Research Article

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Where faith meets geomorphology: The cultural and religious significance of geodiversity explored through geospatial technologies

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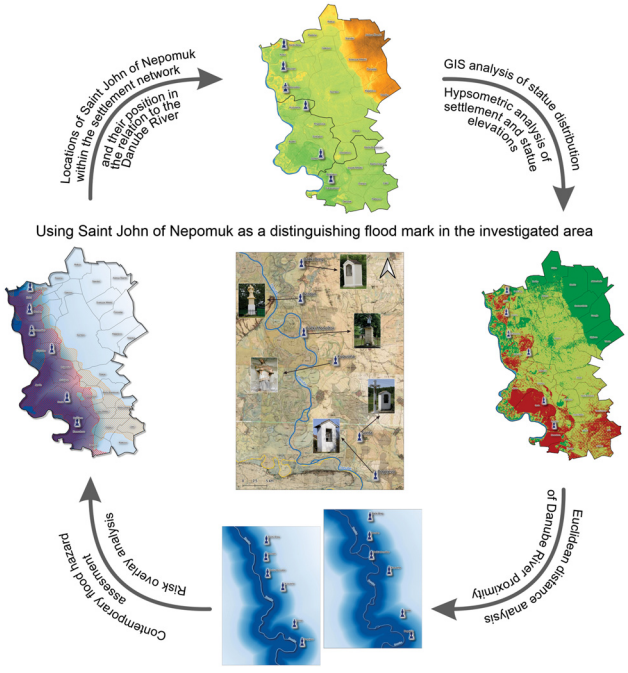
Abstract: This study explores the cultural value of geodiversity through the religious significance of the landscape in Gornje Podunavlje, northwest Serbia. Focusing on the veneration of Saint John of Nepomuk – the patron saint against water hazards – we investigate how his statues reflect historical community responses to flood risks in the Bačka region. Using nineteenth-century maps, geographic information systems (GIS), and geospatial analyses were applied to map statue locations, digitize historical Danube courses, and examine the spatial relationship between statues, settlements, and geomorphological features. Hypsometric and floodplain mapping, along with Euclidean distance and flood risk assessments (Danube Flood Risk Management Plan – DFRMP project data), revealed that all statues in Gornje Podunavlje are located on higher ground at the edges of settlements and oriented toward the Danube. In contrast, statues in other Bačka settlements lack this geomorphological alignment. These patterns suggest a culturally embedded adaptation to flood hazards. Present-day settlement outlines were digitized using satellite imagery to confirm current statue placements. The findings demonstrate how physical geography has influenced religious expression and settlement planning. This research emphasizes the importance of interpreting geodiversity not just as a physical attribute but as a cultural and historical factor shaping human–environment interactions in flood-prone flatland regions like Bačka (northwestern part of Serbia).



Graphical abstract

Keywords: cultural value, abiotic nature, geodiversity, Saint John of Nepomuk, local communities, water hazards, river terraces, geospatial technologies, GIS analysis, Serbia

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1 Introduction

The relationship between humans and the environment has traditionally been present in scientific research and is seen as a reason for establishing stronger connections between natural and social sciences, for example, between physical and human geography [1]. In accordance with the fact of the exponential growth of academic interest in the relationship between humans and nature, researchers

have investigated opinions, emotions, and behaviors related to the natural environment [2]. In such analyses, geodiversity also holds a prominent place, referring to the natural range of geological, geomorphological, and pedological features. The study of geodiversity includes assemblages, relationships, properties, interpretations, and systems [3,4].

It is widely acknowledged that sites valued by geoscientists for their geodiversity significance may also possess significant cultural values, regardless of whether there is a direct link between them [5]. Not only is there a connection between geodiversity and cultural value, but it can also be very obvious and strong [6–8]. When geological features interact with cultural elements (such as historical remains, archaeological sites, and religious monuments), the geoheritage value merges with the cultural value, forming what is known as a geocultural site [9]. Cultural value refers to the significance that society assigns to aspects of the physical environment due to their social or community importance. Such attachments can be found in both past and present societies, and since the physical environment holds this value, preserving the associated landscapes and features is justified [3].

In most cases, associations between cultural heritage and geodiversity are found in landforms rather than geological outcrops, which is unsurprising given their often prominent presence within the regional landscape [5,10]. The strong connection between landforms and cultural elements has led to the development of a specialized field within Earth sciences: cultural geomorphology [11]. Cultural Geomorphology seeks to reveal the multiplicity of dimensions, meanings, and values intrinsic to geomorphological heritage while supporting the cultural landscape in its interaction with the historical and archaeological, architectural, or intangible heritage [12].

The natural environments in which human societies have evolved have shaped the development of spiritual and religious belief systems. Nature, including various landforms, remains a central element in traditional and polytheistic faiths and residually in monotheistic faiths [13]. Archaic societies often explained the origin of rock formations and landforms as the result of supernatural forces. In connection with this, they gave them names that remain in use today, reflecting those past beliefs and associations [3]. Many geosites around the world are considered important to particular faiths and religions, for example, in Australia [13,14], the Americas [15,16], and Europe [9,17]. Most humans and human groups still have some sort of spiritual faith, whether formal or otherwise, in which some legacy of this environmental underpinning remains [13].

Baker [18], in his article *"Flood Threat – (after) Learning from the Past"* published in *Nature*, underscores the critical importance of past flood events as not only invaluable sources of experience but also as historical witnesses to the dynamic relationship between human settlements and the natural environment. According to Melo et al. [19], river floods are among the extreme and most prominent natural phenomena occurring within the Danube River basin. Significant floods happen periodically along the Upper Danube (from the river's source to the Bratislava gauge), the Central Danube, and the Lower Danube (from the Orsova gauge to the river's outlet) [20]. On the Upper Danube, particularly from the town of Passau, the highest recorded floods occurred in 1862, 1897, 1899, 1954, 2002, and 2013. In the Middle/Lower Danube region, which is the focus area of this research, major floods were recorded in 1897, 1940, 1942, 1970, 1980, 1981, and 2014. Notably, floods affected the entire Danube basin in 1897, 1965, and 2006. The causes of these floods differ by region [19]. In the Upper Danube, the most severe floods typically result from localized heavy summer rainfall, with flood durations lasting 10–20 days. Conversely, floods in the Central and Lower Danube region are mainly driven by extensive snowmelt combined with rainfall, leading to longer flood events lasting from one to three months [19].

Starting from the fact of the strong relationship between geodiversity (structures, outcrops, and landforms) and cultural elements of both material (monuments) and intangible nature (religious practices, and traditions) [9], the focus of this paper is on investigating the nature of such a relationship in the Gornje Podunavlje region, in Bačka, in the far northwest of the Republic of Serbia. This area has striking natural characteristics shaped by the hydrological activity of the Danube, which primarily influenced the formation of river terraces suitable for the establishment of settlements. In the stretch between rivers 1,433–1,366 km, six inhabited places are located on higher geomorphological terrains above the Danube's course, with a predominantly Roman Catholic population. This region has historically been exposed to severe flooding from the Danube, especially before the numerous river regulations of the nineteenth and twentieth centuries [19]. It is likely that this contributed to the strengthening of the cult of Saint John of Nepomuk, the protector against floods, which is also present in other parts of Bačka. This form of socio- religious response aligns with broader historical patterns where communities develop specific cultural practices to cope with and make sense of recurring natural hazards [21–24], transforming the river from a mere physical feature into a powerful element of urban and rural identity [25–27]. By connecting the veneration of

Saint John of Nepomuk, the significance of the river terraces where his statues are placed, and the history of past floods in the Upper Danube region, this paper aims to highlight the patterns by which statues of this saint were erected in specific locations, differing from those in Bačka's settlements that are further from the Danube.

To systematically deconstruct these patterns and explore the nuanced relationship between faith, geomorphology, and historical hazard perception, this study is guided by the following research questions:

(1) How can geospatial technologies and GIS analysis reveal the relationship between the locations of Saint John of Nepomuk statues and the key geomorphological features (e.g., river terraces and floodplains) of the Gornje Podunavlje region?
(2) Does the placement pattern of statues in the flood-prone Gornje Podunavlje region differ from the patterns observed in other Bačka settlements located further from the Danube?
(3) In what way does the consistent positioning of statues on high ground and at settlement edges reflect a historical, community-level response to flood risk?
(4) How do the historical statue locations, when analyzed using geospatial overlays, correspond with contemporary flood hazard zones, and what are the implications for the preservation of this cultural heritage?

2 Case study

Gornje Podunavlje is located in the peripheral, northwestern part of Serbia, and as a geographical microregion, it is based on the Special Nature Reserve (SNR) of the same name (19,648 ha). It extends along the left bank of the Danube River, encompassing numerous meanders, oxbow lakes, and canals – In particular, aquatic, marsh, meadow, and forest ecosystems. The protected area of Gornje Podunavlje is best known for its well-preserved floodplain features along the Danube River [28,29]. The living world of Gornje Podunavlje SNR is rich, diverse, specific, and unique, with a large number of rare and unthreatened plant and animal species of national and international importance [30]. The Gornje Podunavlje SNR is also an area of international importance: Ramsar site – International importance [31], Important Bird Area (IBA), Important Plant Area (IPA) [28], Bačko Podunavlje Biosphere Reserve, and Mura-Drava-Danube Transboundary biosphere reserve [32].

The majority of the SNR is located in the floodplain (75–80 m a.m.s.l), which represents both the lowest and one of the two relief units of this area. Before regulation and the construction of embankments, this entire terrain was flooded by the Danube with levels just slightly above the average. Above this unit lies a higher river terrace, approximately 5–6 m higher [33]. Because of this, in the past, it was considered a natural safeguard and protection against floods, leading to the establishment of numerous settlements along its edge. Consequently, this relief unit is also known as the "town terrace" [34,35].

All settlements in the Gornje Podunavlje region were built on the higher river terrace, including six inhabited places where Hungarians and Šokci (Croats) of the Roman Catholic faith reside: Bački Breg, Bezdan, Bački Monoštor, Kupusina, Sonta, and Bogojevo. Due to the traditional threat of floods, these settlements have especially venerated Saint John of Nepomuk (c. 1345 – March 20, 1393), a saint of Bohemia (Czech Republic), who was drowned in the Vltava River at the order of King Wenceslaus IV of Bohemia. Later accounts state that he was the confessor of the Queen of Bohemia and refused to divulge the secrets of the confessional [36]. Because of the way he died, he is widely venerated as a protector against floods and water hazards, a patronage that is a central element of his cult and its expression as cultural heritage [37]. Following his death, the cult of Saint John of Nepomuk spread from Central Europe across the world, with his veneration documented as far away as New Mexico in the United States [37]. This devotion, often materialized through the erection of statues and chapels, represents a key element of religious cultural heritage [38] and a tangible link between faith, community memory, and the landscape. The prominence of this saint in the Bačka region, including areas like Subotica, where water-related challenges have also been historically significant [39], underscores a shared regional experience with and cultural response to water hazards.

Today, the settlements in which statues of Saint John of Nepomuk have been identified are located within the administrative boundaries of three local government units in northwestern Serbia (Figure 1). These include the City of Sombor (Bački Breg, Bezdan, Bački Monoštor), the Municipality of Apatin (Kupusina and Sonta), and the Municipality of Odžaci (Bogojevo).

The combined territory of these municipalities forms the section of the Gornje Podunavlje region, with the Danube River serving as its western boundary (Figure 1). In all identified settlements (except Bački Breg), the Danube River also forms the eastern edge of the built-up area. This geographic feature is crucial for understanding the symbolic and physical logic behind the placement of the statues.

3 Methodology

In the first phase of this research, we conducted a field inventory of locations where statues of Saint John of Nepomuk were erected, both in the region of Gornje Podunavlje, in the northwestern parts of the Bačka region. In this region, statues of Saint John of Nepomuk were erected and still stand in the following settlements: Bački

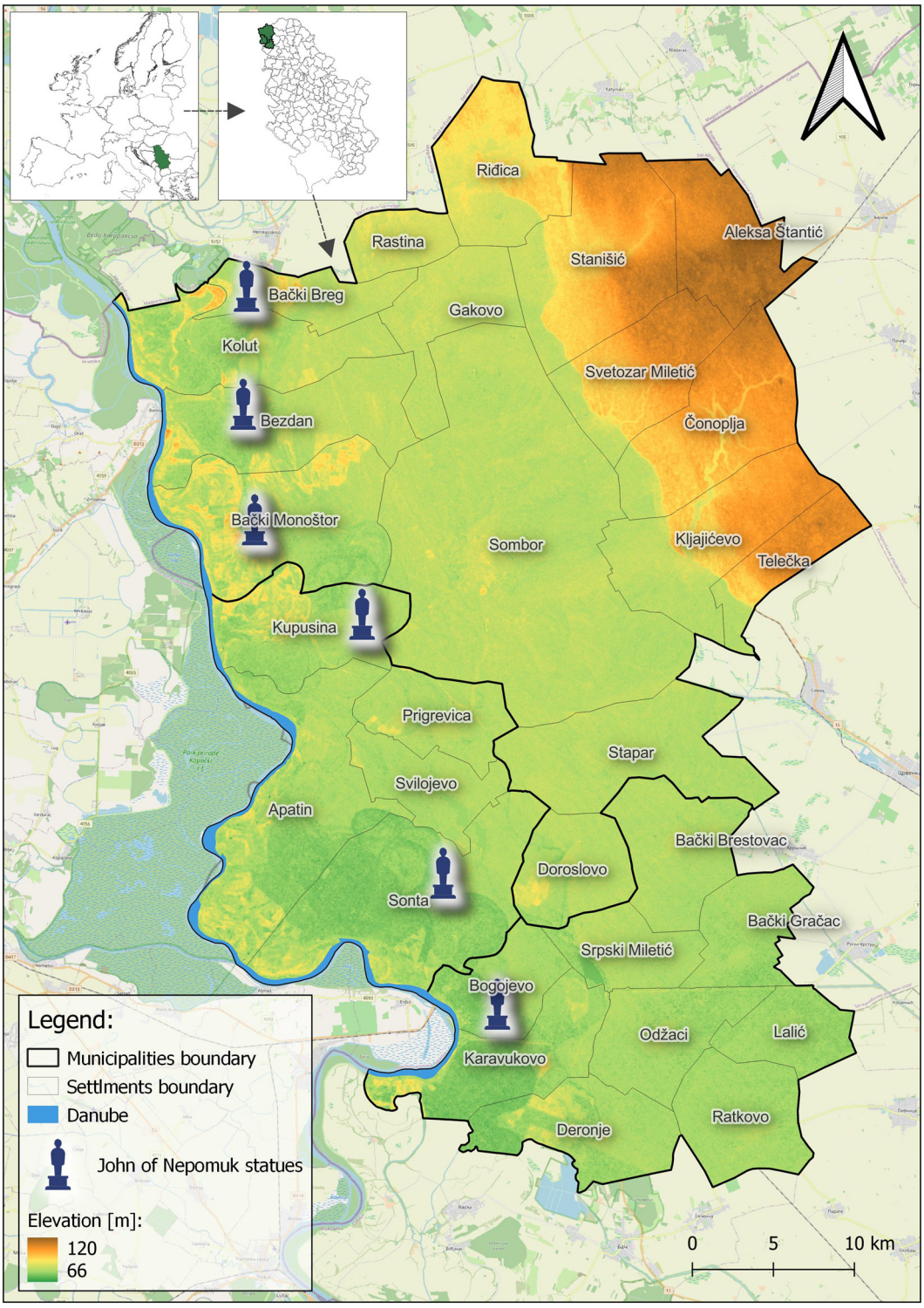

Figure 1: Location of Saint John of Nepomuk statues in relation to municipal boundaries and elevation in northwestern Serbia.

Breg, Bezdan, Bački Monoštor, Kupusina, Sonta, and Bogojevo, dating from the nineteenth century. Outside this region, and more broadly in the Bačka region, farther from major river flows, statues of Saint John of Nepomuk have been identified in the following settlements: Sombor, Odžaci, Bajmok, Mali Iđoš, and Selenča.

In the second phase, a more in-depth analysis of the locations where the statues were erected was carried out. In the Gornje Podunavlje region, the positioning of the statues was observed in relation to the distribution of relief units and altitudes. In the settlements outside the investigated region, the positioning was observed in relation to

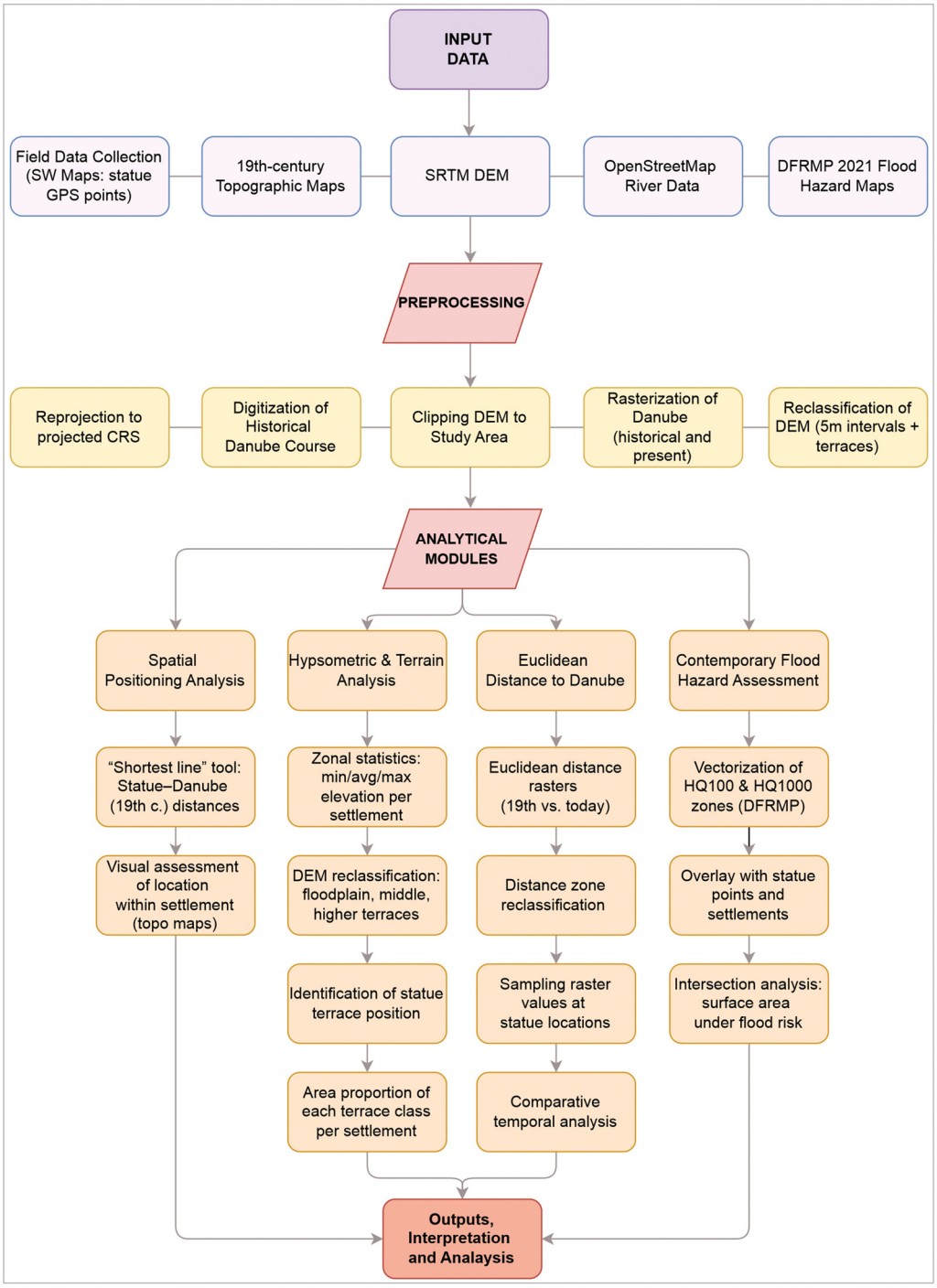

Figure 2: Schematic representation of the methodological workflow, including data sources, GIS-based preprocessing, analytical modules, and interpretative outputs.

the distribution of the relief units on which the statues of Saint John of Nepomuk were erected. Likewise, in both the first and second group of settlements, an analysis was conducted of the statue locations in relation to the boundaries of the rural development of those settlements. For the comparison of the current positions of the statues, archival materials from private collections of the local population were utilized to identify potential changes in their locations over time.

The research methodology was designed to identify, contextualize, and interpret the spatial placement of Saint John of Nepomuk statues. The broader geospatial and analytical framework for this task, which included the analysis of historical hydromorphology and contemporary flood risk, was informed by concepts and techniques presented in studies [40–44]. A schematic overview of the methodological workflow is provided in Figure 2, outlining the progression from input data acquisition through preprocessing, analytical procedures, and final interpretation. Each stage of the process is further elaborated in the subsections below, detailing the specific GIS tools, datasets, and analytical frameworks employed throughout the study.

3.1 GIS analysis of statue distribution

To support the study with empirical geospatial data, field research was conducted using the SW Maps [45] mobile application. The precise locations of statues dedicated to Saint John of Nepomuk were recorded in six settlements of the Gornje Podunavlje region: Bački Breg (45°55′12″N, 18°55′14″E), Bezdan (45°51′15″N, 18°55′14″E), Bački Monoštor (45°47′25″N, 18°55′55″E), Kupusina (45°44′21″N, 18°01′09″E), Sonta (45°35′48″N, 19°05′18″E), and Bogojevo (45°31′28″N, 19°08′02″E). These data points were imported into the QGIS 3.28 ‘Firenze’ software [46] environment for further spatial analysis.

In the data preprocessing phase, all location points, initially collected in the WGS 84 geographic coordinate system, were reprojected into EPSG:8682 (MGI/Serbia TM) to enable accurate metric-based spatial analysis. To contextualize the statue placements within the historical hydromorphological landscape, a georeferenced nineteenth-century topographic map from the Second Military Survey of the Habsburg Empire (Hungary, 1819–1869) was used as a base layer. This map, digitized and georeferenced by Timár et al. [47], served not only as a historical reference but also as the source for manually digitizing the historical course of the Danube River, enabling spatial comparison with present-day river dynamics and settlement patterns.

Using the QGIS software “Shortest line between features” tool [46], minimum linear distances were calculated between each statue and the nineteenth-century river course to identify spatial regularity and potential correlations with flood-prone areas. These numerical values served as the foundation for the subsequent interpretation.

In addition to the distance analysis, a qualitative interpretation was conducted based on large-scale segments of the Second Military Survey of the Habsburg Empire (Hungary, 1819–1869). The map was used in the digitized and georeferenced format developed by Timár et al. [47], while further digitization and interpretation were conducted as part of this study. The aim was to determine the statues’ relative placement within settlements (particularly in relation to the built-up area, road layout, and river orientation). In each settlement, the position of the statue was visually assessed to identify recurring locational patterns that may reflect both symbolic meaning and cultural adaptation to geomorphological constraints.

3.2 Hypsometric analysis of settlement and statue elevations

To assess the relative elevation of Saint John of Nepomuk statues in relation to the topography of the settlements in which they are located, a hypsometric analysis was conducted using geospatial technologies in QGIS software [46]. The input dataset was the Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) with a spatial resolution of 30 m.

The DEM was first preprocessed through spatial reduction to match the extent of the study area, followed by reprojection into the EPSG:8682 coordinate system (MGI/Serbia TM). In the post-processing stage, elevation values were reclassified into 5 m intervals to generate a hypsometric raster map that visually highlights terrain variation across and within settlement boundaries. This reclassification was performed using the r.reclass algorithm, available through the GRASS GIS toolbox in QGIS software [46]. Custom symbology was applied to enhance interpretability and support elevation-based comparisons.

To obtain statistical elevation characteristics for each settlement, zonal statistics were computed using the administrative boundaries of populated places in Serbia. For each settlement, minimum, maximum, and average elevation values were derived. The precise elevation of

each statue was extracted from the SRTM DEM using the "Sample Raster Values" tool in QGIS software [46] and then compared to the settlement's elevation profile to evaluate whether it lies above, below, or near the average terrain level. The applied geospatial procedures were conceptually grounded in the methodological framework presented in [48], which provides a comprehensive overview of spatial analysis techniques in GIS and served as a reference for structuring the analytical approach.

In the next analytical step, a terrain classification schema was introduced to support interpretation in relation to fluvial geomorphology. The SRTM DEM was reclassified into three categories corresponding to typical river terraces in the Danube floodplain: floodplain areas below 80 m, middle terraces between 80 and 85 m, and higher terraces above 85 m a.s.l. This classification provided a framework for identifying which geomorphological unit each settlement predominantly occupies, and more importantly, on which river terrace (or at the contact between terraces) each statue is situated. Since the majority of the Gornje Podunavlje SNR is situated within the floodplain, ranging from 75 to 80 m a.m.s.l., this floodplain represents the lowest of the two primary relief units in the investigated area and is significant both in terms of its present-day extent and its historical development [33]. For the purposes of this study, the term "floodplain" refers to both the modern and historical floodplain extents. This was analyzed through a hypsometric perspective using a DEM derived from SRTM. Areas with elevations below 80 m a.m.s.l, identified via this DEM, were reclassified as floodplain, allowing for a detailed comparison against the current position of the Danube River.

The final component of the analysis involved calculating the proportion of each settlement's area that falls within the defined hypsometric zones (floodplain, middle, higher terrace). This allowed for a comparative assessment of whether the statue's location corresponds to the dominant terrain level of the settlement or represents a deliberate selection of elevated terrain. The overarching goal of this multi-layered hypsometric approach was to assess the symbolic and practical significance of statue placement in relation to flood risk, topographic transition zones, and the spatial structure of the lowland Danube environment.

3.3 Euclidean distance analysis of Danube proximity

To investigate the spatial relationship between the statues of Saint John of Nepomuk and the Danube River (both historically and in the present), a Euclidean distance analysis [49] was conducted using QGIS software [46]. The objective of this analysis was to quantify the change in proximity between statue locations and the river, comparing their relative distances to the Danube as it flowed in the nineteenth-century versus its present-day course.

As a first step, the historical course of the Danube was digitized from nineteenth-century topographic maps of the Second Military Survey of the Habsburg Empire (Hungary, 1819–1869), used in the digitized and georeferenced format developed by Timár et al. [47]. These maps were selected for their cartographic accuracy and georeferenced alignment with the contemporary coordinate system (EPSG:8682). Once digitized, the river vector layer was converted to a raster dataset with appropriate resolution to enable Euclidean distance analysis.

Parallel to this, the current course of the Danube was extracted from OpenStreetMap (OSM) base layers [50]. The present-day river vector was also rasterized using the same cell size and spatial extent as the historical model, ensuring comparability across both datasets. Following the generation of the two distance rasters (historical and current), both were reclassified into four distance zones for interpretative mapping: <2,500 m, 2,500–5,000 m, 5,000–7,500 m, and >7,500 m. These intervals were selected to reflect meaningful thresholds of proximity and to facilitate clearer spatial interpretation of the zones within which the statues are currently or historically located.

Subsequently, the Euclidean distance tool in QGIS software [46] was applied to both raster layers to generate continuous surfaces of straight-line distance from the river (one for the nineteenth-century river course and one for the modern riverbed). These outputs represent pixel-based distance fields, enabling measurement of proximity to the river at any given location within the study area.

To evaluate the historical and current distances of statues from the river, the georeferenced point layer of statue locations was overlaid on each of the two distance rasters. Using the "Sample Raster Values" tool in QGIS software [46], distance values were extracted for each statue from both historical and modern rasters. This allowed for a comparative assessment of how the relative proximity of each statue to the Danube has changed over time due to river regulation, channel migration, and landscape transformation.

The analysis provides a spatiotemporal insight into how environmental and hydrological processes have altered the functional meaning of statue placement. What may have originally been direct proximity to the Danube in the nineteenth-century may now correspond to greater distances, or in some cases, relative isolation from the current riverbed. This approach adds an important temporal

dimension to understanding the cultural and geomorphological logic behind statue positioning.

3.4 Contemporary flood hazard assessment and risk overlay analysis

In order to assess the present-day flood vulnerability of the study area and to evaluate the spatial positioning of the statues of Saint John of Nepomuk within current flood risk zones, an up-to-date flood hazard layer was integrated into the analysis. The source was the 2021 Flood Hazard and Risk Map available via the DanubeGIS portal [51], which forms part of the Danube Flood Risk Management Plan. This official dataset identifies flood hazard zones based on two return periods: medium flood hazard corresponding to a 100-year flood event (1% probability), and low hazard representing an extreme event with a 1,000-year return period (0.1% probability).

The entire area encompassing all six settlements with statues was manually digitized from the web–GIS interface and converted into vector format using the EPSG:8682 coordinate system to maintain spatial consistency with previously used datasets. The digitized hazard zones served as the basis for further spatial analysis conducted within the QGIS environment.

The first stage involved a visual overlay of the hazard zones with the georeferenced statue locations and the current settlement network of Serbia. This provided an initial spatial understanding of whether the statues (and the settlements in which they are located) currently fall within areas designated as flood-prone under either the medium or low hazard scenario. In the second stage, geoprocessing operations (intersection) were performed between the flood hazard polygons and the administrative boundaries of the settlements containing statues. This allowed for the identification and quantification of the portions of each settlement area that are presently exposed to medium or low flood hazard. A similar methodology involving the intersection of settlement boundaries with flood hazard zones was applied in previous studies by Sabljić et al. [44], Ivanišević et al. [52], and Sabljić et al. [53].

This methodological approach places the historical logic of statue placement (which was originally based on the river's nineteenth-century floodplain behavior) within the framework of contemporary flood risk. While the statues were once positioned on elevated terraces at the edge of settlements facing the Danube, their function as protectors from riverine threats remains symbolically significant today. The analysis also introduces a future-oriented dimension: in light of the fact that portions of the settlements remain within zones of medium or extreme flood hazard, there is an evident need to consider cultural heritage within risk-sensitive land use and disaster management planning. The continued presence of these statues in flood-prone areas highlights both their cultural resilience and the spatial legacy of historical hydrological vulnerability.

4 Results and discussion

4.1 Statue proximity to the historical Danube River

Pekárová et al. [20] highlight that floods between Passau and Bratislava since 1500 are generally well documented through flood marks, including those from 1501, 1787, 1809, 1850, and 1895. These flood marks are crucial for estimating flood extents by comparing them with recent high-water levels. Downstream from Bratislava, however, flood marks are less common [19]. Historical flood marks have also been instrumental in determining flood occurrence and frequency in the Middle and Lower Danube Basin. For instance, Kiss [54] analyzed archival sources to study floods in medieval Hungary, while Melo et al. [19] used various historical records to investigate the 1895 floods along the Danube and its tributaries, covering parts of northern Serbia.

For parts of the Serbian territory, watermarks are rather scarce. Nevertheless, the statue of Saint John of Nepomuk – the patron saint against water hazards – is particularly prominent in Bačka, the northwestern region of today's northern Serbia. This prominence is closely linked to the frequent floods that historically troubled the entire region.

The spatial analysis revealed that the statues are distributed unevenly with regard to their distance from the historical course of the Danube River (Figure 3). The shortest distances from the river to the statues are as follows: Bački Breg (8.08 km), Bezdan (3.61 km), Bački Monoštor (0.88 km) Kupusina (3.97 km), Sonta (6.50 km), and Bogojevo (3.14 km). These results indicate a lack of strict regularity, but they reflect deeper geographical reasoning [33].

The observed variability can be attributed to the complex physical geography of the region. The spatial configuration of meanders, backwaters, and flood-prone lowlands surrounding the Danube likely influenced the historical settlement patterns and the placement of cultural-religious landmarks. It generally corresponds well

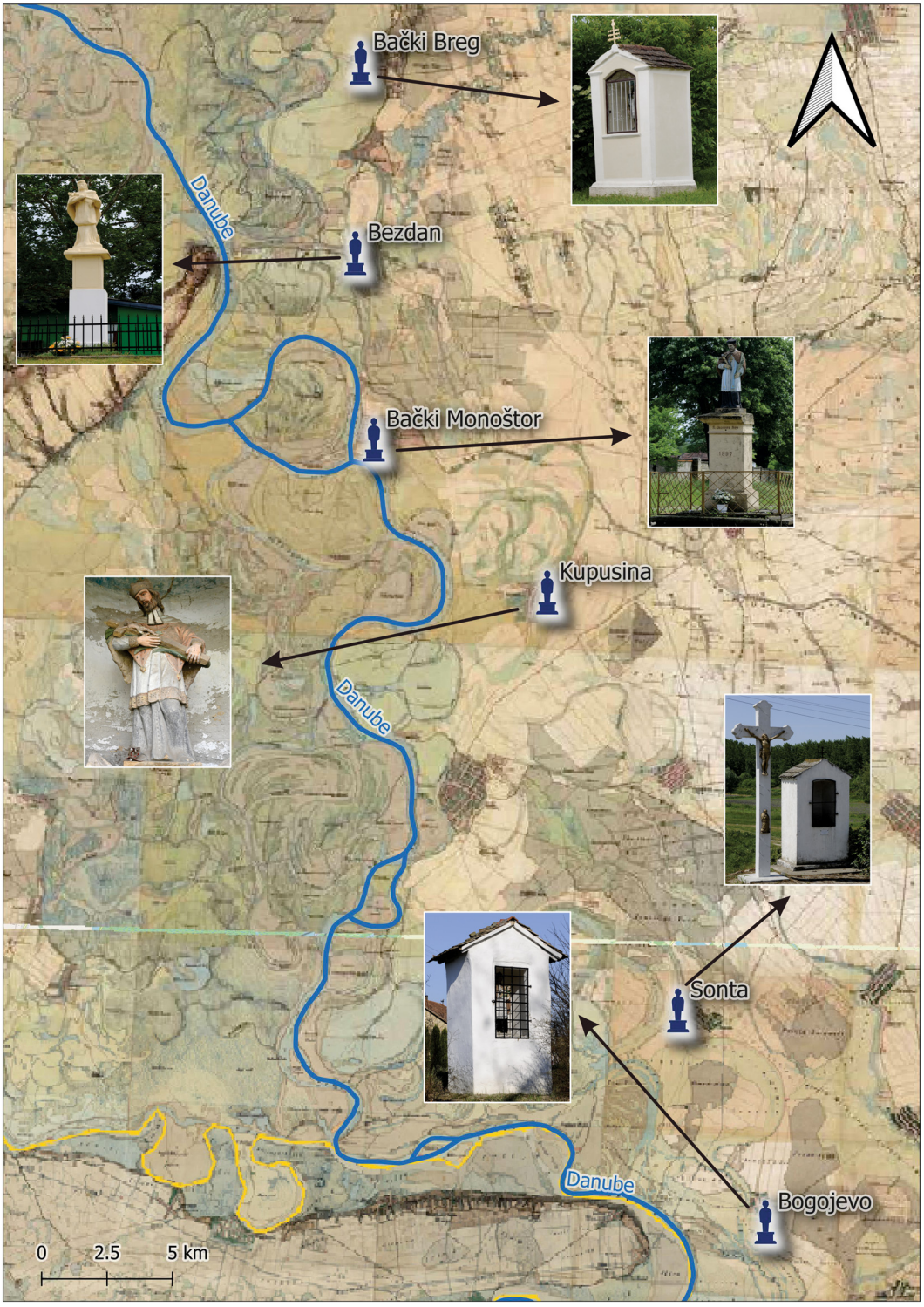

Figure 3: Spatial distribution of Saint John of Nepomuk statues in the Gornje Podunavlje region, superimposed on a georeferenced nineteenth-century topographic map (Second Military Survey of the Habsburg Empire, Hungary, 1819–1869), used in the digitized and georeferenced format developed by Timár et al. [47]. Furthermore, photos on the map are made by V. Stojanović.

with similar international findings (e.g. [9]). Even though some statues are located farther from the river's course, they are uniformly situated on elevated river terraces (natural geomorphological features historically associated with safety from flooding).

Furthermore, all statues were recorded at the periphery of their respective rural settlements, oriented toward the Danube. This consistent positioning supports the hypothesis that the statues served not only as devotional objects but also as symbolic protectors positioned between the human community and the threatening force of the river. The spatial logic of statue placement thus intertwines religious symbolism with geomorphological awareness; reinforcing the thesis that geodiversity (particularly in the form of river terraces) holds substantial cultural and religious meaning in the lowland environment of Bačka.

4.2 Statue positioning within settlements

The examination of large-scale nineteenth-century maps (Figure 4) provides visual confirmation of a shared spatial logic in the placement of statues across all six settlements. In each case – Bački Breg (Figure 4a), Bezdan (Figure 4b), Bački Monoštor (Figure 4c), Kupusina (Figure 4d), Sonta (Figure 4e), and Bogojevo (Figure 4f) – the statue is positioned at the edge of the historical rural footprint, typically along a peripheral road, crossroads, or transitional space that opens toward the Danube River.

Rather than being centrally located within the settlement core, each statue occupies a liminal zone (a boundary between the inhabited and the uninhabited), between cultivated space and the riverine landscape. This positional consistency strongly suggests that these locations were deliberately chosen for both symbolic and practical

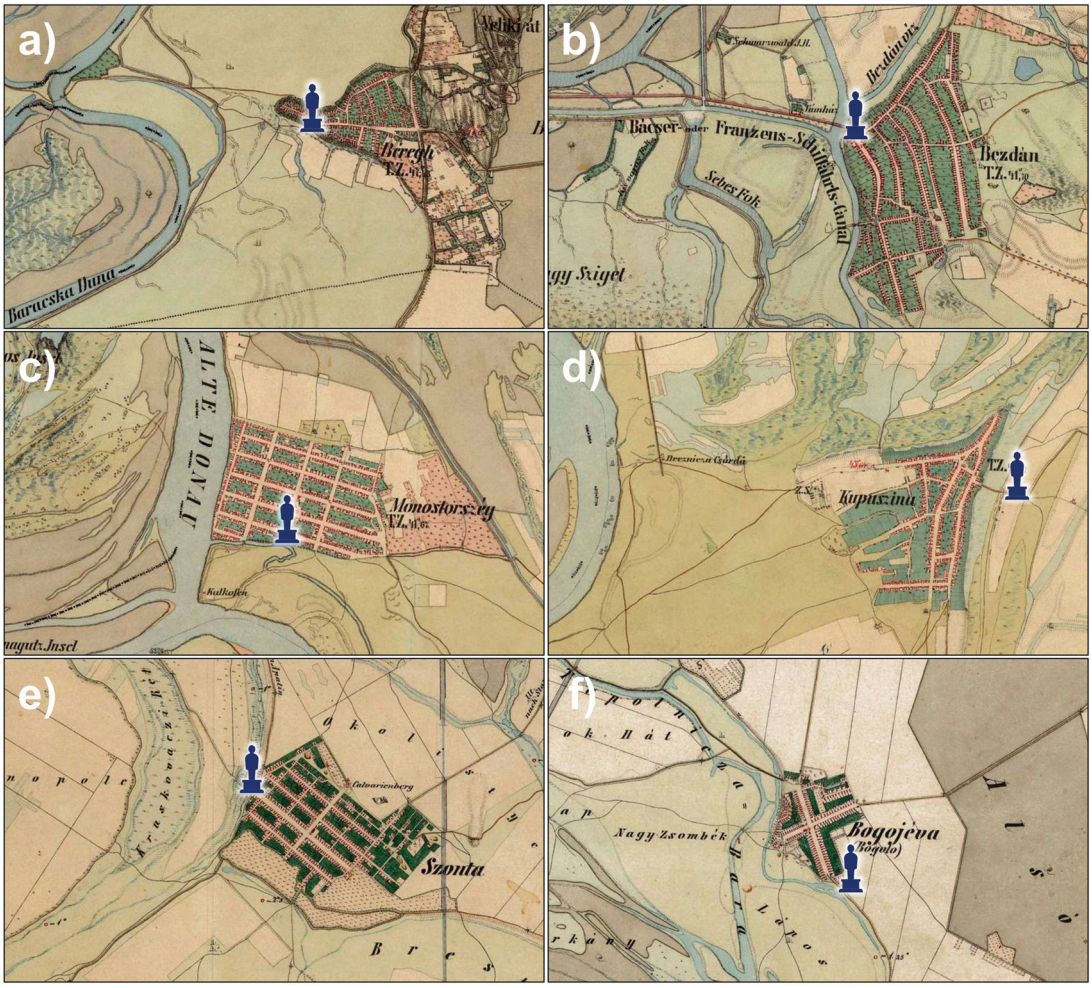

Figure 4: Peripheral placement of Saint John of Nepomuk statues in six settlements (a – Bački Breg, b – Bezdan, c – Bački Monostor, d – Kupusina, e – Sonta, and f – Bogojevo) of Gornje Podunavlje, based on nineteenth-century cartographic sources (Second Military Survey of the Habsburg Empire, Hungary, 1819–1869), used in the digitized and georeferenced format developed by Timár et al. [47].

reasons. The edge-of-settlement placement emphasizes the statues' function as protectors against natural forces, particularly flooding, while their orientation toward the Danube reinforces their spiritual role as intermediaries between the community and the river.

These findings align closely with the results of the geospatial analysis, offering additional historical-cartographic support for the hypothesis that statue placement was neither arbitrary nor purely decorative. Instead, it reflects a spatial logic shaped by religious belief, hydrological threat, and geomorphological awareness – all embedded within the cultural practices of the communities along the present-day Gornje Podunavlje region.

4.3 Hypsometric analysis of settlement and statue elevations

The hypsometric analysis revealed a consistent spatial logic in the placement of Saint John of Nepomuk statues in relation to the elevation structure of their host settlements (Figure 5). Despite variations in absolute terrain height, the statues are generally positioned at or slightly above the average elevation of their respective settlements, often near the transition zones between hypsometric bands, reflecting broader spatial patterns in elevation-dependent settlement distribution as discussed by Petrašević et al. [55].

In Bački Breg, the terrain ranges from 74 to 102 m a.s.l., with a mean elevation of 84.07 m (Figure 5a). The statue is positioned at the boundary between the 85 and 90 m elevation zones (Figure 5b), with a precise elevation of 87 m (slightly above the average). Similarly, in Bezdan, where elevation spans from 74 to 109 m with an average of 82.97 m (Figure 5c), the statue lies between the 80 and 85 m contours (Figure 5d), at 84 m. Bački Monoštor exhibits a comparable pattern: with a minimum elevation of 73 m and a maximum of 105 m, the settlement's average is 83.81 m (Figure 5e), while the statue is located at 83 m, within the 80–85 m zone (Figure 5f). In Kupusina, the terrain extends from 65 to 102 m, with an average elevation of

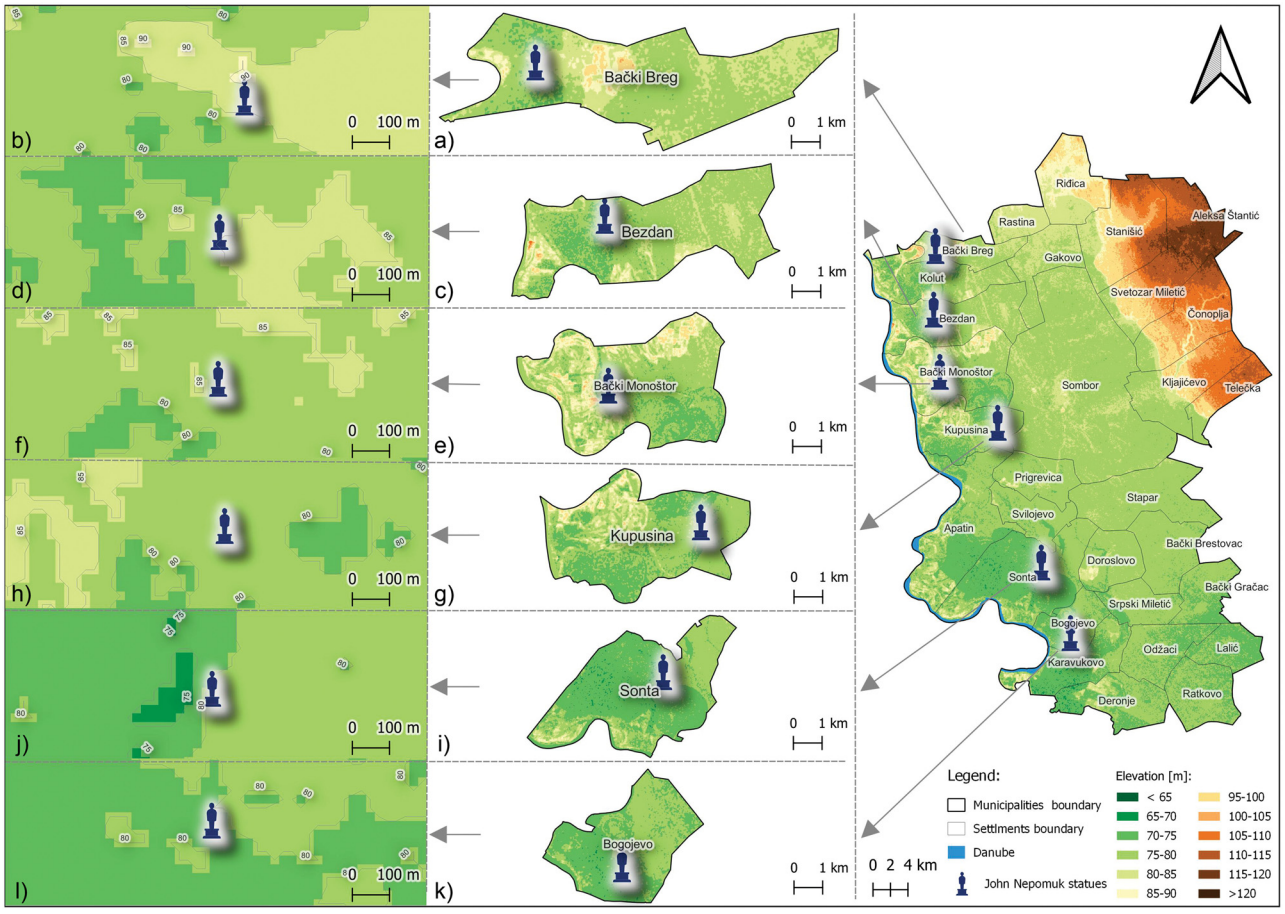

Figure 5: Hypsometric analysis of settlements (a), (c), (e), (g), (i), and (k) and statue locations (b), (d), (f), (g), (j), and (l).

81.66 m (Figure 5g). The statue stands precisely at 81 m (Figure 5h), on the contact zone between the 80 and 85 m bands. In Sonta, the lowest point is at 72 m and the highest at 97 m, with a mean of 78.88 m (Figure 5i). The statue is located at 81 m, in the 80–85-melevation zone (Figure 5j), again exceeding the average elevation. Finally, in Bogojevo, the elevation ranges from 73 to 94 m, and the mean is 79.02 m (Figure 5k). The statue is placed on the boundary of the 75 and 80 m zones (Figure 5l), at exactly 79 m.

These spatial patterns highlight a deliberate preference for placing statues on terrain that is either aligned with or slightly above the settlement average. In lowland flood-prone areas such as Gornje Podunavlje, even minimal elevation differences can have critical implications for flood safety. The placement of statues at the margins of elevation zones suggests both symbolic intent and environmental awareness, reinforcing the notion that these monuments were conceived as spiritual guardians situated in topographically strategic locations.

Moreover, even in cases where the statue elevation matches the mean elevation of the settlement (e.g., Kupusina, Bogojevo), their architectural height (often elevated on pedestals or plinths) grants them both visual prominence and additional topographic advantage, as evident in earlier imagery (Figure 3). Thus, hypsometric positioning further complements the observed spatial pattern of peripheral placement and orientation toward the Danube, confirming a multifaceted cultural and environmental rationale behind the distribution of these religious landmarks.

The reclassification of terrain into three geomorphological categories – floodplain (<80 m a.s.l.), middle terrace (80–85 m), and higher terrace (>85 m) – enabled a detailed assessment of settlement elevation structure and the placement of Saint John of Nepomuk statues relative to river terraces in the Gornje Podunavlje region (Figure 6).

In Bački Breg, the dominant surface is the middle terrace, which covers 19.22 km^2 (53.5%) of the settlement,

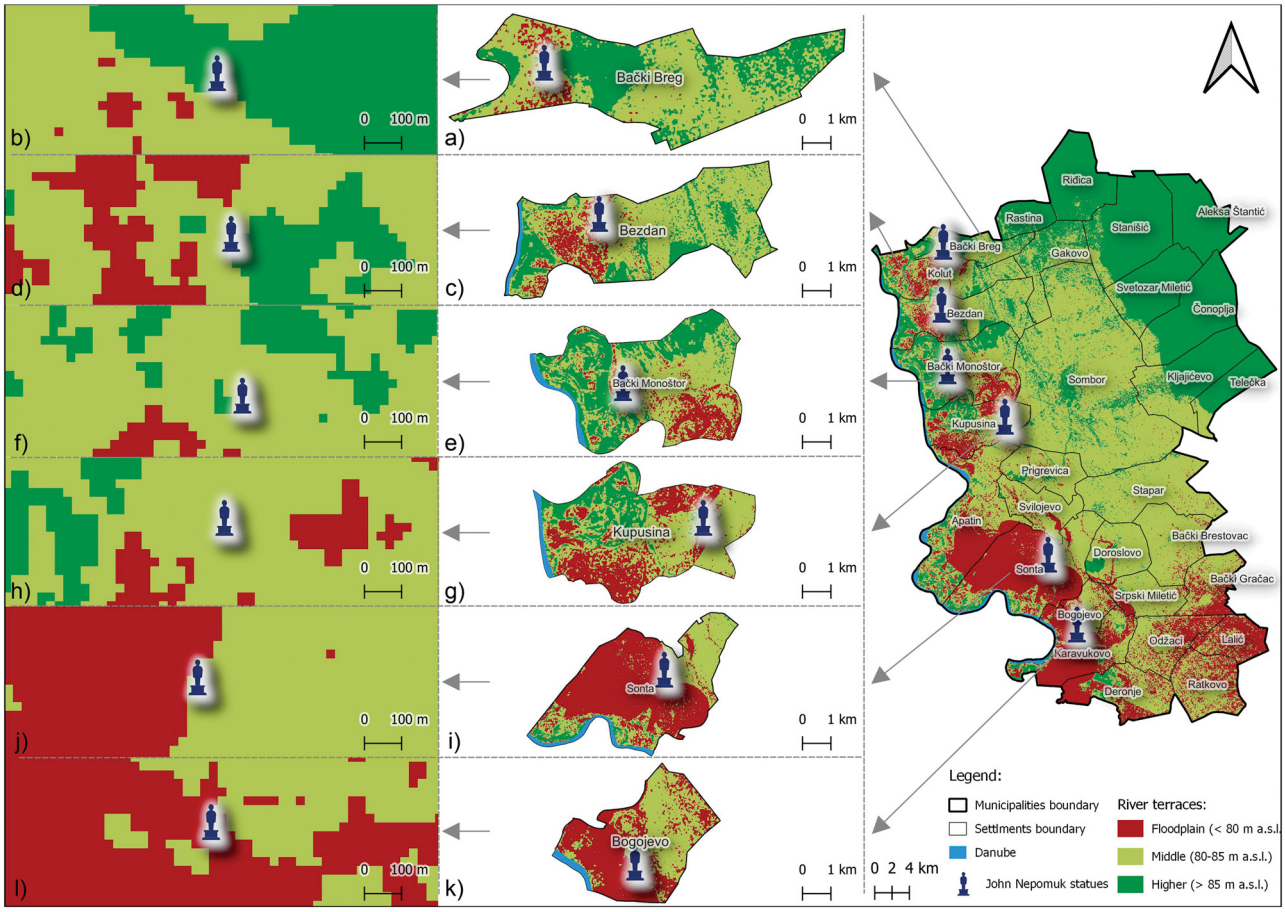

Figure 6: Spatial distribution of river terraces and statue locations: (a), (c), (e), (g), (i), and (k) show the proportions of floodplain (<80 m), middle (80–85 m), and higher (>85 m) terraces within each settlement; (b), (d), (f), (h), (j), and (l) display the terrace classification at the exact location of Saint John of Nepomuk statue.

followed by the higher terrace at 12.07 km^2 (33.6%) and a small floodplain portion of 1.61 km^2 (4.5%) (Figure 6a). The statue, located at 87 m a. s. l., is placed clearly on the higher terrace (Figure 6b), illustrating a conscious elevation-based placement strategy. In Bezdan, the middle terrace dominates with 52.99 km^2 (68.5%), followed by 17.64 km^2 (22.8%) of higher terrace and 9.36 km^2 (12.1%) of floodplain (Figure 6c). The statue stands at 84 m a.s.l., situating it on the middle terrace, close to the upper limit of that class (Figure 6d). Bački Monoštor features a relatively balanced elevation profile: 50.91 km^2 (49.6%) of middle terrace, 33.31 km^2 (32.5%) of higher, and 13.85 km^2 (13.5%) of floodplain (Figure 6e). With an elevation of 83 m, the statue is positioned squarely within the middle terrace (Figure 6f), consistent with the broader spatial pattern observed. In Kupusina, 33.66 km^2 (58.2%) of the settlement falls within the middle terrace, while 18.49 km^2 (32%) is floodplain and 10.27 km^2 (17.8%) lies on higher ground (Figure 6g). The statue, situated at 81 m elevation, also lies on the middle terrace (Figure 6h), avoiding low-lying zones while not reaching the highest available terrain. Sonta stands out due to its strong floodplain dominance – 80.75 km^2 (63.6%) of the total area, followed by 40.10 km^2 (31.6%) of middle terrace and only 5.26 km^2 (4.1%) of higher terrace (Figure 6i). The statue's elevation is 81 m, placing it just within the middle terrace (Figure 6j), and noticeably above the surrounding flood-prone zones. In Bogojevo, most of the territory is categorized as floodplain (20.01 km^2; 52.9%), followed by 17.11 km^2 (45.2%) of middle terrace and a negligible portion of higher terrace (0.14 km^2; 0.3%) (Figure 6k). The statue's elevation is 79 m (Figure 6l), placing it within the floodplain, making Bogojevo the only settlement where the statue does not lie above this critical threshold. However, its position near the upper margin of the floodplain, close to the middle terrace boundary, suggests a strategic placement at the best locally available high point.

Across all six settlements, a clear spatial pattern emerges: statues are placed either on the middle or higher river terraces, with a strong tendency to avoid the floodplain. The only exception is Bogojevo, where the statue lies within the floodplain zone, but even there it is located at its uppermost elevation. In flood-prone settlements such as Sonta and Bogojevo, statues occupy terrain that is locally elevated relative to their surroundings. In contrast, in settlements with greater geomorphological relief (such as Bački Breg or Monoštor) statues are placed on the highest terraces available.

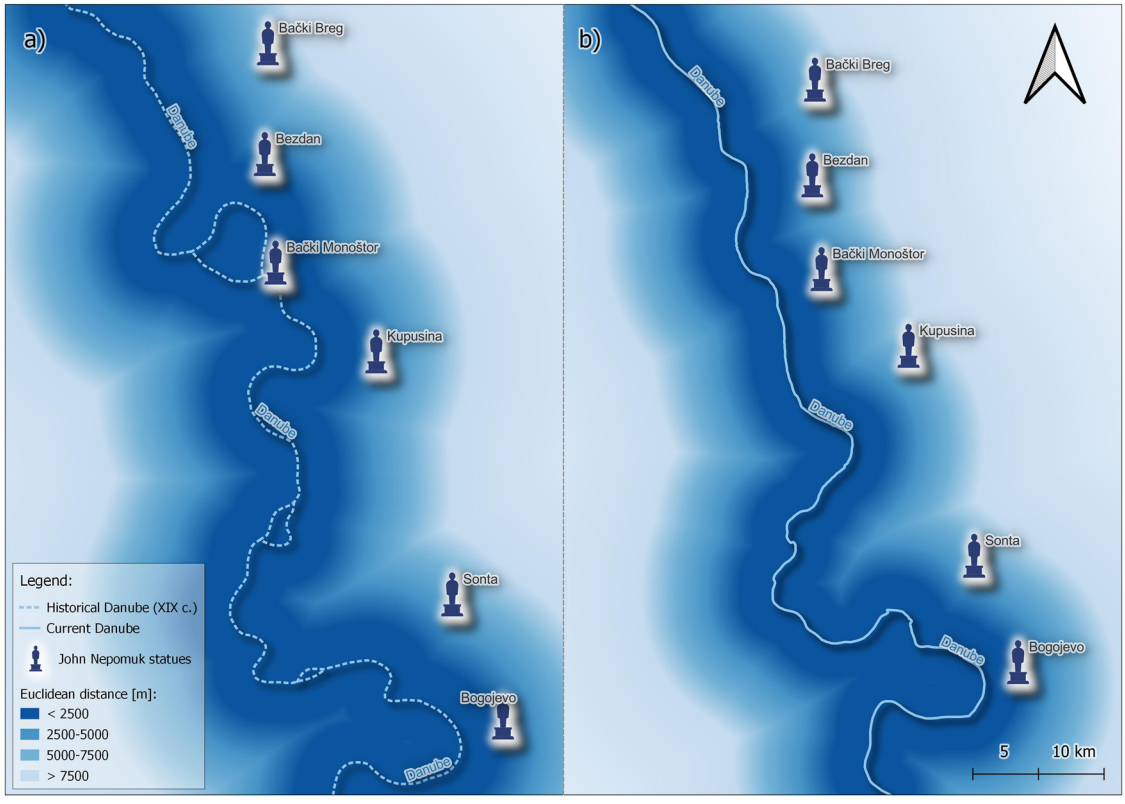

Figure 7: Euclidean distance of Saint John of Nepomuk statues from the Danube: (a) distance from the nineteenth-century river course; (b) distance from the present-day river.

This distribution reinforces the notion that statue placement was guided by both spiritual symbolism and environmental pragmatism. The avoidance of low-lying terrain reflects historical awareness of flood risk, while positioning on transition zones or elevated platforms underscores the protective and intercessory function of the statues. In sum, the pattern of locating Saint John of Nepomuk statues on geomorphologically favorable terrain exemplifies a meaningful cultural response to natural hazards in the lowland Danube environment [29].

4.4 Euclidean distance from the Danube, then and now

The analysis of Euclidean distance between the statues of Saint John of Nepomuk and the Danube River reveals clear spatial differences between their original proximity to the river in the nineteenth-century and their current distance from the modern riverbed (Figure 7). Since Saint John of Nepomuk is traditionally venerated as a protector against floods and river dangers, the proximity of these monuments to the Danube provides crucial insight into their functional and symbolic spatial role.

In the nineteenth-century (Figure 7a), only Bački Monoštor was located within <2,500 m from the river, with a recorded distance of 882.40 m, indicating close proximity to the Danube and direct exposure to floodplain dynamics. Bogojevo (3139.37 m), Bezdan (3607.68 m), and Kupusina (3975.00 m) were situated within the 2,500–5,000 m zone, still within a range where riverine influence (including flood risk) was a real and present concern. Sonta, at 6501.72 m, fell into the 5,000–7,500 m class, while Bački Breg, with a distance of 8087.23 m, was already in the >7,500 m zone, indicating a more peripheral relationship to the main Danube channel.

However, topographic maps from the nineteenth-century (Figures 3 and 4) also show that even these more distant settlements were not disconnected from the river system. In particular, Bački Breg and Sonta, although located far from the Danube's main course, were surrounded by marshes, periodically inundated zones, and small distributaries of the Danube. These features created a landscape heavily influenced by water, where flood risk and hydrological uncertainty shaped local life. In such a setting, the erection of a statue of Saint John of Nepomuk still served as a spiritual response to the omnipresent threat of water.

In the present-day context (Figure 7b), Bogojevo, at 2870.04 m, remains within the 2,500–5,000 m zone, and is now closer to the river than in the nineteenth century. Conversely, Bački Monoštor, once the closest, is now at 3828.40 m, still within the same zone but more removed than before. Bezdan, now at 5006.44 m, has moved into the 5,000–7,500 m class, while Kupusina, at 8073.45 m, now falls into the >7,500 m category, marking the most significant shift in proximity. Sonta, with 6842.44 m, remains in the 5,000–7,500 m band, and Bački Breg, at 7808.20 m, continues to be one of the most distant.

This transition illustrates how hydraulic engineering and river regulation have reconfigured the spatial relationship between communities and the river [53]. Statues once placed within or near flood-prone areas are now often situated at considerable distances from the Danube. Despite this, their original orientation and positioning (especially at settlement edges facing toward the river) continue to reflect the symbolic geography of protection and vigilance [33,56].

The results support the argument that the placement of Saint John of Nepomuk statues was intimately linked to flood risk awareness and hydrological exposure in the nineteenth-century. Even in settlements physically distanced from the main Danube channel, environmental conditions such as surrounding marshes and distributaries maintained a strong connection to the river. As a result, the statues maintained both functional relevance and spiritual significance as mediators between human habitation and natural forces.

4.5 Present-day flood hazard exposure of statues and settlements

The spatial overlay of contemporary flood hazard zones with settlement boundaries and statue locations reveals that almost all monuments of Saint John of Nepomuk in the study area are situated within zones currently exposed to flood risk (Figure 8). According to the 2021 Danube Flood Risk Management Plan (DFRMP) [57], five of the six settlements containing statues (Bezdan, Bački Monoštor, Kupusina, Sonta, and Bogojevo) are today classified under the medium flood hazard zone, which corresponds to a 100-year return period. Only Bački Breg lies outside the medium hazard zone, with a significantly lower level of exposure.

The extent of current flood vulnerability among these settlements varies. Sonta exhibits the highest exposure, with 11.34 km^2 of its area falling under the medium risk zone, and an additional 1.14 km^2 under low risk, totaling 12.48 km^2 at risk. This is followed by Bački Monoštor, with 7.25 km^2 of medium and 1.07 km^2 of low hazard area (8.32 km^2 total). Kupusina follows closely, with 4.69 km^2 medium and 1.55 km^2 low risk (6.24 km^2 total). Bezdan also demonstrates considerable exposure, with 3.84 km^2 in the

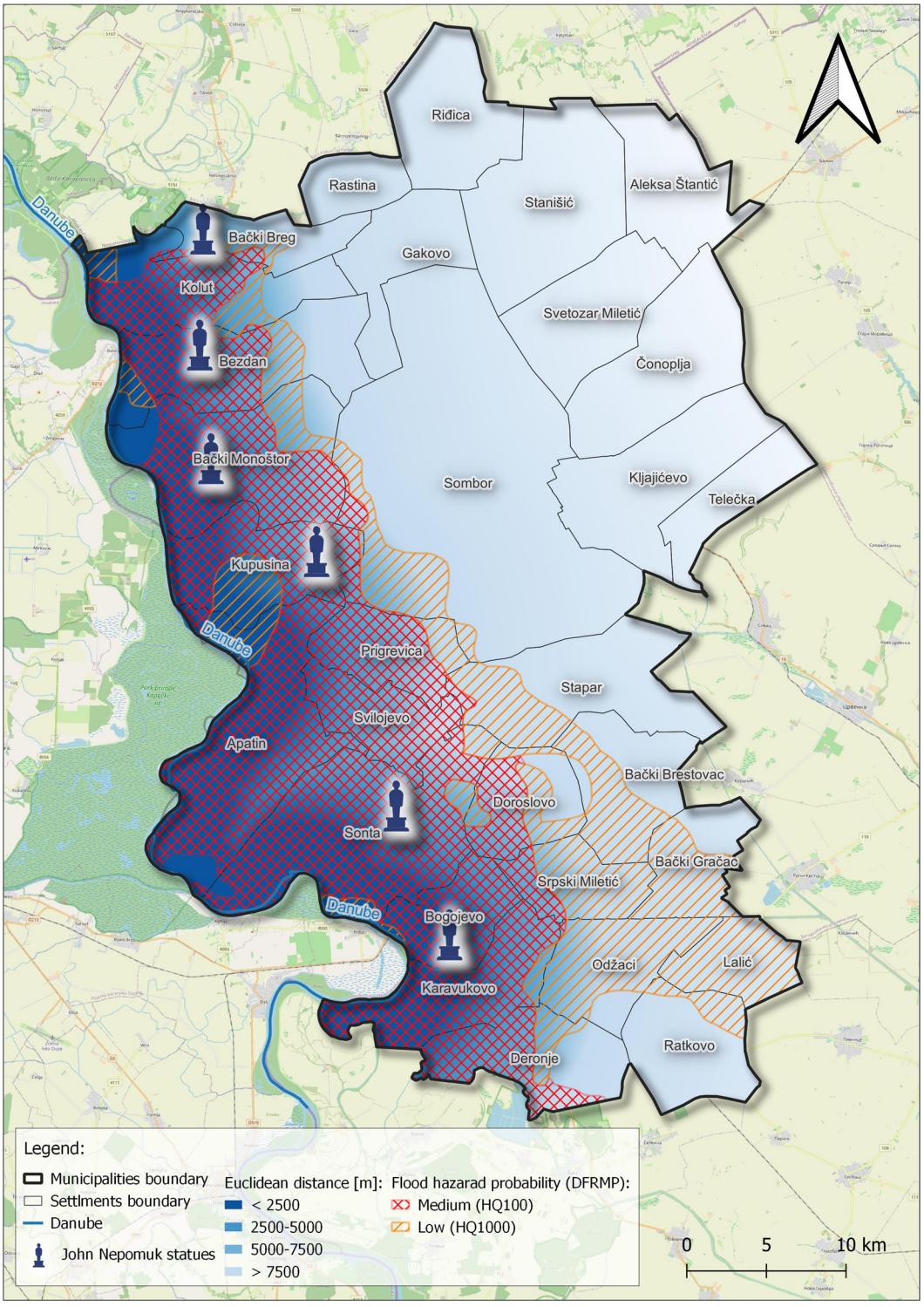

Figure 8: Spatial overlay of flood hazard zones (based on International Commission for the Protection of the Danube River (ICPDR) [57]) with settlements and statue locations. Flood hazard probability is represented by HQ100 and HQ1000 zones, corresponding to flood events with a return period of 100 and 1,000 years, respectively.

medium risk zone and 1.36 km^2 under low risk (5.20 km^2 total). In Bogojevo, although the total exposed area is smaller, 3.63 km^2 still falls under medium hazard, while 0.09 km^2 is under low risk (3.73 km^2 total). In contrast, Bački Breg (the only statue located outside the primary flood zones) is surrounded by just 0.28 km^2 of medium and 0.40 km^2 of low hazard zones (0.68 km^2 total), confirming its peripheral and topographically safer position.

The cartographic visualization (Figure 8) clearly illustrates the spatial pattern of hazard intensity. The western

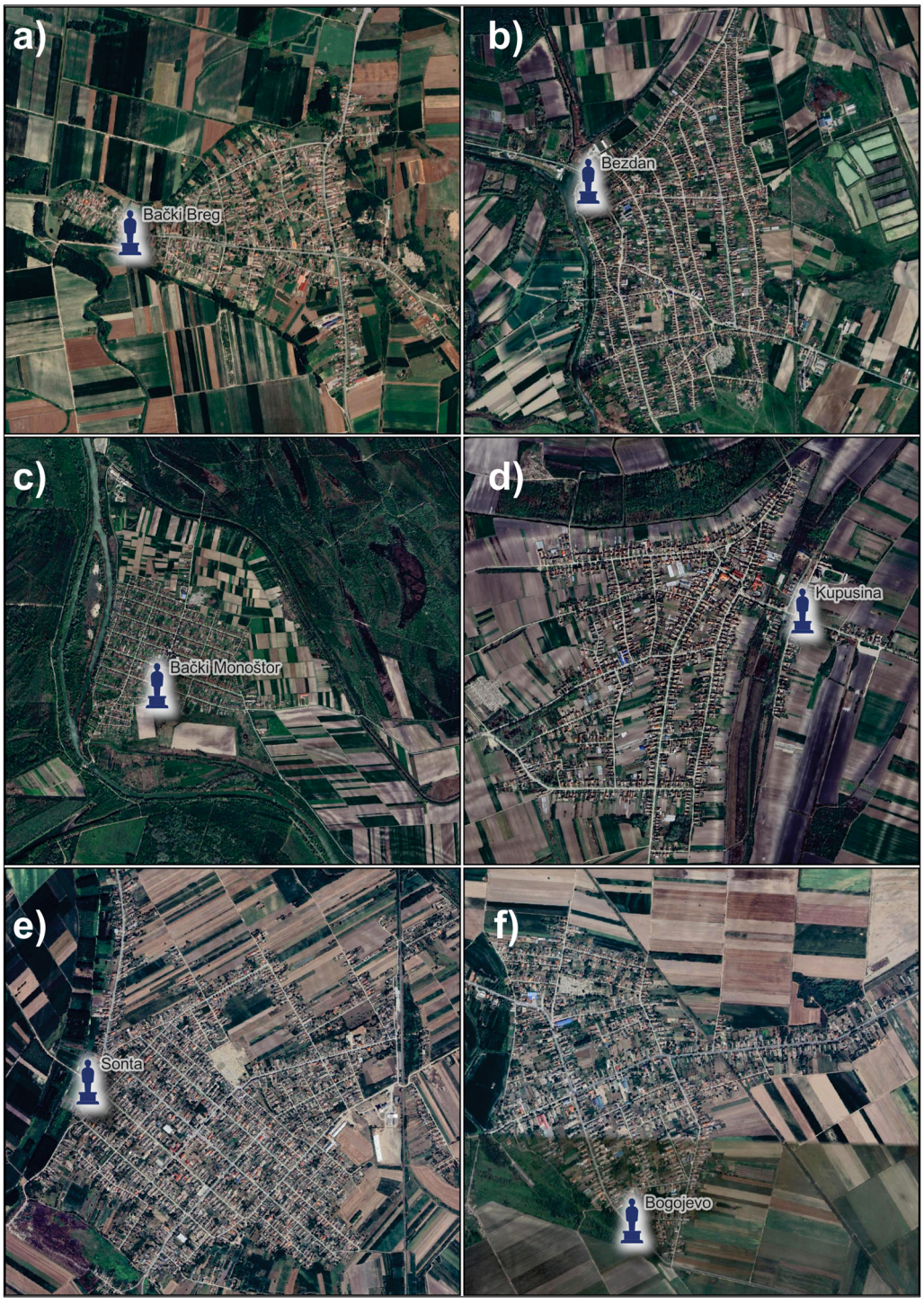

Figure 9: Satellite imagery of present-day settlement structure and statue locations (a – Bački Breg, b – Bezdan, c – Bački Monostor, d – Kupusina, e – Sonta, and f – Bogojevo). Background imagery: Google Satellite, accessed via QGIS software on May 24, 2025.

half of the study area, stretching along the Danube, is dominated by overlapping zones of medium (crosshatched red) and low (striped orange) flood hazard. This includes not only the six target settlements but also neighboring communities such as Apatin, Prigrevica, Svilojevo, and Doroslovo, whose territories also lie within extensive hazard zones.

These results affirm that the spatial logic behind the historical placement of Saint John of Nepomuk statues (as guardians against riverine hazards) remains relevant even today. Despite the transformation of the Danube's hydromorphological profile and the expansion of embankment systems, the settlements where these statues were erected

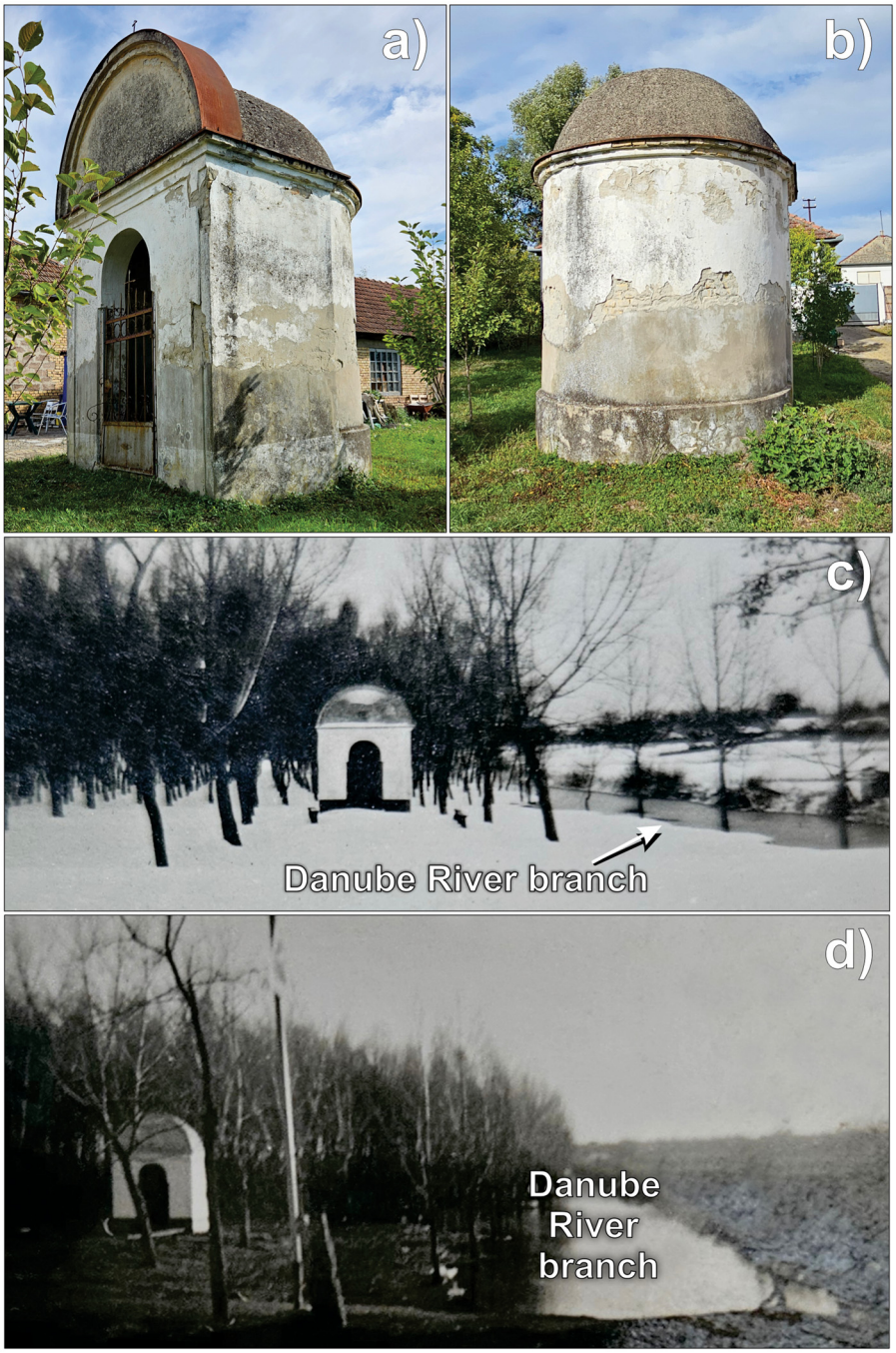

Figure 10: Location of the Saint John of Nepomuk chapel in Kupusina settlement (a, b – present-day location within the yard of a private residence; c, d – twentieth-century position near the Danube River branch before intensive urbanization of the settlement; Photos: V. Stojanović and courtesy of I. Silling).

Figure 11: Location of the Saint John of Nepomuk chapel in Sonta settlement (a – Present day photo and b – Historical photo of the settlement with chapel (indicated by white arrow) during the Danube River flooding in 1924) (Photo: V. Stojanović (a) and K. Lanji [60] (b)).

still face measurable flood risk. Their positioning, typically at the edge of settlements and oriented toward the river, continues to symbolically mark the boundary between the inhabited and the threatened.

In this context, the statues not only represent historical memory and cultural identity but also act as fixed markers within a changing risk landscape. Their persistent location in areas of elevated hazard reinforces the notion that cultural heritage and disaster risk must be jointly considered in contemporary spatial and floodplain planning. This integrated approach is essential for developing effective strategies for the assessment and protection of such unique cultural resources, as has been demonstrated in other vulnerable landscapes [58].

4.6 Present-day settlement configuration and statue location

Satellite imagery of the six settlements (Figure 9) provides additional insight into the current spatial configuration of the built environment and the precise location of each statue of Saint John of Nepomuk in relation to settlement structure, edge morphology, and surrounding land use.

Across all cases, the statues remain situated at the periphery of the built-up area, consistent with their historical role as threshold markers between the inhabited zone and the uncertain floodplain. In Bački Breg (Figure 9a), the statue lies on the western edge of the village, in a transition zone where the compact settlement fabric opens into surrounding agricultural fields. This peripheral siting reinforces its original protective symbolism, despite the settlement's gradual expansion.

In Bezdan (Figure 9b), the statue is positioned along a canalized watercourse near the northern limit of the settlement area, close to the convergence of hydrological and transportation corridors. It marks a liminal zone, still visually and functionally distinct from the densely built interior. Bački Monoštor (Figure 9c) displays a similar pattern: the statue stands at the southern fringe of the orthogonally structured village core, facing a patchwork of cultivated land and forested wetland, further echoing the motif of boundary and defense.

In Kupusina (Figure 9d), the statue is also located at the margin of the linear settlement axis, adjacent to open fields and drainage channels. Its positioning retains spatial meaning even as modern expansion extends eastward. It is interesting to note that the statue in Kupusina was relocated in the 1930s to the bank of a nearby canal. A comparative analysis of black-and-white photographs from the 1940s and color photographs from the autumn of 2024 reveals this change (Figure 10a–d). It is also evident that the small chapel with the statue of Saint John of Nepomuk is now located in the yard of a private household. This happened as the settlement expanded through "spontaneous urbanism," eventually incorporating the chapel into a private property [59]. Sonta (Figure 9e), with a notably dense and grid-like settlement structure, hosts its statue just beyond the western edge of the continuous settlement matrix, oriented toward riverine lowlands and fluvial infrastructure (Figure 11a and b). Bogojevo (Figure 9f) presents a slightly different case, where the statue stands somewhat detached from the main settlement core, nestled between low-density housing and peripheral agricultural terrain – suggesting that even as urbanization progressed, the statue's position remained unchanged in its marginal and river-facing role.

In all six cases, the statues are not integrated into central village spaces or civic cores, but rather occupy spaces of transition – thresholds between habitation and exposure, order and unpredictability. This spatial consistency reinforces the notion that the statues were conceived

not only as devotional objects, but as territorial sentinels, placed deliberately to confront the natural force of the Danube and to mediate between sacred space and environmental threat.

5 Concluding remarks

This study has demonstrated that geodiversity, when viewed through the lens of cultural and religious practices, reveals a deeper layer of meaning in the interaction between communities and their environment. In the case of Gornje Podunavlje region in the Bačka of northwestern Serbia, the veneration of Saint John of Nepomuk – expressed through the placement of statues – serves as both a spiritual response and a cultural record of past flood hazards. Our geospatial and GIS analyses revealed a consistent pattern in the Gornje Podunavlje region: statues were positioned on the rural outskirts, on higher relief terraces, and oriented toward the Danube River, reflecting both an awareness of flood risk and a symbolic appeal for protection. In contrast, similar statues in other Bačka settlements (Sombor, Odžaci, Bajmok, Mali Iđoš, and Selenča) appear without clear geomorphological reasoning, suggesting different historical relationships with the river and flooding.

These findings emphasize the need to view geodiversity not merely as a physical attribute, but as a dynamic component of cultural landscape interpretation. The placement of religious monuments provides a tangible record of how communities have historically adapted to environmental pressures, particularly in lowland riverine areas where such adaptations are often subtle but meaningful.

A key limitation of this study is the use of the SRTM Digital Elevation Model with a 30 m resolution, which limits the ability to capture subtle elevation differences essential for detailed flood risk assessment in lowland areas. A higher-resolution DEM would allow for more precise delineation of river terraces and micro-relief features, thereby improving the accuracy of hypsometric classification and terrain-based interpretation. Additionally, the interpretation of historical spatial patterns is constrained by the positional accuracy of georeferenced nineteenth-century maps, while the contemporary flood hazard data do not reflect local protective infrastructure or anticipated climate change impacts.

Future research should explore the application of multi-criteria flood vulnerability assessment methods, such as the Analytic Hierarchy Process (AHP), to provide a more nuanced understanding of current flood susceptibility. By integrating factors such as elevation, slope, proximity to the river, historical flood events, and existing protective infrastructure, such an approach could identify priority areas for intervention and inform the strategic placement of levees or flood defenses. Combining this with time-series satellite imagery and targeted field verification would strengthen both the analytical depth and practical relevance of the findings. This is of utmost importance for preserving the unique elements of cultural heritage embedded within the locally diverse landscape, particularly the distinctive Danube watermarks found in this part of Europe. These features serve as enduring witnesses to the interaction between natural processes, landscape dynamics, and cultural development under shifting environmental conditions. Moreover, they represent vital anchors of collective memory, contributing to the shared identity of local communities and ensuring their transmission to future generations.

Hence, this research not only illustrates the cultural imprint of environmental dynamics but also highlights the potential of historical-geospatial analysis to inform contemporary flood risk management and cultural heritage preservation in vulnerable lowland landscapes.

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