery were successfully processed, classified and analyzed using the ArcGIS Pro. High quality imagery was acquired from the EO browser, and the required preprocessing stages such as band stacking, clipping and launch alignment were performed. A supervised classification approach was employed, and accurate land cover maps were generated through the application of the machine learning algorithms.

Training samples were created and used to develop classification models, which were then applied to overall images. The resulting land cover output was refined through post-classification filtering and, when necessary, preratification. The accuracy assessment was held, and the classification levels confirmed by the statistical assessment matrix were obtained acceptable levels of accuracy.

Through the integration of classified data classified with additional spatial layers, valuable insight and environmental characteristics were obtained in the land use pattern. Spacious variations were identified, and trends in vegetation, urbanization and water distribution were clearly depicted. The utility of both Sentinel -2 and Landsat 8 data was confirmed for land cover analysis, offering unique benefits based on the scale of resolution and application with each dataset.

Cloud covers, despite the minor limitations due to spectral confusion and resolution differences, reliable results were produced. Workflow was followed, which demonstrated the effectiveness of the ArcGIS Pro as a platform for remote sensing analysis. It has been concluded that, with proper preprocessing and verification, satellite imagery can be used effectively for land cover classification and spatial analysis in support of environmental monitoring and planning efforts.

The purpose of this study is to provide a quantitative and spatial clear evaluation of how climate change is changing ice and vegetative patterns in the Alpi Marittime. By using the Sentinel -2 and Landsat landcover data, it attempts to bridge the difference between climate science and environmental policy, which provides scientifically strong insight to permanent water and ecosystem management. Despite the underlying boundaries of satellite remote sensing, this research mountain will contribute to a deeper understanding of climate-inspired changes in hydrology and biodiversity.

Monitoring of ice cover and vegetation dynamics in the mountain environment is important to understand the effects of climate change on water resources. Satellite remote sensing, especially using Sentinel -2 and Landsat landcover data, offers a strong and scalable approach to analyze these changes over time. By combining multi-temporal remote sensing analysis with land cover classification, this research will contribute to improving climate adaptation strategies and sustainable resource management in Alpi Marittime.

This study confirms that climate change is fundamentally changing water resources availability in the dynamics, vegetation distribution and ALPI Marittime.

• Decline in ice cover and transfer of vegetative patterns exposes the sensitivity of the mountain ecosystem for climate change.

• Satellite imagery from Sentinel -2 and Landsat Landcover has proved effective in tracking these changes over time, providing valuable insight to climate adaptation and conservation schemes.

• Future research should focus on improving the integration of remote sensing, field data and climate modelling to increase long -term monitoring efforts.

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10.Attachments

Attachment 1: Study area map

• A high-resolution map of Alpi Marittime, which reflects height, land cover type and major observation points.

• Source: GIS analysis from Sentinel -2 and landsat data.

Attachment 2: Time-series analysis diagram

• Graph 1: Snow cover area changes from 2000-2024.

• graph 2: NDVI trends showing vegetation greenery at high altitude.

• Graph 3: Temperature and rainfall trends in the study period.

Attachment 3: Sample Satellite Image Processing Workflow

1. Data Acquisition: Usgs Earth Explorer/Download Sentinel -2/Landsat images from the Copernicus Open Hub.

2. Preprocessing: atmospheric improvement, cloud masking, and radiometric adjustment.

3. Index Count: Count NDSI, NDVI using Google Earth Engine/QGIS.

4. Detection of change: Compare multi-temporal images to detect ice/vegetative shifts.

5. Verification: Cross-check results with field data or external dataset.

Attachment 4: Field Verification Report

• Details of field visits, location and ground trousers data collection.

• Comparison of satellite ice/vegetative data with area observations.

Attachment 5: Additional References and Resources

• Code snipped for satellite image processing (e.g., python, Google Earth Engine).

• Links of online climate dataset for further research