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Aspects and methods in reconstructing the medieval terrain and deposits in Vilnius

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ABSTRACT

The article deals with the geomorphological diversity (confluence of Neris and Vilnia rivers, junction of two ice ages, erosion hill terrains, terrace levels, etc.) of Vilnius city which played an important role in choosing the place for the city to be established and in formation of its defence structure. The diversity of terrain of Vilnius city and its environs is demonstrated by the distinguished morphogenetic zones: 20 morphogenetic units including 5 zones within the area of the medieval city. From the point of view of the history of environment, the historical relief of Vilnius city has five types of relief. The research was carried out in one of the five types of city topography: moraines left by glaciers (part of the Kuprijoniškės–Salininkai morainic complex). The shallow till acted as an impermeable barrier and created conditions for accumulation of groundwater. Springs emanated at the slope bottom turning into streams. The largest among them is the Vingrė River, which marks the boundary between two types of topography. The studied territory occupies 2.6 km². Through the reconstruction of the primordial terrain, it would be possible to trace the direction of Vingrė stream and the location of the defensive wall. LIDAR topography and borehole data, topographic maps of 1842 and 1994, and archaeological data were used. Geophysical and digital methods were applied. The research contributes to reconstruction of the pre-anthropogenic terrain, indicating possibilities for its optimal use and living conditions.

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1. Introduction

Land topography is the totality of the vertical and horizontal dimensions (unevenness) of the land's surface as well as a systematic combination of shapes. It is one of the most stable components of inanimate nature and at the same time a geosystem distinguished by causative relationships and dynamics (Česnulevičius, 1998).

Settlements were usually established in watersheds, most of terrain being later altered. Representative investigations of urbanised terrain and anthropogenic deposit changes have been carried out by Popov (2007), Kotlov (1977), Lichačiova (2007) and Lichačiova et al. (1981). They present methods for reconstructing the original urban terrain and evaluating the degree of its change. Urban anthropogenic or 'fill-cultural' deposits have been investigated in many cities, reconstructions of the original terrain having been made in Cardiff, London, Paris, St. Petersburg, Odessa, Kiev,

etc. In Moscow, fragments of the natural landscape have survived only in parks and squares. In Moscow, there are currently about 800 waterways, of which 115–140 are functioning rivers according to the author's work (Nasimovič, 1997), the remainder draining into underground collectors. The city of Vilnius also has channelled drainage.

Many research papers have addressed the three-dimensional aspect of historical cartography and focused on an image-based reconstruction and geometrical evaluation of one of the most remarkable landscape models in history, the topography of Franz Ludwig Pfyffer. Lieutenant General Franz Ludwig Pfyffer von Wyher (1716–1802) devoted 20 years of his life to constructing the topography of Central Switzerland (Niederöst, 2002). According to Fuse and Shimizu (2003, 2005), historical maps are precious materials, which show the spatial distribution of land use, streets, etc. that were of historical importance when the maps were created. They can be a dependable source of information for previous city planning concepts. The reconstruction of Tallinn's historical terraces made by Estonian archaeologists is comparable to the present authors' work in respect to methodology (Nurk et al., 2012, Kadak, 2013).

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For the authors' research, the investigation of medieval terrain was a prerequisite in evaluating the role of natural landforms in the founding and expansion of Vilnius and the development of its transport system. The interpretations of historical sources have long been guided by political considerations, but the old city plans of Braun (1572), Getkant (1648), and von Fürstenhoff (1793) (Morkūnaitė et al., 2008, Morkūnaitė, 2010) were created using contemporary sources and lack precision. Geological geomorphological and geophysical investigations were used to determine the scale of the anthropogenic changes. The geomorphology and relief forming processes of Vilnius city (Morkūnaitė, 2010) has been described in detail by Dvareckas (1961), Vodzinskas (1963–1964), Basalykas and Dvareckas (1981), Gaigalas (1985–1986), Guobytė (2000, 2008), and others in recent decades.

The landscape of the Sapieginė hill terrain of the 14th century in front of the Gediminas Mount was described and evaluated from the point of view of city needs by Vaitkevičius and Kiškienė (2010), Vaitkevičius (2010). These authors made use of geomorphological methods. The primary relief of Vilnius Table Mount (Stalo Kalnas) was reconstructed using the complex *in situ* method and geophysical and geological investigations (Sarcevičius, 2011). The reconstruction of Vilnia valley palaeohydrology and the existence of a high saddle hill between the Gediminas and Three Crosses (Trijų Kryžių) mounts (at the time of formation of the high terraces) were described by Satkūnas (2012). Some researchers think that the impact of the geological and geomorphological processes that formed the topography of Vilnius cannot be compared to the degree of the anthropogenic changes (Šliaupa, 1999). The analysis of this degree presented here was designed to support or oppose this opinion.

Reconstructing the natural terrain helps to determine the influence of the natural heritage, i.e. the geological and geomorphological factors, on the development of Vilnius and the change in its hydrographical network. This reconstruction was made by eliminating the thickness of the anthropogenic layer from the absolute altitude. Stratigraphic diagrams and an evaluation of the city's geomorphological–lithogenic conditions were used for this. Landform reconstruction according to topographic map data is usually made using a computer program but also requires analytical methods.

The goal of the present research was to reconstruct the medieval terrain of the study site by eliminating the upper layer of anthropogenic deposits. The subgoals were to determine the possibilities for building roads, the directions of any transit roads, and the changes in the hydrographic network.

2. Study sites

The investigation was conducted in one of the city's five landscapes, morainic hills where groundwater accumulates on shallow till, an impermeable barrier (Fig. 1). The springs at the bottom of slopes are the sources of streams. The largest stream, Vingrė, divides the landscape into two terrains. It is important in the 2.6 km² study site to determine the changes in the original terrain and to evaluate its influence on the city's development. The selected landscape represents the city only partially, i.e. as a territory, where surface deposits cover moraine left by the second-to-last glaciation and where one of the main streams that supplied water to the inhabitants flowed on a scarp in Medieval and later times.

3. Sources and methods used in the topography reconstruction

Archival data was obtained from the Vilnius County Archives, historical data from the monographs and funds of the Lithuanian Institute of History, sample cores from the Lithuanian Geological

Survey (LGS), data from the archaeological atlas of Vilnius, and data from a geo-scanner (geophysical measurements), gamma radiometer, etc. The following methods were used:

- an archival material analysis
- an analysis and survey of historical sources and of cartographic and visual material
- an analysis of geological boreholes and sections
- geophysical methods.

An archival material analysis was made to determine the development of the hydrographic objects in Vilnius and some of the problematic old areas of water use, especially springs, bogs, and streams and to check the geological borehole data on groundwater depth and impermeable layers. Maps and plans of springs in Vilnius were examined at the Vilnius County Archives. In order to reconstruct the change in natural conditions, borehole data from the Vilnius Geological Survey were analysed for the lithology of the various layers (especially surface layers) and the thickness of the upper (anthropogenic) layers down to the Medieval surface. In order to compile cartographic diagrams, the geological borehole data (depth, date, geographical coordinates, layer thicknesses) were digitised using computer programs and a database was created. The borehole sites were plotted on an orthophotographic basis.

The geomagnetometer Geo-Scanner BPT-3010 was used to measure the average and extreme values of the magnetic field. Under field conditions, the device determines the magnetic field values in 20 linear points, saves the values to memory, and with the

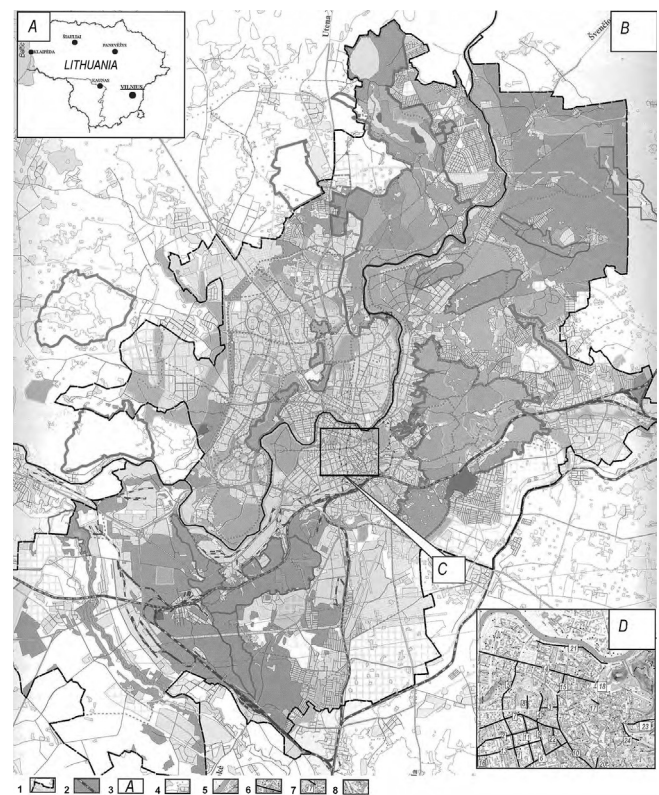


Fig. 1. Main scheme (1. Vilnius city limits; 2. Railways; 3. Insets (Location of Vilnius in SE Lithuania (A); map of Vilnius (B); location of the reference data discussed in the text (C); 4. Suburban areas; 5. River Neris; 6. Streets mentioned in the article (D) Inset; 7. The streets named: (1. Svitrigailos; 2. Vivulskio; 3. Kalinausko; 4. Tauro; 5. Kudirkos; 6. Naugarduko; 7. Basanaviciaus; 8. Valanciaus; 9. Mindaugo; 10. Pylimo; 11. Algirdo; 12. Sierakausko; 13. Ševcenkos; 14. Gedimino; 15. Jogailos; 16. Smolensko; 17. Daukanto; 18. Cathedral Square; 19. Vilniaus; 20. Bazilijonų; 21. Žygimantų; 22. Vingrių; 23. Užupio; 24. Malūnų.) 8. Vilnius Region).

help of the operating system draws profiles of the various magnetic fields. These data were transferred to a PC and processed using GeoReader and Surfer to produce profiles or area maps. Because this was the first time this method was used, the minimal and maximal magnetic field values were checked using an analogue method. The magnetic field strength was measured in an area with known underground stratigraphy and structure.

In addition, gamma radiation was measured in the same areas using a scintillating SRP-68 gamma radiometer. The results were presented together with a situation of the study area part. These geophysical methods were used to determine magnetic and gamma field anomalies, indicative of old watercourses. This investigation allowed the original terrain to be reconstructed, changes to be determined, and the living conditions and changes in the hydrographic network to be described.

4. Results: analysis of the current and reconstructed terrain

An area of Naujamiestis District (Švitrigailos (1), Vivulskio (2), Kalinausko (3), and Tauro (4) Streets) was chosen as a study site (Fig. 2). The anthropogenic layer (according to the LGS and geological atlas data) is 1.0–4.0 m thick (the latter being found south of Kalinausko Street). These thickness variations could have been caused not only by anthropogenic fill layers but also by building postholes. For this reason, the ranges of the anthropogenic level were not analysed, the focus being on the present-day and reconstructed original topography.

The highest topography elevation is about 144.0 m elevation at the intersection of Vivulskio (2) and Švitrigailos (1). Northeast of it, the surface slopes down to 100.0 m in Kudirkos Street (5), south of it, the altitudes range within 142–141 m. According to the analysed map, the terrain has 5 ravines with well-expressed upper reaches and less well-developed mouths opening onto areas with altitudes of 128–123 m (E part) and 112 m (NW part). The upper reaches in Naugarduko Street (6) start at its intersection with Mindaugo Street (9), run to the intersection of Basanavičiaus (7) and Algirdo Streets (11) and to Tauro Street (4) at the facade of the trade union building, ending at the intersection of Kudirkos (5) and Valančiaus Streets (8). The deposit composition at the intersection of Naugarduko (6) and Pylimo (10) Streets and the morphometric differences of the layers follow the pattern of a typical accumulative form, i.e. an alluvial fan, created by sediment transport processes in the ravine.

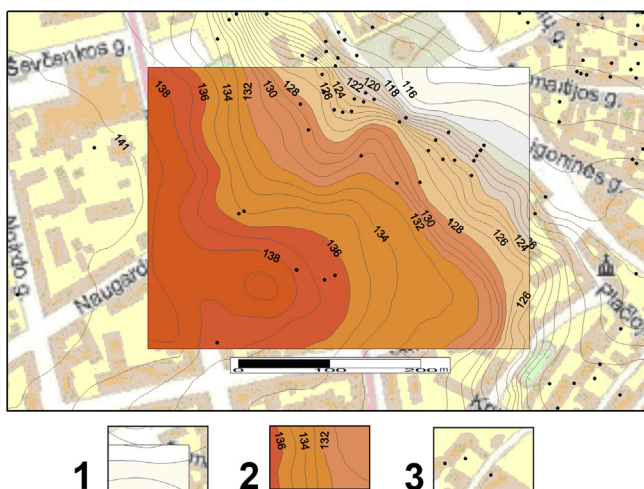


Fig. 2. Study site with the reconstructed terrain in the Naujamiestis District of the Kuprioniškės–Salininkų morainic slope (1. Investigated study site; 2. Contours; 3. Actual material.).

In the map of reconstructed terrain, the upper reaches of the ravines are situated tens of metres to the E (in the E part) and to the N (in the N part). For example, the reconstructed Basanavičiaus ravine is 332 m long, whereas the present ravine is 410 m long. The highest point of the reconstructed terrain, 142 m, is at the intersection of Vivulskio and Švitrigailos Streets. The majority of these gullies were used to create streets, e.g., Basanavičiaus, Naugarduko, etc., and the change in the size of the gullies is now connected with earthwork and the appearance of an anthropogenic layer.

According to the literature (Kozlov, 1947; Basalykas and Dvareckas, 1981), the study site includes the 4th fluvial terrace, which formed in the warm Bølling period during the decay of permafrost due to intensified geomorphological processes. The various terraces of the Neris arose through changes in the base of the fluvial erosion and in the lowering of the river's water level. These ravines open onto the 3rd terrace (e.g. the Antakalnis erosion hill land). The 2nd terrace, which formed at the end of the late interstadial period, is characterised by dunes. This explains the frequent occurrence of ravines in the study site.

5. Lithology of the surface

The occurrence of Late Holocene deposits under the anthropogenic deposits was analysed using the core sample data from the LGS and the archival material in the Vilnius County Archives. The mapping was based on the altitude of the deposits determined by interpolating the point data, which should not be compared to the geological data (Guobytė, 2000).

The greater part of the study site is covered with sand deposits. Fluvoglacial medium-grained yellow sand, somewhat fine-grained sand, fine-grained sand with silt, and coarse-grained sand with small patches of gravel/pebbles predominate.

The geological boring material from some sites, mainly on Kalinausko (3), Sierakausko (12), and Basanavičiaus (7) Streets, shows the occurrence of loam and sandy loam layers. Deposits of this type also are found at the intersection of Gedimino (14) and Jogailos Streets (15), in Smolensko (16) and Ševčenkos (13) Streets, and S of Town Hall Square. In some places, these deposits are indicative of bedrock and in others of small residual ridges.

Peat, which represents deposits that link the city's development with the formation of the hydrographic network (and anthropogenic activity), was found at investigated historical sites in Cathedral Square (18) and part of present-day Daukanto (17) Street. Smaller peat areas can be found in different parts of the city. Most have been left by pools of standing water collected from permanent and temporary streams. The peat areas detected in Malūnų (24) Street and Bernardinai Park are presumably indicative of anthropogenic activity. When the water resources that existed in small ponds were largely exhausted, mud remains gradually covered the anthropogenic layers, forming the oxygen-free conditions necessary for peat accumulation.

The arrangement of the gravel, pebble, and boulder deposits and comparable altitudes allowed old watercourses to be determined. The analysis of these deposits (sometimes with interlayers) located at similar altitudes helped to determine the directions of the old watercourses and the presumed discharge basins. The bulk of these watercourses flowed into the Neris and the Vilnia. Local watercourses ending in Cathedral Square (18), Vilniaus Street (19), and other streets were also identified. The altitude of their beds, determined using the first layer, varied from 125.0 m elevation (Bazilijonų Street (20), SE Vilnius) to 89.0 m in Žygimantų Street (21) and the Neris river valley. The watercourses tend to descend towards the Neris and the Vilnia. The existence of these watercourses serves as a basis for substantiating the history of Vilnius

city planning and highlights many issues related with the population history of Vilnius.

6. Changes in the hydrographic network

The investigation of the development of the hydrographic network (old streams, groundwater fluctuations, etc.) is important for topographic reconstruction. One aim of this work was to correct the Vingrė's course shown in von Fürstenhoff's 1750 plan. To this end, the geophysical magnetic field method was employed for the first time. It was hoped that this method would help to determine the location of Vingriai springs (the source of Vingrė Stream). These were the largest natural springs on the 4th Neris terrace (formed in the late glacial) between Mindaugo (9) and Vingrių (22) Streets. They were shown on almost all of the old maps of Vilnius (Getgant's 1648 plan; the plan from von Fürstenhoff's 1793 collection; the 1908 plan).

The area between Mindaugo (9) and Vingrių (22) Streets is noted for the old springs that supplied the city with drinking water. In the 1880s, Vingriai springs produced 110 thousand buckets of water per day (about 1100–1200 m³/d) (Juodkazis, 2005). The water was used to reinforce the city's defensive system and as drinking water. The Vingrė, which flowed through the city towards Gediminas Castle, was used as a natural water supply (Jurkštas, 1990).

The Vingrė (Kačerga Stream since the 18th century), which began at the springs, existed until the late 19th century. After sanitary conditions deteriorated, the stream was channelled.

The old bed of the Vingrė was reconstructed using cartographic material (von Fürstenhoff's 1750 Vilnius city plan), which coincided with the topographic map of the reconstructed terrain (1:10 000). The source of the stream was identified using the Geo-Scanner BPT-3010 and the scintillating gamma radiometer SRP-68.

The Vingrė begins on the scarp of the 4th terrace of the Neris. According to measurements made on the left bank of the Neris at Vingriai springs, the elevation of the 4th terrace is 108–118 m, the relative height 21–31 m, and the width 500–700 m.

According to the reconstructed topography, the source of the Vingrė is at an elevation of 117 m. The Vingrė flowed towards the Neris and the Vilnia along a gentle slope for about 142.0 m and joined the Vilnia at an elevation of 89 m. The stream's average inclination was 24 cm/km. The greater part of the stream bed was in the area of Pylimo, Liejyklos, and Stuokos-Gucevičiaus Streets (Fig. 3). One section of the stream is now under buildings.

According to von Fürstenhoff's 1750 Vilnius city plan, the Vingrė met the Vilnia at 89 m. In the 1808 city plan, the part of the Vilnia encircling Cathedral Square (18) does not exist. From its confluence with the Vilnia to the Neris, the Vingrė 'used' the old Vilnia channel and is shown in the city plan as a direct left tributary of Neris, meeting it at the Vrublevskis library (Pol. *Biblioteka Wróblewskich*). The lower reaches of the Vingrė used the old Vilnia channel along the approaches to the Vingriai springs (between Mindaugo (9) and Vingrių (22) Streets). Fig. 4 shows magnetic field distribution. A few areas with an anomalous magnetic field distribution can be seen at the slope's bottom where the spring's source existed. The magnetic field strength values drop to 30,000–40,000 nT whereas the average normal undisturbed magnetic field in Lithuania is about 44,000 nT. The lower values could have been caused by a screening effect of groundwater flows (Dubrov, 2009; Mersmann, 2001; Gak and Gridin, 2005). Additional gamma radiation measurements were made using the scintillating gamma radiometer SRP-68. Fig. 4 shows gamma radiation values of 9–19 mkr/h, i.e. within the limits of average gamma radiation background for Lithuania. The smallest values (9–10 mkr/h) also roughly correspond to areas of a weaker

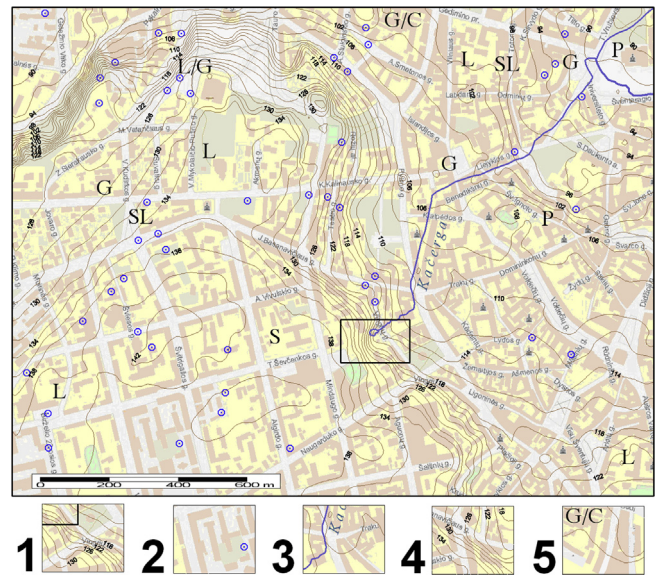


Fig. 3. Vingrė (Kačerga) Stream from its sources to the Vilnia (1. Sources of the Vingrė; 2. The city's residential districts; 3. The bed of the Kačerga (Vingrė); 4. Contours; 5. Deposits (L – Loam; SL – Sandy loam; G – Gravel; GC – Gravel/Clay; L/G – Loam/Gravel; P – Peat).

magnetic field, thereby also indicating the site of the remnants of the Vingriai Springs (Fig. 4).

7. Discussion

The areas chosen for terrain reconstruction (Naujamiestis and the source of the Vingrė) can be compared to the reconstructed historical area of the Curvum Castrum in the Sapiėginė erosion hill land (Fig. 5). The authors of the latter reconstruction (Vaitkevičius and Kiškienė, 2010) have pointed out that the landscape is a dynamically changing natural creation as the angles of the slopes and the shapes of the hills are changing, the gullies are becoming larger, and the surfaces of valleys are becoming deformed. The Sapiėginė hill land is distinguished by sand and gravel on the surface, similar deposits being also characteristic of the investigated study site. The terrain's somewhat different morphometric characteristics caused more intensive slope and erosion processes in the

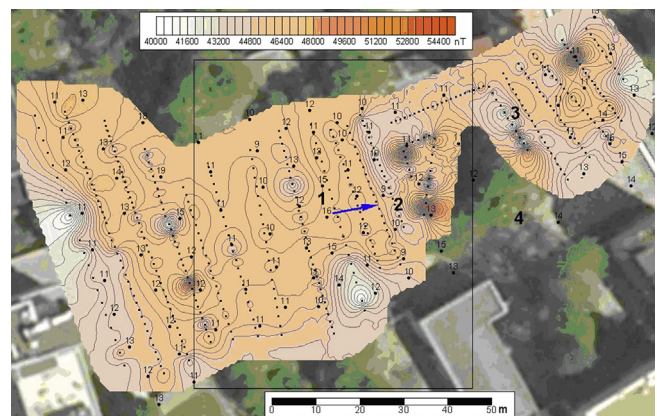


Fig. 4. Distribution of strength of Earth's magnetic and gamma radiation field near Vingriai spring (the blue pointer indicates a spring direction). Note. Strength of Magnetic field H (nT) is shown in contour lines, values of gamma field (mkr/h) are given in points with numbers. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

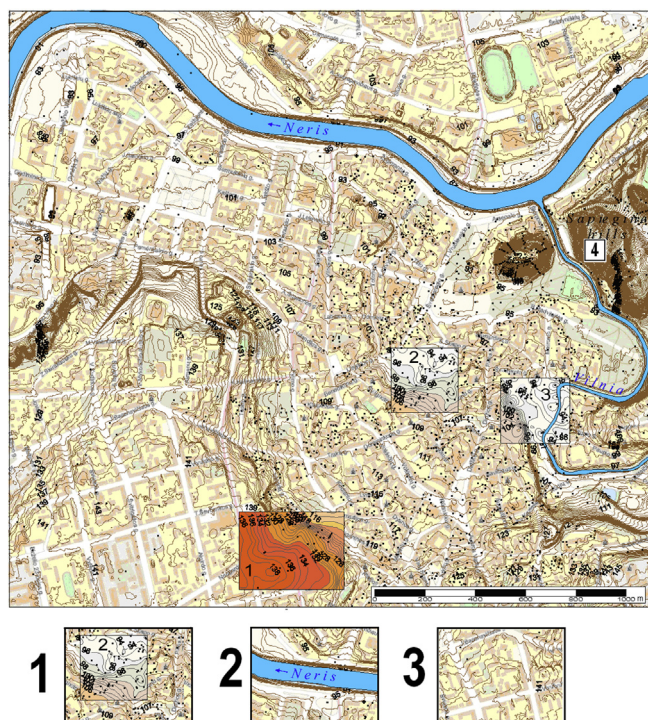


Fig. 5. Reconstructed relief of ravines: (1. Investigated areas: (1. Naujamiestis; 2. Old city; 3. Vilnia River neighbour; 4. Sapiėginė hills terrain); 2. Rivers; 3. Vilnius developments.).

Curvum Castrum area. Similar processes in the study site also occurred in Užupis and partially in the section of the Neris valley above the mouth of the Vilnia. In these two cases, the erosion processes affected the settlement of those parts of the city very differently. The changes in the Curvum Castrum landscape played a decisive role in the defensive functions of the city. Investigation revealed that due to different natural conditions (morainic plateau, groundwater depth, and the distance from the Vilnia), the study site was settled only in the 17th century. Naujamiestis' maximum altitude is 144.0 m an abs a. The cultural layer is 4.0 m thick. The altitude variations (of up to 40 m) in the study site's relief are less conspicuous than in the Sapiėginė hill land (70% of area having slopes $>25^\circ$). The reconstruction of the terrain revealed only changes in the ravines, which are today over 80 m wider and longer. Although the cultural layers were thin, considerable changes in the negative terrain forms were traced back. The recent erection of buildings with piles, which hindered the determination of the cultural layer, and the thinness of the cultural layer made it difficult to reconstruct the terrain in detail. The precise channel of the Vingrė, however, was successfully reconstructed because it was possible to follow the gullies and, as expected, the changes in them.

The identification of the remnants of the watercourses based on deposits and their altitudes is another aspect of terrain reconstruction worthy of discussion. From a historical perspective, a plan of the watercourses would be very helpful in substantiating the city's settlement and would determine the influence of natural conditions on the development of the environment and the population. From a natural-geological perspective, the watercourses show the supply basins and drainage zones. These factors allow the natural medieval urban environment prior to the intensification of the anthropogenic processes to be properly evaluated.

The investigation of the geomagnetic field in order to identify remnant watercourses (e.g., the source of the Vingrė) in an urbanised landscape is problematic due to the dense network of

underground utility lines and other sources of magnetic field distortion. After the introduction of additional research in the future, this method could become promising.

8. Conclusions

The geomorphological–geological diversity of Vilnius may have determined the city's historical beginning and development as shown by the reconstruction of the original topography and deposits. The obtained data show the historical conditions and their employment for human needs, such as the stream beds used for Naugarduko and Basanavičiaus Streets. Reconstruction of the topography of the study site (Naujamiestis District) indicates that the ravines were 80 m longer than they are now, but in other study sites (Old Town), lowering of the height by 2 m is also seen.

The lithological composition of the deposits in the study site also affected the gully formation processes. After eliminating the anthropogenic layer, it was determined that the bulk of the study site has been covered by sandy deposits. Medium-grained yellow sand predominates, fine-grained sand with silt or coarse-grained sand with a gravel or pebble admixture occurring in places. The sand is of mainly fluvioglacial origin.

The historical sources mention that the Vingrė had the most water with other streams being regarded as its tributaries. Based on the reconstructed topography, the length and channel of the Vingrė was determined and, after reconstructing the topography, the Vingrė's outflow was ascertained using geophysical methods to be at 117 m elevation. This location corresponds to the scarp of the 4th terrace, at a relative height of 21–30 m above the Neris. The Vingrė was found to have been 1142 m long, flowing into the former Vilnia channel at 98 m.

The reconstruction of the topography of Vilnius, especially of the Old Town, is less effective than that of the Sapiėginė hill land due to the contrasts of the topography and existing buildings. The presence of watercourses in the lithological cover under the cultural layer is debatable, but can explain the town's road construction possibilities.

The study site was settled only in the 17th century due to its greater distance from the Vilnia and from the terraced valley of the Old Town with its greater mineral resources. The data obtained by reconstructing the terrain will help to reveal the city's cultural, technological, and defensive history (urban development).

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