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ABSTRACT

This study focuses on the spatial analysis of 605 historical objects with historical defensive function in Slovakia in terms of their occurrence at different elevations, distances from river, elevation differences from river, types of representative geoecosystems (REPGES), lithological types, and distances from the centre of the nearest settlement. The spatial differentiation of the occurrence of historical objects with defensive functions (HODFs) was analysed using the local Moran's coefficient of spatial autocorrelation. Similar spatial distribution of clusters with positive spatial autocorrelation between the elevation of HODFs, their lithology, and occurrence in the REPGES type was found. As a result, elevation, REPGES type, and lithology were proved to be important attributes of spatial pattern of HODFs. On the contrary, the clusters of positive spatial autocorrelation in case of the distance and elevation difference from the river and distance from the centre of the nearest settlement did not spatially correlate with each other.

KEYWORDS: Historical objects with defensive function, GIS, Slovakia, spatial analysis, spatial autocorrelation

1. Introduction

Slovakia is a country rich in cultural-historical objects built in different periods, which are either fortified or representative, such as castles, chateaux or manor houses. In the past, they represented the sites of historical events and their owners influenced the course of the country for many centuries. The predecessors of castles were represented by fortifications and fortified courtyards, which were typically built in the territory of today's Slovakia in the 9th and 10th centuries AD. In the 11th and 12th centuries AD, stone castles began to be built in the territory of today's Slovakia and their number increased especially after the Tatar invasion in 1241-1242 AD. Many stone castles were built mainly in border areas, strategic and less accessible places, along important roads, crossroads or fords. In addition to the defensive and administrative functions, they also served for housing purposes. At the end of the 14th century and the beginning of the 15th century AD, several castles were rebuilt in the territory of today's Slovakia and new separate palaces were built in the castle fortifications. Renaissance art brought a significant change in their architecture. In the 17th and 18th centuries AD, most castles in the territory of today's Slovakia started to be abandoned and many remained in ruins (**Kollár and Nešpor 2007**).

The castle complexes in Slovakia are situated on various forms of surface as well as on rocks of various origin, age and degree of disturbance. Most of the castles are located in the Klippen belt, fault-block and volcanic mountains. Most of the castle rocks have a complicated geological structure. The varied rock composition is very often associated with the manifestation of various slope processes. As a result, there is a gravitational loosening of slopes, formation of block sediments and fields, rock crashes, and the like. In addition, the processes of weathering and erosion as well as human activities endanger these historical objects (**Bizubová 2008; Dobrovodská et al. 2019; Vojteková and Vojtek 2019**). In particular, this study focuses on the research of historical objects with defensive functions (HODFs). HODFs include castles, chateaux, manors, strongholds, forts, fortresses, summer houses, watchtowers, fortified mansions, fortified churches, fortified monasteries, citadels, fortified courtyards, city walls and guard bastions, which became extinguished or remained in ruins, but also the ones which preserved until today.

Scientific interest in HODFs focuses mainly on the historical aspects of their research. However, the modern trend of a holistic and comprehensive approach to solving scientific problems opens new opportunities for geography to participate in the research of historical objects. The rationale for the active and useful participation of geographers in such research is based on the assumption that HODF is an element of the landscape which changes in space and time (**Lacika 2016**). Different aspects of historical objects (mainly castles) in Slovakia were studied in a number of works, such as **Janota (1938)**, **Plaček and Bóna (2007)**, **Škubla (2017)**, **Maráky et al. (2017), Lacika (2019)** or **Mladý (2019)**. Furthermore, this topic was approached also by several foreign researchers, for example, **Witz et al. (2017), Baumler (2018), Hove (2018), Ruiz (2019) or Kagan (2019)**.

Spatial statistics, as one of the quantitative statistical methods, deals with statistical analysis of spatial phenomena. The methods of spatial statistics are commonly used in geographical research (**Netrdová and Nosek 2017; Vilinová et al. 2018; Kim et al. 2019; Lima et al. 2020; Salvati et al. 2020; Vilimová 2020**). Moreover, these methods have found their application also in other scientific fields, such as economics, sociology, archaeology, biology or ecology. Spatial statistics differs from classical statistics mainly in the fact that it works with dependent variables, which makes the created models more realistic. The basic attributes of spatial data include distance, direction and relative position while four basic types of spatial data can be recognized: point, area, network and directional (**Anselin 1988**). The research of historical objects (castles) with the use of spatial analysis was performed in several studies. For example, **Oppio et al (2015)** used spatial multicriteria analysis and SWOT analysis in order to define enhancement strategies for cultural built heritage in case of thirteen castles in a mountainous region in the North of Italy. **Niknami and Askarpour (2015)** used integrated satellite imagery and GIS analyses (Thiessen polygons analysis, site-point spatial distribution analysis and buffer analysis) to reconstruct spatial distribution patterns of the Chalcolithic settlements in **Central Zagros, Iran. Furthermore, Kay et al. (1989)** and **Vogel (2004)** used spatial analyses, including the spatial autocorrelation, for understanding the spatial distribution of Caddoan Mounds in the Arkansas River Drainage. However, based on the literature review and our knowledge, spatial analysis (i.e. spatial autocorrelation) has not been applied to study the possible connections between the geographical or environmental characteristics and the construction of HODFs so far, which we consider a novelty of the presented research.

One of the questions which can be answered by spatial analysis is whether the presence of any phenomenon in a given area increases or decreases the probability of the presence of this phenomenon in nearby areas. In this regard, spatial autocorrelation is used as a measure of the relationship between phenomena separated by certain spatial or temporal periods. The autocorrelation refers to the process of evaluating a correlation within a single variable. Spatial autocorrelation is a specific type of correlation, where the relationship of one variable in space or time is evaluated within one observation (**Gregory et al. 2009**). The main idea of spatial autocorrelation is to claim that if the values of the studied attribute for each pair of regions of a given space are uncorrelated, then there is no spatial autocorrelation of the studied attribute in the system of regions. This statement is based on the so-called Tobler's first law of geography (**Tobler 1970**) according to which everything is connected to everything else, but near things are more related than distant things. Spatial autocorrelation has an important position in spatial statistics and it can also be understood as the presence of the spatial structure of mapped variables due to their geographical proximity (**Getis 2008**).

The aim of this study is to analyse six attributes influencing the occurrence of HODF in Slovakia using the spatial autocorrelation (local Moran's coefficient of spatial autocorrelation). The spatial differentiation of HODFs was analysed with respect to the following studied attributes: elevation, its distance and elevation difference from river, occurrence in the type of representative geoecosystems (REPGES), lithology and distance from the centre of the nearest settlement. The intention of this study is to present as much stable (unchanged) factors as possible, which could have influenced the spatial patterns of HODFs in the past and these factors have persisted more or less unchanged until today. Exceptions can be considered the factors of the distance from river and distance from the centre of the nearest settlement, where the river channels as well as centres of settlements have been modified/changed in many cases until today. On the other hand, rivers created natural protection of many HODFs and, therefore, this factor was naturally assumed to be a basic factor influencing the spatial patterns of HODFs, similarly as the distance from the centre of the nearest settlement. In addition, this study intends not only to analyse the spatial differentiation of HODFs, but also to point out the differences in their location in different regions of Slovakia by comparing the results obtained.

2. Methodology

The methodology of this study consisted of the following three main steps:

1. Localization of HODFs in the form of points (vector format) and processing of studied attributes of HODFs (elevation, distance from river, elevation difference from river, occurrence in types of REPGES, lithology and distance from the centre of the nearest settlement) using GIS.
2. Transformation of HODF point data into polygon format using the Thiessen polygons function in GIS.
3. Application of spatial autocorrelation (local Moran's coefficient of spatial autocorrelation) for the analysis of spatial differentiation of HODFs.

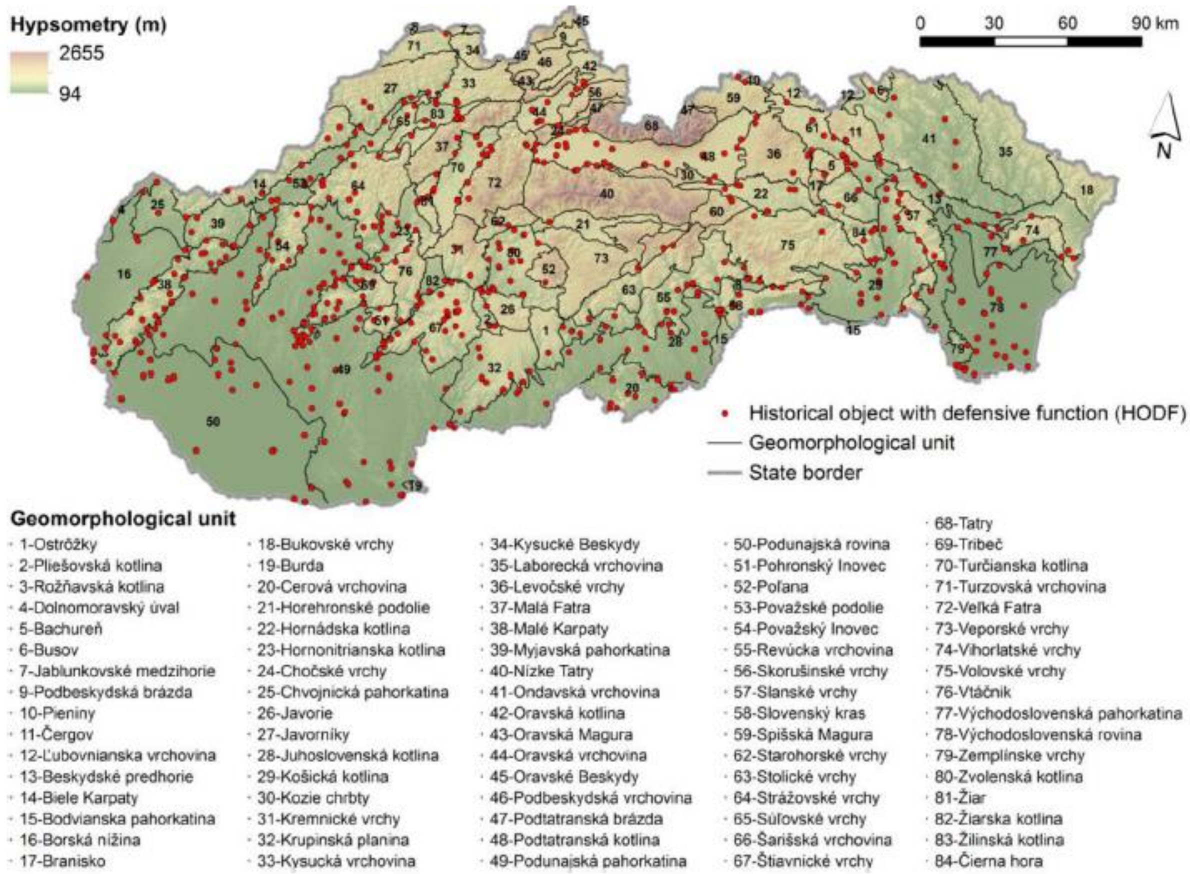

Figure 1. Study area and location of HODFs within geomorphological units.

2.1. Methods of data processing

Localization of 605 HODF in the form of points (vector format) was performed with the use of historical and current orthophotos, topographic maps, GNSS measurements as well as publications from **Mladý (2019)** and **Lacika (2019)**. The map of location points of HODFs within geomorphological units is presented in **Figure 1**.

The first studied attribute, represented by the elevation of HODF, was obtained from two types of a digital elevation model (DEM). Where available, the airborne Light Detection And Ranging (LiDAR) DEM (UGKK SR), which was laser scanned in the period 2017-2020, with a resolution of 1 x 1m was used. As stated by the provider of the LiDAR DEM, the positional accuracy ranges from 0.07 to 0.16 m while the vertical accuracy ranges from 0.02 to 0.07 m, depending on the locality. The second source was the topographic maps at a scale of 1:10,000, which were used for creating the DEM (labelled as DMR3.5) with a resolution of 10 x 10 m. DMR3.5 is based on the original DMR 3.0 model, where various types of adjustments were made, such as correction of gross errors, remodelling of areas from photogrammetrically evaluated data, but mainly its harmonization with the shape of watercourses and water areas. The vertical accuracy of this DEM is estimated to ±2.5 m (**Bobál et al. 2015; Bindzárová Gergelová et al. 2020**). The elevation of HODFs ranged from 98.6 to 1264.3 m a. s. l. Most of the HODFs were located at elevations ranging from 101 to 200 m a. s. l. (135 HODFs) while the least of HODFs were located at elevations from less than 100 m a. s. l. (5 HODFs). The number of HODFs in selected hypsometric intervals is presented in **Table 1**.

The second studied attribute was the distance of HODF from river, which calculated using the Near tool in ArcGIS software based on the vector layer of rivers obtained from the Basic Database for Geographic Information System (ZBGIS).

Table 1. Number of HODFs in hypsometric intervals.

Hypsometric intervals	Number of HODFs
<100	5
101–200	135
201–300	101
301–400	105
401–500	94
501–600	52
601–700	53
701–800	31
801–900	23
901<	6

Table 2. Number of HODFs in intervals of distance from river.

Intervals of distance from river	Number of HODFs
<200	283
201–400	168
401–600	77
601–800	45
801–1000	18
1001–1200	6
1201–1400	4
1401<	4

Table 3. Number of HODFs in intervals of elevation difference from river.

Intervals of elevation difference from river	Number of HODFs
<10	191
11–50	154
51–100	110
101–150	77
151–200	39
201–250	20
251–300	3
301–350	4
350<	7

The ZBGIS contains spatial datasets that are very detailed, accurate and updated with the use of photogrammetric methods as well as local investigations. The primary method for data collection in this case, i.e. localization of rivers, is the photogrammetric method, which uses current orthophotos (2017-2020) with the resolution of 25cm/pixel. Therefore, the positional accuracy of rivers in the ZBGIS depends on the quality of the orthophotos used, which is 0.30 m in case of the root mean square error (RMSE) defined by the provider - Geodetic and Cartographic Institute Bratislava and National Forest Centre in Zvolen. The values of this attribute ranged from 1.7 to 2032.2 m. Most of the HODFs were located within the 200 m distance (283 HODFs) while the least HODFs were located between 1200 and 2032.2 m. Table 2 presents the number of HODFs in the selected intervals of distance from river.

The third studied attribute was the elevation difference between the location of HODF and the river. These data were obtained from the LiDAR DEM or contour-based DEM and vector layer of rivers obtained from the ZBGIS, as mentioned previously. The smallest elevation difference from the river was 0.5 m while the biggest elevation difference was 398 m. Most of the HODFs recorded the elevation difference up to 10 m (191 HODFs). **Table 3** presents the number of HODFs in the selected intervals of elevation difference from river.

The localization of HODF in the type of REPGES was based on the publication by Miklós and Izakovicova (2006). REPGES represent landscape units, which are characterized by a certain diversity of conditions - different geological bedrock, morphometric, climatic, hydrologic and soil conditions, which further condition the occurrence of different forms of ecosystems and biota. Based on the combination of azonal and zonal conditions, 120 types of REPGES were determined in Slovakia (**Izakovičová** and **Miklós 2008**). HODFs were found in 70 types of REPGES and most of them (55 HODFs) were located in the REPGES type 4 (river floodplain in lowlands). The number of HODFs in individual types of REPGES is presented in **Table 4**.

The localization of HODF in the lithological type was based on the vector layer of Map of Engineering Geological Zones at a scale of 1:50,000 (**Liščák 2017**). Based on this map, 47 lithological types were determined in Slovakia. HODFs were found in 37 lithological types and most of them (68 HODFs) were located in the lithological types of limestone rocks. The number of HODFs in individual lithological types is presented in **Table 5**.

The last studied attribute was the distance of HODF from the centre of the nearest settlement, which calculated using the Near tool in ArcGIS software based on the vector layer of the centres of settlements obtained from Geodetic and Cartographic Institute Bratislava. The values ranged from 25.3 to 6.116 km. Most of the HODFs were located within distance from 501 to 1000 m (117 HODFs) while the least HODFs were located in the interval 5001 and 6116 m. **Table 6** presents the number of HODFs in the selected intervals of the distance from the centre of the nearest settlement.

In order to perform the spatial autocorrelation analysis, the points of HODFs were transformed into a polygon format using the Thiessen polygons function in ArcGIS software. Thiessen polygons are formed from a set of input point fields by a process called Voronoi or Dirichlet tessellation. The basic principle of this method is that the space for interpolation is divided into areas with the sphere of influence of the known input point, which also lies in the centre of these areas. The resulting polygons define individual areas of influence around each input point. The attribute of a given point therefore applies to the whole area of influence. The use of this method is not suitable for continuous phenomena since the result of this method is a spatial data structure that has a significant discrete character. Therefore, each estimate is based on only one value (Boots 1986). This concept can be used for the purposes of spatial interpolation, point pattern analysis, localization optimization as well as for spatial process models (**Yamada 2017**).

2.2. Spatial autocorrelation

After the creation of Thiessen polygons, the next step was the analysis of spatial differentiation of HODFs on the basis of studied attributes. The analysis focused on the so-called local indicators of spatial statistics that can be used to identify a spatial unit where neighbouring spatial units have similar values or spatial units that are different from their neighbours. To assess the spatial differentiation of HODFs, the local Moran's coefficient of spatial autocorrelation (**Anselin 2010**) was used, which is given by **Equation (1)**:

$$I = \frac{x_i - \bar{x}}{\frac{\sum_{j=1;j\neq i}^{n} w_{ij}}{n-1} - \bar{x}^2} \cdot \sum_{j=1;j\neq i}^{n} w_{ij}\left(x_j - \bar{x}\right) \qquad (1)$$

where n is the number of spatial units (number of HODFs), W_{ij} is the spatial weight between the ith and jth spatial units, x_i, (i = 1, 2, ..., n) is the value of the studied attribute in the spatial unit i (property for the ith attribute) and X is the arithmetic mean of the studied attribute (spatial unit).

Table 4. Number of HODFs in types of REPGES.

Types of REPGES	Number of HODFs	Types of REPGES	Number of HODFs
2 (Lowland or basin depression)	5	48 (Rugged volcanic highlands – oak-hornbeam forests)	2
4 (River floodplain in lowlands)	55	49 (Rugged volcanic highlands – oak-beech forests)	24
5 (River floodplain in basin or mountain valley)	51	51 (Rugged flysch highlands – oak-hornbeam forests)	4
6 (Fragmented meander plain)	37	52 (Rugged flysch highlands – oak-beech forests)	5
7 (River terrace or proluvial cone – oak-cerium forests)	10	53 (Rugged flysch highlands – beech forests)	10
9 (River terrace or proluvial cone – oak-hornbeam forests)	26	54 (Rugged flysch highlands – beech-fir forests)	1
10 (River terrace or proluvial cone – oak-beech forests)	6	55 (Rugged flysch highlands –fir-spruce forests)	2
12 (River terrace or proluvial cone – fir-spruce forests)	5	56 (Rugged karst highlands – oak-cerium forests)	2
13 (River terrace or proluvial cone)	3	57 (Rugged karst highlands – oak-hornbeam forests)	4
14 (Plain /dune plain or loess cover/ – oak-cerium forests)	1	58 (Rugged karst highlands – beech forests)	7
15 (Plain /dune plain or loess cover/ – oak forests)	2	59 (Rugged karst highlands – beech-fir forests)	3
16 (Plain /dune plain or loess cover/)	4	60 (Rugged highlands on variegated Mesozoic rocks – oak-cerium forests)	6
18 (Loess plateau – oak-cerium forests)	10	62 (Rugged highlands on variegated Mesozoic rocks – oak-hornbeam forests)	18
19 (Loess plateau – oak-hornbeam forests)	1	64 (Rugged highlands on variegated Mesozoic rocks – beech forests)	17
20 (Loess hills – oak-cerium forests)	32	65 (Rugged highlands on variegated Mesozoic rocks – beech-fir forests)	3
21 (Loess hills – oak forests)	1	67 (Rugged highlands or lower mountains on variegated rocks of Klippen belt – oak-hornbeam forests)	4
22 (Loess hills – oak-hornbeam forests)	7	68 (Rugged highlands or lower mountains on variegated rocks of Klippen belt – beech forests)	2
23 (Polygenic hilly or fragmented pediments – oak-cerium forests)	15	69 (Rugged highlands on crystalline rocks – oak-hornbeam forests)	14
24 (Polygenic hilly or fragmented pediments – oak forests)	2	70 (Rugged highlands on crystalline rocks – oak-beech forests)	2
REPGES 25 (Polygenic hilly or fragmented pediments – oak-hornbeam forests)	27	71 (Rugged highlands on crystalline rocks – beech forests)	10
26 (polygenic hilly or fragmented pediments – oak-beech forests)	9	81 (Karst mountain plain – beech forests)	1
27 (Polygenic hilly or fragmented pediments – beech forests)	3	84 (Rugged volcanic lower mountains – beech forests)	9
28 (Polygenic hilly or fragmented pediments – beech-fir forests)	1	85 (Rugged flysch lower mountains – beech forests)	5
29 (Polygenic hilly or fragmented pediments – fir-spruce forests)	4	86 (Rugged flysch lower mountains – beech-fir forests)	3
31 (Low plateau foothills – oak-cerium forests)	10	87 (Rugged flysch lower mountains – fir-spruce forests)	1
32 (low plateau foothills – oak forests)	1	89 (Rugged flysch lower mountains – beech forests)	3
33 (Low plateau foothills – oak-hornbeam forests)	30	90 (rugged karst lower mountains – beech-fir forests)	1
	11		4

Table 4. Continued.

Types of REPGES	Number of HODFs	Types of REPGES	Number of HODFs
34 (Low plateau foothills – oak-beech forests)		91 (Rugged lower rock on crystalline rocks – oak-beech forests)	
35 (Low plateau foothills – beech forests)	10	92 (Rugged lower rock on crystalline rocks – beech forests)	7
39 (Highland plain undifferentiated – beech forests)	1	93 (Rugged lower rock on crystalline rocks – beech-fir forests)	3
40 (Highland plain in volcanic highlands – oak-cerium forests)	1	95 (very strongly rugged karst slope in lower mountains – beech-hornbeam forests)	2
43 (Karst highland plain – oak-cerium forests)	1	97 (very strongly rugged karst slope in lower mountains – beech forests)	2
45 (Rugged volcanic highlands – oak-cerium forests)	7	98 (Very strongly rugged karst slope in lower mountains – beech-fir forests)	7
46 (Rugged volcanic highlands – oak forests)	2	105 (Very strongly rugged karst slopes in higher mountains – beech-fir forests)	4
47 (Rugged volcanic highlands – oak-hornbeam forests)	15	105 (Rugged higher mountains on variegated Mesozoic rocks – beech-fir forests)	7

The Moran's local coefficient can be applied to a regular or irregular network of fields or spatial units of occurrence of a given phenomenon while nominal, ordinal or interval data can be used. Moran's coefficient of spatial autocorrelation I takes values from —1 to + 1. The closer the value of the Moran's index I is to the value 0, the more randomness is indicated, i.e. statistical insignificance of a given variable in space. The closer the value of Moran's index I is to 1, the more positive spatial autocorrelation is indicated. On the other hand, if the value of Moran's index I approaches —1, then a negative spatial autocorrelation is indicated.

The statistical significance of the Moran's index of spatial autocorrelation of spatial units has to be verified (**Fotheringham et al. 2002**). The null hypothesis was tested that there is no spatial autocorrelation between the values of studied attributes on n spatial units. The test statistics Z_I for verifying the statistical significance of the Moran's coefficient I has an asymptotically normal distribution, which is given by **Equation (2)**:

$$Z_I = \frac{I - E(I)}{\sqrt{V(I)}}, \tag{2}$$

Where

$$E(I) = \frac{-1}{n-1}, V(I) = E(I^2) - E(I)^2$$

are the mean value and variance of the Moran's coefficient I.

The test is based on a comparison of the Z_I score and the corresponding value of the probability p (p value). In practice, the higher the value of Z_I score, i.e. the further it moves from the value 0, the higher the level of confidence that the studied phenomenon is autocorrelated.

The p value represents the probability with which the analysed phenomenon is the result of a random process, i.e. p value is the probability of error that is made when the tested hypothesis is rejected. Therefore, the test results were assessed based on the calculated p value.

Table 5. Number of HODFs in lithological units.

Lithological type	Number of HODFs
Limestone rocks	68
Effusive rocks	58
dolomite rocks	37
Deposits of lowland streams	36
Aeolian loess	33
Flyschoid rocks	33
Sandstone rocks	32
Deposits of alluvial plains	31
Deposits of mountain streams	31
Pleistocene river terraces	27
Proluvial cones and shells	27
Colluvial sediments	24
Epiclastic rocks	20
Conglomerate-sandstone rocks	20
Alternating fine-grained to gravelly sediments	19
carbonate and clastic rocks	13
Pyroclastic rocks	12
Deluvial deposits	11
Claystone-limestone rocks	11
Intrusive rocks	11
Epimetamorphosed rocks	10
Valley sediments	7
Neogene conglomerate sediments	5
Fine-grained and clay-silty sediments	3
Metamorphosed rocks	3
River-glacier sediments	3
Travertine accumulations	3
Limestone-dolomite rocks	3
Landslide deluvia	3
Sandy sediments	2
Loess deposits	2
Highly metamorphosed rocks	2
aeolian sands	1
Claystone-siltstone rocks	1
Metamorphosed carbonates	1
Abandoned meander	1
Gravel sediments	1

Table 6. Number of HODFs in intervals of distance from the centre of the nearest settlement.

Intervals of distance from the centre of the nearest settlement	Number of HODFs
<250	79
251–500	97
501–1000	117
1001–1500	110
1501–2500	127
2501–3500	50
3501–5000	21
5001<	4

If the calculated *p* value is sufficiently small ($p < .05$ or $p < .01$), the tested hypothesis (H_0: Moran's coefficient of spatial autocorrelation is not statistically significant) at the significance level of .05 or .01 is rejected. Otherwise, the tested hypothesis cannot be rejected.

Furthermore, it should be noted that in calculating the global characteristics of spatial autocorrelation, the assumption of homogeneity was adopted. If this assumption is not met, there may be a situation where global statistics will erroneously indicate the absence of spatial autocorrelation in the analysed dataset, even though there is actually a strong positive autocorrelation in one part of the locality and a strong negative autocorrelation in another part of the locality.

Table 7. Result of testing the spatial autocorrelation of HODFs based on the values of the studied attributes.

Studied attribute	*I*	*p*	Z_I
Elevation	0.665378	.000	27.6568
Distance from river	0.114831	.000	4.588
Elevation difference from river	0.179774	.000	7.381729
Type of REPGES	0.315026	.000	12.746
Lithology	0.102764	.000	4.362735
Distance from centre of the nearest settlement	0.202453	.000	8.503999

Due to these reasons, it is appropriate to use local indicators of spatial association (LISA), which relate to a specific place. The LISA analysis, which was developed by **Anselin (2010)**, is essentially the local equivalent of the Moran's I criterion because the sum of all indicators is proportional to the global value of Moran's statistics.

Anselin (1996) also introduced the so-called Moran's scatter plot with coordinates (x_i,$\sum_j w_{ij}x_j$), which allows to reveal significant local structures. In addition, the direction of the line of these points represents the Moran's coefficient of spatial autocorrelation. Since the variables are taken as deviations from their averages, the Moran's diagram is cantered at position 0.0. Four quadrants in the Moran's diagram represent four different types of relationships between the original values of a variable located on the horizontal axis and the average values from adjacent units located on the vertical axis. The quadrants in the Moran's diagram indicate the share of individual types of spatial dependence on the generation of the given value of global Moran's statistics.

3. Results

To verify the validity of the null hypothesis, the local Moran's coefficient of spatial autocorrelation was used. The values of this coefficient, *p* values and the Z_1 values are presented in **Table 7**. Since the p value is less than .01 in all studied attributes, the null hypothesis was rejected at the level of significance α= 0.01 and thus the alternative hypothesis, H_1: there is a spatial autocorrelation of HODFs differentiation based on the values of the studied attributes, was accepted. This means that the spatial distribution of HODFs, based on the values of the studied attributes, is not random.

Besides the Z_I-score, the statistical significance of the Moran's coefficient of spatial autocorrelation for all studied attributes was also tested using the Moran's scatter plot (**Figure 2**). The quadrants in the Moran's diagram indicate the share of individual types of spatial dependence on the generation of the calculated value of the Moran's statistics.

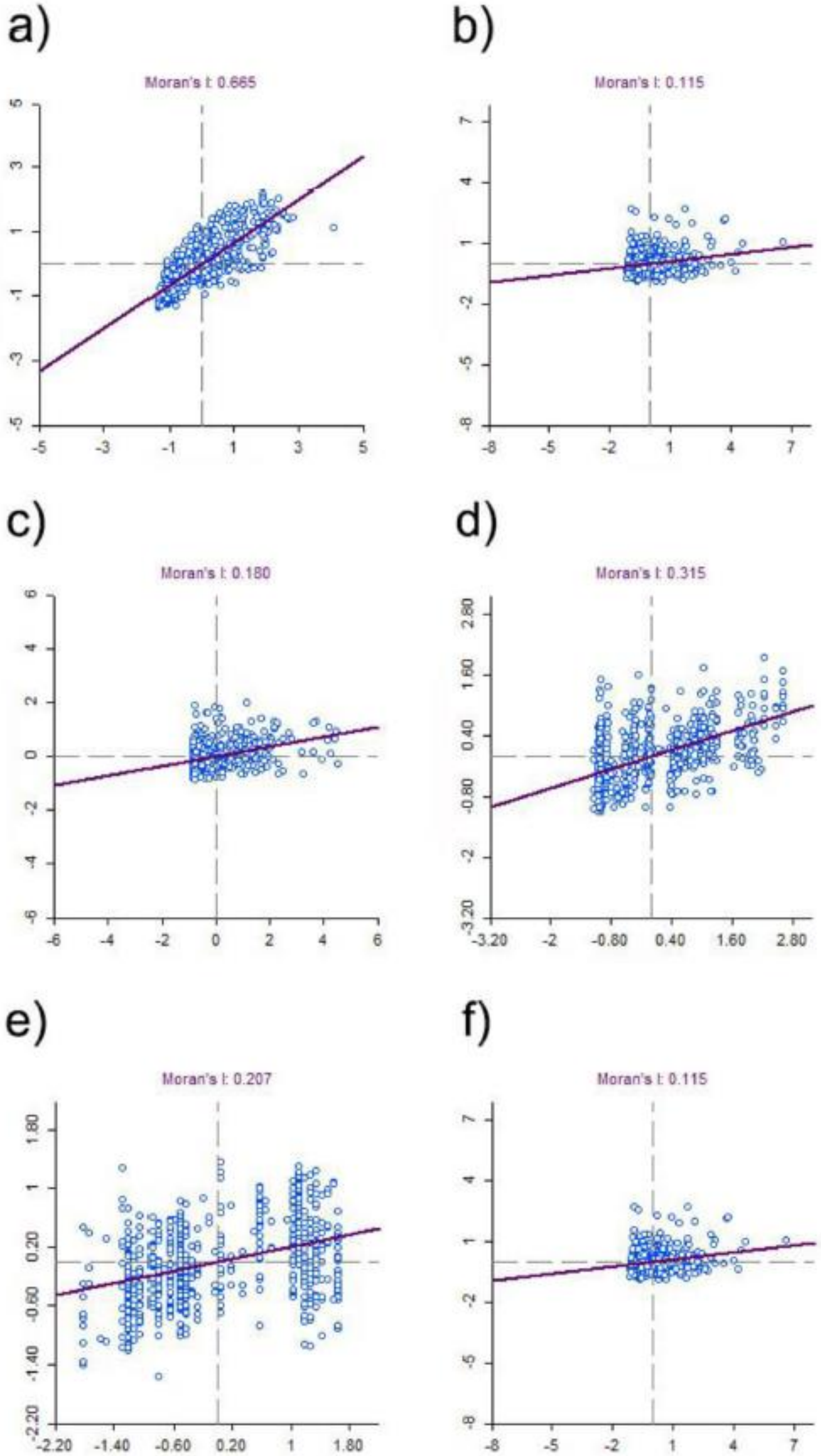

Figure 2. Results of the Moran's coefficient of spatial autocorrelation based on the values of studied attributes: (a) elevation, (b) distance from river, (c) elevation difference between the HODF and river, (d) occurrence in the type of REPGES, (e) lithology and (f) distance from the centre of the nearest settlement.

Figure 2 confirms that there is a statistically significant dependence between the occurrence of HODFs depending on the values of studied attributes in a given area and HODFs depending on the values of studied attributes in neighbouring areas. At the same time, it can be stated that based on the calculated values of spatial autocorrelation, high values that are grouped spatially close, i.e. high values of studied attributes (quadrant High-High), and spatially grouped low values, i.e. low values of studied attributes (quadrant Low-Low), were confirmed. The membership of the HODF to the quadrant High-Low and quadrant Low-High shows spatial 'outliers,' i.e. areas in which significantly higher or lower values of studied attributes were recorded than in neighbouring areas.

Based on the Moran's scatter plot and calculated values of Z_I-score, it can be stated that the Moran's coefficient of spatial autocorrelation of HODFs distribution with respect to the values of the studied attributes is statistically significant.

This means that there are areas next to each other that are closer to each other with respect to the values of the studied attributes. The spatial distribution of HODFs in a given area is thus related to the values of the studied attributes in the surrounding areas. In other words, the values of the studied attributes are influenced by the location of a given area. Figures 3-5 present the results of the calculated local Moran's coefficient of spatial autocorrelation for the studied attributes of HODFs.

3.1. Elevation of HODFs

Based on the results, which were obtained by calculating the local Moran's coefficient (Figure 3(a)), three clusters with high values of elevation (High-High) were identified, which means that there was a positive spatial correlation of the occurrence of HODFs (97 HODFs) with high elevation (high elevation values) at three areas in Slovakia. The largest of these clusters is located in the northern-central Slovakia and it spreads in the west-east gradient between the geomorphological units of Sulovske vrchy (mountain) and Busov (mountain) and in the north-south gradient between the Oravske Beskydy (mountain) and Zvolenska kotlina (basin). The second-largest cluster is located in the geomorphological unit of Stiavnicke vrchy (mountain). The smallest cluster is located between the geomorphological units of Slovenský kras (mountain) and Volovske vrchy (mountain).

Moreover, another three clusters (96 HODFs) with low values of elevation (Low-Low) were recorded, which means that in these areas, there was a positive spatial correlation of the occurrence of HODFs with low elevation. The largest of these clusters is located in southern Slovakia, i.e. geomorphological units of Podunajskýa pahorkatina (hills) and Podunajskýa rovina (plain). The second-largest cluster is located in eastern Slovakia, specifically, in the geomorphological units of Zemplínske vrchy (mountain), Východoslovenská rovina (plain), and Východoslovenska pahorkatina (hills). The smallest cluster binds to the Podunajska pahorkatina (hills). No clusters of HODFs were found in other areas of Slovakia, i.e. they do not show a statistically significant spatial autocorrelation.

3.2. Distance of HODFs from river

Based on the results of the local Moran's coefficient (**Figure 3**(b)), eight clusters with high values of distance from river (High-High) were identified, which means that there was a positive spatial correlation in these areas (23 HODFs). The occurrence of High-High clusters within geomorphological units and principal river basins is shown in **Table 8**.

Moreover, one cluster with low values (Low-Low) was recorded, which means that in this area, there was a positive spatial correlation of the occurrence of HODFs (1 HODF) in this area. This cluster is located between the geomorphological units of Vyýchodoslovenskýa rovina (plain) and Výychodoslovenskýa pahorkatina (hills) and in the principal basin of Bodrog. There were also eight clusters (8 HODFs) of the High-Low type, i.e. areas with high values which are adjacent to areas having low values. On the other hand, another six clusters (7 HODFs) of the Low-High type were identified representing areas with low values, which are adjacent to areas having high values.

3.3. Elevation difference between the HODF and the river

Based on the results of the local Moran's coefficient (**Figure 4**(a)), 11 clusters with high values of elevation difference from river (High-High) were identified, which means that there was a positive spatial correlation of the occurrence of HODF (39 HODFs) in these areas. The occurrence of High-High clusters within geomorphological units and principal river basins is shown in **Table 9**. In addition, three clusters of the High-Low type as well as three clusters of the Low-High type were identified.

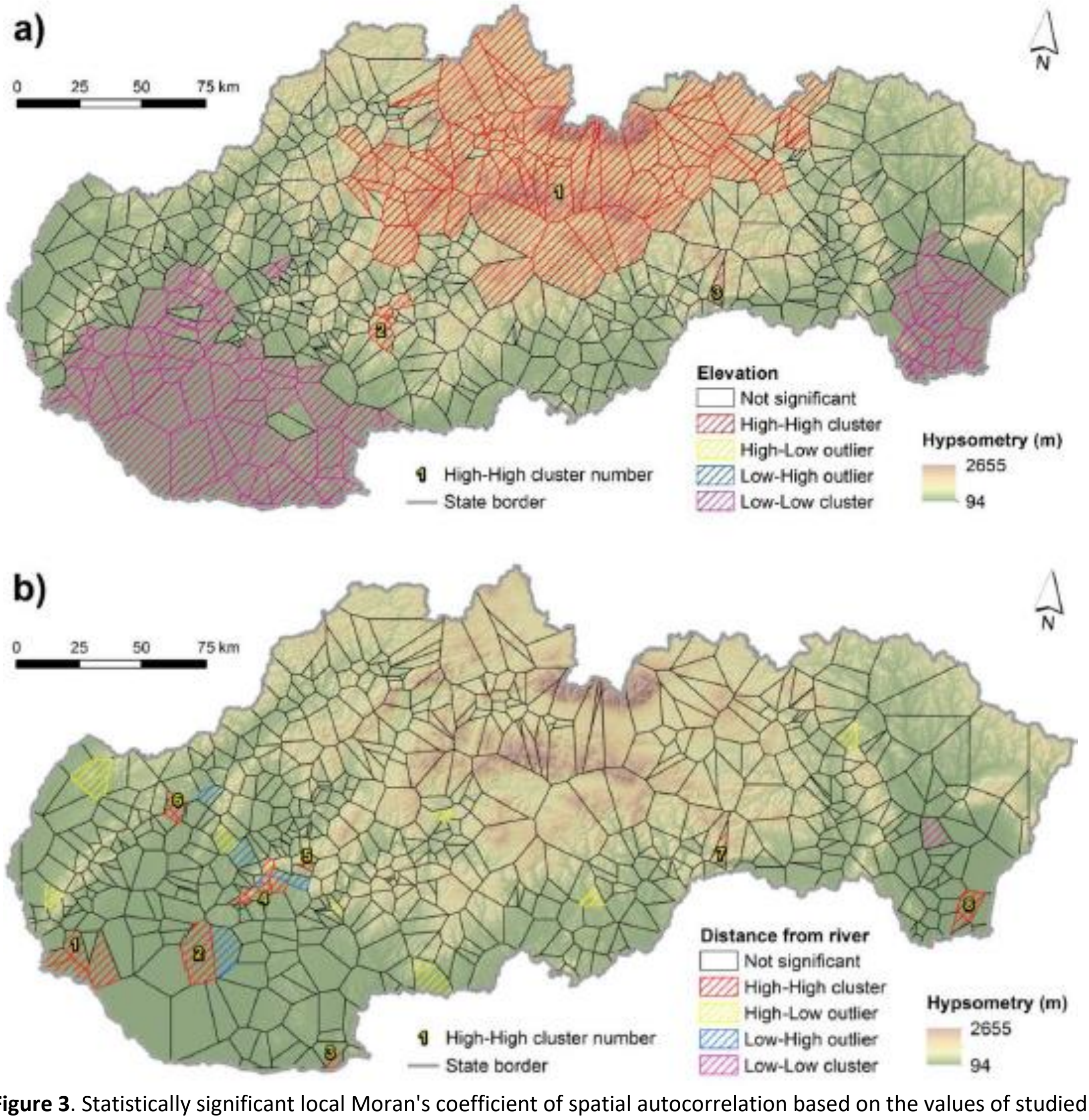

Figure 3. Statistically significant local Moran's coefficient of spatial autocorrelation based on the values of studied attributes: (a) elevation and (b) distance from river.

3.4. Occurrence of HODFs in the type of REPGES

Using the calculated local Moran's coefficient of spatial autocorrelation, nine clusters with high values (High-High) were recorded (**Figure 4**(b)), which means that there was a positive spatial correlation of the occurrence of HODFs (53 HODFs) in these areas. The largest cluster is located in northern Slovakia. Based on the geomorphological units, this cluster extends in the west-east gradient from Mala Fatra (mountain) to Chocske vrchy (mountain) and in the north-south gradient from Kysucke Beskydy (mountain) to Starohorske vrchy (mountain). The occurrence of High-High clusters within geomorphological units is shown in **Table 10**.

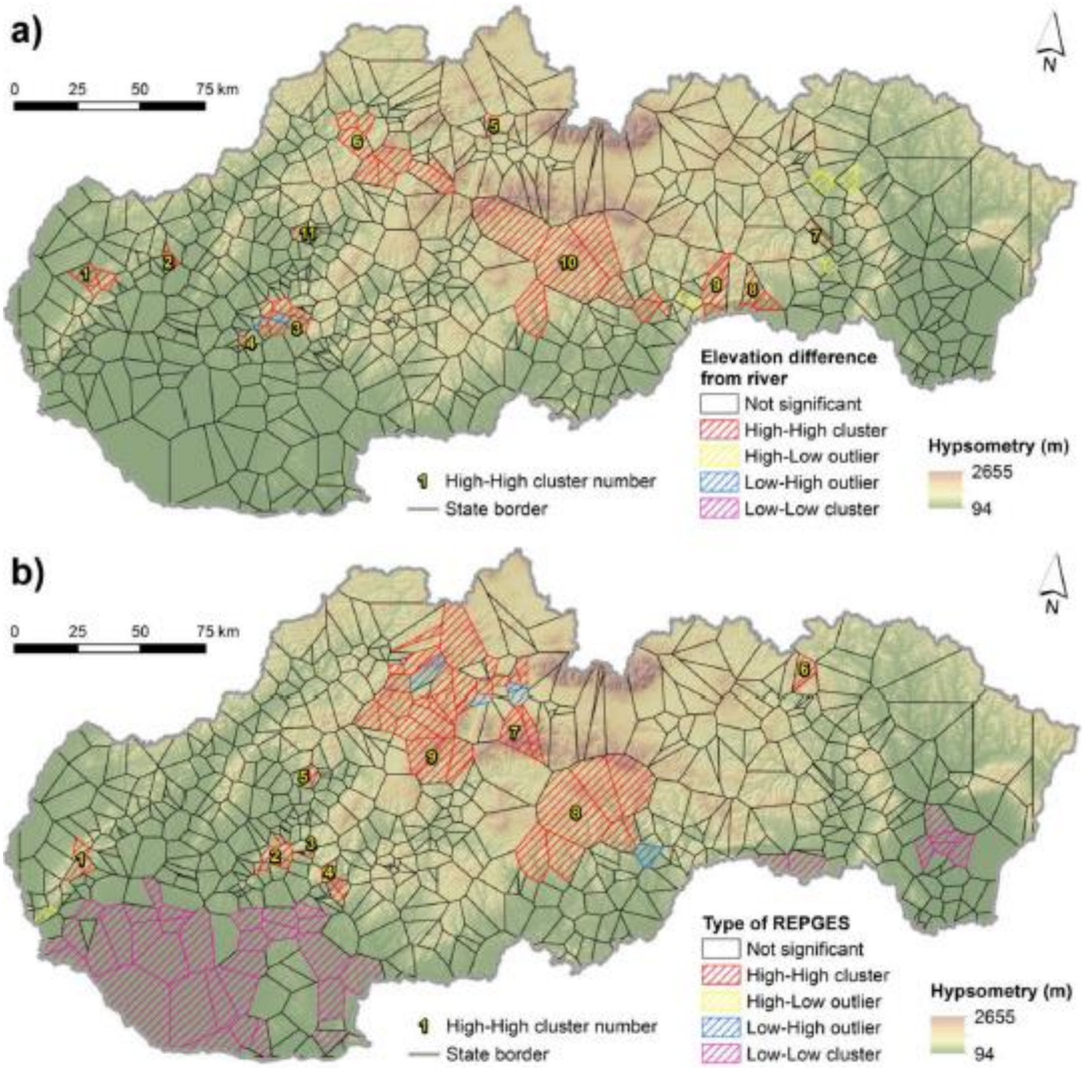

Figure 4. Statistically significant local Moran's coefficient of spatial autocorrelation based on the values of studied attributes: (a) elevation difference between the HODF and river and (b) occurrence in the type of REPGES.

In addition, five clusters with low values of REPGES type (Low-Low) were identified, which means that there was a positive spatial correlation of the occurrence of HODFs (39 HODFs) in this areas. The largest of these clusters is located in southern Slovakia and spreads over the geomorphological units of Podunajska rovina (plain) and Podunajska pahorkatina (hills). The second-largest cluster is located in the Východoslovenska rovina (plain) and Východoslovenska pahorkatina (hills). Three smaller clusters are located on the Podunajskýa pahorkatina (hills), Výychodoslovenskýa rovina (plain), and the last extends between the Bodvianska pahorkatina (hills) and Kosicka kotlina (basin).

There was also one cluster of the High-Low type and six clusters of the Low-High type. No other clusters of HODFs were found in other areas of Slovakia, which means that these areas did not show a statistically significant spatial autocorrelation.

3.5. Lithology of HODFs

Based on the results presented in **Figure 5**(a), which were obtained by calculating the local Moran's coefficient of HODFs' distribution with respect to their lithology, six clusters of areas with high values (High-High) were identified in Slovakia, i.e. there was a positive spatial correlation of the occurrence of HODF (50 HODFs). The largest of these clusters is located in the south-western Slovakia and occupies part of the Podunajská rovina (plain), Podunajská pahorkatija (hills) and it partly extends into the geomorphological unit of Považský Inovec (mountain). The second-largest cluster is located in the geomorphological units of Východoslovenska rovina (plain) and Východoslovenska pahorkatina (hills).

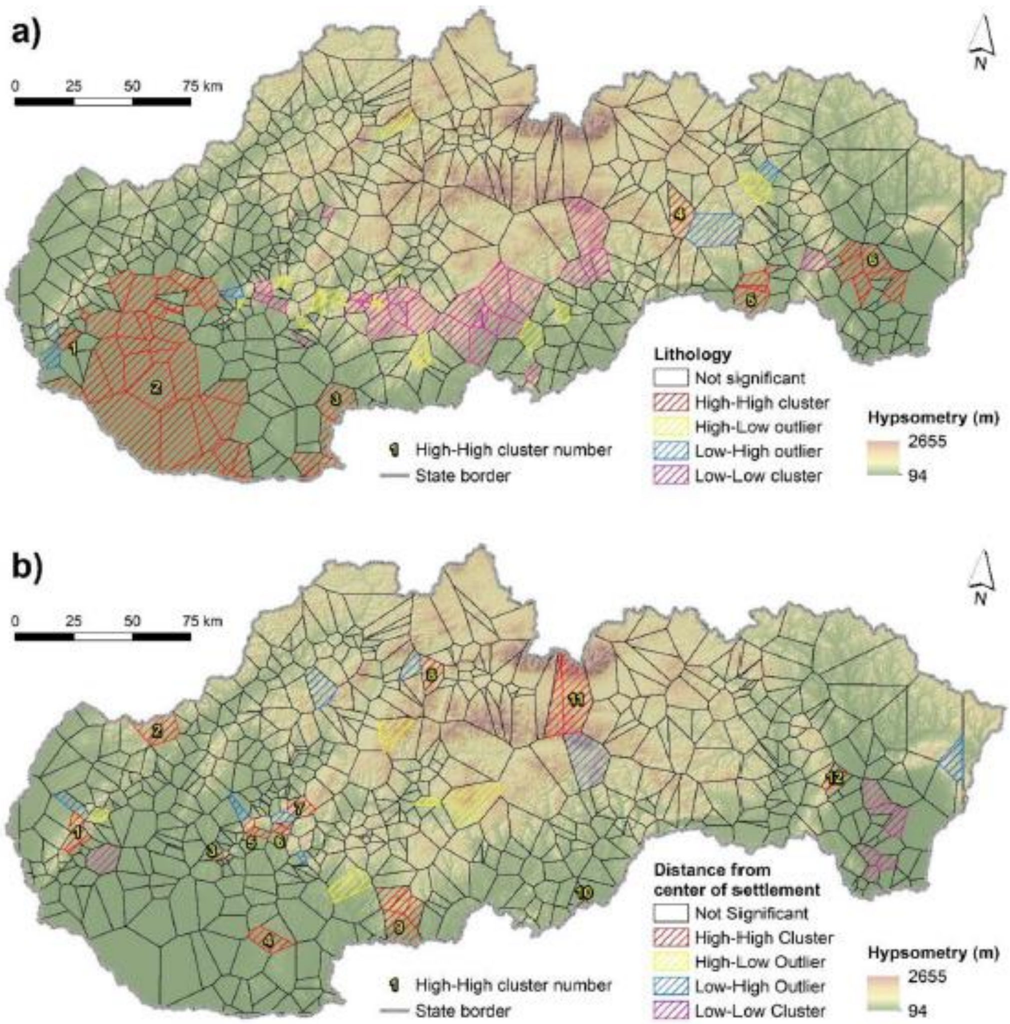

Figure 5. Statistically significant local Moran's coefficient of spatial autocorrelation based on the values of studied attributes: (a) lithology and (b) distance from the centre of the nearest settlement.

Table 8. Localization of eight High-High clusters in geomorphological units and principal basins of Slovakia.

Cluster	Geomorphological units	Principal basins
1	Podunajská rovina (plain)	Dunaj, Váh
2	Podunajská rovina (plain) – Podunajská pahorkatina (hills)	Váh
3	Podunajská pahorkatina (hills)	Hron, Dunaj
4	Podunajská pahorkatina (hills) – Tribeč (mountain)	Váh
5	Tribeč (mountain)	Váh
6	Malé Karpaty (mountain) – Myjavská pahorkatina (hills) – Podunajská pahorkatina (hills)	Váh
7	Slovenský kras (mountain) – Volovské vrchy (mountain)	Slaná, Bodva, Hornád
8	Východoslovenská rovina (plain)	Bodrog

Table 9. Localization of eleven High-High clusters in geomorphological units and principal basins of Slovakia.

Cluster	Geomorphological units	Principal basins
1	Borská nížina (lowland) – Malé Karpaty (mountain)	Váh
2	Malé Karpaty (mountain) – Myjavská pahorkatina (hills) – Podunajská pahorkatina (hills)	Morava
3	Podunajská pahorkatina (hills) – Tribeč (mountain)	Váh
4	Tribeč (mountain)	Váh
5	Oravská vrchovina (highland) – Chočské vrchy (mountain)	Váh
6	Súľovské vrchy (mountain) – Žilinská kotlina (basin) – Malá Fatra (mountain) – Turčianska kotlina (basin) – Žiar (mountain) – Veľká Fatra (mountain)	Váh
7	Čierna hora (mountain)	Hornád
8	Slovenský kras (mountain) – Košická kotlina (basin) – Volovské vrchy (mountain)	Bodva
9	Rožňavská kotlina (basin) – Slovenský kras (mountain) – Volovské vrchy (mountain)	Slaná, Bodva, Hornád
10	Slovenský kras (mountain) – Juhoslovenská kotlina (basin) – Revúcka vrchovina (highland) – Stolické vrchy (mountain) – Veporské vrchy (mountain) – Horehronské podolie (basin) – Nízke Tatry (mountain)	Hron, Slaná, Ipeľ
11	Strážovské vrchy (mountain) – Podunajská pahorkatina (hills)	Váh

Table 10. Localization of nine High-High clusters in geomorphological units of Slovakia.

Cluster	Geomorphological units
1	Malé Karpaty (mountain)
2	Tribeč (mountain)
3	Tribeč (mountain)
4	Pohronský Inovec (mountain) – Štiavnické vrchy (mountain)
5	Strážovské vrchy (mountain)
6	Čergov (mountain)
7	Nízke Tatry (mountain) – Podtatranská kotlina (basin)
8	Horehronské podolie (basin) – Nízke Tatry (mountain) – Veporské vrchy (mountain) – Stolické vrchy (mountain) – Revúcka vrchovina (highland) – Spišsko-gemerský kras (mountain)
9	West-east gradient: from Malá Fatra (mountain) to Chočské vrchy (mountain) north-south gradient: from Kysucké Beskydy (mountain) to Starohorské vrchy (mountain)

There were also seven clusters (35 HODFs) with low values (Low-Low), which also represented the positive spatial correlation of the occurrence of HODFs. The largest of these clusters extends in the west-east gradient from the geomorphological unit of Stiavnicke vrchy (mountain) to the Stolicke vrchy (mountain). There were altogether 13 High-High and Low-Low clusters having positive spatial autocorrelation (**Figure 5**(a)). The occurrence of High-High clusters within geomorphological units and dominant lithological types is shown in **Table 11**.

Furthermore, 11 clusters (12 HODFs) of the High-Low type were also identified, i.e. areas with high values, adjacent to areas with low values. Five clusters (5 HODFs) of the Low-High type were also identified, i.e. areas with low values, adjacent to areas with high values.

3.6. *Distance of HODFs from the centre of the nearest settlement*

Based on the results of the local Moran's coefficient (**Figure 5**(b)), 12 smaller and scattered clusters with high values of distance of HODF from the centre of the nearest settlement (High-High) were identified, which means that there was a positive spatial correlation of the occurrence of HODFs (26 HODFs) in these areas. The occurrence of High-High clusters within geomorphological units is shown in **Table 12**.

Table 11. Localization of six High-High clusters in geomorphological units and dominant lithological types.

Cluster	Geomorphological units	Dominant lithological type
1	Podunajská rovina (plain)	Pleistocene river terraces
2	Podunajská rovina (plain) – Podunajská pahorkatina (hills) – Považský Inovec (mountain)	deposits of alluvial plains
3	Podunajská pahorkatina (hills)	Pleistocene river terraces
4	Volovské vrchy (mountain) – Hornádska kotlina (basin)	Pleistocene river terraces
5	Košická kotlina (basin) – Bodvianska pahorkatina (hills)	proluvial cones and shells
6	Východoslovenská rovina (plain) – Východoslovenská pahorkatina (hills)	deposits of alluvial plains

Table 12. Localization of twelve High-High clusters in geomorphological units of Slovakia.

Cluster	Geomorphological units
1	Malé Karpaty (mountain)
2	Biele Karpaty (mountain), Myjavská pahorkatina (hills)
3, 4	Podunajská pahorkatina (hills)
5, 6, 7	Tribeč (mountain)
8	Veľká Fatra (mountain)
9	Krupinská planina (plain), Juhoslovenská kotlina (basin)
10	Cerová vrchovina (highland)
11	Nízke Tatry (mountain), Kozie chrbty (mountain), Tatry (mountain)
12	Slanské vrchy (mountain)

There were also three clusters with low values (Low-Low), which means that in these areas, there is a positive spatial correlation of the occurrence of HODFs (7 HODFs). In particular, one cluster is localized in the western Slovakia - Podunajská pahorkatina (hills) and two clusters in the eastern Slovakia - Vychodoslovenska rovina (plain) and Východoslovenska pahorkatina (hills). In addition, five clusters (5 HODFs) of the High-Low type as well as eight clusters (8 HODFs) of the Low-High type were identified.

4. Discussion

Besides the use of bedrock or readily available rocks as a building material, other aspects of the impact of geological environment on the distribution of HODFs in Slovakia are more or less indirect. Structural and lithological conditions were determinants for the distribution of HODFs of an attractive reef type. At the same time, the geological environment decided on the location of historic ore mining centres producing profits and protected in the safety of medieval HODFs. Taking into account the research results in terms of the studied attribute of elevation of HODFs, it can be seen that the largest cluster of positive spatial autocorrelation with high values of elevation (High-High) is located in northern Slovakia and the basic types of rocks are mainly limestones, granitoids, clay-stones and metapsamites. Andesites and intermediate subvolcanic intrusives are also common mainly towards the south. The sharply modelled limestone hills of the Klippen belt have become an optimal geological and geomorphological environment for a number of HODFs, such as Oravský castle, Lubovňiansky castle, Likava castle, Liptovský castle, Trniny extinguished castle, Muráň castle, and so on.

The stratovolcanic structure of the central Slovak mountains excels in a higher incidence of HODFs of an attractive reef relief. In addition, the rich occurrence of ores is associated with this geological environment (**Lacika 2016**). This type includes HODFs, such as Kremnica castle or Kalamárka hillfort. The second-largest cluster also includes HODFs with stratovolcanic structure, for example, old chateau in Banská Štiavnica, Sitno castle, Žakýlsky extinguished castle, and so on. The smallest cluster of HODFs with high elevations (High-High) is found on metapsamites, namely it is the Drieňovec castle. Moreover, two large clusters of positive spatial autocorrelation with low values of elevation (Low-Low) were identified, which occur in the southern and eastern Slovakia and are built mainly with claystones.

Due to its monotony, the geological environment of the Slovak lowlands has had a minimal differentiating effect on the natural landscape. Therefore, it has not contributed to the differentiation in frequency or density of HODFs. This role has been taken over by another natural component - water. Unregulated rivers surrounded by side branches, swamps, and dense floodplain forests have taken over the protective role in the lowlands and basins. Water management interventions in natural meadows have weakened the natural protection of the so-called water castles, which became extinguished in greater numbers than other types of castles in Slovakia (**Lacika 2016**). In this regard, examples are the cluster located in southern Slovakia - Parkan extinguished fortress, Malé Kosihy extinguished fortress, Dievčí hrad castle, Komjatice extinguished water castle or the cluster located in the eastern Slovakia - Hatalov extinguished castle, Velké Trakany extinguished castle, Oborín extinguished castle, Pavlovce nad Uhom extinguished castle, and the like. The third-smallest cluster is represented by the Bošany water castle and the watchtower in Žabokreky nad Nitrou.

When comparing the research results in terms of the studied attributes of elevation and type of REPGES, it can be seen that the location of their areas having positive spatial autocorrelation, whether with high or low values, is almost identical. However, when HODF occurs within the REPGES type, the obtained clusters with positive spatial autocorrelation are smaller and more fragmented. In addition, six clusters having positive spatial autocorrelation with high values of REPGES type are located outside the clusters, which were identified on the basis of the studied attribute of elevation. It is the cluster in the western Slovakia, which is located on metapsamites (e.g. Pezinok castle) and clay-stones (e.g. Kuchyňa extinguished fortress). In central Slovakia, there are four clusters, which bind mainly to limestones (e.g. Malý Rokoš extinguished castle), claystones (e.g. Krnča extinguished castle), granitoids (e.g. Čierny castle or Velčice extinguished castle), and on andesites and intermediate subvolcanic intrusives (e.g. Zámčisko fortress or Tekovská Breznica watchtower). One cluster in eastern Slovakia having positive spatial autocorrelation with low values of REPGES is also located outside the clusters identified on the basis of the studied attribute of elevation. This cluster is located on claystones and includes, for example, Chorváty extinguished castle or Velká Ida manor house.

The other two studied attributes concerned distance of HODF from the river and elevation difference between the HODF and the river. The plain types of HODFs are mainly associated with rivers. This type of castles is connected to the lowland and partly also to the basin areas of Slovakia. The flat terrain did not cause any building limits, but at the same time, it was not possible to count on the use of rugged relief as a natural protection of the castle. The plain types of castles were built on river floodplains or river terraces, in rare cases also on the loess plateau. Castles on the river floodplain are also known as water castles because their defence was provided by unregulated river. These castles were built in a dynamic fluvial environment, on heavy clayey and marshy soils. The plain types of castles on plateaus of fluvial terraces were located in higher and drier positions than the water castles. They were built out of the reach of river floods, and thus without natural protection of the river. They were usually incorporated into the urban environment as town castles (**Lacika 2016**). Using spatial autocorrelation for the studied attribute of distance from river, five clusters of positive spatial autocorrelation with high values were identified, which were located in flat relief. These clusters include, for example, Gerulata fortification, Rusovce manor house, Šala water castle, Leles fortified monastery, Královský Chlmec castle, and so on. One cluster of positive spatial autocorrelation with low values of distance from river (Low-Low) is also located in flat relief and it is represented by the Pozdisov castle. However, when we look at the results of positive spatial autocorrelation with high values of elevation difference from river (High-High), it can be seen that there is only one cluster represented by the Čierny castle, which is predominantly located in flat relief.

Valley castles had similar local geomorphological conditions as the plain type of castles. They were built them on river floodplains and terraces, which were, however, trapped by steeper valley slopes. They were identified in the Carpathian basins as well as in large gulley valleys intersecting the Carpathian mountains, which formed important settlement communication corridors from ancient times (**Lacika 2016**). Based on the analysis of the spatial autocorrelation of the studied attribute of distance from rivers, such types of HODFs are located in the cluster in western Slovakia, for example Tlstá hora 1 extinguished castle, Tlstá hora 2 extinguished castle, Cerenec extinguished fortress and in southeastern Slovakia, it is Drieňovec castle. Conversely, when using the studied attribute of elevation difference from rivers, most of the identified clusters of positive spatial autocorrelation are located in large gulley valleys intersecting mountains, but also on a slightly higher relief protruding from the lowland plains, basins and bottoms of main valleys. They are represented by high values of elevation difference from rivers (High-High) and are located in north-western, central, and south-eastern Slovakia. Examples of such HODFs are Bystrička extinguished castle, Rajec extinguished castle, Jelšavká Teplica extinguished tower, Šivetice castle and so on. Many valley castles were structurally incorporated into the territory of towns and villages.

When comparing the results of spatial autocorrelation of the studied attributes of distance from river and elevation difference from river, it can be seen that the clusters of positive spatial autocorrelation of the studied attribute of distance from river are smaller and more scattered, especially, in southern Slovakia. In case of the studied attribute of elevation difference from river, the clusters are larger, more compact and located mainly in western, north-western, central and southern Slovakia. Moreover, clusters of positive spatial autocorrelation identified using the attribute of distance from the centre of the nearest settlement are also smaller, less compact, and scattered throughout the whole territory of Slovakia, while most of them are located in the central part.

The analysed attributes of HODFs were discussed in similar studies, such as Schneeweiss and Schatz (2014), who described the significance of topography for the research of the historical site of Hohbeck in the Early and High Middle Ages. They specifically dealt with the elevation and importance of location of historical objects from the river, pointing out the impact of floods. **Puhmajer (2019)** dealt with the importance of elevation and distance from the river in the construction and defensive function of

Cernik castle in Croatia. Occurrence of HODFs in types of REPGES in Slovakia was analysed by **Izakovičová et al. (2016)**.

The problem that arises in the analysis of HODFs based on distance or elevation difference from river is that some rivers flowed through differently shape channels in the past or they currently do not exist, which could affect the results of the performed spatial autocorrelation. If we wanted to identify statistically significant clusters of HODFs in the past and compare them with the current situation, we would have to determine the distance of these objects from rivers with the use of available historical maps, such as maps from the first military survey (1763-1785), second military survey (1806-1869) and the third military survey (1869-1887). However, the main limitation of using these maps is their accuracy. In addition, there is a problem with georeferencing (geographical transformation of the raster - positional assignment), especially, in case of maps from the first Military Survey. Maps from this period did not have any astronomical-geodetic bases. The absence of mathematical foundations of these maps is reflected in the incorrect geometry of the objects and the inaccurate position of the objects, which reduce their information value and applicability (**Brůna and Křováková 2005**). For instance, **Pestak and Zimová (2005)** analysed the mean positional error (MPE) of the maps of first and second military surveys for two regions (Sušicko and Jindřichohradecko) in Czechia and compared their accuracy with GNSS measurements, Digital Area Model (DMIJ 25) and orthophotos (1 m/pixel). Based on the results, the MPE was 11.7 m (first military survey) and 1.7 m (second military survey) for the Sušicko region and 6.1 m (first military survey) and 1.3 m (second military survey) for the Jindřichohradecko region. However, the average shift of the georeferenced points was 268 and 160 m for the Sušicko and Jindřichohradecko regions, respectively. Using older maps than from the 1st Military Survey for georeferencing is basically impossible, as they did not have mathematical bases at all.

In order to determine the clusters of HODFs that correlate with each other on the basis of spatial autocorrelation of the studied attributes, it was necessary to transform the point data into polygon data. Thiessen polygons were applied for this purpose. The justification and advantages of using Thiessen polygons were confirmed in other works. **Dytchowskyj et al. (2005)** studied the combination of Thiessen polygons and viewshed analysis for the generation of hypothetical prehistoric territories for a group of Iron Age hillforts in the Spanish valley called Alcoy. Similar research is described by **Niknami** and **Askarpour (2015)**, who used Thiessen polygons to the research of Chalcolithic sites in Iran. **Alessandri (2015)** used this method for the reconstruction of ancient settlements from the Latium Vetus and Etruria areas in Italy. The use of spatial autocorrelation for the study of historical objects is also analysed and discussed by **Vojteková et al. (2019)** and **Tirpáková et al. (2021)**. These two studies dealt with the spatial distribution of pottery occurrence in the Pobedim archaeological site (Slovakia) using different methods of spatial analysis. The presented results also correspond to the work by **Maleta** and **Calka (2015)**, who, however, did not use spatial autocorrelation to study historical objects, but real estate in Poland.

5. Conclusion

Based on the comparison of the results of positive spatial autocorrelation with respect to all studied attributes of HODFs, it is evident that in case of elevation and occurrence in the type of REPGES, the obtained clusters correlated significantly. In another words, elevation was proved to be an important attribute of spatial pattern of HODFs as well as type of REPGES since 9% of HODFs are situated in the REPGES type ‘river floodplain in lowlands’. Regarding the other studied attributes, there was no significant correlation of the obtained clusters.

Most of the common areas (up to 64) within the clusters with positive spatial autocorrelation (High-High + Low-Low) were between the studied attributes of elevation of HODFs and their occurrence in individual types of REPGES. In particular, these clusters can be found in the southwestern Slovakia - Podunajská rovina (plain) and Podunajská pahorkatina (hills), northern Slovakia - Velká Fatra (mountain) and Malá Fatra (mountain), central Slovakia - Stolicke vrchy (mountain) and Veporské vrchy (mountain), northeastern Slovakia - Čergov Mountain, and in the eastern Slovakia - Východoslovenská rovina (plain) and Východoslovenská pahorkatina (hills).

There was also a significant correlation in case of the studied attributes of elevation and lithology (47 areas) as well as lithology and the occurrence of HODFs in REPGES types, as 33 areas within clusters with positive spatial autocorrelation (High-High + Low-Low) were identical. Clusters of positive spatial autocorrelation (High-High + Low-Low) identified on the basis of the studied attribute of elevation and lithology correlated with each other in the south-western Slovakia - Podunajská rovina (plain) and Podunajská pahorkatina (hills) and in the eastern Slovakia - Vyýchodoslovenská rovina (plain) and Vyýchodoslovenská pahorkatina (hills). Regarding the clusters of positive spatial autocorrelation (High-High + Low-Low) identified based on the studied attributes of lithology and REPGES type correlated with each other, especially, in the south-western Slovakia - Podunajská rovina (plain) and Podunajská pahorkatina (hills), central Slovakia - Stolické vrchy (mountain), Veporské vrchy (mountain), and Revúcka vrchovina (highland), and in the southeastern Slovakia - Košická kotlina (basin), Východoslovenská rovina (plain) and Východoslovenská pahorkatina (hills).

The largest and most compact clusters of positive spatial autocorrelation were identified based on the studied attribute of elevation. On the other hand, the smallest and most fragmented clusters of positive spatial autocorrelation were identified in case of the studied attributes of distance from river and distance from the centre of the nearest settlement. These clusters correlated only partially with clusters of positive spatial autocorrelation identified on the basis of other factors - elevation, lithology, and REPGES type and they coincided in only two to 13 areas. The results indicate that, during the construction of HODFs in the past, the elevation and lithology were very important, but also the environment (geoecosystem) in which the HODFs were built.

The heterogeneity of geological bedrock contributes to the distribution of castles in Slovakia through the structural-lithologically conditioned and, especially, increased occurrence of reef types of castles as well as the number of castles is higher in the historical areas of ore mining. Most of the castles were built on neovolcanics, in Klippen belt, and on Mesozoic limestones and dolomites. On the contrary, the least castles were built on flysch rocks. Relief is a natural component of the landscape, which is involved in the differentiated distribution of castles in Slovakia the most. Most of the castles were built on fringe of the mountains neighbouring to the lowlands and basins. Castles are rare or completely absent in the inner Carpathian mountains and in the inner parts of the marginal mountains. A higher concentration of castles was also found in the valleys with the function of a communication corridor. Many castles were also built in lowlands and basins, especially, in river floodplains and terraces.

Many castles have disappeared relatively quickly near or in the direct presence of densely populated basins and lowlands, especially, through the process of transformation into another type of historical object, most often a manor house. In mountain landscape, castles have disappeared without being replaced by other buildings and thus became nonfunctional ruins. The most favourable geomorphological conditions for the construction of castles in Slovakia were the marginal slopes of mountains adjacent to the lowland or basin, mainly Podunajská nížina (lowland) and Východoslovenská nížina (lowland), as well as isolated hills of various heights, shapes and genesis rising above the slightly rugged relief of lowlands and basins. Isolated castle hills with a top plateau, such as the Bratislava castle or Saris castle, are considered to be ideal places for building a castle (**Lacika 2016**).

Castles were an important part of the cultural landscape of the medieval Kingdom of Hungary with the function of administrative centres managing or at least influencing the social, cultural and economic events of the medieval population. The 'golden age' of castles in the territory of today's Slovakia is attributed to the middle of the 13th century up to the end of the 14th century. The unfavourable circumstances of the modern history of Slovak castles have led to the fact that only a small part of them has survived to this day. Most castles have been turned into ruins and a relatively large group of castles has disappeared without a trace or only small remains have been preserved. Some castles have been completely forgotten over time while the existence of others is questionable or only hypothetical (**Lacika 2016**). The obtained clusters of positive spatial autocorrelation can help to better understand what decisive factors influenced the construction of HODFs in the past as well as which places were preferred in their localization and construction. Further research could be directed towards the use of other methods for determining the occurrence of HODFs, such as multicriteria analysis or fuzzy sets, and their comparison with spatial autocorrelation.

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