

Article

# Geodiversity Evaluation and Water Resources in the Sesia Val Grande UNESCO Geopark (Italy)

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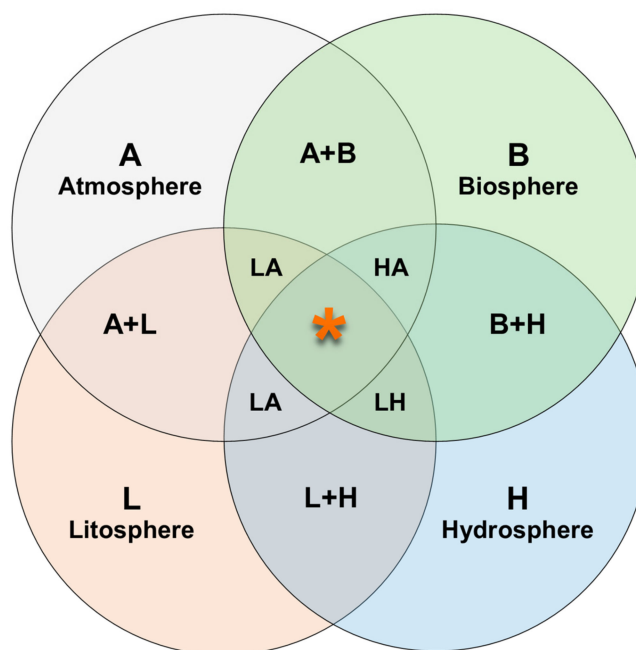


**Abstract:** This paper aims at systemizing knowledge related to geodiversity assessment for water resources and its evaluation. The novel aspect connected to geodiversity of this paper is the analysis of the components of hydrological system, both at the superficial and underground level, in the territory of the Sesia Val Grande United Nations educational, scientific, and cultural organization (UNESCO) Global Geopark (Northwest Italy). More specifically, the research establishes a conceptual model and a specific procedure for the evaluation of geodiversity connected to water resources on a regional scale, by means of a qualitative-quantitative geographic information system (GIS) process, renamed here as hydro-geodiversity assessment. For these purposes, a targeted ecosystem approach is applied to consider the assets of the Geopark territory that has been derived from the interaction between water and other components of geodiversity, i.e., the hydro-geosystemic services. The element selection and processing operations led to the identification of areas characterized by greater values of hydrological geodiversity, in which the link between surface and underground hydrodynamics became closer and intense. The single geodiversity factor maps that were obtained from partial data aggregations were added together in map algebra operations, then subjected to weighing to formulate the hydro-geodiversity map of the Sesia Val Grande UNESCO Global Geopark. The results of the present study strengthen the strategic management of geological, geomorphological, and hydrological heritages of the study area by identifying different landscapes and local peculiarities determined by mutual influences between geology and hydrological dynamics.

**Keywords:** water resources; geodiversity assessment; geosystem services; geoheritage; hydro-geodiversity; Sesia Val Grande UNESCO Global Geopark

## 1. Introduction

The term “geodiversity” has no intrinsic value; its importance relies on the quality of the relationships built between the systems or spheres of which it is composed, i.e., the Earth system science (atmosphere, lithosphere, hydrosphere, and biosphere; Figure 1) [1] and those specifically addressed to describe surface processes, landforms, and materials, such as pedosphere and anthroposphere. Interactions between these different spheres constitute the variety of geological and geomorphological phenomena and landscapes [2] to which human beings attribute several values. Therefore, we agree with Sharples [3] in considering geodiversity as “the quality we are trying to conserve,” and geoconservation as “the endeavor to conserve it”.



**Figure 1.** Conceptual scheme of the relationships between the main spheres considered by the Earth systems science [1]. Asterisk indicates the area of relationships with pedosphere and anthroposphere.

According to Gray's (2013) definition, geodiversity is not just a matter of different Earth features [1] but also of their assemblages, structures, systems, and contribution to landscapes. The complexity of geodiversity is a challenge for its assessment. A system of norms and modes of action, as well as a model of interaction of all the related variables, has to be created in order to achieve significant geodiversity assessment, in term of both biotic and abiotic ecosystem services. Such a comprehensive assessment can offer relevant contributions to both geoconservation and sustainable use of georesources [4].

This work is focused on systematizing the relationships between geodiversity and water resources by analyzing parts of the hydrological cycle that interact with geological features, satisfy essential needs, and for allow biological and human evolution. The first research question we want to address is: What value should be attributed to water resources in the definition of geodiversity?

Despite the broad interests and various focuses of contemporary geodiversity methods and tools, the related literature considers hydrology as a fundamental component of geodiversity assessment [1,5]. However, relationships between geology and water resources have been frequently analyzed in a sectorial way:

- 1) by strictly considering the hydrogeological aspects with a purely quantitative method in order to establish precise numerical values about productivity of an aquifer [6];
- 2) by qualitatively interpreting hydrological details, either in a landscape analysis perspective [7], or by applying a morphographic approach to hydro-geodiversity issues [8].

Although the methods used in the two aforementioned studies have opposite aims and results (quantitative versus qualitative), their main tendency is to perform partial analyses of the interaction between water and geodiversity, i.e., by focusing on specific geological or geomorphological phenomena (in these last two cases: landforms and river dynamics), thus neglecting other relevant elements of the hydrological system.

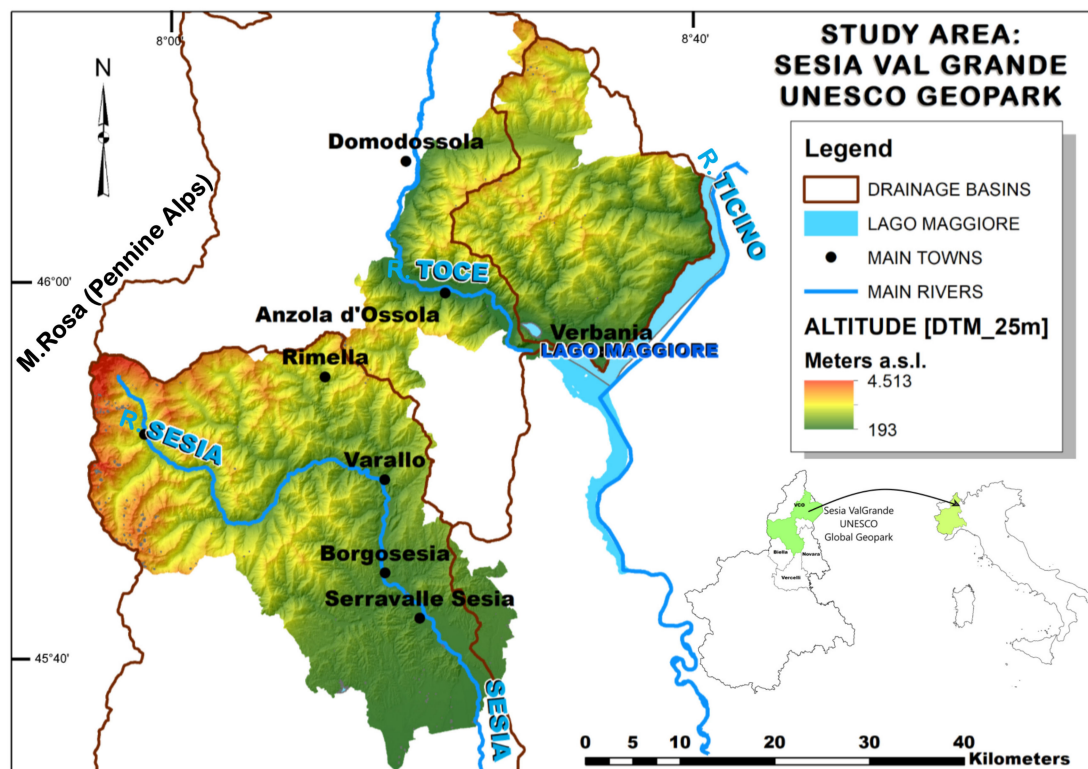
On the other hand, some authors [9,10] posed a greater effort in a systematic attempt to define the structure of the hydrogeological interactions, including factors and variables useful for creating a map of water resources. In the study by Araujo and Pereira, such a factor map represents a fundamental part of the final geodiversity map of the State of Ceará, in Brazil [9].

Despite the undoubted inclusion of hydrological processes in the geodiversity equation adopted by Brazilian and Polish assessments [9,10], the real crux of the matter is that, to date, there is no uniform choice of essential variables to be considered for classification of hydrological elements relevant for geodiversity assessment. This is particularly relevant for regional geodiversity studies, such as large-scale surveys and assessments, where a theoretical framework has to be carefully discussed for achieving successful applications [11].

To overcome the problem, we sought to define and test a set of relevant variables for a qualitative-quantitative assessment of hydrological-geodiversity in the Alpine territory of the Sesia Val Grande UNESCO Global Geopark (UGG). In a preliminary phase, it was necessary to devise a relational model that could provide support for the collection and management of information to be processed. This important and preliminary research operation included the definition of a conceptual model for geodiversity assessment in relation to water resources, based on the specific territorial context, and the adopted regional scale of analysis.

## 2. Study Area

The Sesia Val Grande UGG [12] study area covers about 2000 km<sup>2</sup> and is located in the Piemonte Region (NW Italy) (Figure 2). The area includes 106 municipalities across 4 provinces: Verbania, Vercelli, Novara, and Biella. Elevation of the territory varies from 190 m a.s.l. at the lower alpine piedmont area to 4554 m a.s.l. at the top of Monte Rosa (Pennine Alps), the second highest massif of the European Alps. Indeed, the area is mainly mountainous, including high plains and large floodplains, as well as a portion of the Maggiore Lake.



**Figure 2.** The study area of the Sesia Val Grande United Nations educational, scientific, and cultural organization (UNESCO) Global Geopark (UGG).

The study area comprises three important hydrographic sub-basins of the Po drainage basin (Figure 2): those of the Sesia river (3079 sqkm area, 138 km length), Toce river (1785 sqkm area, 57 km length), and Ticino river (6033 sqkm area, 284 km length) [13]. Many factors and competing morphodynamic processes contributed to the shaping of the mountain relief and the valleys system, i.e.,

the litho-structural and tectonic conditions posed by alpine orogeny and the morphoclimatic variations, such as the Pleistocene glacial/interglacial phases and later Holocene stages. These “regional” factors are related to long-term processes, giving the basic shape of the Alpine mountains and valleys, then followed by important Holocene “local” morphogenetic processes of fluvial/torrential, as well as of gravitational origin. Currently, the dominant geomorphic agency in the valleys of Sesia Val Grande Geopark is the fluvial-torrential one, which is accompanied by consistent gravitational instabilities, where the slopes are steeper. [14]. A large portion of the territory shows fluvial/torrential landforms along steep slopes (16% or more), such as deep river incision, mainly in bedrock, with abundant debris deposits, often forming debris fans up to km-size. On the other hand, in valley floor and high plain areas, rivers created terraces at the valley sides, and multiple to single channels had a tendency to meander at the valley mouth [15].

At higher elevations, glaciers have been the most important morphogenetic agent during Holocene. Indeed, the upper areas of the high valleys are dominated by glacial and periglacial processes [16]. Despite the ongoing climate warming and the predominant southern exposure of the slope of the Monte Rosa Massif, seven glaciers are still present [17], whose hydro-geosystem value is undeniable: they constitute the sources of the Sesia river, as well as of a beautiful landscape, even if they are extremely sensitive and endangered by climate change.

Concerning the tectonic setting, Figure 3 shows the main structural units and geological complexes, in which the geopark is located. Units of the Southern Alps are aligned along a northeast-southwest direction, juxtaposed to the Austroalpine units along the Insubric Line (towards W) and to the lower Penninic units along the Sempione-Centovalli Line (towards N). In turn, the Austroalpine is in tectonic contact by means of complex polyphasic deformation with the Penninic domain, herein represented mainly by oceanic units [18].

The lithological geodiversity constrains the Geopark’s hydrological features. The whole area (Figure 3) is mainly characterized by crystalline basement units, i.e., lithologies whose permeability depends on fractures density. A little portion of conglomerates, limestones, and marbles outcrops in the Lower Sesia Valley, while fluvial and fluvio-glacial deposits characterize the valley floors and the piedmont. These last units represent the reloading areas of the high productivity aquifers present in the territory.

The various geo-lithological complexes, combined with their structural settings, contribute to the large geological diversity of the area and, at the same time, define highly diversified hydrographic network and rich hydrogeological structures [19], as follows:

1. Alpine and pre-Alpine magmatic and metamorphic rocks (a large diversity including granite, gabbro, diorite, peridotite, quartzite, gneiss, micashist, amphibolite, granulite, etc.) from main lithotectonic units of both internal (Southern Alps: Ivrea-Verbano, Serie dei Laghi, and periadriatic magmatic units) and axial alpine belt (Sesia-Lanzo, Monte Rosa, and Liguria-Piemonte oceanic units). Generally, groundwater circulation is absent or limited to surface fracture systems and major faults. The prevalent permeability varies from low to very low but along the most fractured zones, the degree of permeability can also vary from medium to high.
2. Dolostones and breccias of Triassic-Jurassic sedimentary cover the Southern Alps and metamorphic carbonatic rocks (marble) within the mentioned alpine units. They are characterized by remarkable water circulation due to superficial and deep karst phenomena. The prevalent permeability (for fracturing and karst phenomena) results from high to medium.
3. Sands (Pliocene Asti Sand of marine origin): the prevalent permeability for porosity has a medium degree. The coarser terms of this complex represent aquifers of good productivity.
4. Lacustrine, marsh, and fluvial sediments (“Villafranchian” deposits): the prevalent permeability for porosity is of medium degree, even if they are characterized by a high heterogeneity, depending on the depositional environment.
5. Pleistocene to present-day glacial deposits. The prevalent permeability for porosity varies from medium to low.



6. Alluvial deposits: these sediments are located in the valleys bottom and in the piedmont. Due to their porosity they show prevalent permeability from high to medium and contain a shallow unconfined aquifer in connection with surface rivers.

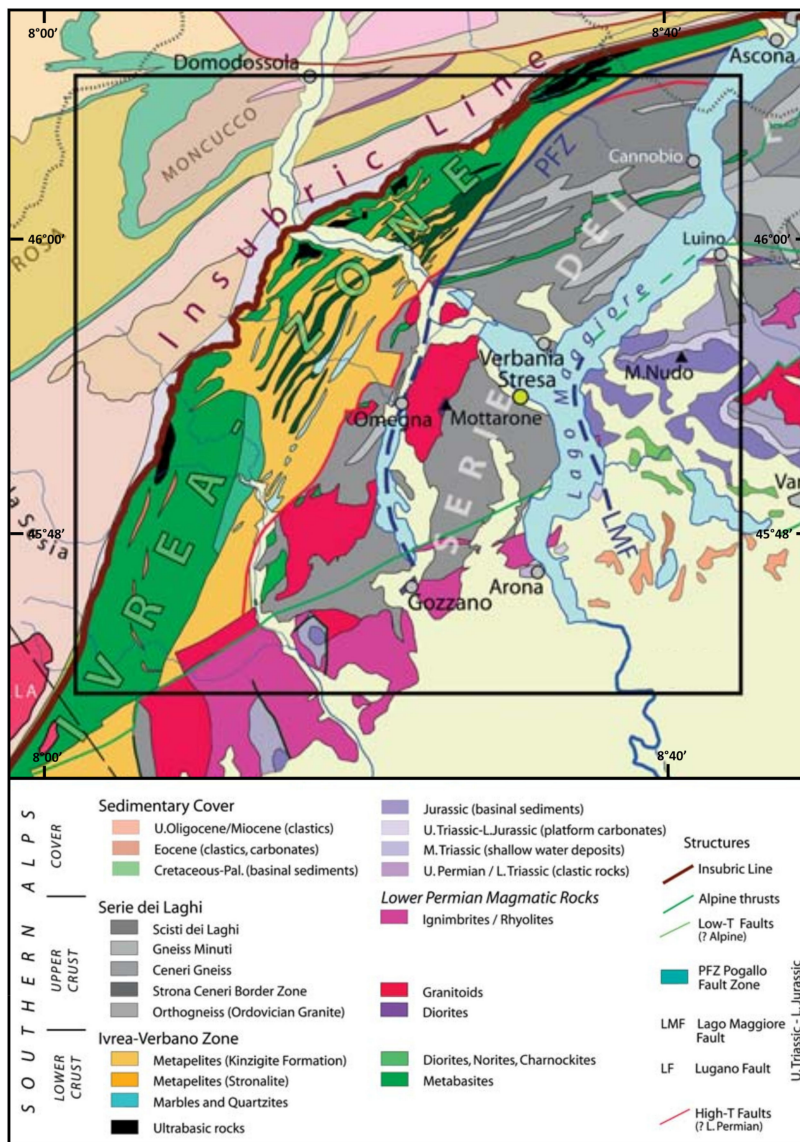


Figure 3. Map of the geological and structural units of the Sesia Val Grande UNESCO Geopark. (modified from Brak et al. 2010) [18].

### 3. Materials and Methods

In the following paragraph, we describe the adopted methodological approach, the selected parameters, and the methodology chosen for carrying out the evaluation process that led to the final map of hydro-geodiversity of the Sesia Val Grande UGG.

#### 3.1. Methodology

Before defining the input data for hydro-geodiversity assessment, it is necessary to define the conceptual structure of the assessment. In this specific evaluation, the intention is to consider values and services that the territory and community derived from the abiotic components in connection with the dynamics of the water and the formation of aquifers.

Gray’s (2013) model of geosystemic services identifies five different categories of geoservices [2] and was adapted in a hydrogeological overview and applied to the local context of Sesia Val Grande UNESCO Global Geoparks area (UGGp). This kind of approach, usually part of qualitative methods to assess geodiversity [20], is human-centered. Our analyses identified hydro-geosystem services, which represented hydrogeological features capable of offering a range of specific services and goods.

The conceptual process guided the assessment of hydro-geosystem services and is described in Figure 4. Starting from the analyses of relationships between geodiversity and water, we proposed a framework for hydro-geodiversity. Since it represents the part of geodiversity concerning the hydrosphere, it includes hydrogeological phenomena that interacts with geolithological features, the component of geomorphological landscape, and the way in which human societies manage them.

According to the conceptual scheme of geosystem services by Gray (2013), interlinked categories have been found and the intensity and types of relationships are described in Figure 4:

- regulating dynamics (atmospheric, geological, geomorphological, and anthropogenic processes);
- provisioning (of drinking water, water for industry, agriculture, or energy production);
- cultural processes (related to the development of the spiritual, religious, and collective identity of local communities and to the maintenance of psycho-physical health);
- knowledge processes (which reconstruct the evolutionary history of terrestrial cycles, deal with monitoring quality, and presence of water in glaciers, canals, aquifers, which develop strategies for the management of hydrogeological risk in a context of climate change).

These interactions determine a range of hydro-geoservices that forge the structure of the hydro-geosystem, which corresponds to a certain degree of hydro-geodiversity. The conceptual definition of the hydro-geosystem services in the territory under study was essential to understand and define the input data to consider the hydro-geodiversity map of Sesia Val Grande UNESCO Geopark.

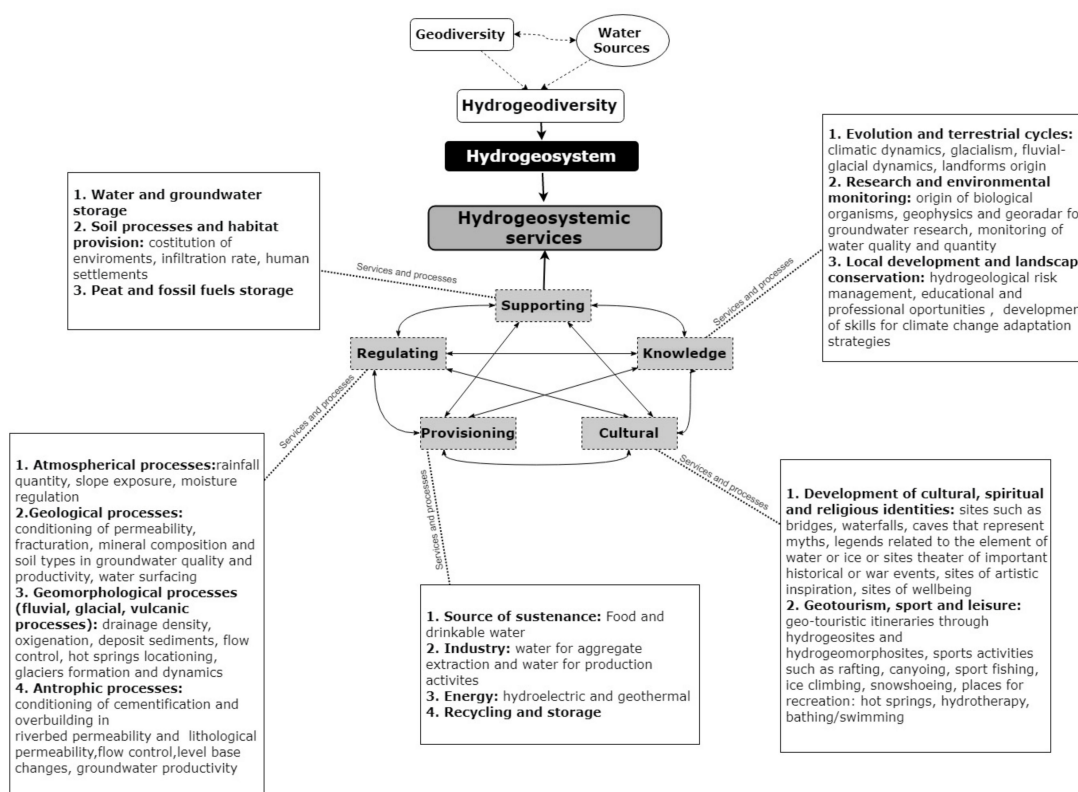


Figure 4. Hydrogeoservices from Gray (2013) [2].

### 3.2. Hydro-Geodiversity Assessment

Once analyzed, the characteristics of the territorial context defined the conceptual setup of the research, it was possible to proceed with the definition of the parameters of the hydro-geodiversity assessment. The specific parameters are described in detail in Table 1. The operational purpose is to identify areas characterized by high hydro-geodiversity using a qualitative-quantitative evaluation technique.

**Table 1.** Chosen parameters for hydro-geodiversity assessment in the case study area (modified from Zwolinski, Najwer, and Giardino, 2018) [20].

Chosen Parameters for Hydro-Geodiversity Assessment in the Sesia Val Grande UNESCO Global Geopark		
<b>Purpose</b>	1° = COGNITIVE	1°: Define a conceptual structure of geodiversity linked to water resources
	2° = OPERATIONAL	2°: Identified areas characterized by high hydrological geodiversity
<b>Data Source</b>	INDIRECT	Cnr-Regione Piemonte [21] Siri - Regione Piemonte [22] PPR piemonte [23] Arpa Piemonte [24] Autorità di bacino po [25] Corine land cover [26]
<b>Subject</b>	SELECTIVE APPROACH	Choice of a set of components of the natural abiotic environment
<b>Spatial Scale</b>	REGIONAL	Analysis Scale 1:100.000
<b>Time Scale</b>	CURRENT	Most updated data
<b>Evaluation Criterion</b>	RELATIVE	Hydro-geosystem services, human-centred
<b>Evaluation Technique</b>	MIXED = QUANTITATIVE-QUALITATIVE	Expert and automatic classification
<b>Representation of the results of evaluation</b>	CARTOGRAPHIC	ESRI ArcGis

The hydro-geodiversity assessment procedure is typically quantitative, based on the pioneering work of Serrano and Ruiz [11]. It is the kind of approach based on the construction of map algebra indexes and techniques, using geographic information system (GIS) software to process information. To achieve this practical purpose, we performed a GIS analysis by using ArcGis 10.5 software (developed by ESRI Redlands, USA) on a complete set of georeferenced spatial data. On the basis of the available data and the survey scale, a hydro-geodiversity equation was established, whose variables corresponded to the factor maps that were added together using weighing techniques in the map algebra phase.

Due to the large study area, the chosen scale for the evaluation was 1:100,000. Indeed, several relevant features for geodiversity assessment are at a nominal scale of 1:10,000. In order to obtain a final representation that was compatible with the finale factor maps and consistent with the chosen scale of representation (1:100,000), we did a semi-automatic data generalization.

Based on the selected scale of analyses, a geodatabase was constructed by collecting the public data provided by regional and territorial agencies, as described in the data source field described in Table 1.

The main steps for the hydrological geodiversity assessment were:

- 1) Construction of a georeferenced database in GIS environment;
- 2) analysis and interpretation of the information retrieved based on the guiding model of hydro-geosystem services created previously and considering the significant factors for local communities;

- 3) define factor maps and variables using an iterative approach;
- 4) combine factor maps, attributing weights in map algebra operations;
- 5) choose and create the final hydro-geodiversity map for the Sesia Val Grande UNESCO Global Geopark;
- 6) identify hydro-geodiversity landscapes and promote their conservation.

Data selected in the initial phase have undergone changes due to scale compatibility or type of input data. An iterative process was adopted [27]. Available data were collected and analyzed, and we observed the results and determined which data could be used and how.

Four main factors were chosen for the evaluation of hydro-geodiversity:

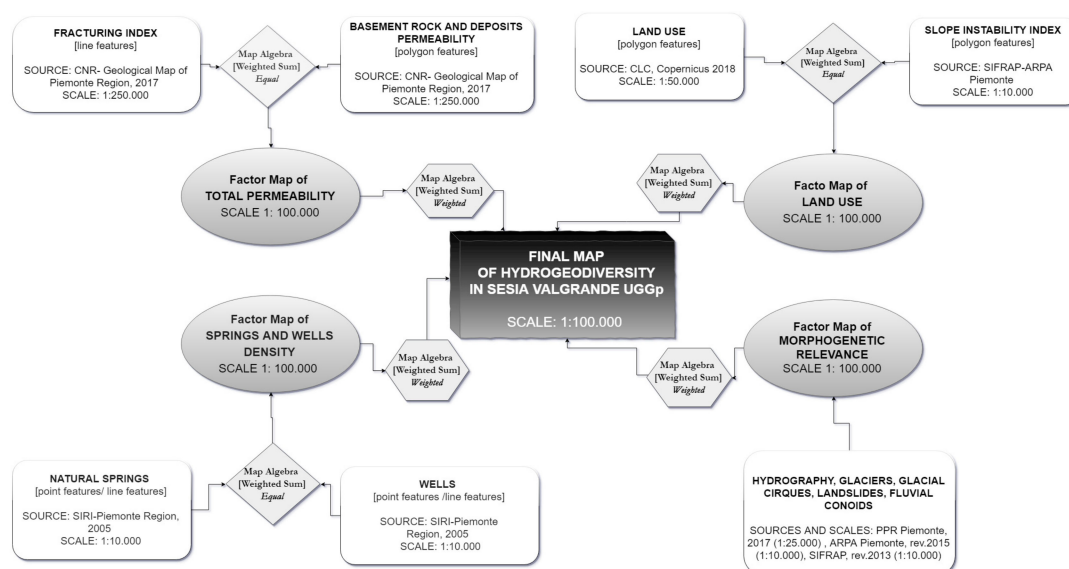
- Basement rocks and deposits permeability, integrated with fracturing index (tP), for the factor map of total permeability;
- land use integrated with the slope instability index (tLU) for the factor map of total land use;
- springs and wells location (SWD) for the factor map of springs and wells density;
- Hydrography, glaciers location, glacial cirques, landslides, and alluvial fan location (MR) for the factor map of morphogenetic relevance.

These factors represent the variables of the hydro-geodiversity (HGD) equation, which can be summarized as:

$$\text{HGD} = \text{tP} + \text{tLU} + \text{SWD} + \text{MR} \quad (1)$$

From the vector data and the expert classification of the elements, the data has been transformed into a raster format. This allows us to assign a value to each identified class and to add the obtained images with a final resolution of 25 m.

Figure 5 briefly describes the methodology adopted in the evaluation assessment, as well as highlighting the relationships between the four factor maps in creating the hydro-geodiversity map.



**Figure 5.** Flow diagram for the creation of the final map of hydro-geodiversity in the Sesia Val Grande UNESCO Global Geopark.

Once the four factor maps have been obtained, the next step includes the processing of partial maps via attributing weights through map algebra. By varying the weight of the individual partial maps in the map algebra phase, it was possible to evaluate and compare the results of the weights assigned to the individual factor maps. To find the best weight proportions used to obtain a result that

identifies sufficiently homogeneous areas of hydrological geodiversity, the AHP (Analytic Hierarchy Process) method [28] was used, which is a multi-criteria decision support technique.

Finally, seven hypotheses of hydro-geodiversity assessment were formulated. Only one was chosen as a representative for the Sesia Val Grande UGG hydro-geodiversity. It was then reclassified into three distinct classes using the natural break method.

Consequently, an interpretation of the results were made, leading to the definition, within the geopark, of a certain number of landscapes characterized by high hydro-geodiversity.

## 4. Results

### 4.1. Factor Map of Total Permeability

The geological lithology [21] was divided by type and degree of permeability. More specifically, the basement rocks, quaternary, and pre-quaternary deposits were classified with values from 1 to 5 based on the hypothetical degree of permeability, which is directly related to the constitution and the productivity of aquifers that hide from lithological formations (Table 2). Both the deposits and rock basements were classified by hypothetical permeability, which underpins their predisposition to constitute aquifers.

**Table 2.** Lithology of rock basement and pre-quaternary deposits in the Sesia Val Grande UGG.

Rock Basement and Pre-Quaternary Deposits	Value
Amphibolite, Diorite, Metabasite, Gneiss, Granite, Granodiorite, Peridotite, Serpentinite	1
Micaschist, Calc-schist, Paragneiss, Phillite, Mylonite	2
Conglomerate, Andesite, Pyroclastic rock	3
Marble, Limestone, Dolomite, Sandstone	4
Villafranchiano, Asti Sand	5

The highest values were assigned to quaternary and pre-quaternary gravelly and sandy deposits. Intermediate values were instead assigned to lithologies such as marble, limestone, and sandstone with mixed deposits or debris flow. Ultimately, very low values were assigned to most coherent lithologies or glacial deposits (Table 3).

**Table 3.** Classification of quaternary deposits in the Sesia ValGrande UGG.

Quaternary Deposits	Value
Glacial deposits and rock glacier deposits (active and inactive)	2
Mixed deposits	3
Alluvial terraces and debris flow (fl2)	4
Fluvial Deposits (fl1) and fluvio-glacial deposits	5

A particular procedure was followed with regard to lacustrine and marsh deposits, since these deposits contain clay and are characterized by low permeability. However, these deposits constitute layers of protection for aquifers and represent superficial environments dominated by the water dynamics that constitute extremely precious biotopes (e.g., peat bogs, marshes, ponds). Thus, classifying these deposits on the basis of permeability means giving them low values; this is not in line with the objective of the present study, which seeks to enhance the centrality of the water element in its interaction with geodiversity. This led to the choice of not considering these deposits in the present classification, but to evaluate them with high value in the factor map of total land use. To complete the factor map of total permeability, the state of fracturing of the substrate and influencing the degree of



permeability of the rock was considered. Indeed, the lithologies of the basement, such as crystalline rocks, have a wide permeability range depending on the level of incidence of tectonic structures. In the study area faults, fault systems and ductile shear systems were distinguished [21]. Moreover, structures responsible for ductile, ductile-fragile, or brittle-ductile deformation were distinguished, because in ductile-fragile areas in the tectonic action produce a greater incidence of fracturing.

In order to create a map of the fracturing index, several hypotheses of classification were advanced. The final decision was to create manually areas of fracturing relevance, attributing more value to fragile deformations as compared to ductile ones. These areas were added to the map of deposits and rock basement permeability, in order to obtain a map of total permeability (Figure 6).

In the map, it is possible to observe how rocks with low degree of lithological permeability assumed maximum values, i.e., the Insubric Line, the Cossato-Mergozzo-Brissago, and the Pogallo Lines.

#### 4.2. Factor Map of Land Use

Land use is an important factor to consider in the equation of hydro-geodiversity because it explains the human impact on natural environments. In the hydro-geodiversity assessment, it is important to highlight all variables that seal or pollute the ground. Thus, the factor map of land use collects all types of land uses identified by the corine land cover satellite tracking system, which integrates them with wetlands, marsh areas, and lakes (Figure 7).

The identified elements were classified based on their possible effect on ground permeability, as well as the possibility to create underground reserves and water resource pollution.

Because of this, the factor map of land use collects all types of land uses identified by the corine land cover satellite tracking system. The elements identified are then classified based on the possible conditioning of the ground or riverbed permeability, as well as the quality of the underground reserves.

Table 4 summarizes the considered variables, classifying them from the lowest hydro-geodiversity value (1) to the highest (5). Regarding the lake data, provided by the regional landscape plan (PPR), only the water elements with a surface greater than 100 m × 100 m were selected. This measure corresponds to the minimum “cartographic” resolution at the 1:100,000 scale.

**Table 4.** Expert classification of Land Use types in Sesia Val Grande UGGp.

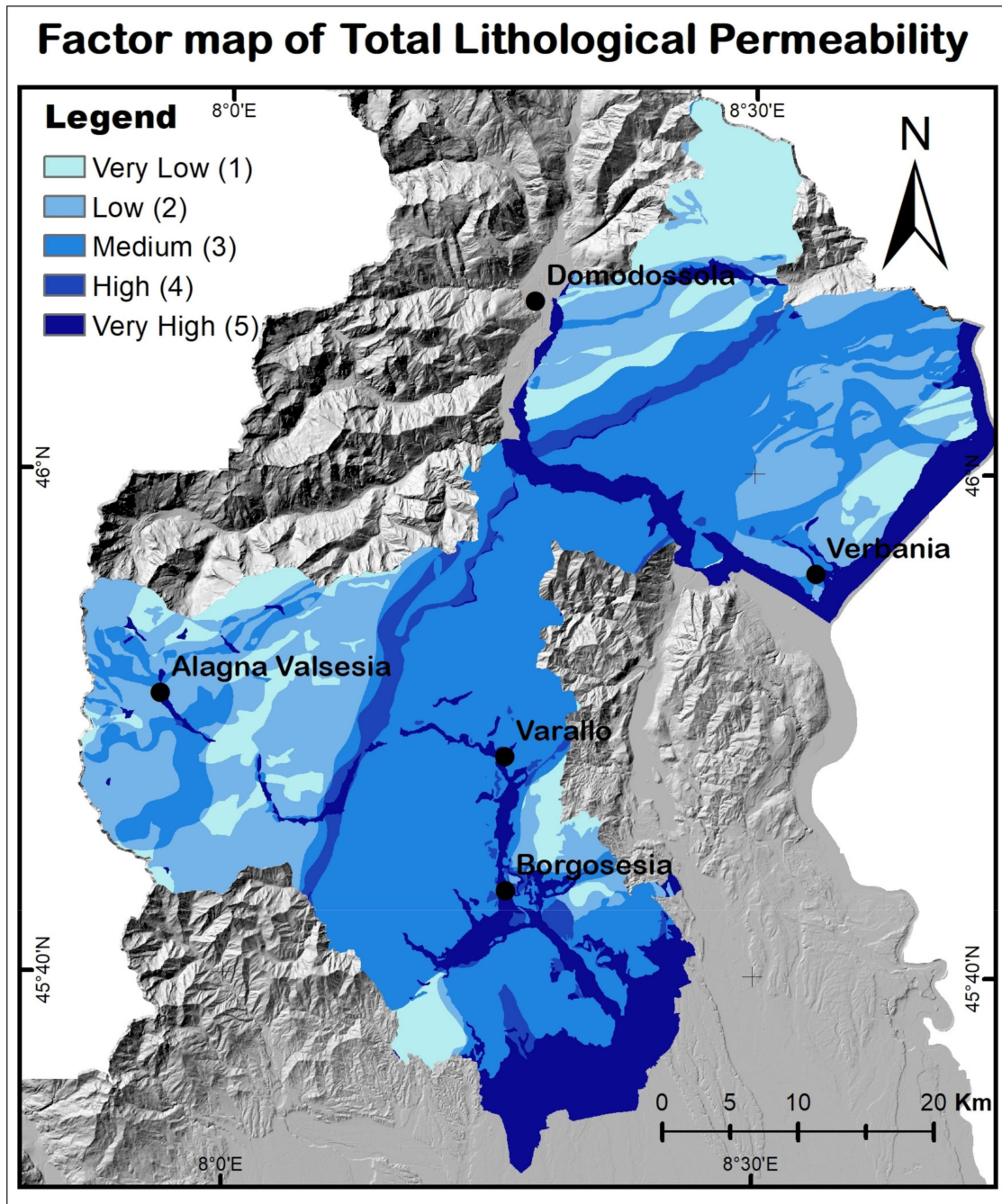
Land Use	Value
Continuous Urban, Fabric, Industrial or Commercial Units, Road and Rail Networks and Associated Land, Bare Rocks	1
Discontinuous Urban, Fabric, Sport and Leisure Facilities, Non-Irrigated Arable Land, Complex Cultivation Patterns, Sparsely Vegetated Areas	2
Pastures, Land Principally Occupied by Agriculture, With Significant Areas of Natural Vegetation, Coniferous Forest, Moors and Heathland	3
Broad-Leaved Forest, Stable Meadows	4
Beaches, Dunes, Sands, Glaciers and perpetual Snow, Inland Marshes, Lacustrine Deposits and Peats, Water Bodies, Lakes, Mineral Extraction Sites, Rice Fields	5

Considering the number of areal landslides, the map of land use has been integrated with the map of slope instability. Landslide phenomena were considered on the basis of their density; for reasons of scale adaptation, only landslides with a surface area greater than 100 m × 100 m were selected. The slope instability index was obtained by analyzing the density of the area landslides converted to point format. The result of the kernel density analysis was then reclassified into three classes using the natural breaks method (values from 0 to 2).

### 4.3. Factor Map of Springs and Wells Density

The location of springs and wells were mapped separately. Then, in order to obtain a final representation compatible with the other factor maps and consistent with the chosen scale of representation, areas with a higher density of springs and wells were identified (Figure 8).

Natural springs and wells were subjected to a kernel density with a radius of 1000 m [29]. The raster file obtained was then reclassified into four classes (0, 3, 4, 5) with manual classification, turning the areas characterized by low density into a value of 0. For this classification, high values were used to stress the importance of these factors.



**Figure 6.** Factor map of lithological permeability integrated with fracturing index. (Esri ArcGis 10.5, [30]).

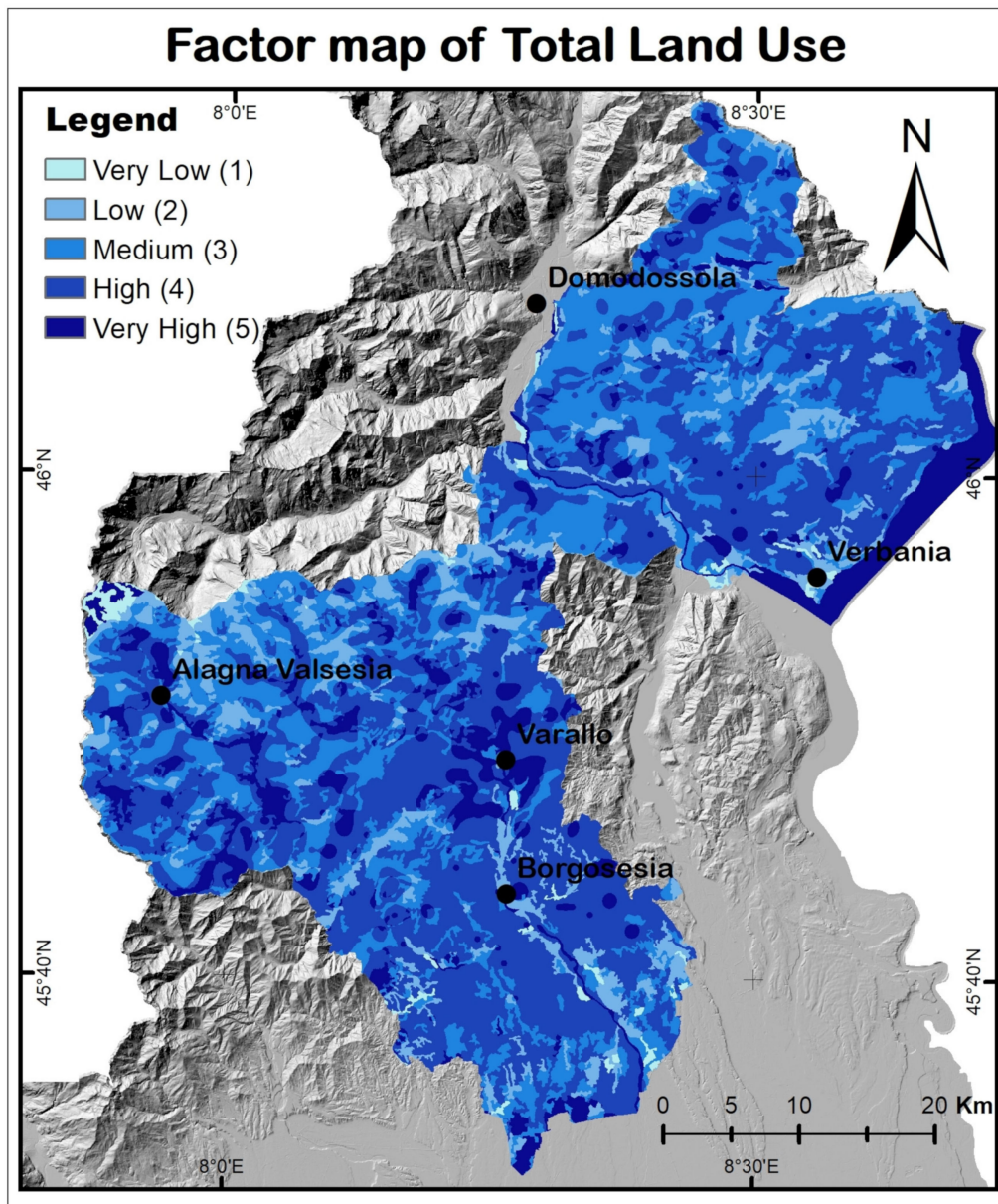
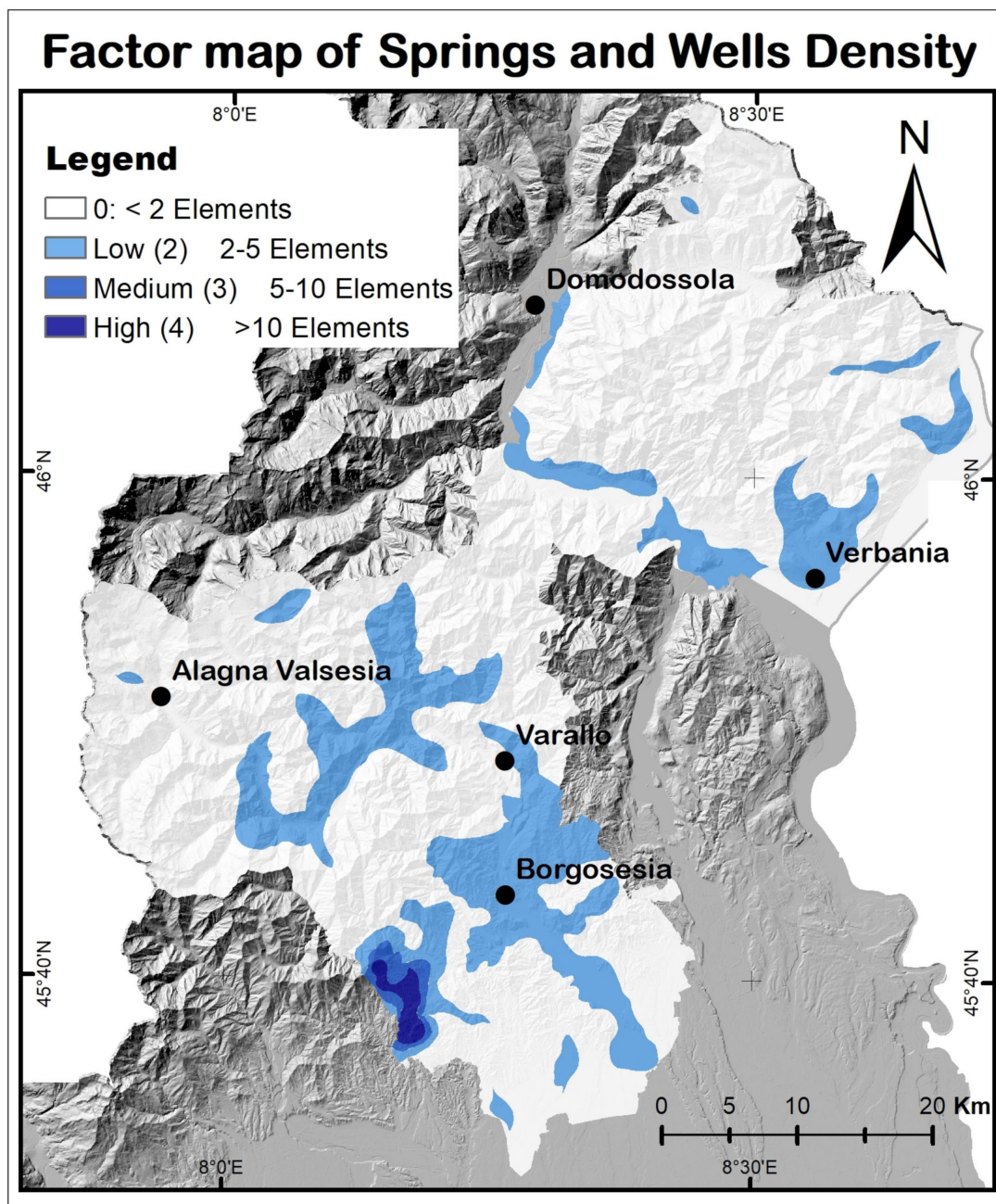


Figure 7. Factor map of land use integrated with landslides density index [30].





**Figure 8.** Factor map of springs and wells density [30].

#### 4.4. Factor Map of Morphogenetic Relevance

The factor map of morphogenetic relevance (Figure 9) is used to consider the predominant geomorphological factors that characterize the study area, as well as the dynamics and genetic processes that are the basis of morphological conformation. The territory of the Sesia Val Grande UGG was therefore divided into three areas of morphogenetic relevance: glacial, fluvial, and gravitational. Geomorphological elements taken into consideration are glaciers and glacial cirques for glacial relevance, hydrographic network, alluvial fan, lakes for fluvial relevance, and areal landslides for gravitational relevance. These areas were expertly classified with values from 3 to 5. For the areas dominated by the glacial processes was given the maximum value (5). Glacial modelling is indeed a central factor in the geomorphology of alpine areas.

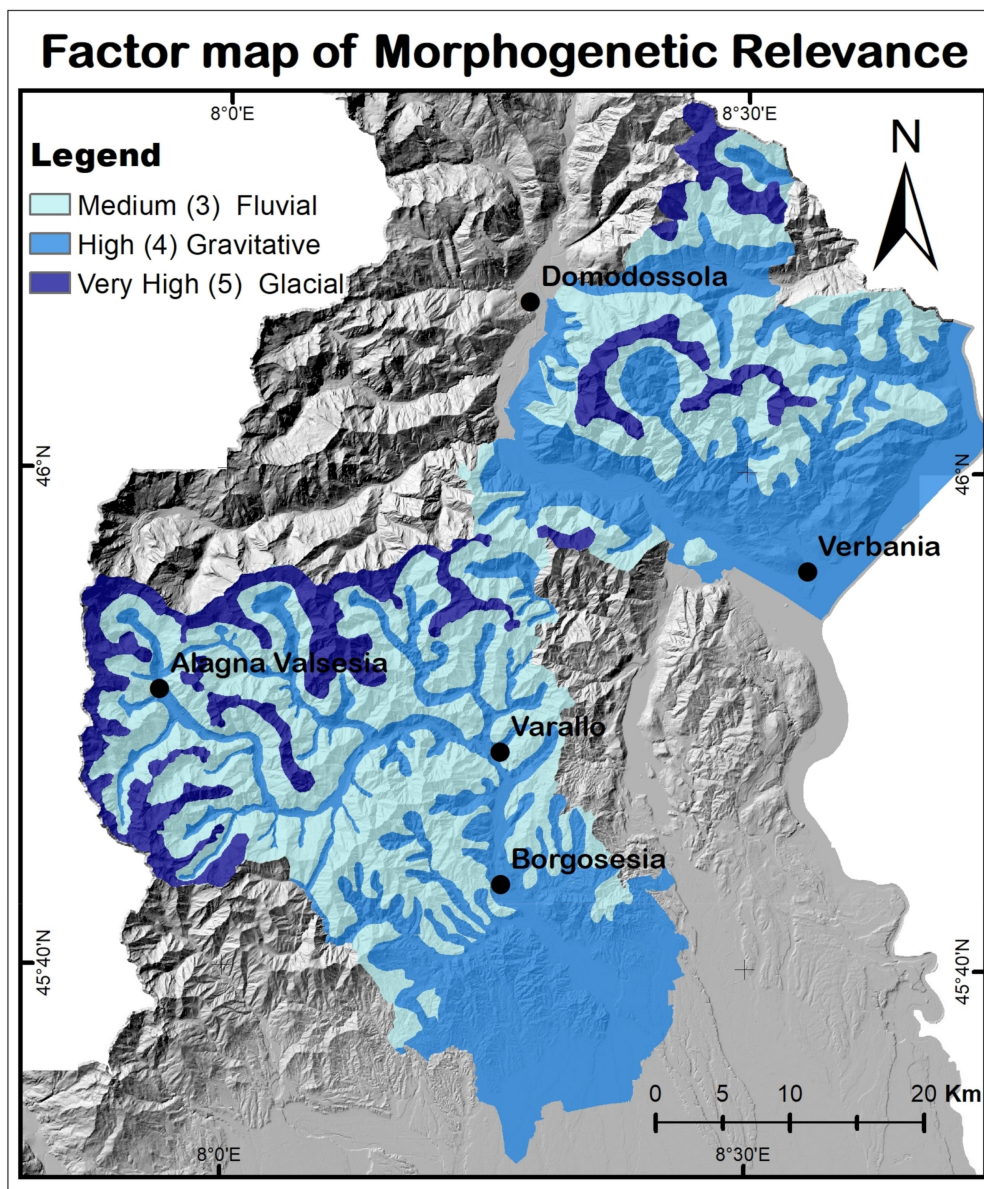


Figure 9. Factor map of morphogenetic relevance [30].

Glacial cirques often host lakes and mountain pastures, which constitute rare habitats and areas used for anthropic purposes for grazing. At the same time, glaciers constitute a reserve for drinkable water and important element of river flow regulation.

The river and lake elements constitute fluvial relevance, which represents a high value of hydrological geodiversity. Lakes and rivers are reservoirs of water. Moreover, rivers can be used for energy production (e.g., dams, hydroelectric power plants) and provide aggregates (e.g., gravel, sand, silt, peat) for various uses. Lastly, the lowest value (3) was attributed to the areas of gravitational relevance. This value has a moderate to high estimation since the landslide processes are firmly interrelated with the water dynamics. They can, in fact, activate and be activated by water processes.

Once the final factor maps were obtained (Figures 6–9), they were added together in a map algebra operation, their sums weighted with GIS, and put through AHP.

This criterion allowed us to create measures that judged consistency, derived priorities between criteria that allowed for comparisons, and established a hierarchy of priorities among the elements. The weighing method adopted made it possible to elaborate many hydro-geo-assessment solutions



(from HG\_A\_1 to HG\_A\_7 in Table 5). Each time, a greater weight was assigned to one of the four factors, as illustrated in Table 5.

**Table 5.** Hydro-geodiversity assessment solutions. The underline values indicate the group of factors that has more weight in the map algebra process.

		Hydro-Geodiversity Assessment; Solution to Be Examined						
		Same Weight	Method Priority Calculation with the Analytic Hierarchy Process (AHP)					
	Factor Maps	HG_A_1	HG_A_2	HG_A_3	HG_A_4	HG_A_5	HG_A_6	HG_A_7
1	Lithological Permeability	1	0,243	0,157	0,157	0,298	0,197	0,175
2	Land Use	1	0,197	0,319	0,281	0,27	0,379	0,409
3	Springs and Wells Density	1	0,182	0,281	0,319	0,246	0,182	0,175
4	Morphogenetic Relevance	1	0,379	0,243	0,243	0,246	0,243	0,241
<b>Consistency rate</b>			4,30%	4,30%	4,30%	2,20%	4,30%	5,70%

The last two solutions, HG\_A\_6 and HG\_A\_7, are the result of a reasoning that considers a more rigorous approach, which was adopted in the present work and the objectives set. A greater weight was used in the land use factor map, containing the elements interacting with the human dimension. While the HG\_A\_6 shows an increasing value of factors, the HG\_A\_7 shows that lower weights are equal. In the HG\_A\_7 solution, land use weight is equal to 40% of the total weight. Moreover, the springs and wells density is equal to 25%. In fact, since these factors are connected to human activities, these results indicates systems of provisioning and pumping of water resources, as well as a strong point for monitoring the quality and quantity of water in deep and shallow aquifers. To the natural abiotic factors, like permeability and areas of morphogenetic relevance, a weight of 17% was assigned to both levels. It was therefore considered that the HG\_A\_7 solution was the best solution for the hydro-geodiversity assessment.

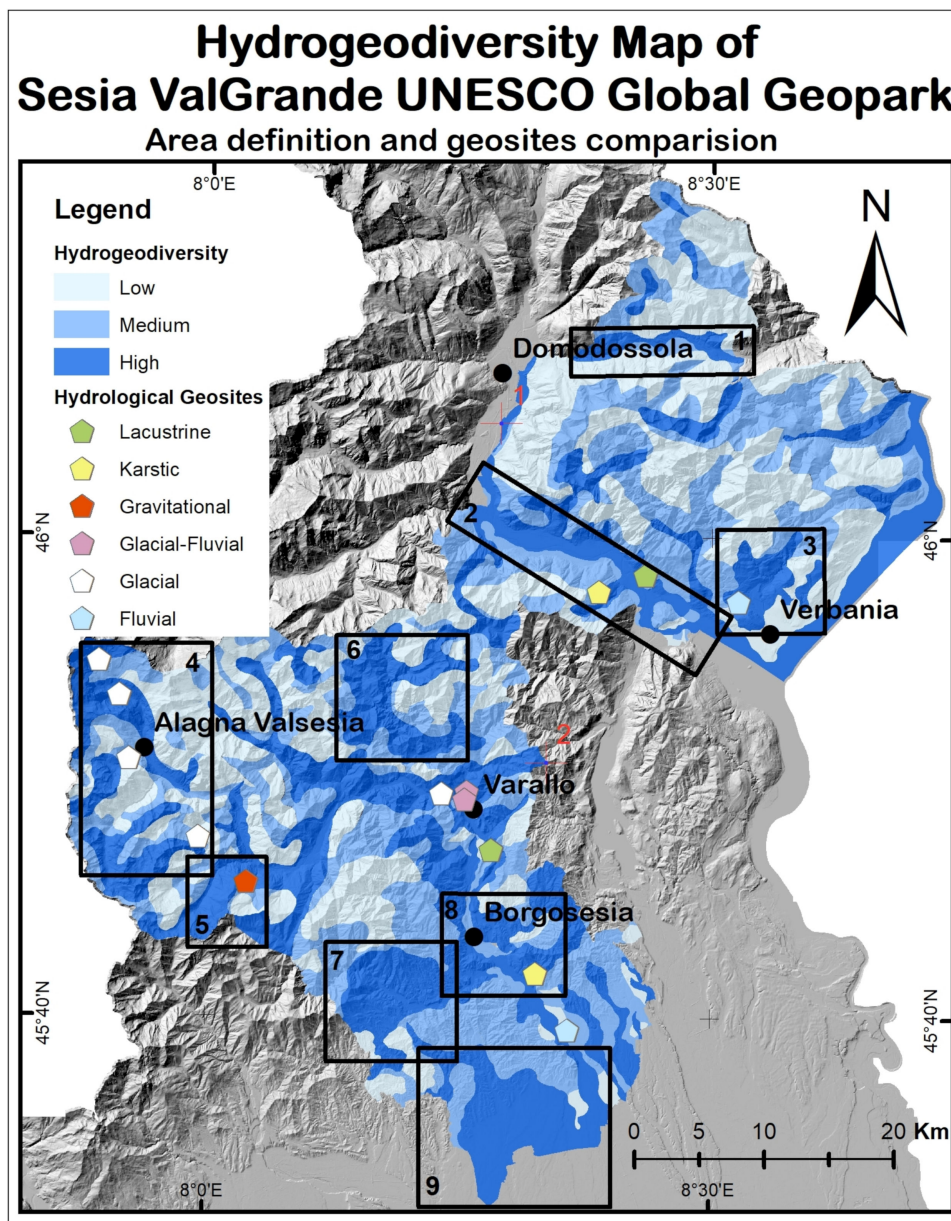
In order to obtain more homogeneous areas, the raster file was reclassified into three classes using the natural breaks method (presented in Figure 10 with specific areas and hydrogeosites).

## 5. Discussions and Conclusions

In this study, nine peculiar areas in the Sesia Val Grande Geopark were identified on the base of the prevailing landscape and its propensity to develop a sustainable relationship between man and the hydro-geosystemic services (Figure 10):

- Area 1: Vigezzo Valley: Landscape of hydrogeological instability
- Area 2: Valley and Piana del Toce: Landscape of alluvial dynamics
- Area 3: San Bernardino and San Giovanni Intra: Landscape of torrential dynamics
- Area 4: Monte Rosa: Landscape of Alpine glacialism
- Area 5: Alpe di Mera: Landscape of deep gravitational instability
- Area 6: Val Mastallone, Upper Val Strona: Landscape of deep valley incisions
- Area 7: Trivero-Val Ponzzone: Landscape of the springs
- Area 8: Monte Fenera and Borgosesia: Karst Landscape
- Area 9: High Po Plain: Landscape of the deep aquifers of the Upper Po Plain

Once identified, hydro-geodiversity areas were compared with the geosite location in order to validate the correspondence between them and the areas of hydro-geodiversity, as well as to verify their representativeness and to test the functioning of the qualitative-quantitative procedure previously applied.



**Figure 10.** The final solution of the hydro-geodiversity assessment reclassified into three classes with natural breaks in the area definition and hydrogeosites [30].

Geosites from the list of that identified for candidacy to the UNESCO program of the Sesia Val Grande Geopark [31], as well as those extrapolated from the ISPRA national inventory of geosites [32] were selected.

Only geosites with a significance in terms of hydro-geodiversity were chosen. In particular, 25 geosites in this selection were plotted on the final map. All geosites (with the exception of 1) fell into areas with high hydro-geodiversity.

Despite this good correspondence, it should be noted that in some areas there are more than one geosite (areas 4, 8) and in other areas, geosites are classified with a high hydro-geodiversity. Occasionally, we noted the total lack of geosites (areas 1, 2, 6,7). If we were analyze the features of geosites, we would note that the categories of representativeness expressed are fluvial, glacial, gravitational, karst, and lacustrine.

Geosites that represent and test the aquifer dynamics and the relationship between the geological structure and the concentration of springs are missing. However, this aspect is considered fundamental

in the hydro-geodiversity classification. This is not surprising and is in line with the tendency to underestimate hidden geosystem features, such as underground processes. This is also demonstrated by recent results of a systematic literature review [33] that show how goods and services derived from the subsurface are underrepresented in the contemporary literature on ecosystem services.

Based on the results and the comparison with the current state of geoconservation of the study area, area 7 (landscape of springs) and area 9 (landscape of the deep aquifers of the Upper Po Plain) are the most important areas in terms of hydro-geosystemic services, as they are directly related to the withdrawal and consumption of water (e.g. drinking water, for agriculture, for breeding). They are also the areas in which human impact is deeper and where there are no instances of hydrogeological protection sufficient for a good preservation. Therefore, more studies and insights about these issues is needed.

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