GIS and geomatics for hydrogeodiversity assessment of glaciated mountains: examples from the Western Alps (Italy) and the Coast Mountains (Canada)

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Geological and geomorphological constrains to mountain geodiversity

Structure of the contribution

1. FOREWORD - Theoretical issues related to both spatial and temporal dimensions of natural components of the geo-environmental system

2. METHODS - Systematization of knowledge related to geodiversity of mountains (issues related to scale of analysis and representation)

3. RESULTS – GIS mapping and qualitative-quantitative assessment of geodiversity (Examples from glaciated/deglaciated mountains of Europe and Canada)

4. DISCUSSION - Classification and presentation of components of mountain geodiversity based on their spatial and temporal dimension, and the related geomatics tools
Geological, geomorphological, ..., (E.g. many) constrains to mountain (hydro)Geodiversity

Monte bianco – Veny Valley

Geodiversity: the natural range (diversity) of geological (rocks, minerals, ...), geomorphological (landforms, topography, processes), soil and hydrological features.

It includes their assemblages, structures, systems and contributions to landscapes.
Conceptual framework at a global scale, field mapping and remote sensing at regional and local scales
The study area is on the **Mount Meager** Volcanic Complex (MMVC), 200 km N of Vancouver.
1. **FOREWORDS on Geodiversity Glocal Approach**

2. **METHODOLOGY** – Assessment of regional geodiversity connected to hydro(cryo)sphere by means of: 1) base data acquisition and mapping; 2) qualitative-quantitative GIS process (factor maps, map algebra, comparison to ecosystem services)

3. **RESULTS – Hydrogeodiversity Assessment Map, Identified hydrogediversity landscapes and promote their conservation,**

4. **GENERALIZATION – Examples of dynamic geodiversity in the glacial environment of the Alps and effects of landscape and ecosystem services**

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**Structure of the presentation**

1. FOREWORDS on Geodiversity Glocal Approach

1. METHODOLOGY – Assessment of regional geodiversity connected to hydro(cryo)sphere by means of: 1) base data acquisition and mapping; 2) qualitative-quantitative GIS process (factor maps, map algebra, comparison to ecosystem services)

2. RESULTS – Hydrogeodiversity Assessment Map, Identified hydrogeodiversity landscapes and promote their conservation,

3. GENERALIZATION – Examples of dynamic geodiversity in the glacial environment of the Alps and effects of landscape and ecosystem services
1) Geodata Acquisition and mapping

2) Qualitative-quantitative GIS process (factor maps, map algebra, Zwolinsky et al., 2018)

Comparison of final hydrogeodiversity to ecosystem services
1) Example of Base Geodata Acquisition and mapping
## Geodata acquisition and elaboration

<table>
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<tr>
<th>Data</th>
<th>Source Data</th>
<th>Year</th>
<th>File</th>
<th>GIS layer name</th>
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<td>Mount Meager landforms</td>
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<td>Glaciers</td>
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<td>.shp</td>
<td>Glacier 1947...2016</td>
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<td>DEM</td>
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<td>Multitemporal Orthophoto</td>
<td>1947-2006</td>
<td>.geotiff</td>
<td>Orthophoto 1947...2006</td>
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</table>

Total layers: 41

Geomorphological map  
Land system map
Geomorphological Map
Mt. Meager Massif

Multi-Spatial Interpretation: Mount Meager Geomorphological setting
A land-systems map defines those areas, which certain predictable combinations of landforms and their associated soils and vegetation are likely to be found.
It was possible to document the glacial fluctuations that took place between 1947 and 2016, thanks to geomorphological analysis based on Orthophotos and DEM shaded relief model.
Sesia-Val Grande UNESCO Global Geopark
**Choosen parameters for hydrogeodiversity assessment**

<table>
<thead>
<tr>
<th>Purpose</th>
<th>1°: Define a conceptual structure of geodiversity linked to water resources</th>
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<td>2°: Identified areas characterized by high hydrological geodiversity</td>
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<td>Data Source</td>
<td>SESIA VAL GRANDE UGGp [27]</td>
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<td>Analysis Scale 1:100.000</td>
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<td>Time Scale</td>
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<td>Evaluation</td>
<td>RELATIVE</td>
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<td>Evaluation</td>
<td>Hydrogeosystem services, human-centred</td>
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<td>MIXED= QUANTITATIVE-QUALITATIVE</td>
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<td>CARTOGRAPHIC</td>
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<td>ESRI ArcGis</td>
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<tr>
<td>Representation</td>
<td>of the results of evaluation</td>
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</tbody>
</table>
1. Atmospherical processes: rainfall, quantity, slope exposure, moisture regulation
2. Geological processes: conditioning of permeability, fracturation, mineral composition and soil types in groundwater quality and productivity, water suracing
3. Geomorphological processes (fluvial, glacial, volcanic processes): drainage density, oxygenation, deposit sediments, flow control, hot springs locationing, glaciers formation and dynamics
4. Antrophic processes: conditioning of cementification and overbuilding in riverbed permeability and lithological permeability, flow control, level base changes, groundwater productivity

1. Source of sustenance: Food and drinkable water
2. Industry: water for aggregate extraction and water for production activities
3. Energy: hydroelectric and geothermal
4. Recycling and storage

1. Development of cultural, spiritual and religious identities: sites such as bridges, waterfalls, caves that represent myths, legends related to the element of water or ice or sites theater of important historical or war events, sites of artistic inspiration, sites of wellbeing
2. Geotourism, sport and leisure: geo-touristic itineraries through hydrogeosites and hydrogeomorphosites, sports activities such as rafting, canyoning, sport fishing, ice climbing, snowshoeing, places for recreation: hot springs, hydrotherapy, bathing/swimming

1. Evolution and terrestrial cycles: climatic dynamics, glacialism, fluvial-glacial dynamics, landforms origin
2. Research and environmental monitoring: origin of biological organisms, geophysics and georadar for groundwater research, monitoring of water quality and quantity
3. Local development and landscape conservation: hydrogeological risk management, educational and professional opportunities, development of skills for climate change adaptation strategies
The 4 main factors of hydrogediversity

1. Basement rocks and deposits permeability, integrated with Fracturing Index (tP), for the **Factor Map of Total Permeability**

2. Land use, integrated with Slope Instability Index (tLU), for the **Factor Map of Total Land Use**;

3. Springs and wells location (SWD) for the **Factor Map of Springs and Wells Density**;

4. Hydrography, glaciers location, glacial cirques, landslides and fluvial conoids location (MR) for the **Factor Map of Morphogenetic Relevance**.

These factors represent the variables of the hydrogeodiversity (HGD) equation, that can be summarized as:

\[
\text{HGD} = tP + tLU + SWD + MR
\]
Hydrogediversity facto map construction scheme

- **Fracturing Index**
  - Source: CNR-Geological Map of Piemonte Region, 2017
  - Scale: 1:250,000
  - Map Algebra: [Weighted Sum] Equal

- **Basement Rock and Deposits Permeability**
  - Source: CNR-Geological Map of Piemonte Region, 2017
  - Scale: 1:250,000
  - Map Algebra: [Weighted Sum]

- **Land Use**
  - Source: CLC, Copernicus 2018
  - Scale: 1:50,000
  - Map Algebra: [Weighted Sum] Equal

- **Slope Instability Index**
  - Source: SIFRAP-ARPA Piemonte
  - Scale: 1:10,000

**Factor Map of Total Permeability**
- Scale: 1:100,000
- Map Algebra: [Weighted Sum] Weighted

**Factor Map of Springs and Wells Density**
- Scale: 1:100,000
- Map Algebra: [Weighted Sum] Weighted

**Wells**
- Source: SIRI-Piemonte Region, 2005
- Scale: 1:10,000
- Map Algebra: [Weighted Sum] Equal

**Natural Springs**
- Source: SIRI-Piemonte Region, 2005
- Scale: 1:10,000
- Map Algebra: [Weighted Sum] Equal

**Final Map of Hydrogediversity in Sesia Valgrande UGGp**
- Scale: 1:100,000

**Factor Map of Land Use**
- Scale: 1:100,000
- Map Algebra: [Weighted Sum] Weighted

**Factor Map of Morphogenetic Relevance**
- Scale: 1:100,000
- Map Algebra: [Weighted Sum] Weighted

**Hydrography, Glaciers, Glacial Cirques, Landslides, Fluvial Conoids**
- Sources and Scales: PPR Piemonte, 2017 (1:25,000), ARPA Piemonte, rev.2015 (1:10,000), SIFRAP, rev.2013 (1:10,000)
Sesia Val Grande - Factor maps examples

Factor map of Total Lithological Permeability integrated with Fracturing Index.

Factor map of Total Land Use integrated with Landslides Density Index.
Sesia Val Grande - Factor maps examples
Structure of the lecture

1. FOREWORDS on Geodiversity Glocal Approach

1. METHODOLOGY – Assessment of regional geodiversity connected to hydro(cryo)sphere (qualitative-quantitative GIS process: (factor maps, map algebra, comparison to ecosystem services)

2. RESULTS – Hydrogeodiversity Assessment Map, Identified hydrogediversity landscapes and promote their conservation,

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Hydrogeodiversity Map of the Sesia ValGrande
UNESCO Global Geopark

Legend

HYDROGEODIVERSITY VALUE

LOW
MEDIUM
HIGH

RESULTS
Comparison of final hydrogeodiversity to ecosystem services

Focus on Glacial Landscape of Monte Rosa
HYDROGEOSYSTEMIC SERVICES PROVIDED:

**Regulating:**
- Climate: precipitation density, humidity and winds
- Geomorphology: flow of melt water and hydrographic network, slope stability

**Support:** surface water reserve and establishment of natural habitats (glacial, periglacial environments, rockwalls, lakes) and platforms for human settlement (basins and glacial valleys), pedogenesis.

**Provisioning:** drinkable water, energy.

**Culture:** places of spirituality, myth, conquest, artistic inspiration (*Dragon glacier, Fata Morgana in the Anthropocene*), Celebrations (*Rosario Fiorito*).

**Knowledge:** Glacial evolution and stages, current deglaciation, climate-sensitive landscape, adaptation strategies.
1. **FOREWORD - FOREWORDS on Geodiversity**
   Glocal Approach

2. **METHODS - Systematization of knowledge related to geodiversity of mountains** (addressing issues related to scale of analysis and representation)

3. **RESULTS - GIS mapping and qualitative-quantitative assessment of geodiversity** (Examples from glaciated/deglaciated mountains of Europe and Canada)

4. **DISCUSSION - Classification and presentation of components of mountain geodiversity based on their spatial and temporal dimension, and the related geomatics tools**
Possible outputs for analysis of geological and geomorphological constraints to geodiversity in mountain areas

A. Regional geological setting, geometry of drainage basins and major valley slopes

B. Glaciation/deglaciation (Long-term and areal glacial processes)

C. Holocene gravitational evolution

D. Recent evolution

Time dimensions:
- PLEISTOCENE
- HOLOCENE

Spatial dimensions:
- SLOPE
- RELIEF
- VALLEY
- RANGE
Following the spatial and temporal “sizes” of phenomena it is possible to operate appropriate selections of geomorphometrics techniques …

..to get better results, both in reconstructing the evolutionary stages of the relief and in hazard and risk assessments, preventions, remedial measures projects
A proposal for a targeted multidimensional (S/T) classification of geomatics for geodiversity

A Regional geological setting, geometry of drainage basins and major watersheds

B Pleistocene Glacialism Long-term and areal glacial processes

C Holocene gravitational evolution

D Recent evolution

Regional geological setting, geometry of drainage basins and major watersheds

Time dimensions

Spatial dimensions