Sensitivity of the hypsometric integral (HI) and its connections with lithology and neotectonics in the Rodna Mountains, Romanian Carpathians

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ABSTRACT: This study investigates the hypsometric integral (HI) correlations with lithology and neotectonics from northern Romanian Carpathians, Rodna Mountains. Two types of DEM were used in the analysis (a 30 m DEM resolution with specific grid size and a non-gridded 30 m DEM resolution). Several methods have been applied in order to calculate HI: the CalHypso GIS extension was used to automatically extract multiple hypsometric curves from digital elevation model (DEM) and to calculate the main statistics related to the HI by applying polynomial fits; local indices of spatial autocorrelation were applied using Anselin Local Moran's I and Getis-Ord Gi* in order to see if HI distribution has spatial patterns values and selection of valid squares (500-m^2 grid using 30-m DEM using ArcMap 10.1) for the lithological analysis. The values of the hypsometric kurtosis density, kurtosis, skew and density skew are increasing eastwards. Values of hypsometric skewness for the northern slope are in range between 0.290-0.816 and southern part between 0.414-0.507. The results show that HI values are higher than 0.5 in the areas with recent tectonic influences especially in northern part near Dragoş Vodă fault system. The Oligocene, Miocene, Pleistocene and Holocene formations have low values (<0.5) while Precambrian, Cambrian, Silurian, Eocene, Miocene and Pliocene formations have higher values (>0.5). By comparing the HI values from the two analyses (500 m grid size DEM and the DEM without grid size) of the DEM we find slight differences in the HI values, especially in the northern part of the range in Repedea, Negoiescu Mare, Fântâna and Lala basins.

KEY WORDS: hypsometric integral, lithology, northern Romanian Carpathians, spatial analysis

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1. Introduction

The hypsometric curve and hypsometric integral are non-dimensional measures of the proportion of the catchment above a given elevation (Strahler, 1952) and have been interpreted in terms of degree of basin dissection and relative landform age: convex-up curves with high integrals are typical for young, undissected (disequilibrium stage) landscapes; smooth, s-shaped curves crossing the center of the diagram characterize mature (equilibrium stage) landscapes, and concave up with low integrals typify old and deeply dissected landscapes (Strahler, 1952). Some studies have shown that hypsometric integral values (HI) are sensitive to the erosional resistance of rocks, catchment characteristics, relief or where the topography is eroded during uplift (Ohmori, 1993).

The study of Schmidt et al. (2013) - based on zircon fission track analysis highlights that in early Cretaceous (Austrian phase), the close spatial neighborhood of Coniacian to Campanian zircon FT central ages and Cenomanian sediments in the eastern part of the Rodna horst indicates 7-11 km differential exhumation between the internal area of the Rodna horst and the more external Maramureş Mountains, exhumation that occurred mainly by extension. The Miocene-age differential exhumation did not exceed some 2 km, while in the Eastern Carpathians was in the order of 5-7 km (Gröger et al., 2008; Merten et al., 2010). The presence of Upper Cretaceous sediments deposited on exhumed pre-Permian basement indicates exhumation of parts of the basement of the Bukovinian nappe stack to the earth's surface in Late Cretaceous times (Schmidt et al. 2013).

2. Data and methods

The analyzed region (Figure 1) covers a small part of the Northern Romanian Carpathians. The Rodna Mountains are one of the longest continuous ridges in Romania, extending over 50 km from west to east, which makes it the most important mountain range in northern Romania, in terms of the geological features. The highest elevations occur in Pietrosul Rodnei peak 2303 m asl (the highest point in the Eastern Carpathians) and Ineu peak, 2279 m asl. The entire Eastern Carpathian Range collided in the Miocene with the European foreland closing the Carpathian embayment and forming the external Miocene-age flysch (Matenco et al., 2003).

The main evolutionary stages can be summarized as follows: a) volcano-sedimentary formations belonging to Bretila and Rebra groups deposited around 1650-850 Ma have been metamorphosed during Cadomian orogenesis (from Proterozoic); b) in the first part of Paleozoic (Silurian-Carboniferous inf. approx. 325-250 Ma BP) by removing a portion of the southwestern edge of the East European plate, the Hercynian geosyncline was opened, leading to volcanic and sedimentary rocks accumulation and subsequent metamorphosis during the Hercynian orogenesis (Rusaia, Repedea, Cîmpoiasa and Ţibău groups); c) there was an quasi-stability stage in the Permian-lower Triassic. From the upper Triassic until the end of Jurassic, the Transylvanian paleo-rift-zone was opened west of Median Dacid nappe. From the Lower Cretaceous, the central Carpathian rift have been opened east of Median Dacid nappe (Săndulescu, 1984); d) In the most important orogenic phase from Aptian, collision between Transylvanian-Pannonian microplate and Central Carpathian block resulted with the Bucovina Nappe formation; e) In the upper Cretaceous-Paleogene erosion dominated. On a large area of western Rodna Mountains, Borşa bays to north and Bârgău to south have accumulated flysch and molasses rocks; f) In the Burdigalian, due to the compression of major structural units, flysch rocks located in Ţibleş Mountains and western part of Rodna Mountains were involved in the movement (Mutihac et al., 2004). Extensive thrusting process started in the Eostiric phase with a maximum in the Attic phase. As a result, Rodna Mountains have been uplifted by about 6000 m (Sanders, 1988; Hyppolite et al., 1999); g) associated with compression and uplifting, northeast-southwest and northwest-southeast faults were accentuated. They are most common in the southeastern half, from Anies fault toward Bârgăului Mountains contact. To the south of Rodna Mountains lava advanced along on some extensional faults (Seghedi şi Szakács, 1996); h) between Middle Miocene-Upper Miocene, under temperate or subtropical climate (rainfall of 1200-2000 mm), denudation took place with approx. 4 cm thick column of rock in Rodnei Mountains. It is thus an average rate of 375 m/1 million years or 0,375 mm/year (Sanders et al., 1999); i) erosion has diminished significantly under progressive climate cooling since the Pliocene (2.5 Ma in the final). Erosion products have been removed by the river network.

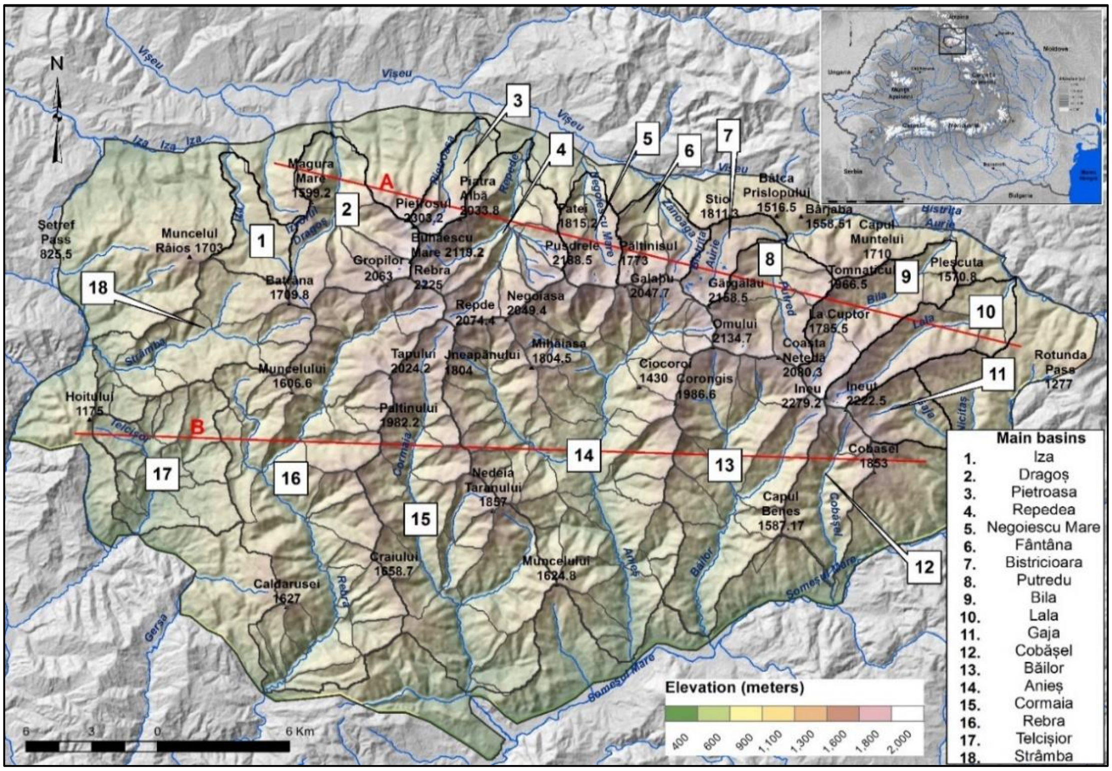


Figure 1 Area of study (Rodna Mountains from Northern Romanian Carpathians) with basins included in the analysis. Line A and B represent cross profiles on main basins (see text and Fig. 10).

The entire crystalline of Rodna has also been affected by tectonic movements after the Eocene and Oligocene sedimentation. The sedimentary rocks from Cretaceous and Paleocene surrounding the massif have been affected also by tectonic movements. These sedimentary Cretaceous and Paleocene deposits are represented by marls, conglomerates and sandstones. To the south some Neogene volcanic rocks (rhyolite-dacite-andesite) are found in the high hills that are located along Someşul Mare River.

As a part of Eastern Carpathians of Dacia Mega –Unit (Csontos et al. 1992; Csontos and Voros 2004; Schmidt et. al. 2005), Rodna Mountains appear as a horst of crystalline build up by the Bucovinian nappe stack and delimited by Dragoș Voda fault to north (Fig. 2) and Rodna (to south). The Bucovinian nappes of Dacia-Unit belonging to the Precambrian-Paleozoic period consists of sediments and subordinated by orthognaise (Krautner, 1991; Voda et Balintoni, 1994). This nappe, from bottom to top has the following succession: Infra Bucovinian nappes, Sub Bucovinian nappe and Bucovinian nappe (Sandulescu 1994). There are tree crystalline layers (Krautner 1968, 1972) Bretila, Repedea and Rebra (Figure 2). A more briefly presentation of lithofacies types that occurs in the area is given in table 1. The Dragos Voda fault forms the boundary of the Borsa Graben (north) with Rodna horst like crystalline body (south). These faults were active during Mid-to Late Miocene times (Tischer et al. 2007).

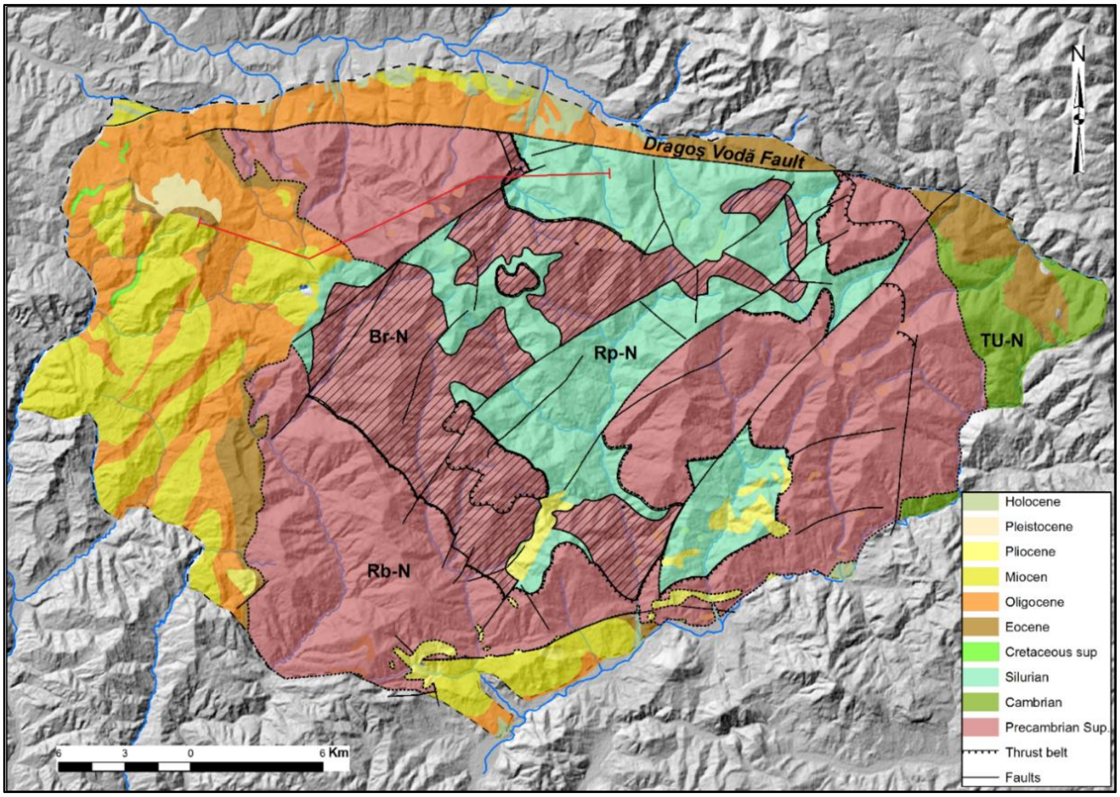


Figure 2 Main geological features in the study area. Codes represent the main tectonic units: Rb-N for Rebra nappe, Br-N for Bretila nappe, Rb-N for Repedea nappe and TU-N for Tulgheș nappe. Red line represent a geological profile (See text and Fig. 14).

Table 1 Description of main lithofacies from study area, 1:50.000 scale map and corresponding codes

Stratigraphy classes	Lithologies	Unit	Age
Ineu Formation IN	Micaschists, paragneisses, quartzites, limestones, green schists	Rb-N	Precambrian Sup.
Voșlăbeni Formation VO	micaschists and granat, micaschists and quartzites	Rb-N	Precambrian Sup.
Izvorul Roșu Formation IR	micaschists, paragneisses, amphibolitic limestone	Rb-N	Precambrian Sup.
Negoiescu Formation NE	green schists, sericite-chlorite schist	Ci-N	Devonian
Gura Fântânii Formation GF	quartzites, sericito-chlorite-calcareous schists	Ci-N	Devonian
Izvorul Cepii Formation IC	sericito-chlorite schists, quartzite schists	Rp-N	Silurian
Știol Formation ST	sericito-chlorite schists, green schists	Rp-N	Silurian
Lespedea Formation LS	gneisses, biotitic plagiogneisses	Br-N	Precambrian Sup.
Mireaja Formation MJ	gneisses, biotitic plagiogneisses	Br-N	Precambrian Sup.
Prislopaș Formation PR	sericit and graphite schists, sericito-chlorite schists	Ci-N	Devonian
Rotunda Formation RO	sericit and graphite schists, sericito-chlorite schists, quartzites, limestones, dolomite	Ru-N	Silurian
Pârâul Omului Formation PO	dolomites, limestones, metabreccia, sericite and graphite schists, metaconglomerate	Ru-N	Silurian

Stratigraphy classes	Lithologies	Unit	Age
Buhăescu Formation BU	sericite-chlorite schists and green schists	Ci-N	Carbonifer Inf.
Metagrauwackelar Formation MGW	quartzite and feldspar	Ci-N	Carbonifer Inf.
Fântâna Formation	sericite-chlorite schists , sericite and graphite schists, limestones, dolomite, green schists	Ci-N	Silurian

3. Materials and methods

Hypsometric curves and integral values of the study area were calculated for equal squares of a specific grid size from a 30m DEM resolution based on the Shuttle Radar Topography Mission (SRTM) 1 arc-second digital elevation data and for a 30 m DEM without grid size. To record efficiently the topographic signal of the region a 500 m grid analysis was computed in ArcMap 10.1. The DEM was pit-filled using ArcGIS tools in order to fill possible voids. Zonal statistics where used in order to compute maximum, minimum and mean elevation of DEMs to obtain HI values for each square. Due to the variety of landscape some high and low HI values can occur together. In order to see if HI distribution has spatial patterns values, local indices of spatial autocorrelation were applied using Anselin Local Moran’s I (Anselin, 1995) and Getis-Ord Gi* (Ord and Getis, 1995). For the Anselin Local Moran’s I the Cluster & Outlier Analysis tool in ArcMap 10.1 calculates a Local Moran's I value, a Z score, a p-value, & a code representing the cluster type for each feature (COType). The Z score & p-value represent the statistical significance of the computed index value. The COType field distinguishes between a statistically significant (0.05 level in this study) cluster of high values (HH), cluster of low values (LL), outlier in which a high value is surround primarily by low values (HL), & outlier in which a low value is surrounded primarily by high values (LH).

The Getis-Ord Gi* tools from ArcMap 10.1 works by looking at each feature within the context of neighboring features. The Gi* statistic returned for each feature in the dataset is a z-score. For statistically significant positive z-scores, the larger the z-score is, the more intense the clustering of high values (hot spot). For statistically significant negative z-scores, the smaller the z-score is, the more intense the clustering of low values (cold spot). The threshold are used in Anselin Local Moran’s I and Getis-Ord Gi* analysis for the 3rd order basins was 0.038627 Degrees respectively 0.067183 Degrees for 4th order basins.

At catchment level, hypsometric characteristics were investigated based on the same DEM. Using TecDEM (Shahzad and Gloaguen, 2011) and taking into account the Horton-Strahler order of the streams, the main catchments/sub catchments from the study area were extracted. Using CalHypso (Perez-Pena et al., 2009) hypsometric integral with their statistical moments were computed for each catchment of Strahler order greater than 2.

The lithological influence on the distribution of HI values has been analyzed using a regional geological map (from a 1:50.000 scale map). Due to a large area HI values, computed for the 500-m2 grid using 30-m DEM, where correlated with main lithological units and age of study area. The lithology information data was obtained for each 500-m2 grid cell and only those where the main lithology covered more than 85% of the cell area (fig.3) have been used for comparison between HI values and main lithological units. The HI values and standard deviation of HI values were computed for each lithological unit. Using R Statistics Software some indexes and variables where generated.

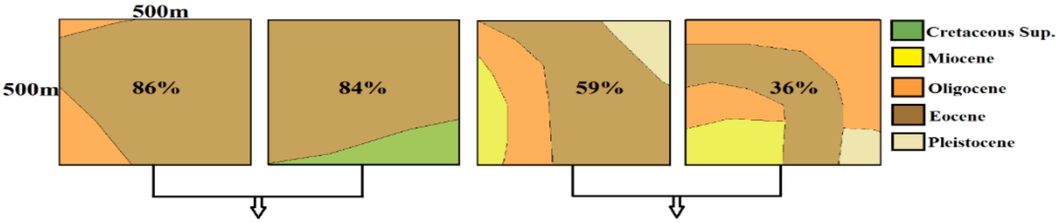


Figure 3 Method of selection of valid squares using ArcMap 10.1 for the lithological analysis (proposed by Pérez Peña et al., 2009b) where the cells that have more than 80% of the same lithological type are taken into consideration.

4. Analysis of the Hypsometric Integral

4.1. 30 m DEM with 500 m grids

For Rodna Mountains the Hypsometric Integral was calculated using a DEM of 30 m resolution. The inset analysis grid was 500 m (Figure 4). The HI values follow a distribution with under a 0.5 mean average value. Hypsometric Integral values spatially depend on the relative topographic position of the squares within the basin. Correlating HI with relief altitude, slope and curvature the HI values are distributed around HI mean we tell that these factors are highly variable.

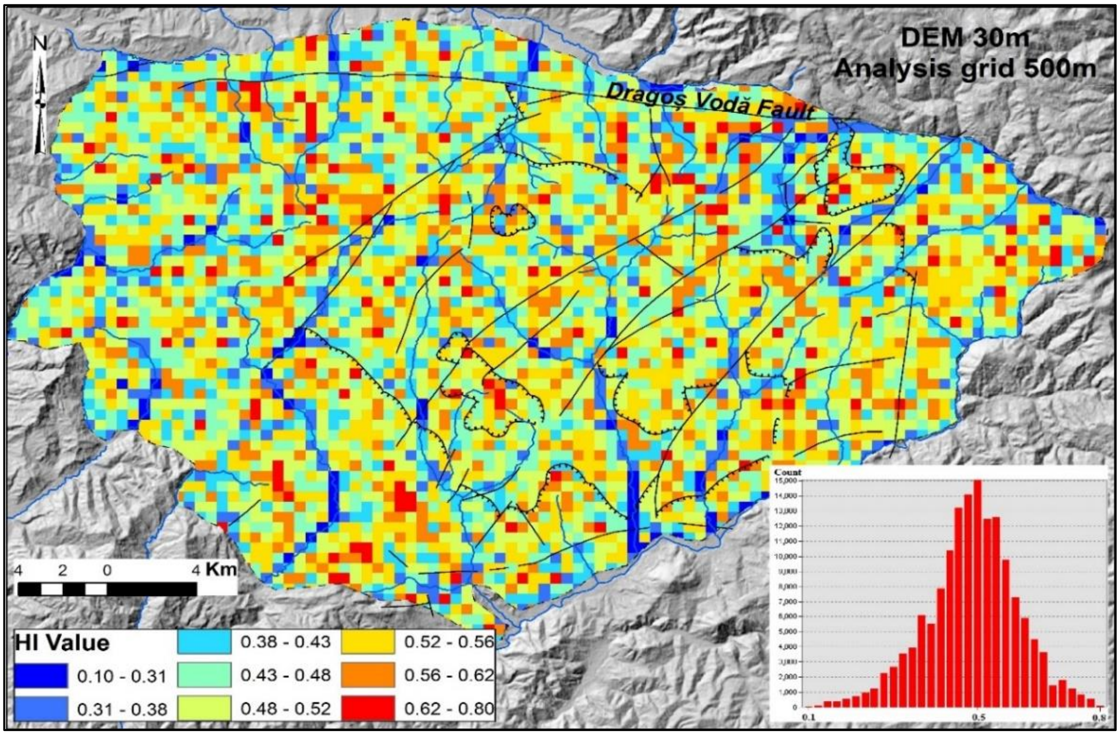


Figure 4 HI distribution in Rodna Mountains using 30m DEM with 500m grid analysis.

There are slight spatial patterns of HI values distribution along E – W towards the mountain range (Figure 5) both in the north with lower values and southern with lower mean values also a clear trend eastwards of the range both north and south. The high values (≥0.55) correspond to less erode "young" landscapes, 0.5 to intermediately mature stage and low values (≤0.35) are related to old, highly eroded landscapes. The 3rd, 4th and 5th order basins, data, do not have a normal distribution regarding the HI values (Fig. 6).

4.1. 30 m DEM without grids

There is a specific pattern of HI in the northern and southern part of the mountain range (Figure 7). The determined HI values for the northern and southern part are given in table 2, also for the sub basins. Hypsometric curves from the southern part have very similar S-shapes denoting intermediately mature stage comparing with the northern part where are concave, S-shaped and convex curves. The concave hypsometric curves that corresponding to Lala, Bila, Putredu and Bistricioara basins on the north-east part of the ridge and also in the north-western part are showing a mature stage. The basins with S-shaped hypsometric curves, are located in the north-west (Iza, Dragos) and north-east ridge (Gaja) of the mountain range. These with the ones from the southern part are intermediately mature. Basins with convex hypsometric curve (Repedea, Negoescu and Fântana) with a less mature stage are found in central part of the northern slope.

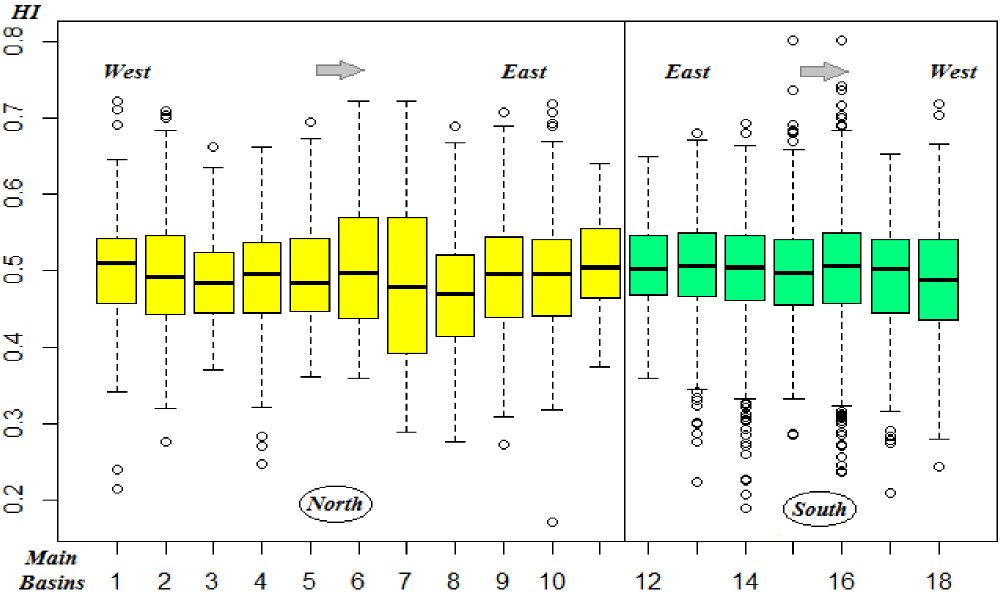


Figure 5 Box-plots showing the distribution of HI on main basins in Rodna Mountains using 30 m DEM with 500 m grid analysis. The error bars represent computed standard deviations.

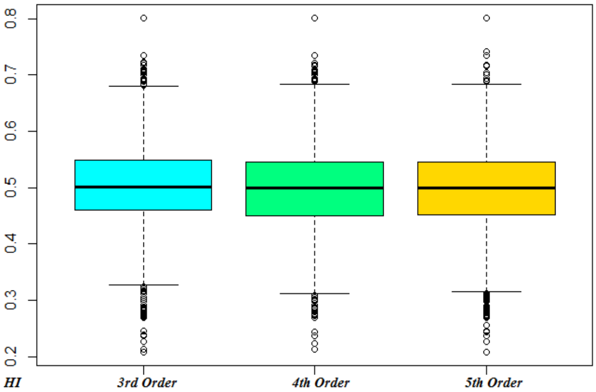


Figure 6 Box-plots showing the distribution of the HI values for different Horton-Strahler basin orders using 30m DEM with 500m grid analysis. The error bars represent computed standard deviations.

The basins that are draining the northern part of the range have much or less contoured S-shape comparing with the southern part where the basins have a good contoured S-shape. Iza, Dragos, Repedea, Negoiescu si Fantana have the less developed curves with a negative density skewness. For the Horton-Strahler rank the basin data have a normal distribution especially for the 4-5th order (Figure 8). Analyzing the HI values and their statistical moments of the main basins (Figure 9, Table 3), there are important variations that could be a good indicator for different stages of erosion.

Table 2 HI values for different Horton-Strahler basin orders from north and south part of Rodna Mountains

Main basin	HI	5th Order			4th Order			3rd Order		
		No	Mean Area	Mean HI	No	Mean Area	Mean HI	No	Mean Area	Mean HI
Iza	0.53							1	11.49	0.48
Dragos	0.447				1	27.3	0.47	5	23.04	0.53
Pietroasa	0.375				1	8.56	0.34	3	9.09	0.36
Repedea	0.507	1	37.35	0.49	3	25.56	0.55	9	24.68	0.49
Negoiescu	0.51				1	12.02	0.5	2	9.96	0.5
Fantana	0.493				1	12.69	0.5	3	10.05	0.54
Bistricioara	0.422				1	31.59	0.42	1	8.93	0.42
Putredu	0.426				1	31.59	0.42	3	14.56	0.46
Bila	0.39				1	22.94	0.38	3	8.34	0.46
Lala	0.372				1	21.12	0.36	2	15.94	0.43
Gaja	0.466							1	10.85	0.45
Stramba	0.481	1	37.67	0.48	2	35.28	0.46	7	16.2	0.48
Telcisior	0.419	1	32.47	0.42	2	19.88	0.42	9	23.11	0.49
Rebra	0.441	1	113.04	0.44	4	52.87	0.47	18	52.01	0.46
Cormaia	0.451	1	80.09	0.45	2	47.23	0.48	10	50.07	0.49
Anies	0.444	3	70.91	0.5	9	72.09	0.5	31	72.36	0.51
Bailor	0.417				1	61.2	0.41	7	35.02	0.51
Cobășel	0.442				1	18.66	0.44	2	3.21	0.58

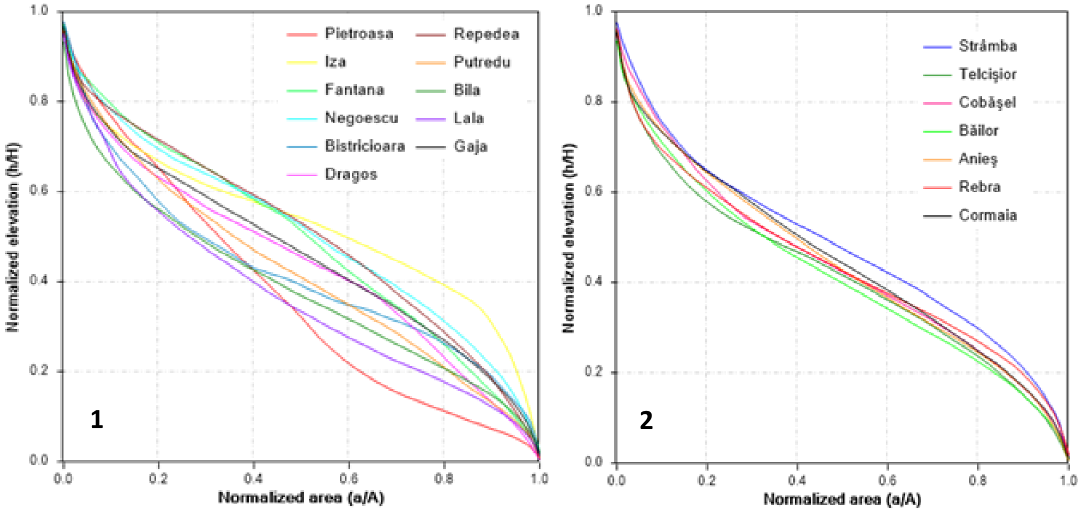


Figure 7 Hypsometric curves of main basins draining northern part (1) and southern part (2) of Rodna Mountains using 30 m DEM without grid squares analysis.

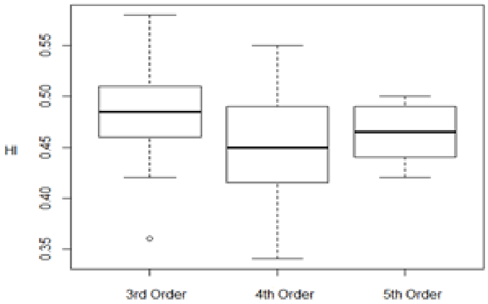


Figure 8 Box-plots showing the distribution of the HI values for different Horton-Strahler basin orders using 30m DEM without grid squares analysis. The error bars represent computed standard deviations.

Table 3 HI values and their statistical moments of the main basins

Basin	HI	Kurtosis	Density kurtosis	Skew	Density skew
Iza	**0.53**	1.954	1.388	0.29	**-0.178**
Dragos	0.447	2.141	1.514	0.444	**-0.069**
Pietroasa	0.375	2.918	2.221	0.816	0.469
Repedea	**0.507**	2.14	1.664	0.417	**-0.239**
Negoiescu	**0.51**	2.096	1.544	0.402	**-0.141**
Fantana	0.493	2.206	1.672	0.464	**-0.144**
Bistricioara	0.422	2.071	1.573	0.458	0.403
Putredu	0.426	2.251	1.607	0.532	0.211
Bila	0.39	2.201	1.623	0.518	0.306
Lala	0.372	2.34	1.858	0.613	0.505
Gaja	0.466	2.134	1.52	0.443	0.011
Stramba	0.481	2.072	1.447	0.414	0.079
Telcisior	0.419	2.116	1.461	0.452	0.12
Rebra	0.441	2.093	1.493	0.436	0.161
Cormaia	0.451	2.178	1.563	0.474	0.067
Anies	0.444	2.198	1.578	0.493	0.134
Bailor	0.417	2.197	1.58	0.507	0.233
Cobășel	0.442	2.149	1.535	0.481	0.231

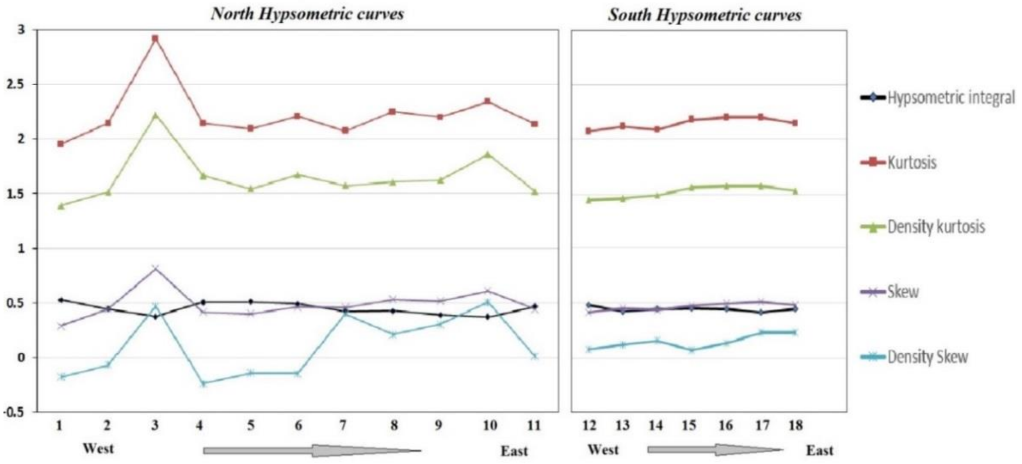


Figure 9 Values of main statistical moments of hypsometric curves for analyzed drainage basins.

The values of the hypsometric kurtosis density, kurtosis, skew and density skew are increasing eastwards. Values of hypsometric skewness for the northern slope are in range between 0.290 – 0.816 and southern part between 0.414-0.507. The Kurtosis have a range of values for norther slope between 1.954-2.918 and south with 2.072-2.198. Iza, Repedea and Negoiescu basins have negative values of density skewness, compared with the hight hypsometric integral values in range of 0.51-0.53.

Comparing HI values from these two analysis (500 m grid size DEM and the DEM without grid size) of the DEM we find some slightly differences in HI values specially in the northern part of the range on Repedea, Negoiescu Mare, Fântâna and Lala basins (Figure 10).

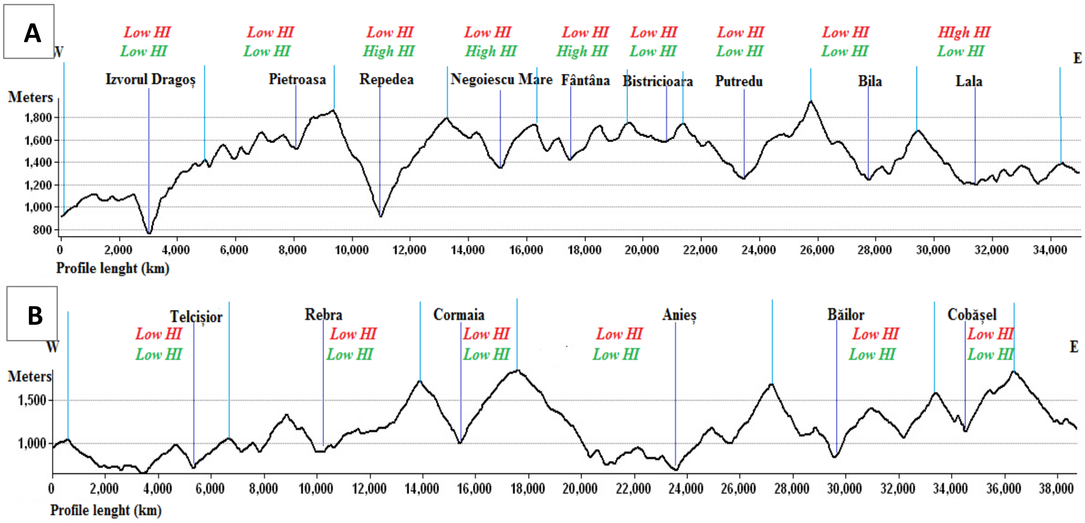


Figure 10 West-East longitudinal profiles on main basins in Rodna Mountains showing the HI values. A) Northern part of the mountain ridge; B) Southern part of the mountain ridge. With red are represented HI values obtained from 500m grid size DEM and green the DEM without grid size.

5. Lithological influence

5.1. 30 m DEM with 500 m grids

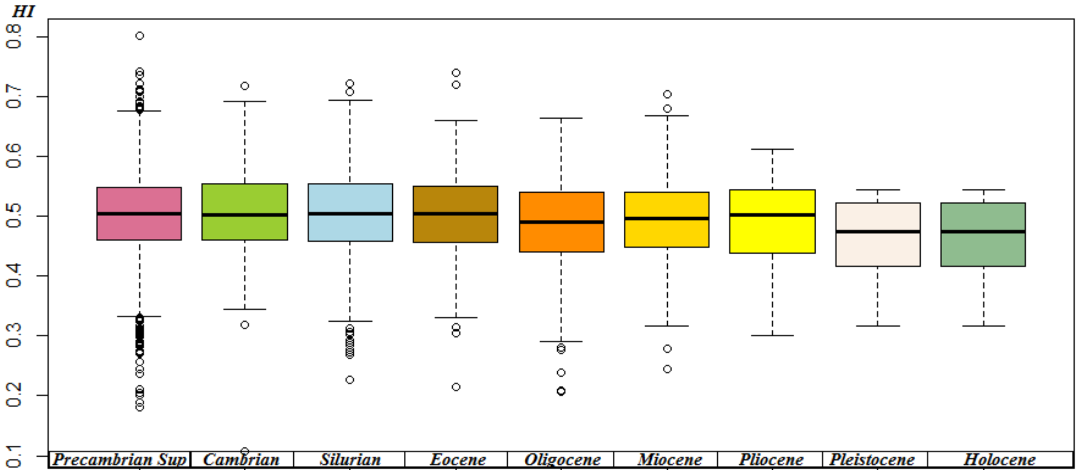


Figure 11 Mean HI values obtained for the age of formations of the main tectonic units. The colors represent the age of formations. Error bars represent computed standard deviations for the HI mean values for each age of the formations.

Taking into account the age of main lithological formations from entire area of study there is a not sure clear trend eastwards of the massif regarding the mean values of hypsometric integral. The formations with Oligocene, Miocene, Pleistocene and Holocene age have low values (<0.5) while the other ones from Precambrian, Cambrian, Silurian, Eocene, Miocene and Pliocene age have higher values (>0.5). The HI values for time units are represented in Fig. 11.

5.2. 30 m DEM without grids

The analysis was performed on main basins also on different Horton-Strahler basin orders. The 4th order catchments developed in Proterozoic formations have the hypsometric integral values in range of 5.1 (Figure 12) while these values are lower in Oligocene-Miocene Inf. formations. From the total 4th order basins only 30% of them have a proportion of main lithofacies above 80%. For the 3rd order basins the number of homogenous features is above 65% with a very similar hypsometric integral value.

The basins developed in Proterozoic Superior and Paleozoic Inferior formations have values in range of 0.5 while those developed in Proterozoic-Paleozoic have values in range of 0.45 and are increasing in Oligocene-Miocene formations with 0.46 mean values of hypsometric integral. Taking into account the entire area of Rodna Mountains related mainly to 3 crystalline layers we can observe that on Rebra and Bretila series, hypsometric integral have the highest values of 0.5 but also the same value is corresponding to Repedea series that have the major percent in the analysed basins. The Tulgheș series with a Proterozoic Superior age situated in the eastern part of the mountain range have values in range of 0.45.

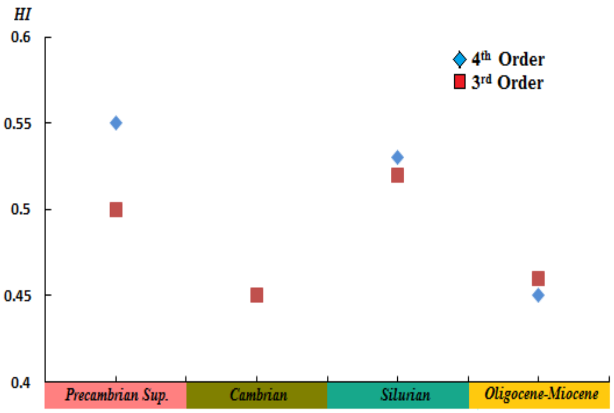


Figure 12 Mean HI values for different Horton-Strahler basin orders obtained for the age of formations of the main tectonic units.

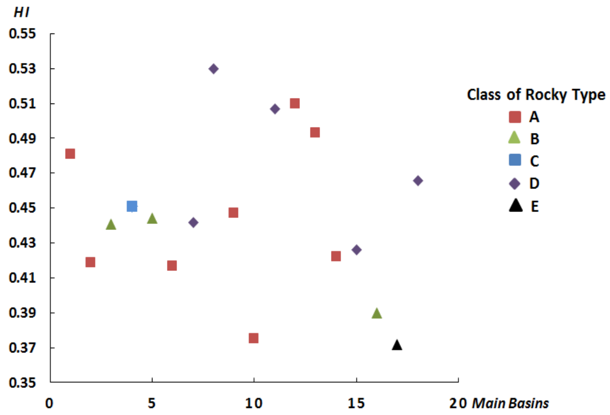


Figure 13 Mean HI values for each lithologic group from main basins.

In the main basins the dominant rock type (Figure 13) consist of micaschists and paragneisses (class A) such in Rebra (79.44%) and Cormaia (56.5%) basins, epimetamorphic schist of Repedea series (class D) in Anies (51.08%) basin, flysch (class B), sandstones and marls (class E) and sericito-chlorite schists (class C). In Figure 14, that represents a geological section through Dragos basin (Bătrâna and Gropile subbasins), Repedea and Negoiescu Bains in the western part of Rodna Mountains, HI values are lower in western part (V) and higher in the east. Mean low values of HI correpond to to Rebra nappe mainly with micaschists, paragneisses, quartzites, limestones, green schists, micaschists and mean high values on Bretila nappe and Cimpoiaș nappe.

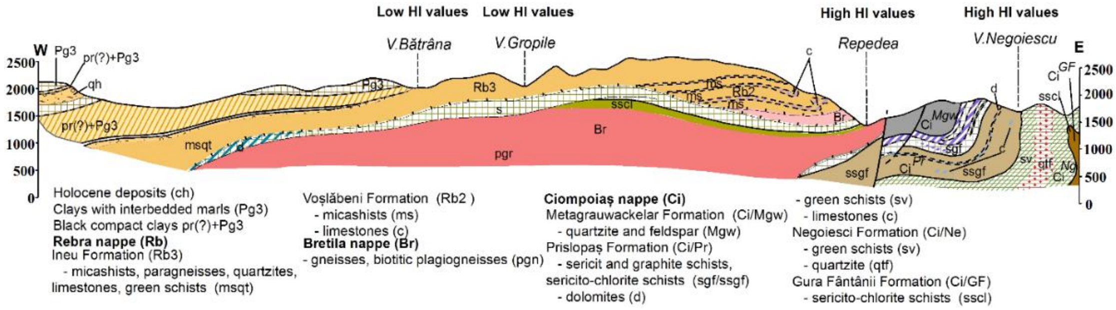


Figure 14 Geological section in western part of Rodna Mountains (West - East), after 1:50 000 map, Romanian Institue of Geology and Geophysics, 1892.

6. Spatial-cluster and hot spot analyses

Spatial-cluster analysis and hot/cold-spots are important in order to have a better visualization on spatial data analysis. The spatial variations identified were statistically tested using Local Moran's I and Getis Gi*. These methods of correlation on the entire Rodna Mountains do not show a clear interpretation therefore spatial-cluster and hot-cold-spots analysis were applied al level of 3rd and 4th basin order.

High-high clusters are mostly in the eastern part of mountain range in Putredu, Bila, Lala, Gaja, Cobasel and Bailor basins and low values clusters (cold-spots) are associated with basins developed in mostly in southern part of main range. The 3rd order basins have a Moran I index of 1.1 and a Z-score of 21.96 while the 4th order basins have a Moran I index of 0.9 and a Z-score of 8.6. The Local Moran's I index is more sensitive to outliers unlike that Gi* scores that provide a more complete visual image on Hypsometric Integral.

The spatial autocorrelation (Moran I) is strongly positive (Fig. 15), meaning that the values **are clustered together** (Moran's Index: 0.04). The Z-score of 5.96 shows that there is less than 1% likelihood that this clustered pattern could be the result of random choice. The Observed General G for the 3rd order (Fig. 16C) is 0.1 with a Z-score of 10.86 while the 4th order basins (Fig. 16D) have an Observed General G 0.19 and a Z-score of 2.53. The basins from the western part (Figs 16A and B) corresponding to Oligocene-Miocene formations have lower scores, as well as the ones that are crossing the Dragos-Voda fault, Local Moran's I analysis showing for this region presence of low values outliers.

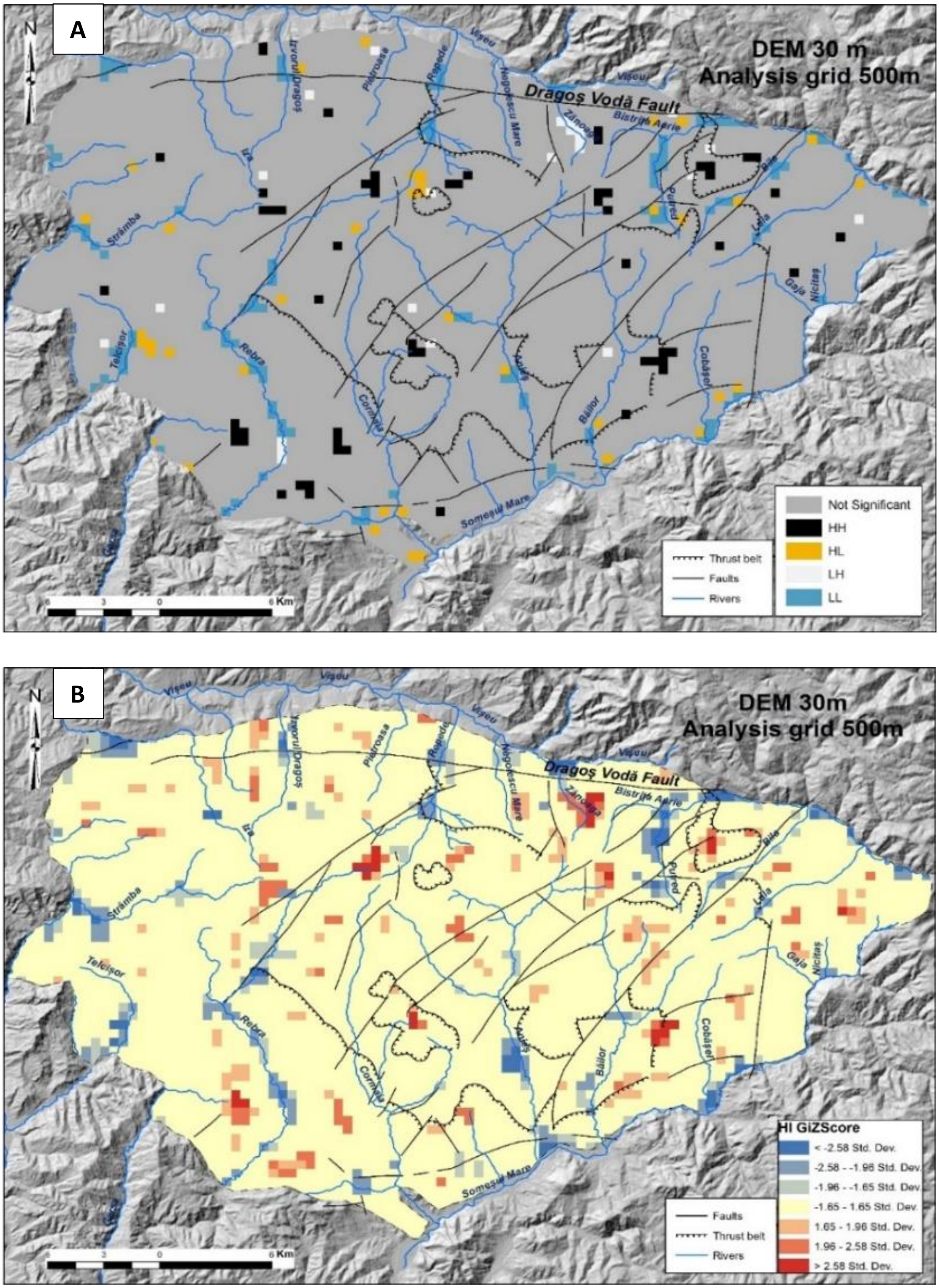
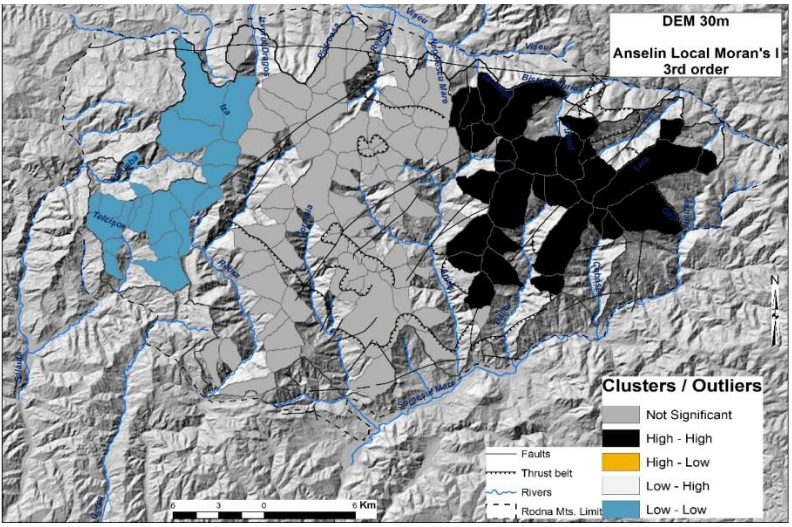
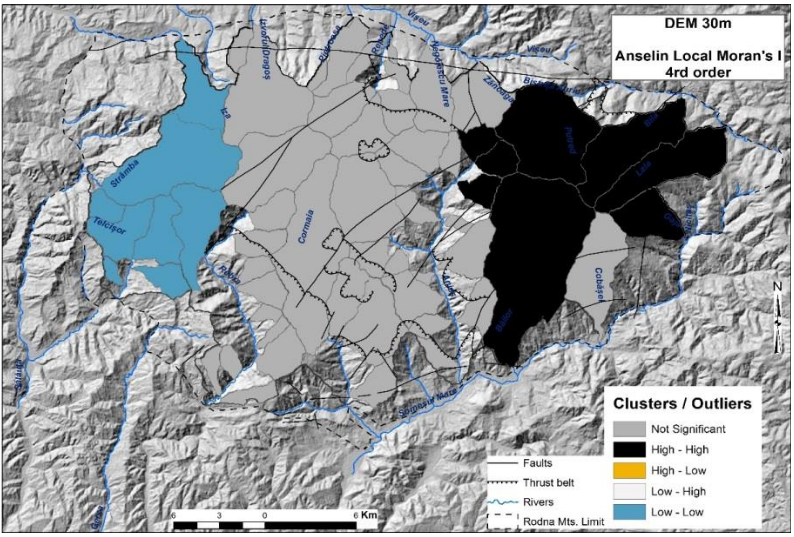


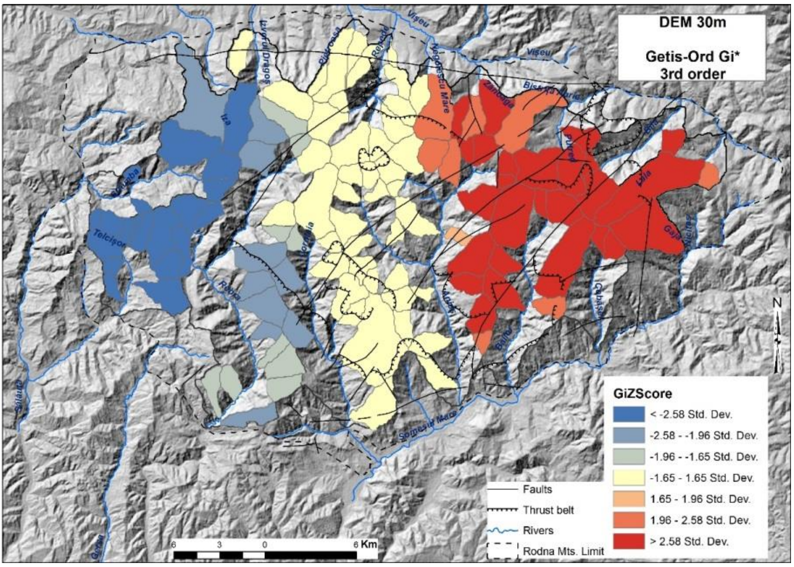
Figure 15 Results of the Local Moran's I (B) and Getis-Ord Gi* statistical analysis (A).


DEM 30m
Anselin Local Moran's I
3rd order
Clusters / Outliers
Not Significant
High - High
High - Low
Low - High
Low - Low
Faults
Thrust belt
Rivers
Rodna Mts. Limit
6 3 0 6 Km
N
Izvorul Dragoș
Vișeu
Bistrița Aurie
Iza
Telcișor
Rebra
Someșul Mare
Lala
Cobășel

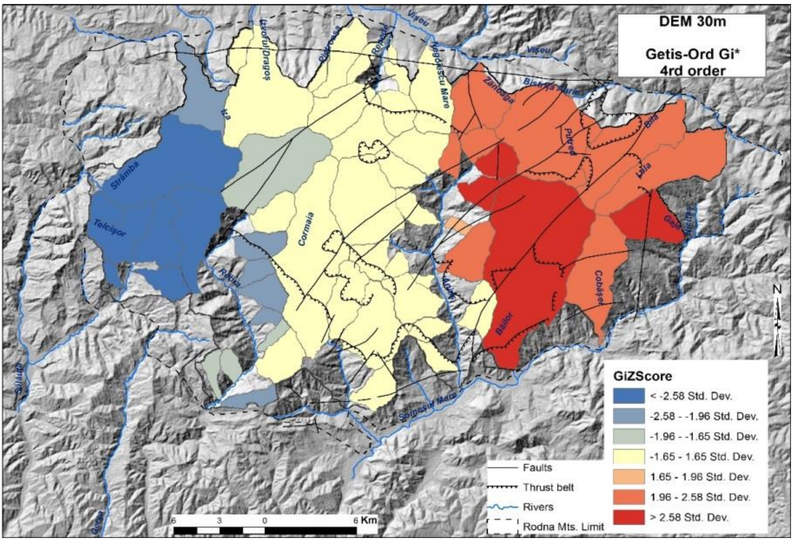
A.


DEM 30m
Anselin Local Moran's I
4rd order
Clusters / Outliers
Not Significant
High - High
High - Low
Low - High
Low - Low
Faults
Thrust belt
Rivers
Rodna Mts. Limit
6 3 0 6 Km
N
Izvorul Dragoș
Vișeu
Bistrița Aurie
Iza
Strâmba
Telcișor
Rebra
Cormaia
Someșul Mare
Lala
Cobășel

B.


DEM 30m
Getis-Ord Gi*
3rd order
GiZScore
< -2.58 Std. Dev.
-2.58 - -1.96 Std. Dev.
-1.96 - -1.65 Std. Dev.
-1.65 - 1.65 Std. Dev.
1.65 - 1.96 Std. Dev.
1.96 - 2.58 Std. Dev.
> 2.58 Std. Dev.
Faults
Thrust belt
Rivers
Rodna Mts. Limit
6 3 0 6 Km
N
Izvorul Dragoș
Vișeu
Bistrița Aurie
Iza
Telcișor
Rebra
Cormaia
Someșul Mare
Lala
Cobășel

C.



D.

Figure 16 Results of the Local Moran’s I and Getis-Ord Gi* statistical analysis.

7. Conclusions

The HI values are higher than 0.5 in the areas with recent tectonic influences especially in northern part near Dragoş Vodă fault system. HI high values correspond to Iza basin where the main lithology is Oligocene. After the Eocene - Oligocene sedimentation the old faults within Rodna horst, having as limits Dragoş-Vodă fault in north and Rodna fault along Someş in south, have been reactivated. The central compartments, especially Repedea-Negoiescu, are more uplifted then that ones from extremities (Rodna and Ineu) of the Rodna horst. A consequence of the strong uplift of Repedea section led to removal of Paleozoic facies. This can be show also in high values on HI values in Repedea and Negoiescu basins. Very low values of HI are found in the western and eastern part compared with the higher values in the internal part of Rodna horst. The low HI values from the western part of Rodna from Stramba and upper part of Rebra basins correspond to Bătrâna denudation surface. The differences in HI values from north and south part of the mountain range are clearly visible; also, the ridges from northern part of the mountain range are shorter then southern ones, which is explained by the appearance of faults.

Many studies showed that in the Eastern Carpathians between 17 and 8 Ma, Miocene subduction and collision induced up to 6 km of bulk exhumation (Sanders et. al., 1999). In the Rodna horst two stages have been documented in the exhumation history: enhanced exhumation of at least 1.0 mm/a between 12 and 11 Ma, followed by slower exhumation after 10 Ma (Gröger et al. 2008).

The statistics, applied to the distribution function of hypsometric curve could be interpreted in terms of erosion and basin slope (Harlin, 1978; Luo, 2000). Erosion has diminished significantly under progressive climate cooling since the Pliocene (2.5 Ma in the final) and erosion products have been removed by the river network. The amount of headward erosion in the upper reach of the basin is represented by hypsometric skew while the density skew shows changes in slope (Harlin, 1978; Luo, 2000). The erosion in the upper and lower reaches of the basins and midbasin slope correspond with hypsometric kurtosis and density kurtosis coefficients, respectively. Regarding the lithological factor, Oligocene, Pleistocene and Holocene formations have low values

(<0.5) while Precambrian, Cambrian, Silurian, Eocene, Miocene and Pliocene formations have higher values (>0.5).

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