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Front cover photography: The central part of the Durmitor mountains in Montenegro with the highest peak, Bobotov Kuk (2523 m), and distinctive high-mountain karst shaped by glacial processes (photograph: Jure Tičar).
Fotografija na naslovnici: Osrednji del gorovja Durmitor v Črni gori z najvišjim vrhom Bobotov kuk (2523 m) ter značilnim visokogorskim krasom, ki so ga preoblikovali ledeniški procesi (fotografija: Jure Tičar).

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Contents

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MORPHOGENESIS AND CLASSIFICATION OF CORROSION PLAINS IN SLOVENIA

Uroš Stepišnik, Mateja Ferk

The surface of Rajndol Plain is dissected by numerous dolines.

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Uroš Stepišnik[1], Mateja Ferk[2]

Morphogenesis and classification of corrosion plains in Slovenia

ABSTRACT: A new study of corrosion plains in Slovenia provides a systematic classification based on their geological settings and morphology. They are grouped into four types: karst plains, dry poljes, marginal plains of contact karst, and marginal plains of fluviokarst. Karst plains are the largest, formed through denudation under stable tectonic and hydrogeological conditions. Dry poljes are closed basins composed of bedrock and scattered sediment. Marginal plains of contact karst are formed at the boundary between non-karst and karst environments, while marginal plains of fluviokarst result from multiphase formation of poljes due to tectonic activity. This study enhances understanding of corrosion plains and can assist in their identification and management in karst areas.

KEYWORDS: geomorphology, karst, corrosion plain, Slovenia, Dinaric Karst

Morfogeneza in klasifikacija korozijskih uravnav v Sloveniji

IZVLEČEK: Raziskava korozijskih uravnav v Sloveniji podaja sistematično klasifikacijo korozijskih uravnav na podlagi njihovih geoloških in morfoloških značilnosti. Klasifikacija jih združuje v štiri kategorije: kraški ravnik, suho kraško polje, robna uravnava kontaktnega krasa in robna uravnava fluviokrasa. Kraški ravniki so največji in nastanejo z denudacijo v stabilnih tektonskih in hidrogeoloških razmerah. Suha kraška polja so zaprte živoskalne kotanje le mestoma prekrite s sedimenti. Robne uravnave kontaktnega krasa so nastale na stiku kraških in nekraških kamnin. Robne uravnave fluviokrasa so nastale z večfaznim razvojem kraških polj zaradi tektonske dejavnosti. Ta raziskava prispeva k boljšemu razumevanju korozijskih uravnav in lahko pomaga pri njihovi identifikaciji in upravljanju v kraških območij.

KLJUČNE BESEDE: geomorfologija, kras, korozijska uravnava, Slovenija, Dinarski kras

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[1] University of Ljubljana, Faculty of Arts, Ljubljana, Slovenia
uros.stepisnik@ff.uni-lj.si (https://orcid.org/0000-0002-8475-8630)

[2] Research Centre of the Slovenian Academy of Sciences and Arts, Anton Melik Geographical Institute, Ljubljana, Slovenia
mateja.ferk@zrc-sazu.si (https://orcid.org/0000-0003-0145-7590)

1 Introduction

Karst is a distinct geomorphologic system characterized by the dominance of underground water flows. Chemical denudation, resulting from chemical weathering of bedrock, mainly by congruent dissolution, is the most important process at the surface. The predominance of chemical denudation and the absence of aggradation are evident in the rocky surface and the diversity of landforms (Sweeting 1973; Šušteršič 1986; White 1988; Ford and Williams 2007; Stepišnik 2020; De Waele and Gutiérrez 2022).

Karst areas exhibit a high degree of complexity and variability due to the interplay of both typical karst surface and subsurface processes, as well as diverse sediment transport mechanisms such as fluvial, glacial, and coastal processes. These interactions can lead to a wide array of unique surface and subsurface formations within different karst landscapes. The functioning of these geomorphologic processes is strongly influenced by geologic, hydrologic, and climatic conditions, resulting in significant differences in karst morphology around the world (Jennings 1985; Ford and Williams 2007; De Waele and Gutiérrez 2022).

Early attempts at a typology of karst in Slovenia were based on hydrological and geomorphological characteristics, with Šerko (1947) being the first to establish a classification system. Later typologies of karst areas were subdivided according to a number of geomorphological and hydrological features (Gams 1959; 1972; 1974; 1995; 2004; Habič 1969; 1980; 1982; 1986, Žebre and Stepišnik 2015; Stepišnik 2017; 2020; Stepišnik, Stojilković and Hočevar 2019).

The latest karst typologies in Slovenia (Stepišnik 2020) provide a detailed classification system based on the dominant geomorphologic processes on karst, specifically the morphodynamic characteristics of karst environments. In Slovenia, deep karst and shallow karst are distinguished based on their hydrogeological characteristics (Stepišnik 2017; 2020), while fluviokarst (Roglić 1958; Komac 2004; Stepišnik 2021a; De Waele and Gutiérrez 2022) and glaciokarst (Žebre and Stepišnik 2015; Ferk et al. 2017) are distinct types based on the different surface processes that occur. General classifications of karst landscapes and landforms are also included in almost all landscape typologies of Slovenia (Perko, Ciglič and Hrvatin 2019; 2021).

Deep karst environments are characterized by the pattern of water discharge, with all water flowing underground. Due to this underground flow, there are no surface water streams or stagnant bodies of water present in deep karst areas (Stepišnik 2020). The primary process operating on the surface of deep karst is chemical denudation in a vertical direction, which is not uniform, leading to the development of circular landforms (Šušteršič 1986; 1994; 2000; Stepišnik 2020). These landforms give rise to the conical hills and uvalas that are characteristic of deep karst, forming a distinctive cone karst topography that is often dissected by numerous dolines and collapse dolines. In addition to the cone karst topography, deep karst areas are also characterized by extensive flattened areas known as corrosion plains, which cut horizontaly across geological structures and lithological deformations (Roglić 1957; Gams 2004; Ford and Williams 2007; Bočić, Pahernik and Mihevc 2015; De Waele and Gutiérrez 2022). These bedrock plains extend across all areas of deep karst that are not conical karst, with some corrosion plains measuring tens of kilometres in diameter (Stepišnik 2020). These plains can be impressively planar but are usually intersected by numerous dolines and individual conical hills. Some of the corrosion plains are entrenched by canyons that may or may not be hydrologically active (Roglić 1957; Stepišnik 2020).

Earlier researchers explained the formation of corrosion planes by fluvial processes (Cvijić 1893; 1901; 1918; Penck 1900; Davis 1901; Grund 1914). Roglić (1957) undertook a systematic study of corrosion plains and divided them into four types based on their geomorphological-hydrological position. He also stated that the formation of corrosion plains is a consequence of suitable climatic conditions (Roglić 1957). Other researchers, who studied karst in different parts of the world (Lehmann 1954; Wissmann 1954), reached similar conclusions. In the literature, corrosion plains are thought to form by dissolutional planation at the base level, followed by lateral extension of periodically flooded plains. Their formation is not dependent on climate, although prolonged and stable periods of base level flattening are favourable (Ford and Williams 2007; Mocochain et al. 2009; De Waele and Gutiérrez 2022).

Although there are numerous interpretations in the literature, the processes involved in the formation of corrosion plains are much more complex than previously thought. Corrosion plains are formed not only by the base level flattening, but also in specific lithologically conditioned environments where sedimentary deposits are superimposed over the karst surface.

Depending on the morphographic and morphogenetic features, different terms for corrosion plains are used in the literature, such as karst plain, corrosion terrace, pediment, plateau, marginal plain, marginal flattening, dry polje, etc. (Roglić 1951; 1957; Gams 1973; 2004; Gams, Kunaver and Radinja 1973; Mihevc 1986; De Waele and Gutiérrez 2022). Also, corrosion plains are not always clearly distinguished from flat areas in aggradational environments (e.g., poljes, accumulation terraces, etc.). The inconsistencies and use of various terms has led to confusion in their classification and understanding. Furthermore, corrosion plains in Slovenia have not been thoroughly studied, and there is a pressing need for a comprehensive study of these features in the region. To address this gap, the authors of this article propose a systematic approach to distinguish the basic types of corrosion plains.

The aim of this research was: (1) to identify and analyse corrosion plains in Slovenia; (2) to evaluate the morphogenesis of these features by assessing their morphographic, morphometric, and morphostructural characteristics using data from the existing literature; (3) to propose a new classification system for corrosion plains based on their geological settings and morphology by interpreting the processes involved in their formation and function.

This classification system has been adapted for karst areas in Slovenia and is transferable to other similar areas in the Dinaric Karst and worldwide where similar karst processes occur or have similar geological and hydrological characteristics. The results of this study will lead to a better understanding of the formation and evolution of karst environments in Slovenia and provide a valuable basis for future research in this field. The proposed classification system will also allow a more accurate and comprehensive analysis of corrosion plains and related processes in karst environments.

2 The evolution of the understanding of corrosion plains: a historical overview

In the transition from the 19th to the 20th century research of karst features and processes became increasingly popular with the focus especially on the Dinaric Karst (Cvijić 1893). Among other things, Cvijić (1900) also discussed corrosion plains, the formation of which he interpreted as the final stage of development of corrosion and denudation processes through the understanding of cyclic surface development at the time, when the surface is flattened near the water table level in karst. At that time, the scientific debate on the formation of corrosion plains was influenced by contemporary interpretations of processes in fluvial geomorphology (Penck 1900; 1904; Davis 1901). Influenced by the early interpretations of Cvijić (1900), Grund (1903; 1910; 1914) linked the formation of corrosion plains to hydrographic zones in karst. He explained their formation by the groundwater level in the karst aquifer near the surface, which prevents denudation into the depths. Denudation only affects the shallow zone of the surface above the karst water table and lowers it to this level, creating extensive flat plains. Cvijić (1900) tried to build on his original interpretation that karst flattening occurs near the water table by introducing fluvial processes. He defined corrosion plains as fluviokarst features (Cvijić 1909) that could not be formed by karst processes alone (Cvijić 1918), but rather by a gradual transition from a prekarst phase to a karst phase - a process he defined as *karstification* (Cvijić 1921). Some authors have interpreted specific corrosion plains as marine abrasion terraces (Cvijić 1924, Stefani 1930). An alternative explanation for the origin of the corrosion plains was provided by Terzaghi (1913), who attributed the flattening at the surface to accelerated corrosion due to the effect of biochemical processes in the soil. His ideas were not confirmed and accepted by the wider scientific community until several decades later (Roglić 1951; Birot 1954; Oertli 1954).

After a period of several decades without significant progress in understanding karst processes, Roglić (1951, 1957), who undertook a systematic study of corrosion plains, made an important breakthrough. Roglić (1957) focused on corrosion plains and divided them into four types according to their geomorphological-hydrological position: (1) plains along rivers (e.g., the Severnodalmatinska Zaravan along the rivers Krka, Čikola and Zrmanja), (2) plains open to the sea (e.g., Istria), (3) plains in closed basins (e.g., Popovo Polje, Lika Polje) and (4) plains on the margins of poljes (e.g., Gatačko Polje, Duvanjsko Polje, Livno Polje). He concluded that plains form in the area of contact karst, where water from the non-karst environment brings sediment into the karst, similar to what he observed in the blind valleys of Matarsko Podolje Plain and Istria. Sediment is deposited on the periodically flooded surfaces, keeping moisture close to the surface and allowing the growth of vegetation, which through biochemical processes causes accelerated corrosion of the carbonate bedrock and expansion of the plains through lateral corrosion. Other researchers who have studied corrosion plains have come to the same conclusion: Lehmann (1954) in his studies of karst in Cuba, Wissmann (1954) in his studies of karst in SE Asia. Based on observations from tropical karst, where flattening processes are very active, Roglić (1957) concluded that the plains of the Dinaric Karst are relics from a time when a suitable climate prevailed (he assumed a Pliocene age).

During the next decades the theories of corrosion plain formation were increasingly linked to their tectonic predisposition; an extensive literature review on corrosion plain formation is provided by Bočić, Pahernik and Bognar (2010) who studied the formation of the Slunj Plain. Internationally, the formation of corrosion plains was summarised by Ford and Williams (2007) and De Waele and Gutiérrez (2022). According to them corrosion plains form by dissolutional planation at the base level by solutional removal of surface irregularities to the level of the water table, after which the periodically flooded plains expand laterally. Usually the plains form at the output side of karst terrains, however they are also found at the input margins and as corrosion terraces within poljes. The morphogenesis of these landforms is not reliant on specific climatic conditions; however, extended periods of adequate humid environments and tectonic stability are needed for their formation (Ford and Williams 2007; De Waele and Gutiérrez 2022).

3 Materials and methods

The analysis was conducted in two stages, utilizing the polygon layers of the extent of karst rocks in Slovenia (Gostinčar and Stepišnik 2023) and lidar data digital elevation model (DEM) obtained from the Slovenian national aerial laser scanning between 2011 and 2015 (the lidar data was provided by the Slovenian Environmental Agency).

In the first stage a polygon of karst areas was created based on the layer of the extent of karst rocks in Slovenia (Gostinčar and Stepišnik 2023). By using ArcGIS Pro 10.8.1 a surface slope map was created for all karst areas and than a smoothed topography to 20-m grid cells was created to eliminate noise in the data. Subsequently, the polygons representing the levelled karst areas with a slope of less than 3° were manually delineated. To identify corrosion plains, we primarily looked for areas without conical hills and uvalas, which are characteristic of cone karst topography. Additionally, we excluded regions containing flattened sections of shallow karst covered by alluvium (i.e., poljes) (Stepišnik 2021b). This approach led to the mapping of corrosion plains in Slovenia.

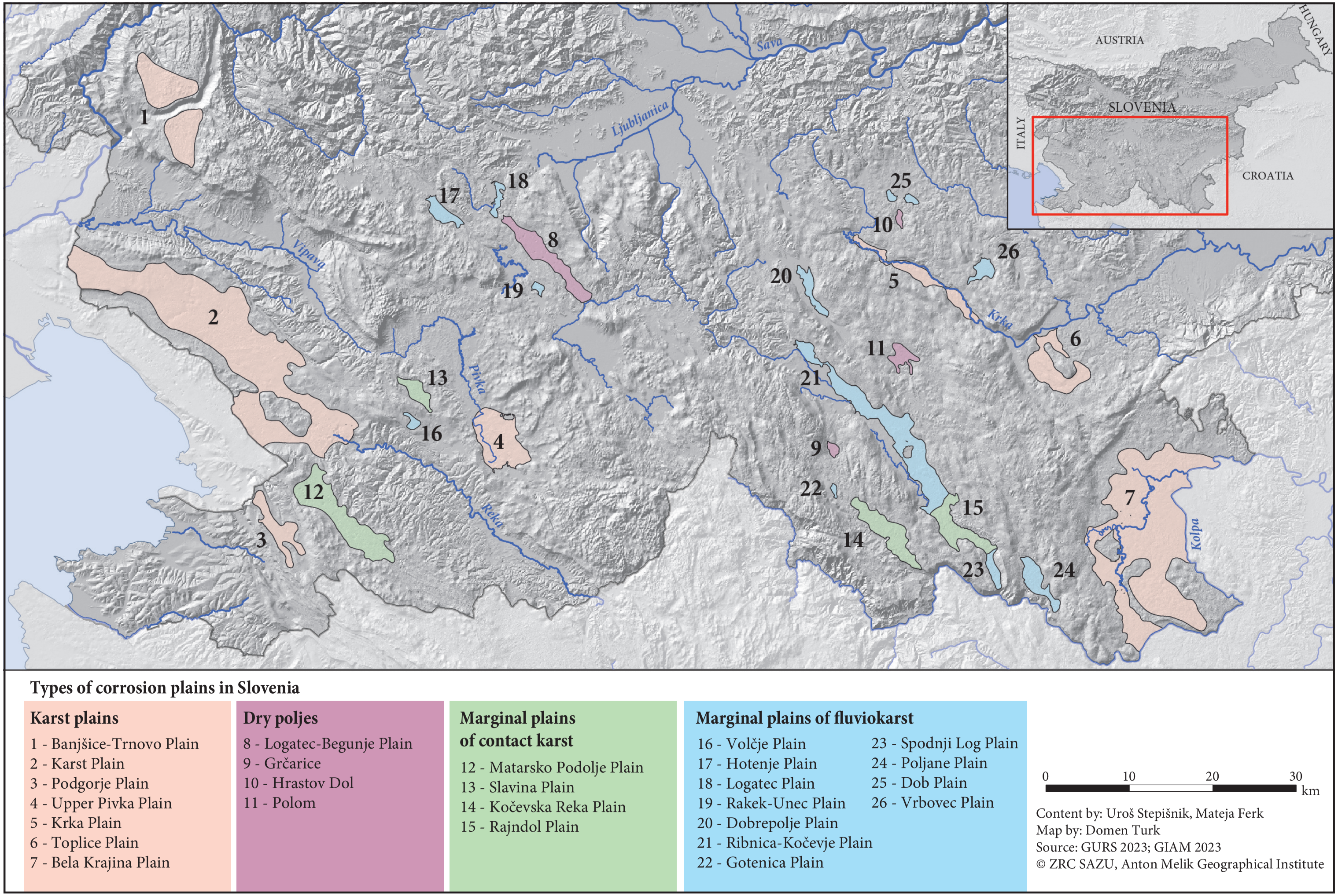
In the second stage, we classified the corrosion plains based on their geological settings and morphology; their morphographic, morphometric, and morphostructural characteristics were examined in detail, which are essential for the morphogenetic interpretation and classification. Morphographic features were visualy interpreted from lidar DEM data (hillshade) and field analyses of individual sites to verify the initial interpretation from the lidar-derived data. The morphometric analysis of each corrosion plain was performed with GIS analyses using ArcGIS Pro, providing the extent of the corrosion plains. The morphostructural analysis relied on the geological map of Slovenia at a scale of 1:100,000 (Buser 2009; Pleničar, Ogorelec and Novak 2009; Hrvatin 2016) in combination with lidar DEM data (hillshade). Based on the lithological characteristics of the tributary parts of marginal plains, we determined the specific type of marginal plain (i.e., contact karst, fluviokarst).

4 Results: corrosion plains in Slovenia

Corrosion plains (slv. *korozijske uravnave*) are a unique feature of karst landscapes, characterized by extensive, flat areas made up of a rocky karst surface with patchy sediment coverage (Roglić 1957). They are usually dissected by dolines and other karst formations. Unlike plains in other geomorphologic environments, which are formed primarily by fluvial or coastal aggradation of sediments, corrosion plains are formed in the bedrock (Sweeting 1973; Benito-Calvo and Pérez-González 2007).

In the scientific karst literature (see introduction chapter), different terms are used for corrosion plains; e.g., karst plain, corrosion terrace, pediment, plateau, marginal plain, marginal flattening, dry polje, etc. The use of various terms in the scientific karst literature to describe corrosion plains has led to confusion in their classification and understanding. To address this, the authors of this article propose a systematic

Figure 1: The location and classification of corrosion plains in Slovenia. ➤ p. 12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Types of corrosion plains in Slovenia
Karst plains
1 - Banjšice-Trnovo Plain
2 - Karst Plain
3 - Podgorje Plain
4 - Upper Pivka Plain
5 - Krka Plain
6 - Toplice Plain
7 - Bela Krajina Plain
Dry poljes
8 - Logatec-Begunje Plain
9 - Grčarice
10 - Hrastov Dol
11 - Polom
Marginal plains of contact karst
12 - Matarsko Podolje Plain
13 - Slavina Plain
14 - Kočevska Reka Plain
15 - Rajndol Plain
Marginal plains of fluviokarst
16 - Volčje Plain
17 - Hotenje Plain
18 - Logatec Plain
19 - Rakek-Unec Plain
20 - Dobrepolje Plain
21 - Ribnica-Kočevje Plain
22 - Gotenica Plain
23 - Spodnji Log Plain
24 - Poljane Plain
25 - Dob Plain
26 - Vrbovec Plain
0 10 20 30 km
Content by: Uroš Stepišnik, Mateja Ferk
Map by: Domen Turk
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approach to distinguish four different types of corrosion plains in Slovenia (Figure 1): (1) **karst plain (slv. *kraški ravnik*)**, (2) **dry polje (slv. *suho kraško polje*)**, (3) **marginal plain of contact karst (slv. *robna uravnava kontaktnega krasa*)**, and (4) **marginal plain of fluviokarst (slv. *robna uravnava fluviokrasa*)**.

Karst plains are the largest type of corrosion plains found in karst areas around the world (e.g., the 200,000 km^2 large Nullarbor Plain in Australia). These plains are characterized by their vast size, reaching up to tens of kilometres across, and their exceptionally flatt surface cutting horizontaly through the underlaying bedrock. Karst plains, like other corrosion plains, are typically dissected by a large number of karst depressions, such as dolines and collapse dolines, as well as occasional cone-shaped hills. The unique feature of karst plains compared to other corrosion plains are canyons, which dissect their surface. The canyons are hydrologicaly active, if they reach the water table of the regional aquifer (i.e., the process of river entrenchment is still active). Hydrologicaly inactive canyons are in the vadose hydrographic zone and are an indicator of past hydrological processes (Nicod 1997).

Slovenia has a number of extensive karst plains, each with its own unique characteristics. The largest of these is the Karst Plain (slv. *Kraški ravnik*) and covers an area of 217 km^2 (Figure 2). The Bela Krajina Plain (slv. *Belokrajnski ravnik*) is the second largest with an area of approximately 187 km^2. The Upper Pivka Plain (slv. *Ravnik Zgornje Pivke*), the fragmented Krka Plain (slv. *Krški ravnik*) located upstream between Krka and Dvor, and the Toplice Plain (slv. *Topliški ravnik*) southwest from Novo Mesto, are also considered as karst plains. Despite their different sizes and geological compositions, these karst plains share one common feature: they are intersected by canyons. In the Karst Plain, the Veliki Dol and the Mali Dol are two such canyons, which are hydrologically inactive (dry canyons). Other karst plains have hydrologicaly active canyons: Kolpa, Lahinja, and Krupa rivers in the Bela Krajina Plain, Pivka River in the Upper Pivka Plain, Krka River in the Krka Plain, and Sušica River in the Toplice Plain.

There are two karst plains that offer a distinct set of geological and geomorphological features. The Podgorje Plain (slv. *Podgorski ravnik*) is a more complex karst plain, characterized by its alternating layers of limestone and flysch. It is partially dissected by the Grižnik Canyon, which merges into the Glinščica Canyon across the border in Italy. The canyon was formed through antecedent incision but was eventually stopped due to the bifurcation of water into the karst, resulting in a ponor-type of contact karst (Gams 2004). The Banjšice-Trnovo Plain (slv. *Banjško-trnovski ravnik*) is also a unique karst plain. The former


UROŠ STEPIŠNIK

Figure 2: The largest karst plain in Slovenia is the Karst Plain.

uniform karst plain is divided in two by the dry canyon Čepovanski Dol. The plain is extensively karstified and has a more dissected surface with karst features compared to other karst plains in Slovenia. This and its high topographic position compared to its surrounding indicate its older age. The Trnovo nappe was formed from Eocene to Miocene (Pleničar, Ogorelec and Novak 2009; Placer, Mihevc and Rižnar 2021), and the subsequent formation of fault zones in the Neogene (Placer and Čar 1975) most probably already caused the hydrological changes that in the end led to the abandonment of the Čepovanski Dol.

Corrosion plains that are located in closed depressions but are not hydrologically active, i.e., not shallow karst or fluviokarst, are defined as **dry poljes**. The flat floors of these dry poljes are rocky, which are only covered by sediment patches. The floor of these poljes is dissected by a high density of dolines, collapse dolines, and small cone-shaped hills (i.e., former hums).

The largest dry polje in Slovenia is the Logatec-Begunje Plain (slv. *Logaško-begunjski ravnik*), covering an area of 22 km^2. This plain is situated between Logatec and Begunje pri Cerknici and is characterized by a rocky surface that is only partially covered by sediment. According to the morphodynamic classification of poljes (Stepišnik 2021), the Logatec-Begunje Plain was once an inflow type of polje, as indicated by the sediment on the plain and the former flow of the Cerkniščica River in the area (Šušteršič and Šušteršič 2003). Another example of a dry polje that once functioned as an inflow type of polje is the Hrastov Dol (slv. *Hrastov dol*) in the northern part of the Suha Krajina (Figure 3). This plain has a flat floor dissected by dolines and covered by patches of sediment, its northern slope, which once fed sediment into the polje floor, is now dissected by dry erosion gullies.

Two dry poljes in Slovenia are former overflow poljes, as classified by morphodynamic classification (Stepišnik 2021). One is located in the western part of the Suha Krajina near the settlement Polom, covering an area of approximately 6 km^2. Its floor is characterized by a flattened surface, dotted with numerous dolines, and irregularly covered with sediment patches. In some areas, the remnants of a former watercourse are visible, which had its source in two locations in the western part of the polje and drained into a sinking area in the southeastern part. The second dry overflow polje is situated between Ribniška Velika


UROŠ STEPIŠNIK

Figure 3: The sediment-covered part of the floor of the dry polje Hrastov Dol in Suha Krajina is already dissected by suffosion dolines.

Gora and Stojna mountains, near the settlement Grčarice. Its floor is dissected with dolines and features a distinctive pocket valley in the southern part, which once functioned as a karst spring.

The marginal plains are a unique type of corrosion plains that form at the former aggradation areas of contact karst and fluviokarst. These areas were created when fluvial sediments covered the margins of adjacent karst areas. Later, the areas became hydrologically inactive and the sediments were denuded, exposing the flat underlying bedrock (Gams 1973; Stepišnik 2021b).

In Slovenia, the **marginal plains of contact karst** are found at the geological contact between Eocene flysch, Carboniferous and Permian clastic rocks and karstified carbonate rocks. The water from fluvial environments deposited sediments in the form of alluvial fans (Stepišnik et al. 2007a; 2007b; Stepišnik 2009) or flattened alluvial plains over the karst, and once sediment delivery ceased, the subsequent denudation of the sediments caused the previously flat areas to be superimposed on the bedrock, resulting in the formation of the marginal plains of contact karst (Stepišnik 2021b).

Marginal plains of contact karst are the Matarsko Podolje Plain (slv. *Ravnik Matarskega podolja*) and Slavina Plain (slv. *Slavinski ravnik*), where water from Eocene flysch prolongued on the karst surface and deposited sediments (Figure 4). In case of the Kočevska Reka Plain (slv. *Kočevskoreški ravnik*) and the Rajndol Plain (slv. *Rajndolski ravnik*) sediments were sourced from non-carbonate clastic sedimentary rocks of Carboniferous and Permian age. At the lithological contact, blind valleys have formed in the former tributary areas where water still flows underground. In Matarsko Podolje Plain and Slavina Plain, relict alluvial fans are also preserved in the tributary areas, resulting in a slightly sloping surface. The Kočevska Reka Plain and Rajndol Plain are relatively flat up to the lithological contact.

The marginal plains of fluviokarst form in areas where sediment from fluviokarst areas (De Waele and Gutiérrez 2022) have accumulated and flattened the surface. These sediment deposits create larger plains, classified as inflow poljes, according to the morphodynamic classification (Stepišnik 2021b). As sediment influx decreases, the distal margin of the poljes move towards the tributary, leading to the eventual hydrologic inactivity of distal parts of the poljes (i.e., formation of relict parts of poljes). The transition between active and relict parts can be gradual or sudden, with active parts shifting to higher, relict

UROŠ STEPIŠNIK

Figure 4: The Slavina Plain is a marginal plain of contact karst formed at the lithological contact between Eocene flysch and Cretaceous limestone.

Figure 5: The Ribnica-Kočevje Plain is the largest marginal plain of fluviokarst in Slovenia and is the remnant of a former inflow type of polje, once the largest polje in Slovenia.

parts with a slight slope. The relict parts of the poljes become flat rocky plains with patches of sediment cover, and are characterized by a high density of dolines. Although this flattening is often attributed to tectonic activity (Gams, Kunaver and Radinja 1973; Gams 1974), it is actually due to a reduction in the supply of fluvial clastic sediments to the polje floors (Stepišnik 2021a; 2021b).

The marginal plains of fluviokarst in the Slovenian karst are formed at the distal part of inflow poljes in the form of bedrock terraces, intersected by a high density of dolines: Hotenje Plain (slv. *Hotenjski ravnik*), Logatec Plain (slv. *Logaški ravnik*), Rakek-Unec Plain (slv. *Rakovško-unški ravnik*), Vrbovec Plain (slv. *Vrbovški ravnik*) and Dobrepolje Plain (slv. *Dobrepoljski ravnik*). The largest marginal plain of fluviokarst in Slovenia, the Ribnica-Kočevje Plain (slv. *Ribniško-kočevski ravnik*), is located on the eastern edge of the Ribnica and Kočevje poljes, with a total area of 52 km^2 (Figure 5). In the past, besides the Bistrica River, which has its catchment in a fluviokarst area, the Tržiščica River also flowed in from the north, from the area of Permian clastic sedimentary rocks. There are quartz pebbles in the plain, which come from the catchment area of the Tržiščica River. The size of this plain is most likely related to the combined inflow from two different catchments. Based on the combined sediment supply, this marginal plain can be defined as a combination of marginal plains of the contact karst and marginal plains of fluviokarst. A riverbed of the Zadnja Rinža River also extends over the plain, which flows from Ribnica Polje to Kočevje Polje only during floods. The spatial dispersion of this floodplain suggests that it once formed a single polje, the largest in Slovenia.

Some marginal plains of fluviokarst in Slovenia are unique in their development as they are not located on the margins of poljes. Instead, they have formed below the fluviokarst slopes from where sediment was once supplied, covering the lower parts of the karst terrain. The interruption of sediment supply led to the denudation of flattened sediment and superimposition into the rocky karst surface, resulting in the formation of these plains. The Poljane Plain (slv. *Poljanski ravnik*) received sediment inflows from the north, where an occasional stream still springs today, while the Spodnji Log Plain (slv. *Spodnjeloški ravnik*) received sediment from the east slope, now marked by a series of inactive gullies.

5 Discussion

Corrosion plains are extensive bedrock planation surfaces cutting through various rocks and structures and occur in different climatic settings (Roglić 1957; Ford and Williams 2007; Bočić, Pahernik and Bognar 2010; De Waele and Gutiérrez 2022). Although, they are usually impressively flat, the surface can be dissected by numerous dolines and individual conical hills. Generally, the formation of corrosion plains is attributed to dissolutional planation during prolonged and stable periods of base level flattening, followed by lateral extension of periodically flooded plains (Ford and Williams 2007; De Waele and Gutiérrez 2022). However, corrosion plains form also in specific lithologically conditioned environments where sedimentary deposits are superimposed over the karst surface; e.g., contact karst, fluviokarst. The bedrock dissolution under dump and CO_2-rich soils can be particularly intense, causing rapid dissolution and planation of the bedrock at the water-rock boundary (Cui et al. 2002).

The determination of the time frame of corrosion plain formation is particularly challenging. The amount of preserved sediment cover could potentially be an indicator of the relative age when comparing corrosion plains (Bočić, Pahernik and Mihevc 2015). However, the initial amount of sediment differs, as does the geochemical and granulometric composition. The repeated climatic and environmental changes in the Quaternary (Augustin et al. 2004; Lisiecki and Raymo 2007; Šibrava 2010), causing sea-level fluctuations and significant changes in hydrological conditions (Šibrava 1986; Bintanja, van de Wal and Oerlemans 2005; Dumas, Guérémy and Raffy 2005; Zupan Hajna et al. 2008; Edwards 2016; Ferk 2016; Ferk et al. 2019), could have led to certain areas becoming hydrologically inactive (i.e., dry poljes, marginal plains of contact karst and fluviokarst). However, for the formation of larger karst plains it could be assumed, more stable pre-Quaternary environmental conditions would be more favourable, like it was demonstrated in the case of the formation of the Slunj Plain (Bočić, Pahernik and Bognar 2010). Furthermore, in the karst landscapes, corrosion plains are affected only by dissolutional denudation, which evenly lowers the surface (Ford and Williams 2007; De Waele and Gutiérrez 2022). At the same time, there are no geomorphological processes that would break up the surface irregularly in the lateral direction as e.g., fluvial erosion. Due to the principal of »karst imunity« (Mocochain et al. 2009), the corrosion plains can be preserved for considerably long periods of time (Webb and James 2006; Benito-Calvo and Pérez-González 2007; Mocochain et al. 2009; Audra et al. 2012; Burnett et al. 2020). Nevertheless, generalisations are inadequate, and individual corrosion plains have to be independently morphochronologicaly studied to elaborate their age and period of their formation.

Corrosion plains are not particularly well studied karst features. Usually they are categorised based on their geomorphological-hydrological position (Roglić 1957; Gams 2004; Ford and Williams 2007; De Waele and Gutiérrez 2022), not clearly separating hydrologically active aggradational environments (e.g., poljes) from bedrock planation surfaces (i.e., corrosion plains). The inconsistencies and use of various terms has led to confusion in their classification and understanding. In this study, corrosion plains in Slovenia were identified and analysed based on their morphographic, morphometric, and morphostructural characteristics and a new systematic classification of corrosion plains based on their geological settings and morphology is proposed. Corrosion plains in Slovenia were classified into four basic types (Figure 6): karst plain, dry polje, marginal plain of contact karst, and marginal plain of fluviokarst. The proposed classification focuses on the karst environments in which the corrosion plains were formed through which it provides a robust basis for future studies of the formation and evolution of corrosion plains in Slovenia and in other karst areas.

Karst plains are a type of corrosion plains defined by Roglić (1957) as plains along rivers, and by more recent literature (Ford and Williams 2007; De Waele and Gutiérrez 2022) defined as corrosion plains at the base level. These are the largest corrosion plains on a global scale and also in the area of Slovenia.

The exact origin of karst plains remains a topic of debate among researchers. In early literature, the formation of karst plains was linked to the influence of rivers and fluvial or lacustrine sediments in shallow karst areas, which Roglić (1957) referred to as planation of contact karst. The process of sedimentation and subsequent denudation resulted in the superimposition of the flattened areas onto the bedrock, giving rise to karst plains (Roglić 1957). From a climatic geomorphology perspective, Roglić (1957) related the flattening processes to warmer climatic conditions that existed in the Dinaric Karst region during the Pliocene.

More recent literature, however, views the formation of karst plains as a result of base-level levelling (Gams 2004; Ford and Williams 2007; Stepišnik 2017; 2021a; De Waele and Gutiérrez 2022). The stable base level allows for chemical denudation to occur up to that level, with the process halting below it, resulting in extensive rock levelling. This process requires stable tectonic and hydrogeological conditions to persist for a long period of time, allowing the surface to flatten (Gams 2004). Although the specific environmental conditions that enabled these conditions remain unclear, karst plains are widely recognized as a common and defining characteristic of karst landscapes.

The presence of canyons is a distinctive feature of karst plains. The canyons are antecedent valleys created through incision during tectonic uplift or lowering of the erosional base (Summerfield 1996; Nicod 1997). The presence of meandering patterns in the canyons suggests that rivers once flowed in low-gradient floodplains prior to canyon formation (Huggett 2007). The existence of floodplains in karst areas is a characteristic of epiphreatic karst zone, indicating that their formation was closely linked to the proximity of the base level. This is in line with previous interpretations of karst plain formation being regulated by base-level denudation (De Waele and Gutiérrez 2022). In all the karst plains in Slovenia, we confirmed that they were formed through denudation at the base level, followed by tectonic uplift that led to the formation of canyons. In some cases, canyons have become hydrologically inactive as water drains underground.

Dry poljes are a type of corrosional plains, which was referred to as »plains in closed basins« by Roglić (1957). Some previous authors have also included hydrologically active poljes and karst basins in their classifications of corrosion plains (Roglić 1957; 1964), which is not entirely accurate, as these are aggradational sedimentary plains and not bedrock plains (Stepišnik 2020). In fact, the flat floors of dry poljes are mostly composed of exposed bedrock with only scattered patches of sediment. Some poljes become dry due to stream piracy or changes in the hydrogeologic conditions within the karst aquifer. The interruption of water inflow from the fluviokarst is a common cause of the absence of surface water in inflow poljes, similarly to the marginal plains of the fluviokarst (Stepišnik 2021a). In these poljes, inactive erosion gullies or dry valleys are preserved on the sides of the tributaries, which once supplied sediment. In addition to former inflow poljes, there are also former overflow poljes in Slovenia (Stepišnik 2021b). These are closed basins with flat bottoms and undisturbed slopes in the surrounding area. All dry poljes have a high density of dolines. In those parts of polje floors that are still covered by patches of sediment, suffosion dolines are formed. However, in some cases dry river beds are still visible that indicate past surface water flow.

Marginal plains of contact karst were considered by (Roglić 1964) to be a special type of corrosion plains, where water from the non-karst environment transports sediment into the karst. These plains are also referred to as input-marginal corrosion plains in more recent literature (De Waele and Gutiérrez 2022). In Slovenia, such plains are positioned at the boundary between Eocene flysch and Carboniferous and Permian clastic rocks with karstified carbonate rocks. The surfaces of these plains are densely dissected by dolines and collapse dolines, which are typically formed in the hinterland of submerging streams. At the lithological contact, blind valleys have formed in the former tributary areas, and today the water drains underground.

These plains were formed through the process of denudation, which involved the superimposition of the flattened sedimentary surfaces with the underlying bedrock. In the area of the blind valleys, relict alluvial fans are preserved in the tributary areas and form a gently sloping surface that is in contact with Eocene-age flysch rocks (Stepišnik et al. 2007a; 2007b; Stepišnik 2009). On the other hand, the marginal plains of contact karst, which are in contact with Carboniferous and Permian clastic rocks, are relatively flat near the lithologic contact and lack alluvial fans (Stefanovski, Grk and Hočevar 2021). The reasons for the different shapes of the marginal plains of contact karst in relation to different lithology in the tributary areas, however, remain unclear.

Our interpretation of the formation of the marginal plains of contact karst is supported by a recent example in the northwestern part of Matarsko Podolje Plain near the settlement of Rodik. In this area, watercourses flow from the Eocene flysch toward the karst, transporting significant amounts of sediment. Here, an alluvial fan has formed on top of the karst, which transitions into a flattened alluvial plain at its lower part. Intermittent watercourses flow over the sediment-covered carbonate bedrock, draining into the karst at its edges. This process of formation of such plains is ongoing and can be observed in real-time (Stepišnik et al. 2007a; 2007b).

The fourth type of corrosion plains is commonly found in fluviokarst environments (Stepišnik 2020), where sediment is transported into karst basins and forms inflow poljes. As sediment input decreases, the distal parts of the poljes become inactive, leading to faster denudation of sediments than aggradation. This type of plains has been referred to in the literature as plains on the edges of poljes (Roglić 1957) or as corrosion terraces within poljes (Ford and Williams 2007; De Waele and Gutiérrez 2022). In our study, we refer to them as **marginal plains of the fluviokarst** because this term explains the morphodynamic environment in which such plains occur. The morphogenesis of these marginal plains was described by Gams (1973) as being a result of the multiphase formation of poljes due to tectonic activity. A small topographic displacement is often formed between the active and relict parts of the poljes, which separates the two parts. The reason for this elevation anomaly is not well understood and requires further study in the future.

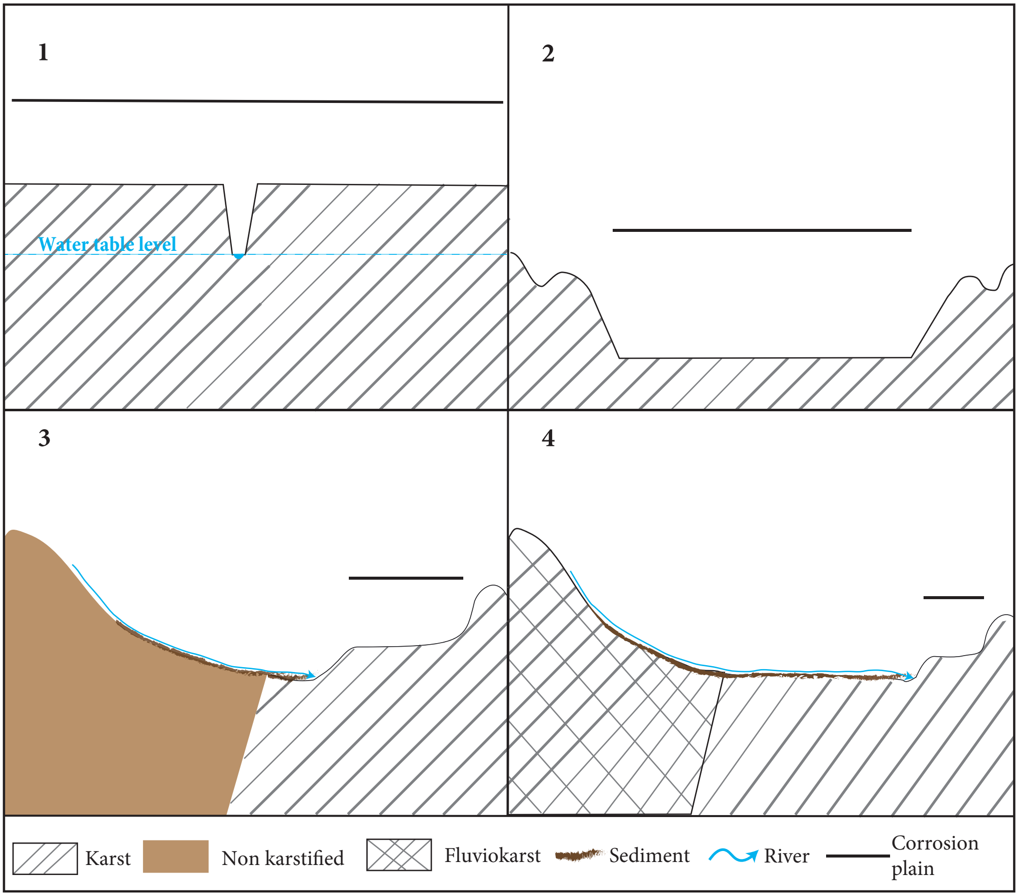

Figure 6: Classification of corrosion plains in Slovenia based on their geological settings and morphology: (1) karst plain, (2) dry polje, (3) marginal plain of contact karst, (4) marginal plain of fluviokarst.

6 Conclusion

We classified corrosion plains in Slovenia into four types based on their geological settings and morphology: karst plains, dry poljes, marginal plains of contact karst and marginal plains of fluviokarst.

Karst plains, the largest corrosion plains, are defined by their location along canyons and their extensive bedrock levelling resulting from base-level denudation. The presence of canyons is a distinctive feature of karst plains, indicating the proximity of the base level during their formation.

Dry poljes are found in closed basins and are composed mostly of exposed bedrock with scattered patches of sediment. These poljes become dry due to stream piracy or changes in the hydrogeologic conditions within the karst aquifer.

Marginal plains of contact karst are found at the boundary between non-karst and karst rocks. The formation of these plains is attributed to the process of denudation, which involved the superimposition of the flattened sedimentary surfaces with the underlying bedrock.

Marginal plains of fluviokarst are found in fluviokarst environments where sediment was transported into karst basins and formed inflow poljes. These plains result from the flattening of the sediments being superimposed on the bedrock, with a small topographic displacement often formed between the active and relict parts of the poljes.

The classification of corrosion plains is useful in understanding the morphology and evolution of karst landscapes, and can aid in the identification of similar landscapes in other regions.

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7 References

Audra, P., Mocochain, L., Camus, H., Gilli, É., Clauzon, G., Bigot, J. Y. 2012: The effect of the Messinian Deep Stage on karst development around the Mediterranean Sea. Examples from Southern France. Geodinamica Acta 17-6. DOI: https://doi.org/10.3166/ga.17.389-400

Augustin, L., Barbante, C., Barnes, P. R., Barnola, J. M., Bigler, M., Castellano, E., Cattani, O. et al. 2004: Eight glacial cycles from an Antarctic ice core. Nature 429. DOI: https://doi.org/10.1038/nature02599

Benito-Calvo, A., Pérez-González, A. 2007: Erosion surfaces and Neogene landscape evolution in the NE Duero Basin (north-central Spain). Geomorphology 88-3–4. DOI: https://doi.org/10.1016/j.geomorph.2006.11.005

Bintanja, R., van de Wal, R. S., Oerlemans, J. 2005: Modelled atmospheric temperatures and global sea levels over the past million years. Nature 437. DOI: https://doi.org/10.1038/nature03975

Birot, P. 1954: Esquisse d'une etude zonale de l'erosion en pays calcaire. Das Karstphänomen in verschiedenen Klimazonen 1. Bericht von der Arbeitstagung der internationalen Karstkommission. Erdkunde 8-2.

Bočić, N., Pahernik, M., Bognar, A. 2010: Geomorfološka obilježja Slunjske zaravni. Hrvatski geografski glasnik 72-2. DOI: https://doi.org/10.21861/hgg.2010.72.02.01

Bočić, N., Pahernik, M., Mihevc, A. 2015: Geomorphological significance of the palaeodrainage network on a karst plateau: The Una–Korana plateau, Dinaric karst, Croatia. Geomorphology 247. DOI: https://doi.org/10.1016/j.geomorph.2015.01.028

Burnett, S., Webb, J. A., White, S., Lipar, M., Ferk, M., Barham, M., O'Leary, M. J. et al. 2020: Etched linear dunefields of the Nullarbor Plain; A record of Pliocene-Pleistocene wind patterns across southern Australia. Palaeogeography, Palaeoclimatology, Palaeoecology 557. DOI: https://doi.org/10.1016/j.palaeo.2020.109911

Buser, S. 2009: Geološka karta Slovenije 1 : 250.000 / Geological Map of Slovenia 1 : 250.000. Geološki zavod Slovenije. Ljubljana.

Cui, Z., Li, D., Feng, J., Liu, G., Li, H. 2002: The covered karst, weathering crust and karst (double-level) planation surface. Science in China Series D: Earth Sciences 45-4. DOI: https://doi.org/10.1360/02yd9038

Cvijić, J. 1893: Das Karstphänomen. Geographischen Abhandlungen Wien 5-3.

Cvijić, J. 1900: Karsna polja zapadne Bosne i Hercegovine. Glas Srpske kraljeve akademije nauka 59-1.

Cvijić, J. 1901: Morphologische und Glaciale Studien aus Bosnien, der Herzegowina und Montenegro. Abhandlungen der Geographisen Gesellschaft 3.

Cvijić, J. 1909: Bildung und Dislozierung der Dinarischen Rumpfflächen. Petermanns Geogr. Mitteilungen 6.

Cvijić, J. 1918: Hydrographie souterraine et évolution morphologique du karst. Revue de Géographie Alpine 6-4.

Cvijić, J. 1921: Abrazione i fluvialne površi. Glasnik Geografskog društva 6.

Cvijić, J. 1924: Geomorfologija. Beograd.

Davis, W. M. 1901: An excursion in Bosnia, Hercegovina und Dalmatia. Bulletin of Geographical Society of Philadelphia 3-2.

De Waele, J., Gutiérrez, F. 2022: Karst Hydrogeology, Geomorphology and Caves. London. DOI: https://doi.org/10.1002/9781119605379

Dumas, B., Guérémy, P., Raffy, J. 2005: Evidence for sea-level oscillations by the »characteristic thickness« of marine deposits from raised terraces of Southern Calabria (Italy). Quaternary Science Reviews 24-18–19. DOI: https://doi.org/10.1016/j.quascirev.2004.12.011

Edwards, R. 2016: Sea levels: change and variability during warm intervals. Progress in Physical Geography: Earth and Environment 30-6. DOI: https://doi.org/10.1177/0309133306071959

Ferk, M. 2016: Paleopoplave v porečju kraške Ljubljanice. Ljubljana. DOI: https://doi.org/10.3986/9789612548452

Ferk, M., Gabrovec, M., Komac, B., Zorn, M., Stepišnik, U. 2017: Pleistocene glaciation in Mediterranean Slovenia. Quaternary Glaciation in the Mediterranean Mountains. Geological Society of London, Special Publication 433-1. DOI: https://doi.org/10.1144/SP433

Ferk, M., Lipar, M., Šmuc, A., Drysdale, R. N., Zhao, J. 2019: Chronology of heterogeneous deposits in the side entrance of Postojna Cave, Slovenia. Acta Geographica Slovenica 59-1. DOI: https://doi.org/10.3986/AGS.7059

Ford, D., Williams, P. 2007: Karst Hydrogeology and Geomorphology. Chichester. DOI: https://doi.org/10.1002/9781118684986

Gams, I. 1959: H geomorfologiji kraškega polja Globodola in okolice. Acta Carsologica 2-1.

Gams, I. 1972: Geografsko raziskovanje krasa v Sloveniji. Geografski vestnik 44-1.

Gams, I. 1973: Die zweiphasige quartärzeitliche Flächenbildung in den Poljen und Blindtälern des nordwestlichen Dinarischen Karstes. Neue Ergebnisse der Karstforschung in den Tropen und im Mittelmeerraum: Vorträge des Frankfurter Karstsymposiums 1971. Weisbaden.

Gams, I. 1974: Kras: zgodovinski, naravoslovni in geografski oris. Ljubljana.

Gams, I. 1995: Types of the contact karst. Studia carsologica 6-1.

Gams, I. 2004: Kras v Sloveniji - v prostoru in času. Ljubljana.

Gams, I., Kunaver, J., Radinja, D. 1973: Slovenska kraška terminologija. Ljubljana.

Gostinčar, P., Stepišnik, U. 2023: Extent and spatial distribution of karst in Slovenia. Acta geographica Slovenica 63-1. DOI: https://doi.org/10.3986/AGS.11679

Grund, A. 1903: Die Karsthydrographie. Geographischen Abhandlungen 7-3.

Grund, A. 1910: Der Dobrido-Gletscher des Orjen. Beiträge zur Geomorphologie des Dinarischen Gebirges. Geographische Abhandlungen 9-3.

Grund, A. 1914: Der geographische Zyklus im Karst. Zeitschrift der Gesellschaft fur Erdkunde zu Berlin 52.

Habič, P. 1969: Hidrografska rajonizacija krasa v Sloveniji. Krš Jugoslavije 1-6.

Habič, P. 1980: Nekatere značilnosti kopastega krasa v Sloveniji. Acta Carsologica 9-1.

Habič, P. 1982: Pregledna speleološka karta Slovenije. Acta Carsologica 10-1.

Habič, P. 1986: Površinska razčlenjenost Dinarskega krasa. Acta Carsologica 14-15.

Hrvatin, M. 2016: Morfometrične značilnosti površja na različnih kamninah v Sloveniji. Ph.D. thesis, Univerza na Primorskem. Koper.

Huggett, R. J. 2007: Fundamentals of Geomorphology. London. DOI: https://doi.org/10.4324/9780203947111

Jennings, J. N. 1985: Karst Geomorphology. Oxford, New York.

Komac, B. 2004: Dolomitni kras ali fluviokras? Geografski vestnik 1-76.

Lehmann, H. 1954: Der tropische Kegelkarst auf den Grossen Antillen. Erdkunde 8-2.

Lisiecki, L. E., Raymo, M. E. 2007: Plio–Pleistocene climate evolution: trends and transitions in glacial cycle dynamics. Quaternary Science Reviews 26-1–2. DOI: https://doi.org/10.1016/j.quascirev.2006.09.005

Mihevc, A. 1986: Geomorfološka karta ozemlja Logaških Rovt. Acta Carsologica 14-15.

Mocochain, L., Audra, P., Clauzon, G., Bellier, O., Bigot, J.Y., Parize, O., Monteil, P. 2009: The effect of river dynamics induced by the Messinian Salinity Crisis on karst landscape and caves: Example of the Lower Ardèche river (mid Rhône valley). Geomorphology 106-1–2. DOI: https://doi.org/10.1016/j.geomorph.2008.09.021

Nicod, J. 1997: Les canyons karstiques »Nouvelles approches de problèmes géomorphologiques classiques« (spécialement dans les domaines méditerranéens et tropicaux). Quaternaire 8-2–3. DOI: https://doi.org/10.3406/quate.1997.1563

Oertli, H. 1954: Karbonatharte von Karstgewassern Stalaktite. Zeitschrift der Schweizerischen Gesellschaft fur Hohlenforschung 4.

Penck, A. 1900: Geomorphologische Studien aus der Herzegovina. Zeitschrift der deutschen und osterreichishen Alpenvereins 31.

Penck, A. 1904: Uber das Karstphanomen. Vortrage des Vereins zur Verbreitung naturwissenschaftlicher Kenntnisse 44-1.

Perko, D., Ciglič, R., Hrvatin, M. 2019: The usefulness of unsupervised classification methods for landscape typification: The case of Slovenia. Acta Geographica Slovenica 59-2. DOI: https://doi.org/10.3986/ags.7377

Perko, D., Ciglič, R., Hrvatin, M. 2021: Landscape macrotypologies and microtypologies of Slovenia. Acta Geographica Slovenica 61-3. DOI: https://doi.org/10.3986/ags.10384

Placer, L., Čar, J. 1975. Rekonstrukcija srednjetriadnih razmer na idrijskem prostoru. Geologija 10.

Placer, L., Mihevc, A., Rižnar, I. 2021: Tectonics and gravitational phenomena (Nanos, Slovenia). Geologija 64-1. DOI: https://doi.org/10.5474/geologija.2021.003
Pleničar, M., Ogorelec, B., Novak, M. 2009: Geologija Slovenije / The Geology of Slovenia. Ljubljana.
Roglić, J. 1951: Unsko-koranska zaravan i Plitvička jezera. Geografski glasnik 13.
Roglić, J. 1957: Zaravni na vapnencima. Geografski glasnik 19-1.
Roglić, J. 1958: Odnos riječne erozije i krškog procesa. V. kongres geografa FNR Jugoslavije. Cetinje.
Roglić, J. 1964: »Karst valleys« in the Dinaric Karst. Erdkunde 18-2. DOI: https://doi.org/10.3112/erdkunde.1964.02.06
Šerko, A. 1947: Kraški pojavi v Jugoslaviji. Geografski vestnik 19.
Šibrava, V. 1986: Correlation of European glaciations and their relation to the deep-sea record. Quaternary Science Reviews 5. DOI: https://doi.org/10.1016/0277-3791(86)90209-x
Šibrava, V. 2010: Quaternary climatic changes in the Alpine foreland – New observation and new conclusions. Global and Planetary Change 72-4. DOI: https://doi.org/10.1016/j.gloplacha.2010.01.013
Stefani, C. 1930: I due versanti dell' Adriatico. Atti del VIII Congresso geographico italiano 2. Firenze.
Stefanovski, S., Grk, J., Hočevar, G. 2021: Kvantitativni model vrednotenja geodiverzitete na podlagi raznolikosti in gostote elementov geodiverzitete na primeru kontaktnega krasa med Kočevsko reko ter Kostelom. Dela 54. DOI: https://doi.org/10.4312/dela.54.75-103
Stepišnik, U. 2009: Active and relict alluvial fans on contact karst of the vrhpoljska brda hills, slovenia. Acta Geographica Slovenica 49-2. DOI: https://doi.org/10.3986/ags49201
Stepišnik, U. 2017: Dinarski kras: plitvi kras Zgornje Pivke. Ljubljana. DOI: https://doi.org/10.4312/9789612379223
Stepišnik, U. 2020: Fizična geografija krasa. Ljubljana.
Stepišnik, U. 2021a: Fluviokras Žibrške planote s Hotenjskim in Logaškim kraškim poljem. Dela 55. DOI: https://doi.org/10.4312/dela.55.41-68
Stepišnik, U. 2021b: Kraška polja v Sloveniji. Dela 53. DOI: https://doi.org/10.4312/dela.53.23-43
Stepišnik, U., Černuta, L., Ferk, M., Gostinčar, P. 2007a: Reliktni vršaji kontaktnega krasa severozahodnega dela matarskega podolja. Dela 28. DOI: https://doi.org/10.4312/dela.28.29-42
Stepišnik, U., Ferk, M., Gostinčar, P., Černuta, L., Peternelj, K., Štembergar, T., Ilič, U. 2007b: Alluvial fans on contact karst: An example from matarsko podolje, slovenia. Acta Carsologica 36-2. DOI: https://doi.org/10.3986/ac.v36i2.189
Stepišnik, U., Stojilković, B., Hočevar, G. 2019: Geomorfološke značilnosti Severnega Velebita. Dinarski kras: Severni Velebit. Ljubljana.
Summerfield, M. A. 1996: Global geomorphology: an introduction to study of landforms. London.
Šušteršič, F. 1986: Model čistega krasa in nasledki v interpretaciji površja. Acta Carsologica 21.
Šušteršič, F. 1994: Classic Dolines of Classical Site. Acta Carsologica 23-1.
Šušteršič, F. 2000. Are collapse dolines formed only by collapse? Classical Karst - Collapse Dolines, Papers presented at 8th International Karstological School. Postojna.
Šušteršič, F., Šušteršič, S. 2003: Formation of the Cerkniščica and the Flooding of Cerkniško Polje. Acta Carsologica 32-2. DOI: https://doi.org/10.3986/ac.v32i2.342
Sweeting, M. M. 1973: Karst Landforms. New York.
Terzaghi, K. 1913: Beitrage zur Hydrographie und Morpologie des kroatischen Karstes. Mitteilungen aus dem Jahr. der Geologischen Reichsanstalt 20-6.
Webb, J. A., James, J. M. 2006: Karst evolution of the Nullarbor Plain, Australia. Perspectives on karst geomorphology, hydrology, and geochemistry. Boulder. DOI: https://doi.org/10.1130/2006.2404(07)
White, W. B. 1988: Geomorphology and hydrology of karst terrains. Oxford.
Wissmann, H. 1954: Der Karst der humiden heissen und sommerheissen Gebiete Ostasiens. Erdkunde 8-2.
Žebre, M., Stepišnik, U. 2015: Glaciokarst geomorphology of the Northern Dinaric Alps: Snežnik (Slovenia) and Gorski Kotar (Croatia). Journal of Maps 12-5. DOI: https://doi.org/10.1080/17445647.2015.1095133
Zupan Hajna, N., Mihevc, A., Pruner, P., Bosák, P. 2008: Palaeomagnetism and Magnetostratigraphy of Karst Sediments in Slovenia. Ljubljana. DOI: https://doi.org/10.3986/9789612540586

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THE ENTROPY AS A PARAMETER OF DEMOGRAPHIC DYNAMICS: CASE STUDY OF THE POPULATION OF SERBIA

Mirko Grčić, Mikica Sibinović, Ivan Ratkaj

Knjaževac – a shrinking town in the depopulation region of eastern Serbia.

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Mirko Grčić[1], Mikica Sibinović[1], Ivan Ratkaj[1]

The entropy as a parameter of demographic dynamics: Case study of the population of Serbia

ABSTRACT: The aim of this article is to apply Shannon's entropy model in the study of demographic reproduction dynamics of the population in the Republic of Serbia from the regional aspect (NUTS 3 level) in the period from 1961 to 2021. Based on the values of absolute and relative entropy, the tendencies of demographic dynamics are determined, which is one of the most important parameters for building an optimal scheme of territorial organization and population distribution. In this context, explanations and conclusions were given about the homogeneity (or heterogeneity) of demographic dynamics and regional differentiation of demographic space in Serbia.

KEYWORDS: geography, population, demography, system, region, organization

Entropija kot kazalnik demografske dinamike: študija primera prebivalstva Srbije

POVZETEK: Avtorji v članku na podlagi Shannonovega modela entropije preučujejo dinamiko demografske reprodukcije prebivalstva Republike Srbije na ravni regij NUTS 3 med letoma 1961 in 2021. Na podlagi vrednosti absolutne in relativne entropije so določili težnje demografske dinamike, ki je eden najpomembnejših parametrov za oblikovanje optimalnega načrta prostorske ureditve in razporeditve prebivalstva. Avtorji so podali razlage in predstavili sklepne ugotovitve o homogenosti (ali heterogenosti) demografske dinamike in regionalne razčlenjenosti srbskega demografskega prostora.

KLJUČNE BESEDE: geografija, prebivalstvo, demografija, sistem, regija, prostorska ureditev

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[1] University of Belgrade, Faculty of Geography, Belgrade, Serbia
mirko.grcic@gef.bg.ac.rs (https://orcid.org/0009-0007-1146-8695), mikica.sibinovic@gef.bg.ac.rs (https://orcid.org/0000-0002-1521-4285), ivan.ratkaj@gef.bg.ac.rs (https://orcid.org/0000-0001-9628-3778)

1 Introduction

Mathematical and statistical methods are increasingly used in geography in connection with the development of the model paradigm and the systemic approach, especially in the study of population dynamics, which deals with the changes in the number and distribution of inhabitants in the demographic system and the factors that cause these changes. The process of regional differentiation of demographic development represents one of the most complex problems of science in general and of demography and population geography in particular. The objects of study of these two scientific disciplines are the tendencies and laws of population reproduction under the conditions of the social and natural environment in which the factors determining them are formed. The development of population statistics and technology GIS leads to the emergence of a huge amount of data that require mathematical analysis and the development of appropriate models. In this field, population geography and demography have a repertoire of various statistical and mathematical models for describing population dynamics (Breznik 1980).

Demographic dynamics as a result of the process of population reproduction has been studied by many demographers in the world and in the Republic of Serbia (Macura 1997; Spasovski and Šantić 2013; Marinković and Radivojević 2016; Penev and Predojević-Despić 2019). Models of population dynamics are treated not only by demographers, but also by biologists (Rudnicki and Łoskot 1991; Rudnicki 2023). However, models of dynamics cannot be transferred from biological to sociobiological populations. In general, models of population growth can be divided into deterministic and stochastic models. An example of the first is the Malthusian model of exponential population growth, where the whole complex of influences is included in the exponent, and an example of the second is the Shannon model of entropy as a parameter of the internal state of the system.

The novelty of the entropy model is that it can explain the driving forces and the course of the demographic process in a new way. Our goal is to provide a statistical description of population dynamics in Serbia using Shannon's entropy model. Entropy can be interpreted as a parameter for the internal state of a system. The aim of this work is to determine entropy as a parameter for regional demographic dynamics in the population system of Serbia.

2 Review of the concept of entropy

The concept of entropy (from Greek *εν τροπη* – internal change) entered the geographic and demographic sciences in the 1960s in connection with the conception of the geosystem as a self-organizing territorial system. The term »information« is defined as a signal or influence of one element (or system) on another so that the latter changes in a certain direction. Information expresses the ability of organized matter to determine its state in time (Kapica 2008). The amount of information determines the ability to predict the behaviour of the system in time – the higher the level of organization (more information), the lower the influence of the environment, the lower the dose of randomness. The measure of the expected amount of information is called entropy, which can be understood as a measure of the uncertainty or heterogeneity of the system. The more complex the system is, i.e., the more elements and connections it has, the more stable it is. The degree of entropy change of the system depends on the information resource. Perhaps this is one of the basic laws of progressive organization of matter in general. In geography, it can also be interpreted as a measure of the complexity of the territorial structure. Moreover, negentropy (a measure of organization) can be understood as a potential measure of predictability, a quantitative measure of the possibility of extrapolating the state of the system (Grčić 1990). The potential error of extrapolation is determined by entropy – mathematically, entropy is a measure of uncertainty. The mathematical model for information entropy was developed by Claude Shannon (1948) as a quantitative measure of the »vagueness« or uncertainty in the probability distribution of randomly varying characteristics of a quantity.

Wilson (1970) modified Shannon's concept and entropy formula and introduced the so-called »entropy maximizing model« into the study of spatial interactions, the task of which is to determine the most probable distribution (configuration) of observed phenomena in geographic space (Wilson 2010). Based on the application of the principle of maximum entropy in the social sciences, an attempt is being made to formulate a theory of social thermodynamics that could be useful for developing predictive models for the dynamics of certain sociogeographic systems such as cities, migration flows, mass consumption, or even election outcomes (Hernando et al. 2012; Cardona-Almeida, Obregón and Canales 2019).

The Shannon model of entropy has been used in the study of various processes and interactions in geographic and demographic systems (Bailey 1990; Lesne 2014; Damos 2015). Today, the following research directions can be distinguished in geographic and demographic work on entropy: 1) entropy as expected information used to test the hypothesis about the spatial distribution of phenomena; 2) entropy as a measure of the dispersion of random phenomena; 3) entropy maximization models to determine the most likely spatial distribution and allocation of phenomena in the system (Czyż and Hauke 2015). Entropy as a measure of spatial order or homogeneity (uniformity) of the empirical system under study is widely used in research on urban and demographic systems (Medvedkov 1967; Sonis 1968; Zborowski 1985; Deka, Tripathi and Khan 2010; Cabral et al. 2013; Batty et al. 2014; Purvis, Mao and Darren 2019).

3 Research area and data

3.1 Research area

The Republic of Serbia (excluding data for Kosovo and Metohija) has an area of 77,474 km^2 and a population of about 6,690,887 (according to the 2021 census). From the point of view of the demographic transition theory, the trend of birth and death rates in the period 1961–2021 in Serbia has not stabilized within expectations (13.6 per thousand).

The trajectory of birth and death rates from 1961 to 1991 approached the steady-state model of demographic transition in proportions that ensure positive natural growth (Figure 1). As early as 1992, the paths of birth and mortality trends crossed – mortality continued to increase, reaching 20.1‰ in 2021, while birth rates declined, reaching 9.1‰. Natural growth continued to decline, reaching –10.9‰ in 2021. In this

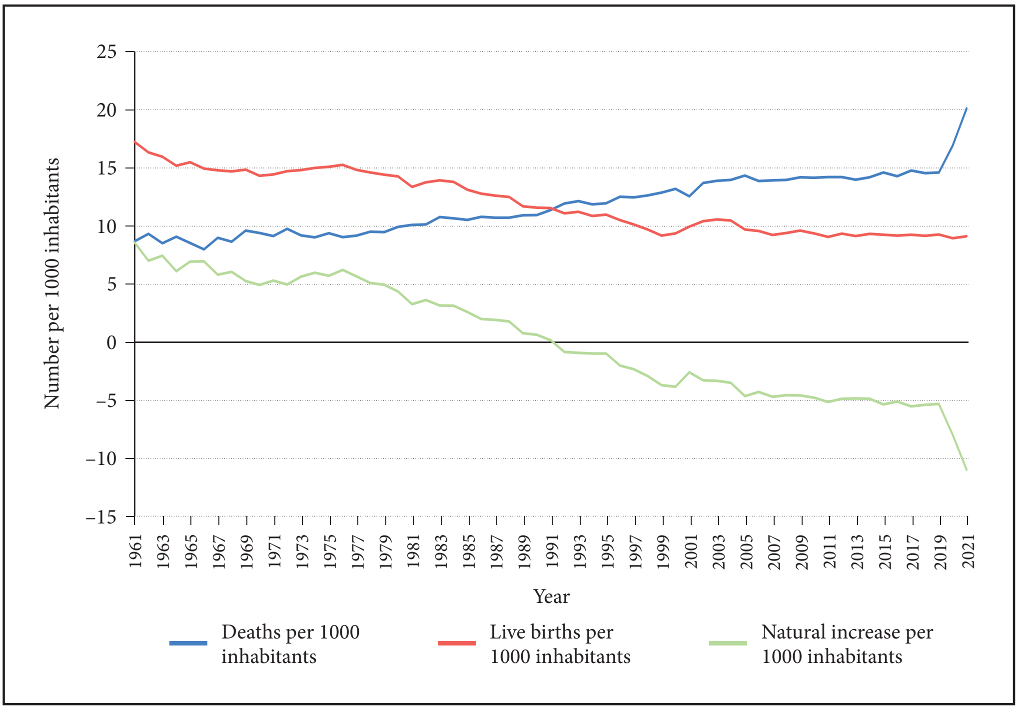

Figure 1: Evolution of mortality, birth rate and natural population growth in Serbia in the period 1961–2021 (Statistical office of the Republic of Serbia 2022).

way, the population entered a phase of demographic crisis, which does not ensure the sustainability and homeostasis of the functioning of the demographic system (Javor 2014; Penev and Predojević-Despić 2019).

3.2 Data

The focus is on research of dynamics of natural population movement in Serbia based on data series of vital statistics in spatial and temporal terms. The data source is Natural population trends in the Republic of Serbia, 1961–2010 (2012) and Municipalities and regions of the Republic of Serbia for the years 2011–2021 (2022), both from Statistical Office of the Republic of Serbia. These publications enable comparability of data on population size and changes in natural population in territorial statistical areas at the level NUTS 3. The information base for determining entropy in this research consists of matrices in which temporal and spatial data series on demographic determinants of natural population movement in Serbia are crossed (61 years in the period 1961–2021 and 25 NUTS 3 territories).

4 Methods

4.1 The Shannon's model of entropy

According to the Shannon equation for entropy, the quantities p_i express the degree of independence of the following system states from the previous ones. The next system state is related to the previous one by the probabilities p_i. The probability p_i represents the probability that the system will take the *i*-th new state independently of the previous one.
If we calculate the probability:

$$p_i = \frac{n_i}{n_i} \tag{1}$$

where n_i is an indicator of certain demographic determinants (number of inhabitants, number of live births, number of deaths, etc.) in a given area *i*. To obtain information about the statistically most probable distribution of events (system states), the monotonic event probability function *p* is preferably used:

$$hp \quad \log_2 \frac{1}{p} \qquad \log_2 p \tag{2}$$

This function decreases from ∞ (infinite number of information, probability equal to 0) to 0 (zero information, probability equal to 1). It should be noted that the unit of measurement of the information depends on the base of the logarithm. In computer science, base 2 logarithms (i.e. $\log_2$) are most commonly used, and information is measured in bits (binary digits – binary numbers; natural logarithms can also be taken, but then the unit of information is nit – natural digits). An important feature of the entropy measure is the common unit (bit), with which we can compare the study of phenomena and processes (Zborowski 1985). The expected value of the information about the occurrence of each event in the set S (which is equal to the entropy of the distribution with probabilities $p_i \ldots, p_n$) is equal to:

$$\mathrm{H(S)} = \;{}^{N}_{i\;1}\; p_i(h_{p_i}) \quad {}^{N}_{i\;1}\; p_i \log_2 \frac{1}{p_i} \quad {}^{N}_{i\;1}\; p_i \log_2 p_i \tag{3}$$

The minus sign is added because the logarithm of a number less than one and greater than zero is a negative number, and entropy cannot be a negative number. The values of p_i are constantly between 0 and 1. Entropy is a measure of order or disorder of the system and is denoted by the letter »S«. If all events in the system are equally likely, then uncertainty (chaos) is at maximum. The probability p_i for the *i*-th state is a measure of uncertainty. The lower bound of entropy is 0, i.e., there is only one alternative for the realization of the event, and the probability is $p_i = 1$. The upper bound of entropy (maximum entropy) means that all events (or states) have the same probability, i.e., where:

$$p_1 = \frac{1}{n},\ p_2 = \frac{1}{n}, \ldots p_n = \frac{1}{n} \tag{4}$$

so then it is the upper or maximum limit of entropy:

$$H_{max}(S) = \sum_{i\ 1}^{N} \frac{1}{n}\log_2\frac{1}{n} \quad \log_2 n \tag{5}$$

Therefore, if all $p_1 = \frac{1}{n}$ then the maximum entropy is $H_{max}(S) = \log_2 N$.

From all this follows that the entropy values of the system H(S) constantly move within the limits: $0 \leq H \leq H_{max}$. With increasing number *n*, the number of possible states increases, and the entropy of the system S increases monotonically.

4.2 Methodological steps in the study

Using the described mathematical procedure, we obtain the actual entropy (H) and the relative entropy (H_0) of territorial homogeneity of the given determinant in year *i*. By comparing the evolution of the entropy measure by years in a given time interval for a set of territorial units (areas), we can draw a conclusion about the changes in territorial homogeneity (or heterogeneity) of the demographic system. By comparing this measure in the time sequence, we can determine the isotropy (uniformity) or anisotropy of the spatial process, which can be used to predict the number of inhabitants, the number of live births, and the number of deaths, as well as natural growth. The relative entropy H_0 shows the percentage ratio to the maximum entropy H_{max}. The relative entropy is calculated using the following formula:

$$H_0 = H/H_{max} \tag{6}$$

or in expanded form:

$$H_0 = \frac{1}{\log_2 N}\sum_{i\ 1}^{N} pi\log_2 pi \tag{7}$$

Actual entropy can take values between zero and infinity. The use of relative entropy facilitates the comparison of data, and its values are constant within the limits $0 \leq H_0 \leq 1$. Relative entropy is maximum (1) when the probability of an event occurring is equal, and minimum (0) when one of the events is absolutely probable while the others are impossible. The relative measure (H_0) allows to compare the growth differentiation with the maximum differentiation ($H_{max} = \log_2 n$). At the same time, the given measure H_0 can be easily converted into percentage values (provided $0 \leq H \leq 1$). The analysis performed using the entropy measure allows us to compare the degree of homogeneity of the observed determinants of natural population movement in each studied area. Relative entropy values of demographic dynamics of administrative areas, comparison and grouping can be used in the process of demographic regionalization.

A measure of entropy provides information about the dynamics of the determinants of the demographic process, but not about the causes of changes in demographic dynamics in space and time. The intensity of the synergetic influence of external factors can be calculated as the homogeneity limit (L) (Sonis 1968; Zborowski 1985).

If the maximum value of entropy is $H_{max} = \log_2 n$ and $H = \log_2 \lambda n$, where *n* is the number of parts of a whole (e.g., the number of years of observation of a process, the number of territorial units of the distribution, etc.) and λ is the multiplier of homogeneity:

$$\lambda = \frac{1}{n} 2^H \tag{8}$$

also, we can calculate the *Limiter*:

$$L = 1-\lambda, \text{ where: } 0 \quad L \quad 1-\frac{1}{n} . \tag{9}$$

The homogeneity limiter expresses the summary effect of the totality of factors of the process under study. The characteristics of homogeneity are inversely proportional to the homogeneity limiter, such as negentropy inversely proportional to entropy (Figure 3).

Theoretical ideas pointing to the possibilities of a systemic approach in defining the problem of the dynamics of demographic processes are not new (Radovanović 1987; 1988), but concrete application is complicated by the limitations of statistical databases. More recently, GIS technologies and statistical databases enable the application of complex system methods, models, and parameters in the study of specific demographic processes (Aburto et al. 2019; Li et al. 2015; Marius, Lenart and Canudas-Romo 2019; Costa-Cabanas, Chalub and Souza 2022). A systemic approach to the complex process of demographic evolution requires parameterization of the spatiotemporal determinants of the demographic system with a broad application of geographic information databases and statistical, mathematical, and cartographic methods and models.

Shannon's entropy model is based on probability theory and statistical data as carriers of information about the state of the system. In demographic systems, we use as information the movement of the absolute number of inhabitants, the number of births, the number of deaths, and the ratio between the number of births and the number of deaths. Each of these determinants has a matrix of 25 ranges of 61 years filled with absolute natural positive numbers. Relative numbers have the problem that negative values appear as zero in the probability calculation. Absolute entropy is converted to relative entropy (H_0) to allow comparability of results by territorial units. The territorial division into districts, which territorially corresponds to the statistical regions of NUTS 3, was not changed in the considered period, so there are no problems with the comparability of the data in time and space. The absolute values for the calculation of entropy represent the number of inhabitants in each region of NUTS 3. Differences between regions in population numbers lead to a MAUP (modifiable real unit problem), but the entropy is based on the probability of the state, so this problem is put into perspective.

5 Results

In the following text, we explore the possibility of using the concept of entropy as a measure of the diversity or homogeneity of demographic dynamics. The starting point for the calculation is a matrix in which the statistical evolution of a given demographic determinant (e.g. the number of inhabitants, the number of live births, or the number of deaths) is crossed in a series of years and in a series of areas. In this way, we can calculate the probability distribution of some determinants (p_i) horizontally (matrix rows) and vertically (matrix columns), in our case by years in the period 1961–2021 and by 25 regions in Serbia (NUTS 3).

5.1. Entropy as a measure of demographic dynamics over time

The entropy curves of demographic dynamics in the territorial division as a function of time in the period 1961–2021 show a downward trend (Figure 2). The entropy values range from 0.97 to 0.88 for the total population, from 0.98 to 0.92 for the number of deaths, and from 0.96 to 0.85 for the number of live births. From a thermodynamic point of view, this means that the system is gradually »cooling down« but is still far from absolute zero, which would mean the end of the dynamics of the system. Decreasing paths of relative entropy indicate the transition from territorial heterogeneity to territorial homogeneity of these determinants. In other words, decreasing entropy values signify the process of simplification of territorial structure, which can be understood as an indicator of territorial concentration and polarization. The relative entropy of the number of inhabitants and deaths in Serbia decreases monotonically, while the entropy of the number of live births shows greater instability and even a sharp decrease in the last two decades of the observation period.

A decrease in entropy means that the spatial concentration of demographic dynamics increases and the territorial core of the system decreases. In other words, the decrease of entropy value involves the process of simplification of territorial structure, which can be understood as an indicator of territorial polarization.

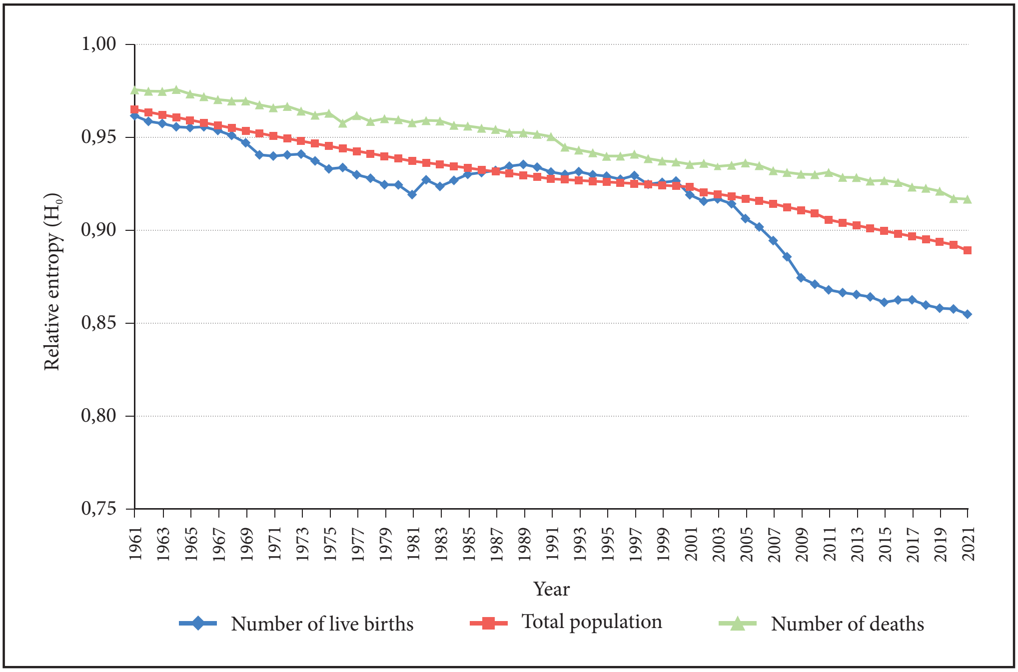

Figure 2: Distribution of relative entropy (H_0) of some demographic determinants in Serbia, as a function of time in the period from 1961 to 2021.

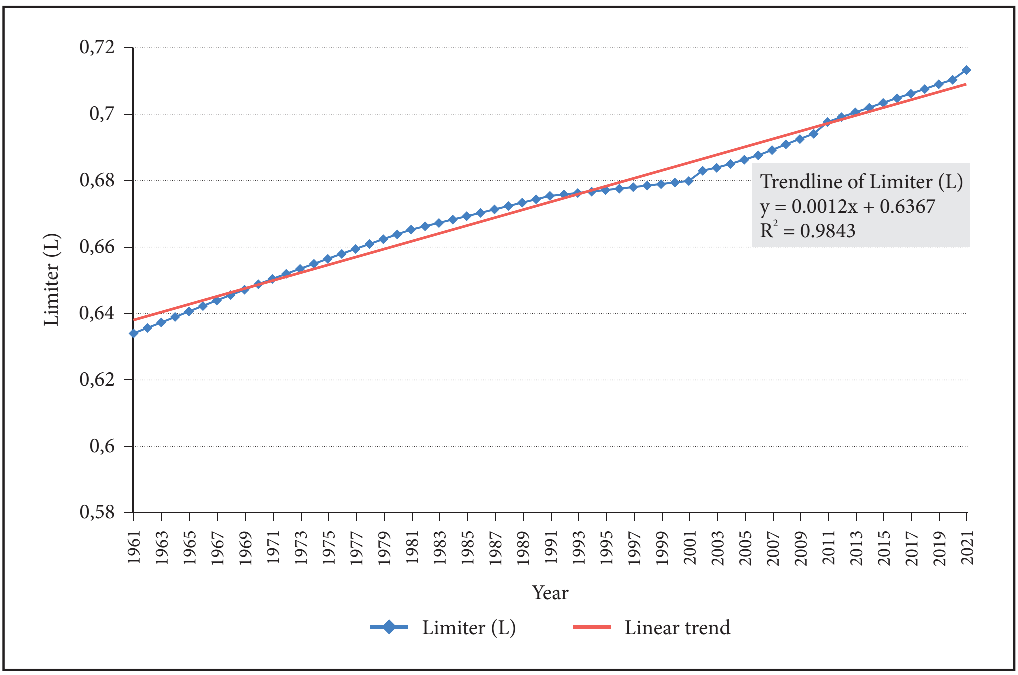

Figure 3: Entropy Limiter (L) of the changes in the spatial distribution of the total population of Serbia by areas. The characteristics of homogeneity are inversely proportional to the homogeneity limiter.

The relative entropy of the number of inhabitants and deaths in Serbia decreases monotonically, while the entropy of the number of live births shows greater instability and even a sharp decrease in the last two decades of the observation period. The trajectories show that the demographic dynamics during the observation period ranges from more uniform to less uniform spatial distribution. The trajectory of the entropy of live births decreases faster than the trajectory of the number of deaths and the total population.

5.2 Entropy as a measure of demographic dynamics in space

If we consider the areas (NUTS 3) as subsystems of the demographic system and calculate for each subsystem the value of entropy of demographic dynamics in a given period, we can hierarchize and classify the areas for each of the observed demographic determinants (Table 1; Figures 4–7). According to the results presented in Table 1, the differences in entropy values by region are relatively small, but still sufficient to distinguish two models of dynamic natural reproduction of a population – the first model is below the level of the entropy average, the second above the average. This indicates a process of territorial polarization of demographic dynamics on the territory of Serbia.

In the further procedure, the standard deviation from the average entropy value was calculated to obtain four area categories that serve as criteria for regional classification. According to the »two-sigma rule«, about 95% of the values are within the interval of –2 to +2 standard deviations from the mean. The classification of the areas according to the intervals of relative entropy values is presented cartographically (Figures 4–7).

The trends of relative entropy in each of the 25 areas show territorial differentiation of demographic population dynamics during the observation period. These maps show areas where the dynamics of the observed determinants were more homogeneous or heterogeneous during the indicated period. In this way, the process of polarization of the territorial structure of demographic dynamics in Serbia becomes

Table 1: Entropy of demographic dynamics from 1961 to 2021, by regions in Serbia.

Region	Number of inhabitants		Number of live births		Number of deaths		Births per 100 deaths	
	H	H_0	H	H_0	H	H_0	H	H_0
Belgrade	5.91375	0.99714	5.91956	0.99812	5.83050	0.98310	0.48354	0.08153
West Bačka	5.92611	0.99922	5.85863	0.98784	5.90803	0.99617	0.34752	0.05860
South Banat	5.92308	0.99871	5.88517	0.99232	5.91974	0.99815	0.24479	0.04127
South Bačka	5.92163	0.99846	5.92522	0.99907	5.89259	0.99357	0.25941	0.04374
North Banat	5.92753	0.99946	5.86094	0.98823	5.86143	0.98831	0.90492	0.15258
North Bačka	5.92446	0.99894	5.89435	0.99386	5.92160	0.99846	0.27749	0.04679
Central Banat	5.92800	0.99954	5.87421	0.99047	5.91459	0.99728	0.30557	0.05152
Srem	5.92722	0.99941	5.90343	0.99540	5.89104	0.99331	0.39574	0.06673
Zlatibor	5.92689	0.99935	5.84061	0.98480	5.90219	0.99519	0.51779	0.08731
Kolubara	5.92677	0.99933	5.87150	0.99001	5.90837	0.99623	0.35972	0.06065
Mačva	5.92783	0.99951	5.87090	0.98991	5.89993	0.99481	0.42865	0.07228
Moravica	5.92916	0.99973	5.89009	0.99315	5.89532	0.99403	0.39769	0.06706
Pomoravlje	5.92295	0.99869	5.87737	0.99100	5.90670	0.99595	0.34029	0.05738
Rasina	5.92670	0.99932	5.87266	0.99021	5.89560	0.99408	0.38497	0.06491
Raška	5.92497	0.99903	5.91664	0.99762	5.87645	0.99085	0.61588	0.10385
Šumadija	5.92704	0.99938	5.90072	0.99494	5.89827	0.99453	0.38279	0.06454
Bor	5.91299	0.99701	5.82711	0.98253	5.92200	0.99853	0.34321	0.05787
Braničevo	5.91192	0.99683	5.85293	0.98688	5.92683	0.99934	0.29882	0.05039
Zaječar	5.91197	0.99684	5.85419	0.98709	5.92502	0.99904	0.22501	0.03794
Jablanica	5.92533	0.99909	5.84467	0.98549	5.89782	0.99445	0.44365	0.07480
Nišava	5.92892	0.99969	5.90694	0.99599	5.88304	0.99196	0.39070	0.06588
Pirot	5.91110	0.99669	5.80817	0.97933	5.92048	0.99827	0.30427	0.05130
Podunavlje	5.92676	0.99933	5.88677	0.99259	5.90630	0.99588	0.39419	0.06647
Pčinja	5.92709	0.99939	5.85530	0.98728	5.92319	0.99873	0.58608	0.09882
Toplica	5.91386	0.99715	5.84429	0.98542	5.91485	0.99732	0.36556	0.06164
Average	*5.92899*	*0.999705*	*5.901659*	*0.995097*	*5.90028*	*0.994864*	*0.404197*	*0.068153*

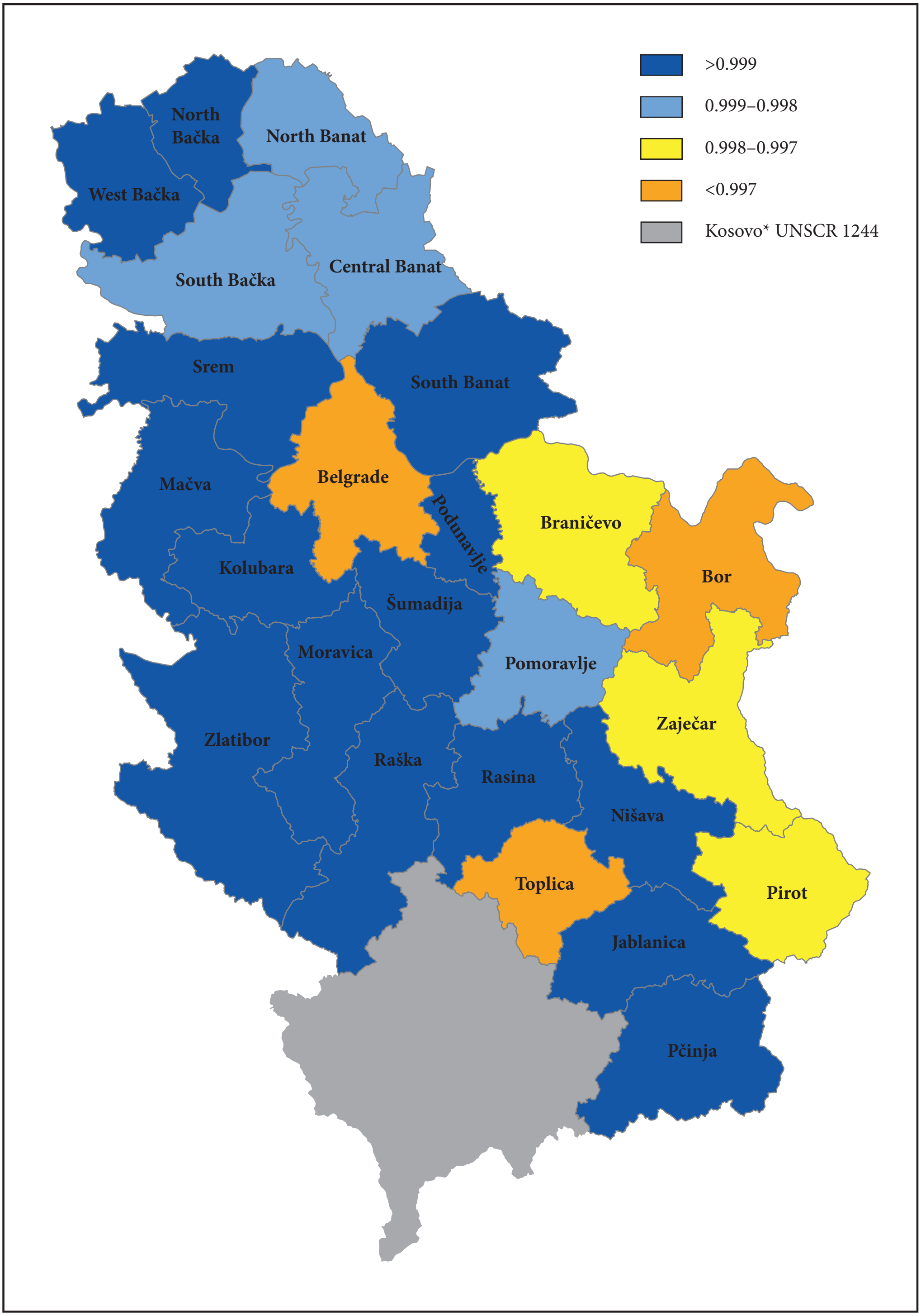

Figure 4: The relative entropy (H_0) of population movements by region.

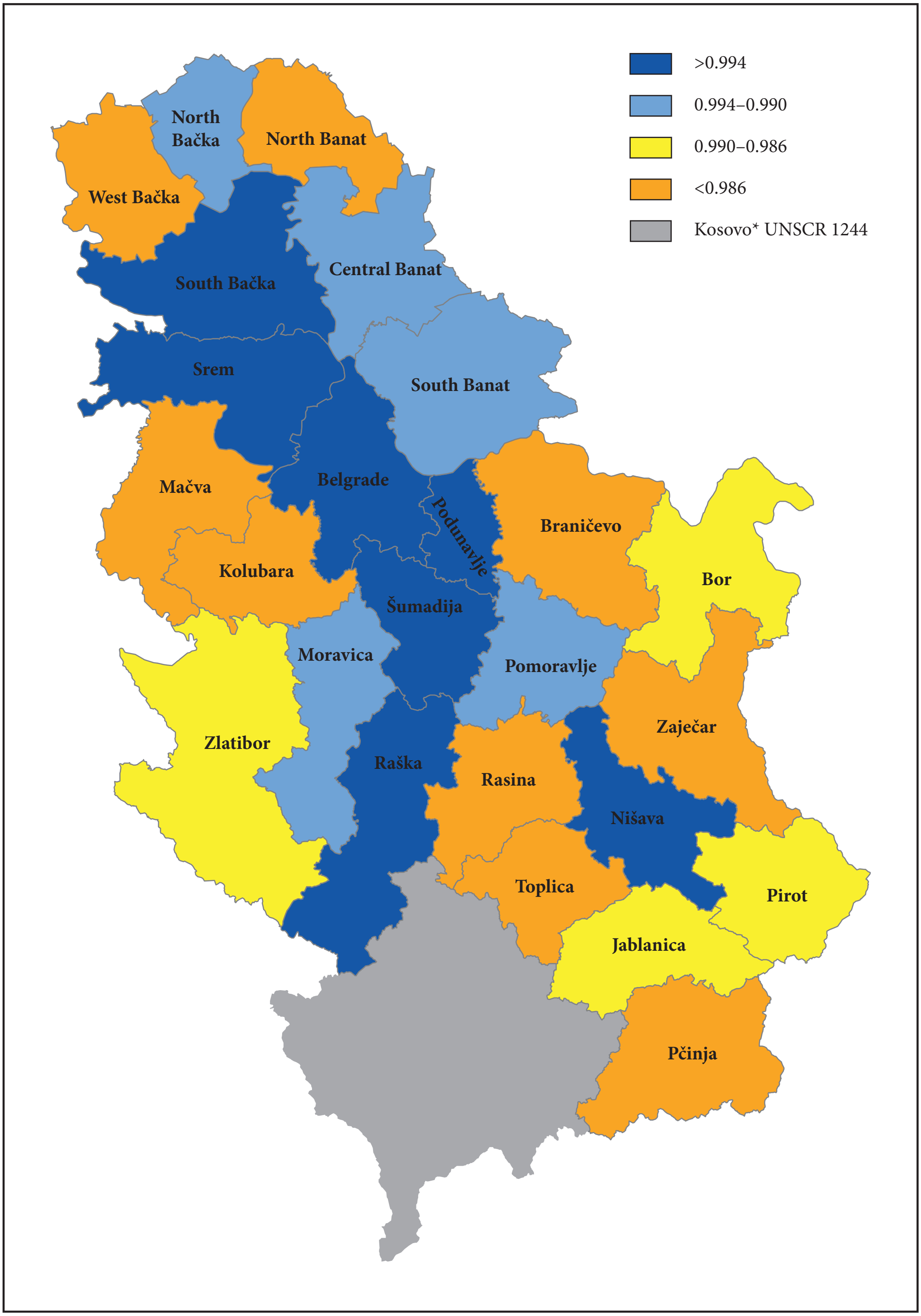

Figure 5: The relative entropy (H_0) of the number of live births movements by region.

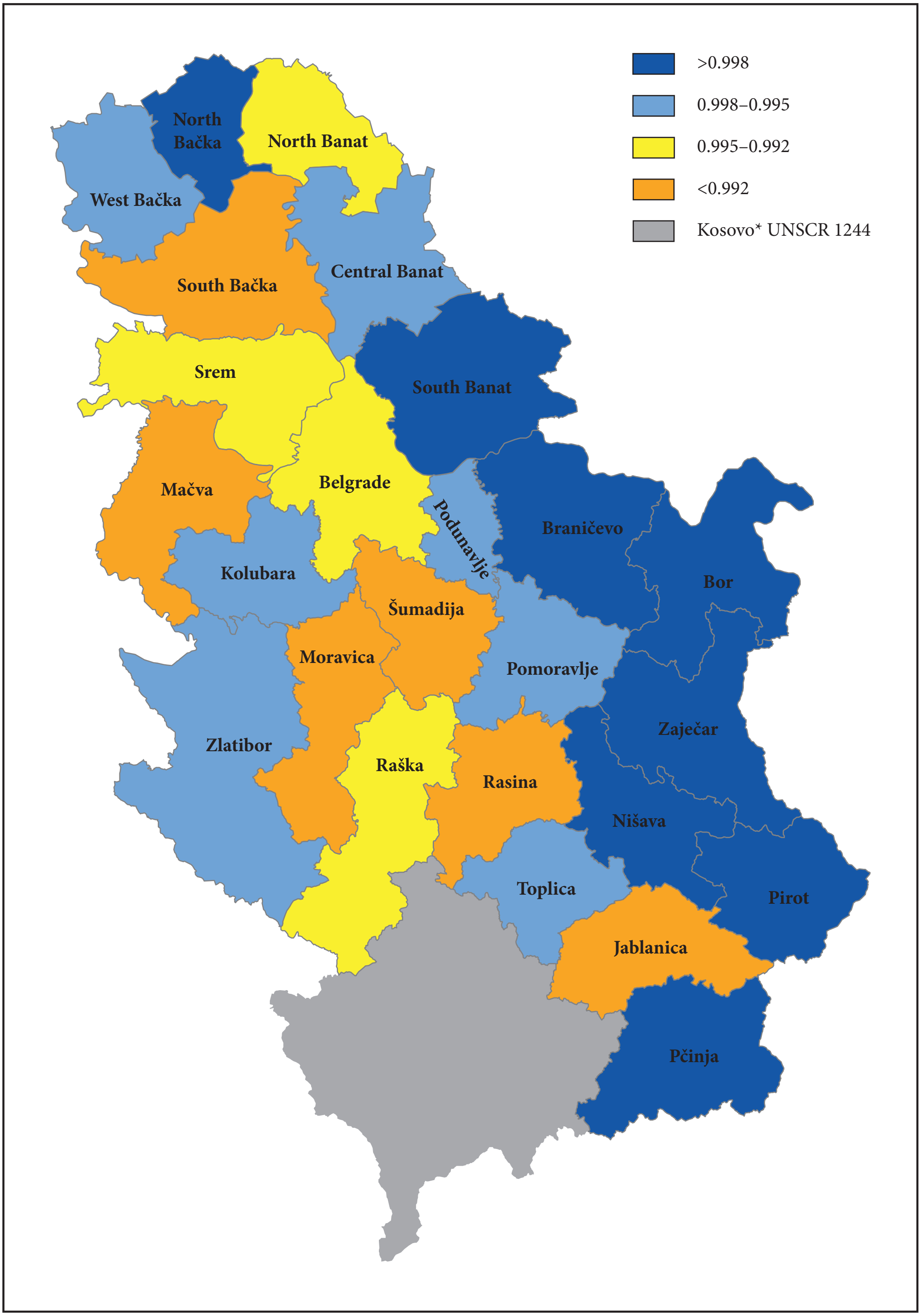

Figure 6: The relative entropy (H_0) of the movement of the number of deaths by region.

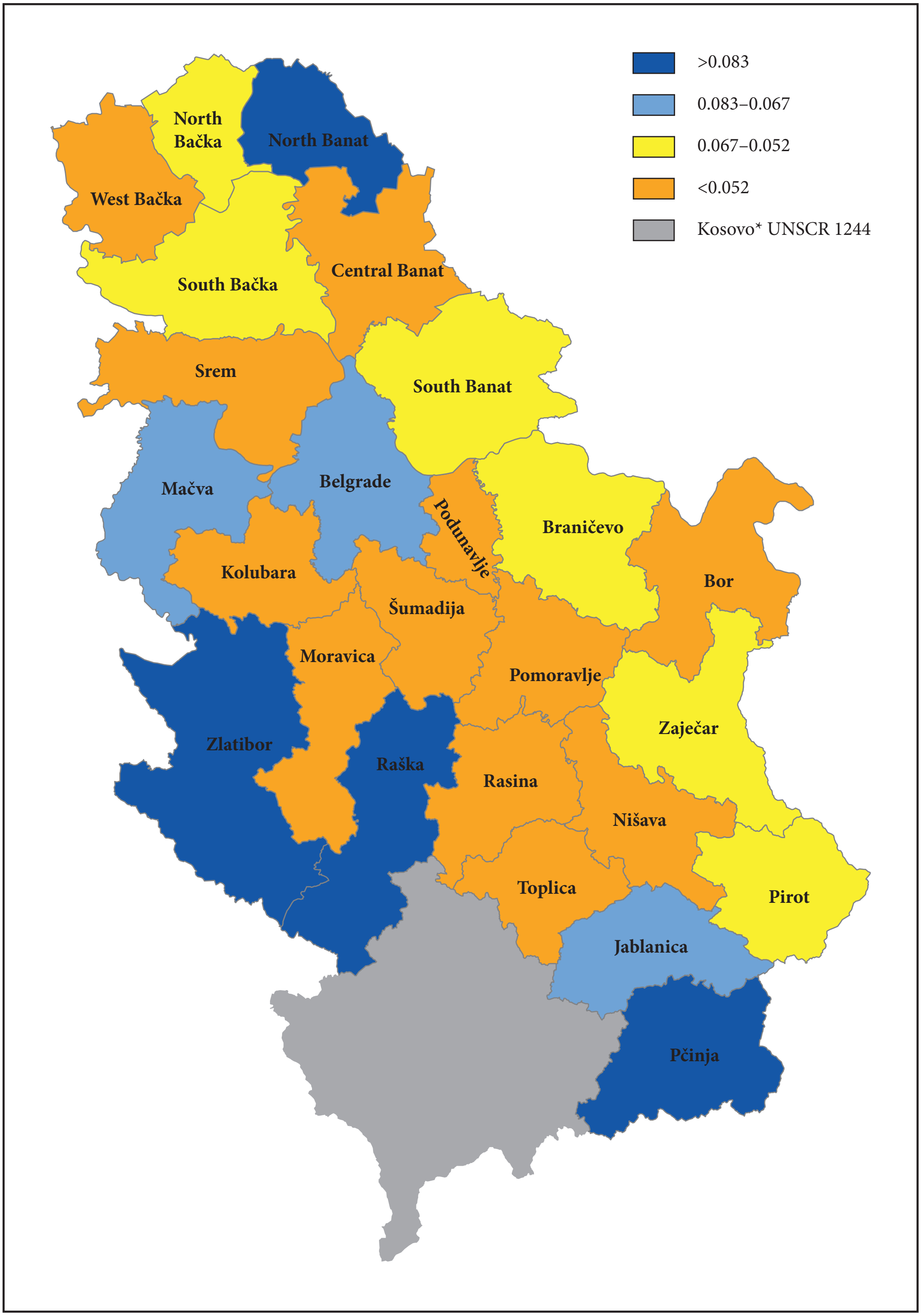

Figure 7: The relative entropy (H_0) of the number of live births per 100 deaths by region.

visible. Interregional differences in the values of relative entropy of the same demographic determinants are relatively small, but they are sufficient as an indicator of the different pace of depopulation and spatial concentration of the demographic system of Serbia in the last 61 years (see Table 1 and Figures 4–7).

Considering the homogenization of Central Serbia and Vojvodina in terms of negative population growth (and demographic aging), we can discuss regional differences in natural population renewal only at the level of this »negativity«. Small interregional differences in the relative values of entropy within the same demographic determinants confirm the statement that almost the entire territory of Central Serbia and Vojvodina has become a relatively homogeneous area characterized by depopulation from the point of view of natural population movement (Vojković 2007).

The number of live births by region (Figure 5) is above average in the middle belt regions with larger cities and nodes that act as centers of attraction for young people and families with children (Subotica, Novi Sad, Belgrade, Niš, Užice Kraljevo, Čačak, Pažarevac, etc.). Below-average values are characteristic of depopulation areas in border and hilly or mountainous regions, for which emigration and population aging are typical (Kerbler 2015). In Serbia, during the period under consideration, there was an intensive process of population aging in rural settlements and migration of young population to cities. As a result of this process, there was a polarization of the dynamics of natural reproduction of the population between rural and urban settlements and regions (Nikitović 2019). As early as the 1980s, depopulation became evident in cities as well (Živanović 2013; Djurkin, Antić and Budović 2021).

The relative entropy of the movement of the number of deaths (Figure 6) in the eastern and western peripheral areas and in the hilly and mountainous regions of Serbia shows clearly above-average values. As for the evolution of the number of live births per 100 deaths, a below-average relative entropy is characteristic for the Pannonian districts (except for the northern Bačka district) and some districts in central Serbia, where the probability of a repetition of the system state due to depopulation decreases (Figure 7).

6 Discussion

The entropy approach to the study of demographic dynamics as a stochastic process, in contrast to the Malthusian and neo-Malthusian deterministic theories of population reproduction, leads to the design of the »internal environment« of the demographic system that ensures its self-organization and the relative independence of its functioning from external conditions and resources. The higher the entropy, the greater the stability of the system. Maximum entropy means the most probable state of the system. The opposite of entropy is the concept of negative entropy, i.e. negentropy. The effect of entropy and negentropy is a prerequisite for the sustainability of the system. The term stability usually refers to the behavior of a system near the equilibrium state. We say that the state of the system is stable when the system returns to equilibrium after small perturbations. When this is not the case, instability increases. Considering the fact that population is a biosocial system, it is a very complex question where is the »X« factor that triggers the demographic process (Višnjevski 2005). Population policy tries to direct the natural movement of the population in the desired direction through (economic, social) fertility measures (Josipovič 2003; Vasić 2019; Graovac 2021). Some countries try to compensate for negative natural population growth by positive net migration (Nikitović 2017). Small changes on an annual basis indicate high sustainability of the system state, but over a longer period of 60 years, an entropy indicator suggests that decreasing demographic dynamics increasingly disrupts the demographic equilibrium and threatens the sustainability of the homeostasis of the country's demographic system. In this context, the question of how to respond to the demographic challenges inevitably arises (Vojković, Kokotović-Kanazir and Bakić 2022).

Shannon's model of entropy as a parameter of population dynamics, while important, is not the only basis for demographic regionalization of Serbia. Besides dynamic stability, it is necessary to study the parameters of territorial structure (i.e. its viable and measurable characteristics), such as: territorial concentration, territorial differentiation, territorial integration (homogeneity) and composition, as well as sub-parameters and aspects (Vasilevski and Polan 1978). Only such a set of variables is essentially a complete coordinate system in a multidimensional demographic space, where each of the parameters serves as the coordinate axis of the next. Such a set is not only a tool for analysing the dynamics of the territorial structures of the population, but also an important constructive lever for the territorial organization and management of the demographic system. The theoretical and methodological importance of parameterization should be emphasized. On the theoretical side, by combining a qualitative and quantitative component of demographic analysis, parameterization aims to provide an objective comparison and typology of different territorial structures and a deeper study of regional demographic characteristics. As for the methodology, it is topical because it offers the possibility of combining different approaches and methods in a single and coherent indicator method necessary for regionalization.

7 Conclusion

The problem of stability and harmony of the demographic process in time and space is increasingly raised in scientific debates and is the subject of spatial planning and population policies of European countries in the face of worsening demographic crisis and territorial polarization. In this context, the concept of demographic region also becomes an important element for understanding the meaning of demographic transition and transformation at different spatial scales. In this article, a modest attempt has been made to apply the concept of entropy to the study of demographic imbalance in Serbia over the last six decades. We have tried to determine the parameters of demographic dynamics using Shannon's concept of entropy, in the context of the change in the statistical state of the system in time and space. The conceptual and methodological postulates presented are hypothetical in nature and undoubtedly require further logical-methodological elaboration and empirical confirmation. Of course, emphasizing the process aspect of this preliminary theory does not mean that we abandon its structural-territorial aspect, especially since the territorial structure can be considered as the current state of the demographic process. The study of the process of changes in the territorial structure should be studied together with the changes in other structures of the demographic system. The spatial dynamics of change should be studied from the point of view of special territorial processes such as territorial division, concentration, integration and territorial composition, using complex mathematical models and appropriate statistical bases.

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8 References

Aburto, J. M., Alvarez, J. A., Villavicencio, F., Vaupel, J. W. 2019: The threshold age of the lifetable entropy. Demographic Research 41. DOI: https://doi.org/10.4054/DemRes.2019.41.4

Bailey, K. D. 1990: Social entropy theory: An overview. Systems Practice 3. DOI: https://doi.org/10.1007/bf01063441

Batty, M., Morphet, R., Masucci, P., Stanilov, K. 2014: Entropy, complexity, and spatial information. Journal of Geographical Systems 16. DOI: https://doi.org/10.1007/s10109.014-0202-2

Breznik, D. 1980: Demografija: analize, metodi i modeli. Beograd.

Cabral, P., Augusto, G., Tewolde, M., Araya, Y. 2013: Entropy in urban systems. Entropy 15. DOI: https://doi.org/10.3390/e15125223

Cardona-Almeida, C., Obregón, N., Canales, F. A. 2019: An integrative dynamic model of Colombian population distribution, based on the maximum entropy principle and matter, energy, and information flow. Entropy 21. DOI: https://doi.org/10.3390/e21121172

Costa-Cabanas, D., Chalub, F., Souza, M. 2022: Entropy and the arrow of time in population dynamics. Biosystems 223. DOI: https://doi.org/10.1016/j.biosystems.2022.104817

Czyż, T., Hauke J. 2015: Entropy in regional analysis. Quaestiones Geographicae 34-4. DOI: https://doi.org/10.1515/quageo-2015-0037

Damos, P. 2015: Bio-demographic aspects of population entropy in quantifying population heterogeneity and its consequences for population fitness and species adaptation. 2nd International Electronic Conference on Entropy and its Applications. DOI: https://doi.org/*10.3390/ecea-2-D003*

Deka, J., Tripathi, O., Khan, M. 2010: Urban growth trend analysis using Shannon entropy approach – A case study in North-East India. International Journal of Geomatics and Geosciences 2-4.

Djurkin, D., Antić, M., Budović, A. 2021: Demographic and economic aspects of urban shrinkage in Serbia: Typology and regional differentiation. Bulletin of the Serbian Geographical Society 101-2. DOI: https://doi.org/10.2298/GSGD2102043D

Graovac, M. V. 2021: Recent marriage and childbearing trends in Croatia and Slovenia: A comparative review. Acta geographica Slovenica 61-1. DOI: https://doi.org/10.3896/AGS.8596

Grčić, M. 1990: Analiza prostorne organizacije industrije regiona Beograd. Beograd.

Hernando, A., Hernando, R., Plastino, A., Plastino, A. R. 2012: The workings of the maximum entropy principle in collective human behaviour. *Journal of the Royal Society Interface* 78. DOI: https://doi.org/10.1098/rsif.2012.0758

Javor, V. 2014: Tranzicija tipova kretanja stanovništva Vojvodine 1961–2011. Demografija 11.

Josipovič, D. 2003: Geographical factors of fertility. Acta geographica Slovenica 43-1. DOI: https://doi.org/10.3986/ags43104

Kapica, S. R. 2008: Očerk teorii rosta čelovečestva. Demografičeskaja revolucija i informacionnoe obšestvo. Moskva.

Kerbler, B. 2015: Population aging in Slovenia: A spatial perspective. Acta geographica Slovenica 55-2. DOI: https://doi.org/10.3986/AGS.1885

Lesne, A. 2014: Shannon entropy: A rigorous notion at the crossroads between probability, information theory, dynamical systems and statistical physics. Mathematical Structures in Computer Science 24-3. DOI: https://doi.org/10.1017/s0960129512000783

Li, G., Zhao, D., Xu, Y., Kuo, H., Xu, Y., Hu, N., Zhao, G. et al. 2015: Entropy based modelling for estimating demographic trends. PLoS ONE 10-9. DOI: https://doi.org/10.1371/journal.pone.0137324

Macura, M. 1997: Razmišljanja povodom osnova demografske teorije. Beograd.

Marinković, I., Radivojević, B. 2016: Mortality trends and depopulation in Serbia. Geographica Pannonica 20-4. DOI: https://doi.org/10.5937/GeoPan1604220M

Marius, D. P., Lenart A., Canudas-Romo V. 2019: The maximum entropy mortality model: Forecasting mortality using statistical moments. Scandinavian Actuarial Journal 8. DOI: https://doi.org/10.1080/03461238.2019.1596974

Medvedkov, Y. V. 1967: The concept of entropy in settlement pattern analysis. Papers of the Regional Science Association 18. DOI: https://doi.org/10.1007/BF01940320

Natural changes of population in the Republic of Serbia. Statistical Office of the Republic of Serbia. Belgrade, 2012.

Nikitović, V. 2017: Zašto je potrebna nova paradigma populacione politike u Srbiji? Knjiga sažetaka sa okruglog stola Poruke demografa kreatorima javnih politika u Srbiji. Beograd.

Nikitović, V. 2019: U susret regionalnoj depopulaciji u Srbiji. Beograd.

Penev, G. D., Predojević-Despić, J. R. 2019: The population change in Serbia in the post-Yugoslav period (1991–2017): Significant demographic aspects. Sociološki pregled 53-3. DOI: https://doi.org/10.5937/socpreg53-21902

Purvis, B., Mao, Y., Darren, R. 2019: Entropy and its application to urban systems. Entropy 21. DOI: https://doi.org/10.3390/e21010056

Radovanović, M. V. 1987: Geografija kao fundamentalna nauka o geosistemima. Beograd.

Radovanović, M. V. 1988: Stanovništvo kao autonomni biosocijalni i geografski sistem. Zbornik radova GIJC 40.

Rudnicki R., Łoskot, K. 1991: Relative entropy and stability of stochastic semigroups. Annales Polonici Mathematici, 53-2.

Rudnicki, R. 2023: Dynamika populacyjna. Katowice.

Saopštenje SN40, 171. Statistical Office of the Republic of Serbia. Belgrade, 2022.

Shannon, C. 1948: A mathematical theory of communication. The Bell System Technical Journal 27.

Sonis, M. G. 1968: Značenie entropijnyh mer odnorodnosti dlja analiza pereraspredelenij naselenija. Matematika v Ekonomicheskoi Geografii. Voprosy Geografii 77.

Spasovski, M., Šantić, D. 2013: Development of population geography from anthropogeography to spatial-analytical approach. Stanovništvo 51. DOI: https://doi.org/102298/STNV1302001S

Vasić, P. 2019: Lokalna samouprava i politika prema rađanju – analiza demografskih i socioekonomskih pokazatelja. Demografija 16.

Vasilevski, L. I., Polan, P. M. 1978: Sistemno-strukturny podhod i ekonomičeska geografia. Moskva.

Vojković, G. 2007: Population as an element of regionalization of Serbia. Belgrade.
Vojković, G., Kokotović-Kanazir, Bakić, D. 2022: Ka boljem razumevanju demografskih dispariteta u Srbiji. Beograd.
Wilson, A. 2010: Entropy in urban and regional modelling: Retrospect and prospect. Geographical Analysis 42-4. DOI: https://doi.org/10.1111/j.1538-4632.2010.00799.x
Wilson, A. G. 1970: Entropy in urban and regional modelling. London.
Zborowski, A. 1985: Analiza komponentów wzrostu ludności miejskiej za pomocą miar entropii. Prace Geograficzne 62.
Živanović, U. 2013: Razlike u fertilitetu stanovništva gradskih i ostalih naselja Srbije. Demografija 10.

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PRECIPITATION VARIATION AND WATER BALANCE EVALUATION USING DIFFERENT INDICES

Lidia Maria Apopei, Dumitru Mihăilă, Liliana Gina Lazurca, Petruț Ionel Bistricean, Emilian Viorel Mihăilă, Vasillică Dănuț Horodnic, Maria Elena Emandi


LIDIA MARIA APOPEI

The Cotnari Cellar and vineyard. Cătălina Hill (east view).

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Lidia Maria Apopei[1], Dumitru Mihăilă[1], Liliana Gina Lazurca[1], Petruț Ionel Bistricean[1], Emilian Viorel Mihăilă[2], Vasillică Dănuț Horodnic[1], Maria Elena Emandi[1]

Precipitation variation and water balance evaluation using different indices

ABSTRACT: The study evaluates the variability of water balance using different indices for the period 1961–2018 in Cotnari and surroundings, in the middle part of the Moldavian Plateau (MP), Romania. With the aid of statistical analysis and remote sensing, we discovered that the Cotnari's SPEI (Standardized Precipitation and Evapotranspiration Index) variability is characterized by severe values that alternate between significant excess and significant deficits. According to SPEI, between 57.2 and 61.4% of the months were near normal in terms of water balance. There were between 19.3 and 25.1% months with water excess and between 17.1 and 20.8% with water deficit. The links between NDVI and SPEI become stronger as SPEI reaches extreme values (above 1.5 units or below −1.5 units). The water balance indicates a decrease in available water resources.

KEYWORDS: SPEI, water balance, NDVI, trend analysis, Romania

Preučevanje sprememb v količini padavin in vodni bilanci z uporabo različnih indeksov

POVZETEK: Avtorji v članku z različnimi indeksi preučujejo spremenljivost vodne bilance v romunski vasi Cotnari in njeni okolici na osrednji Moldavski planoti med letoma 1961 in 2018. Statistična analiza in daljinsko zaznavanje sta pokazala, da je za standardizirani padavinsko-evaporacijski indeks (SPEI) preučevanega območja značilna velika spremenljivost, pri kateri vrednosti nihajo med izrazitimi presežki in primanjkljaji. Na podlagi vrednosti indeksa SPEI je bila vodna bilanca v 57,2 do 61,4 % mesecev blizu normale, v 19,3 do 25,1 % mesecev je bila pozitivna (s presežki), v 17,1 do 20,8 % mesecev pa negativna (s primanjkljaji). Korelacija med indeksoma NDVI in SPEI se okrepi, ko SPEI doseže ekstremne vrednosti (nad 1,5 enote ali pod −1,5 enote). Vodna bilanca v preučevanem obdobju kaže upadanje razpoložljivih vodnih virov.

KLJUČNE BESEDE: SPEI, vodna bilanca, NDVI, analiza trendov, Romunija

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[1] Stefan cel Mare University of Suceava, Suceva, Romania
lidiapapaghiucc@gmail.com, dumitrum@atlas.usv.ro (https://orcid.org/0000-0002-5876-7963), lazurca.gina@yahoo.ro (https://orcid.org/0000-0002-8671-4551), petricabistricean@gmail.com (https://orcid.org/0000-0001-9617-0773), vasilica.horodnic@gmail.com (https://orcid.org/0000-0001-6803-4571), marina@atlas.usv.ro (https://orcid.org/0000-0001-6342-460X)

[2] Alexandru Ioan Cuza University of Iași, Iași, Romania
emilian955@gmail.com (https://orcid.org/0009-0003-4521-5654)

1 Introduction

In the last 60 years, the frequency of extremes and rainfall imbalances has increased in the middle part of the temperate climate zone (Mihăilă et al. 2017). The Cotnari territory and its surroundings are in this climatic type and are frequently subject to these extremes. The Carpathian region itself, located only 50 km to the west, is higher and more exposed to oceanic influences. Its vulnerability to climate changes was revealed by various indices: Standardized Precipitation and Evapotranspiration Index (SPEI), Standardized Precipitation Index (SPI), Drought Recognition Index (RDI) and Palfai Aridity/Drought Index (PADI) (Spinoni et al. 2013). The alternation of excess and deficit rainfall in relation to different components of the geographical landscape requires an adaptation of risk management induced by these rainfall extremes (Mihăilă and Tanasă 2013; Morar et al. 2021). SPEI as a multiscale index of water balance analysis has not raised research constraints in any climate zone regardless of the spatial or temporal extent of the analysis. The World Meteorological Organization (2012) recommends SPEI for scientific research purposes. SPEI gives significant results regardless of the size of the area surveyed if its calculation algorithm is applied correctly (Cheval 2015; Stagge et al. 2015). SPEI can be used from global scale (Begueria et al. 2013) to regional and local scale (Hakam et al. 2022). SPEI was proposed by Vicente-Serrano et al. (2010; 2012) and was mainly used to analyse the drought phenomenon at different time scales.

In Romania and the Republic of Moldova relevant water balance (WB) studies have been carried out based on SPEI and other indices (Mihăilă et al. 2017). Pascoa et al. (2020) analysed the relationship between drought and vegetation stress between April and October, since 1998 until 2014. Dragotă et al. (2012) and Roşca (2020) studied, using SPEI, Normalized Difference Vegetation Index (NDVI) and other indices, the effects of rainfall excess or deficit on land use for the Carpathians and the Curved Subcarpathians, respectively the Romanian Plain. The results of the cited studies practically justify the approval of SPEI as a regional indicator in the water excess/water deficit assessment for the EU Member States according to Global Water Partnership. Water deficit in the soils of the eastern and southern Carpathians is stronger than in the interior of the intracarpathian area, negatively affecting all environmental components (Onțel et al. 2021). The water balance dynamics in the eastern and southern Carpathian Mountains show that, in equivalent periods to those in our study, there has been recorded an increase in climatic water scarcity, which is of concern to both researchers and local communities (Bandoc and Prăvălie 2015). Potop (2003; 2011) and Neadealcov et al. (2015) have studied droughts in the Republic of Moldova based on SPEI (and SPI). The current and prospective climatic context indicates through the Palmer Drought Severity Index (PDSI) for the area under investigation a trend towards drought (Dascălu et al. 2016). NDVI was used in the present study to validate SPEI values and especially its extremes. This index is normally used for the analysis of vegetation dynamics (Milanović et al. 2019), but also for the identification of major land cover categories such as water bodies, barren soil, grasslands, moderate vegetation and dense vegetation (tropical forest). NDVI has been used early in such climate-related studies (Rouse et al. 1973; 1974) and is the most widely used index in remote sensing analyses of vegetation cover (Tucker 1979). In Romania, a close analysis using NDVI was performed by Angearu et al. (2020) for the Oltenia Plain, the Baragan Plain and the Banat Plain. However, the NDVI index along with other spectral indices, such as Normalized Difference Water Index (NDWI), Temperature Condition Index (TCI) has been quite rarely used in Romania (Prăvălie Sîrodoev and Peptenatu 2014; Bordun, Nertan and Cimpeanu 2018).

The lack of water balance studies focusing on the Cotnari wine region, and its surroundings was reason enough for this analysis. The Cotnari territory and its surroundings are intensively used in agriculture (viticulture in Cotnari, viticulture and cereal-cultivation in Iasi, cereal and technical crop cultivation in Roman), and the deterioration of the water balance in recent years requires in-depth studies to support efficient agricultural management. For agronomists, this study can provide a basis for the analysis of crop varieties, sowing periods, phytosanitary treatments, etc.

The objectives of our study are the following: i) to outline the SPEI parameters (minimum, average, maximum) by month and season (cold: October–March; warm: April–September) in Cotnari to evaluate the variability of water excess/deficit in the analysed area; ii) to validate the consequences of SPEI extremes on the vegetation by analysing several relevant satellite scenes and NDVI; iii) to identify trend evolution of SPEI for the period 1961–2018, its magnitude and degree of confidence in order to predict the future value trajectory of these indices.

2 Study area

The territory around Cotnari weather station is part of the geographical landscape of forest and steppe, heavily modified by human interventions. The water balance in the investigated area has tended to lean toward a water deficit in recent years (Piticar 2013; Piticar et al. 2016; Mihăilă et al. 2017). This study also complements and updates the water balance research for Cotnari as base station and two other supporting meteorological stations (Iasi and Roman).

Cotnari station is in the southeastern extremity of the Suceava Plateau at the contact with the Moldavian Plain. The Iasi station is in the southern end of the Moldavian Plain and Roman station is in the north of the Siret Corridor. The data representativeness from Cotnari and Iasi weather stations extends within a radius of up to 70 km around the station in the Moldavian Plain and is reduced to 30–35 km towards the Suceava Plateau and Central Moldavian Plateau. The representativeness area of Roman station is

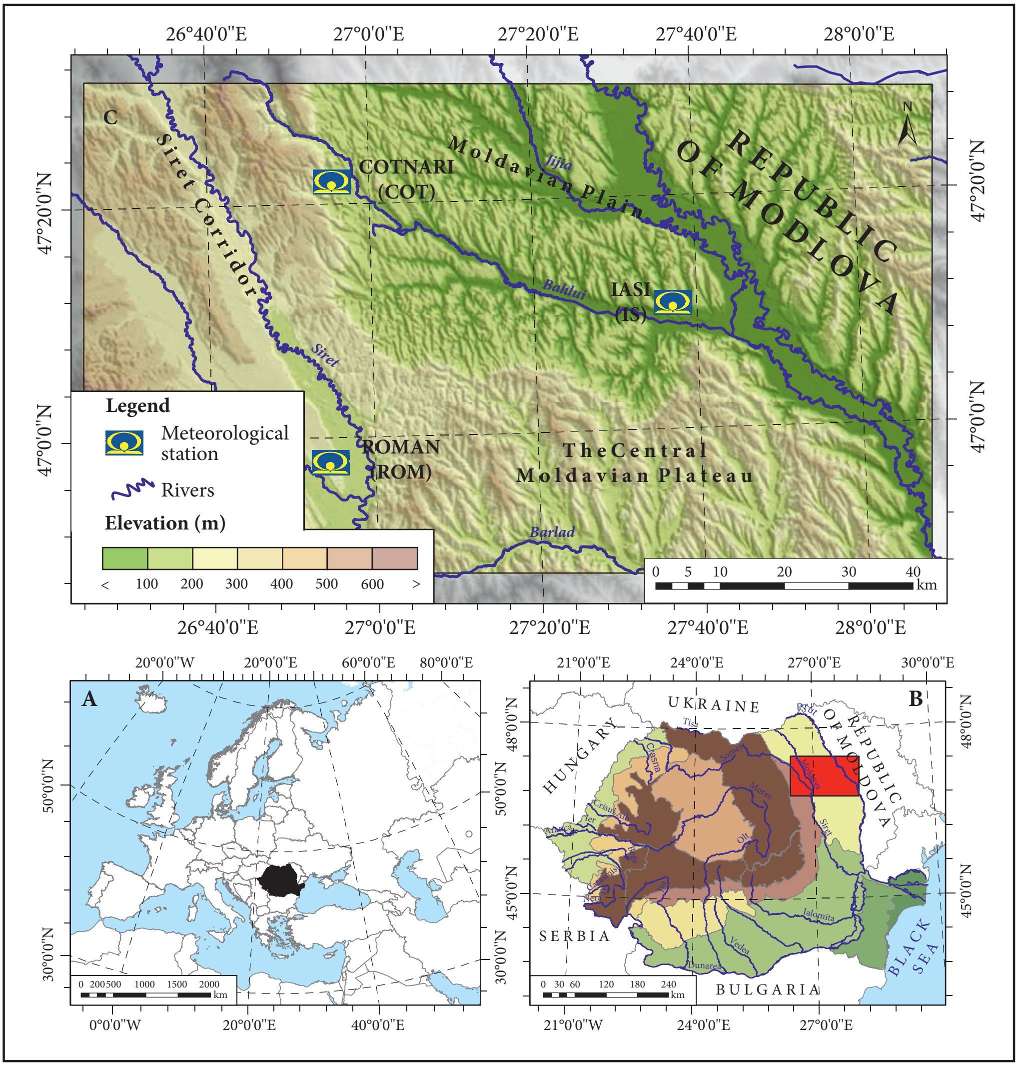


Figure 1: The Cotnari, Iași and Roman weather stations in Moldavian Plateau territory and its location within NE Romania.

limited to a circle with a radius of 30–35 km having the station in question in the center (World Meteorological Organization 2018).

At the mesoclimatic level, the three stations are found in the continental climate with warm summers (Dfb), according to the Köppen-Geiger classification (KG) (Sandu 2008). The geographical weather station position, the atmospheric circulation and the variety of the relief, determine, however, a great spatio-temporal variation of the climatic elements and phenomena. The Moldavian Plateau has a temperate climate with continental influences from the east and oceanic influences from the west (Mihăilă 2006; Tănasă 2011).

At Cotnari, the local hilly topography favours the formation of foehn circulation when the westerly winds descend, firstly over the eastern flank of the Eastern Carpathians and afterwards over the eastern slopes of the Moldavian Coast. The foehn effect, the moderate slopes, the favorable exposure to the east-southeast and the carbonaceous chernozems soils favored the cultivation of the vine on large areas (1750 ha) (Cotea et. al. 2006).

For this study we choose to focus on SPEI analysis around the Cotnari viticultural area (influenced by dynamic foehn processes; Apopei, Mihăilă and Bistricean 2020) comparing the results with those from Roman and Iași, because Roman station is a landmark for the Siret River valley topoclimate (Sfîcă 2015), and Iași station is a typical lowland station, where the influences of the continental climate and of the city are more obvious (Sfîcă et al. 2018).

3 Data and methodology

We took three steps in order to assess the water balance variation in the study area. In the first phase, we extracted, processed, and examined the SPEI value variability. In the second phase, we collected and processed satellite images, extracted NDVI values, and analysed their spatial and statistical distribution in comparison to SPEI values. In the third phase, we tested the SPEI values with Mann-Kendal trend tests.

3.1 Extraction and processing of SPEI data

The total amount of precipitations, air temperatures, latitude, and potential evapotranspiration are used to calculate SPEI (Vicente-Serrano, Beguería and López-Moreno 2010). The normalized monthly difference between precipitation and potential evapotranspiration is represented by relative values of the water balance. The three weather stations' SPEI data series are uninterrupted and homogeneous since 1961 until 2018. SPEI values have been retrieved out of the University of East Anglia's Climatic Research Unit's database. Table 1 lists the SPEI value thresholds and ratings.

The processing of SPEI data was performed by statistical methods in the Microsoft Excel program. Monthly SPEI values represent the actual SPEI values for the month in question. For monthly values denoted by SPEI 3, 6, 9 and 12 the calculation was made based on the SPEI simple moving averages, this procedure involved dragging these averages into units of 3, 6, 9, 12 months including the month actually referred to. Following a similar algorithm, we calculated SPEI by quarters (winter, spring, summer, autumn), seasons (warm, cold) and years. Through boxplot charts we analysed the annual regime of the SPEI index. Boxplot charts were made in the Python programming language (in the Pycharm program), using different libraries containing data types that help to process .csv files and functions for building boxplots both for retrieving data from the Excel document and for creating the charts.

Table 1: Framing according to the SPEI values of the analysed time units (according to Jianqing et al. 2016).

Categories	SPEI
Extremely wet	≥ 2
Severely wet	1.5 to 1.99
Moderately wet	1.0 to 1.49
Near normal	−0.99 to 0.99
Moderately dry	−1.49 to −1.0
Severely dry	−1.99 to −1.5
Extremely dry	≤−2.0

3.2 Extraction and processing of NDVI data

NDVI is calculated as the ratio of the difference to the sum of the reflectance in the infrared and red spectral regions of electromagnetic radiation.

The NDVI calculation formula is:

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}$$

where NIR is the reflectance measured in the near infrared wave bands and RED is the reflectance corresponding to the red wave bands (Rouse et al. 1974). Note that these are average values and that it varies spatially and temporally. Based on spectral signature variation, NDVI differencing method helps to delineate land cover variation, and more specifically to assess the change in vegetation cover (Table 2).

3.2.1 Acquisition and processing of NDVI data for temporal analysis

In this step we have made a quantitative analysis based on mean values of NDVI for the last 36 years (16th April, 1984 – 29th December, 2020). The statistic values were obtained by the help of Climate Engine platform (https://app.climateengine.com/climateengine), which allowed us to extract the available mean values of NDVI for the pixels related to our study area, generated from corrected surface reflectance Landsat 5, 7 and 8 images (Figure 5a). In this step of the methodology, the extracted data are related to the entire study area and are used to present the general dynamic of NDVI index. After this the data was organized and the daily, monthly, seasonal, and yearly time profiles were generated using Microsoft Excel software and these are presented in the section 4.2.1.

3.2.2 Acquisition and processing of NDVI data for spatial analysis

In this stage we have conducted a spatial analysis based on Landsat satellite images that cover the study area and from which the NDVI values were obtained by extracting the pixel values representing the three weather stations reported in this analysis.

The Landsat 5 TM and 8 OLI&TIRS satellite images corresponding to Path 182 and Row 27 from Collection 2 – Level 2 related to the period 16th April, 1984 – 29 December, 2020 were downloaded from the USGS Earth Explorer portal, because they are already corrected at the level of surface reflectance. More specifically, the bands 3 and 4 were downloaded from 29 Landsat 5 TM satellite images corresponding to the periods with a rainfall surplus, while for the rainfall deficit intervals bands 3 and 4 were downloaded from other 21 Landsat 5 TM satellite images. We have identified only two Landsat 8 satellite images from the years 2015 and 2018 because they are the only years corresponding to the rainfall deficit time step according to SPEI values. We have also noted that Landsat 5 TM satellite data were only available until June 2013, so we had to rely on Landsat 8 OLI&TIRS satellite images, available since February 2014.

The relevant yearly SPEI values for the two rainfall contexts were the criteria for choosing the representative years for which to calculate and extract the specific NDVI values. The starting point were the SPEI values: greater than 1.5 for the rainfall surplus periods and –1.5 for rainfall deficit periods.

The spatial resolution of the satellite images used in the analysis was 30 m, and the degree of cloudiness of the downloaded satellite scene bands was less than 10%, and strictly for the study area the level of cloudiness was less than 5%, a requirement met according to the results of Chavez (1996).

Table 2: Land cover categories related to NDVI values (according to Bannari et al. 1995; Weier and Herring 2000).

Categories	NDVI
Water, snow, clouds	−1.0 to 0.0
Barren land, built up, rocks	0.0 to 0.2
Grassland and shrubland vegetation	0.2 to 0.3
Coniferous forests	0.3 to 0.4
Deciduous forests	0.6 to 0.8
Very dense and healthy vegetation	≥ 0.8

At this stage the monthly SPEI values were analysed in relation to NDVI. The spatial analysis was broken down into two approaches: 1) spatial-statistical quantification of the yearly average for representative years in terms of the variation of SPEI and 2) illustration of two case studies reflecting the extremes of the two types of SPEI values (above 1.5 units, below –1.5 units corresponding to wet and dry weather conditions).

Firstly, we have made two synthetic maps with associated histograms which emphasize the spatial and statistical distribution of NDVI values by the mediation of 29 satellite images for wet weather conditions and 23 satellite images for dry weather conditions, respectively. The entire procedure was made by applying the raster calculator and cell statistics functions from ArcGIS 10.4.

Secondly, the case studies of the extremes of the two types of weather were based on the processing of two representative images: one from 17th August, 1991 for rainy weather and one from 28th July, 2007 for dry weather. In this case, we have generated two different NDVI maps at 30 m spatial resolution and their associated histograms using ArcGIS 10.4.

The results of this part of the study are presented in the chapter 4.2.2.

3.3 Trend analysis (Mann-Kendall test)

To analyse the trend with SPEI values we used the Mann-Kendall statistical test. The Mann-Kendall statistical test is widely used because it does not require a normal distribution of data and is straightforward to calculate. The Mann-Kendall test is applicable if the Xi data values of a time series are subordinate to the model: $Xi = f(ti) + \varepsilon i$ where: $f(ti)$ is a monotonous continuous function and εi is residue (Patriche 2009). The non-parametric Mann-Kendall test is widely used to analyse climatic trends (Mann 1945; Sen 1968; Kendall 1975).

4 Results and discussion

4.1 SPEI analysis

4.1.1 Multiannual statistical framework of SPEI variability in Cotnari and the surrounding areas

Regional warming is a proven reality for NE Romania and for the stations related to our study (Mihăilă and Briciu 2012; Piticar 2013) as in all regions of Europe, where increases in average and extreme temperatures are reported (Pörtner et al. 2022).

Analysing the statistics of the monthly values of SPEI 1 to SPEI 12 for the entire period 1961–2018 (Figure 2), we can firstly notice that the number of months considered near normal for all SPEI calculation intervals is between 57.2% for SPEI 1 in Iași and 61.4% for SPEI 6 in Roman. The months in which the values of SPEI 1–12 indicated surplus (varying between 19.1% SPEI 3 in Roman and 25.1% SPEI 12 in Iași) or pluvio-hydric deficit (varying between 17.1% for SPEI 6 in Iași and 20.8% for SPEI 3 in Roman) were numerous. For all three considered stations, significant percentages can be distinguished that must be taken into account (between 0.4% SPEI 12 Iași and 2.4% SPEI 3 Cotnari) during severely dry months when the SPEI values 1–12 were below –1.99. Additionally, the percentages of months with very high humidity held between 0.6% and 3% in Iași for SPEI 9 and SPEI 3, respectively.

SPEI renders the reality of the water balance in the MP very accurately. The results provided are in agreement with those obtained by calculating other climatic indices (potential evapotranspiration, water balance) for geographic territories neighbouring or including the analysed stations (Mihăilă et al. 2017; Piticar et al. 2016).

4.1.2 Annual and multiannual variability of SPEI

The seasonal SPEI values at Cotnari (Figure 3) reveal a series of temporal differences in precipitation and water balance in the MP. First, we note that the variability of SPEI is higher in the warm season than in the cold season in all cases. The water balance for the investigated territory was at the limit of a dysfunctional dynamic equilibrium, with evolution towards water deficit and increasing vulnerability in relation to SPEI extremes. The seasonal extremes of SPEI varied in the value range between –2.4 and +2.7 (Figure 3), indicating a contrasting and pluvio-hydric continentalism. We notice a slight preponderance of months with SPEI 3 mean values above the 0 threshold. Most months have average SPEI values between −1 and +1. In the case of SPEI 3, the minimum values are below −2 in most months and the maximum values are above the 2 threshold.

The extreme SPEI values (−2.4 and 2.7) and those defining the ends of the Q1-Q3 interquartile range (−1.6 and 1.7) increase from SPEI 1 to SPEI 12 (Figure 3).

The variation spaces of the extremes and of the Q1–Q3 interquartile range preserve their graphical and statistical pattern in the aggregation ranges of SPEI 3–6, where both deficit and excess water are most pronounced. SPEI shows extremely dry/wet ranges in both seasons across all averaging intervals (SPEI 1–12). This is a signal that the investigated territory has a water balance that can be significantly unbalanced, regardless of the season, and above the 6-month cumulation threshold. Both the deficit and the extreme surplus are more pronounced in the warm season of the year, indicating a higher risk for drought or excess water from precipitation.

The graphic arrangement of the monthly values of SPEI 1–12 shows us the whole picture of the value variations of these indices, for the period between 1961 and 2018 at Cotnari (Figure 4).

As a standardized index SPEI does not have a uniform multi-year regime. The pattern of the index becomes more regular as we move from one-month analysis to longer time frames (3–12 months). The high variability of this index is induced by the variability of atmospheric dynamics (Boroneant et al. 2011).

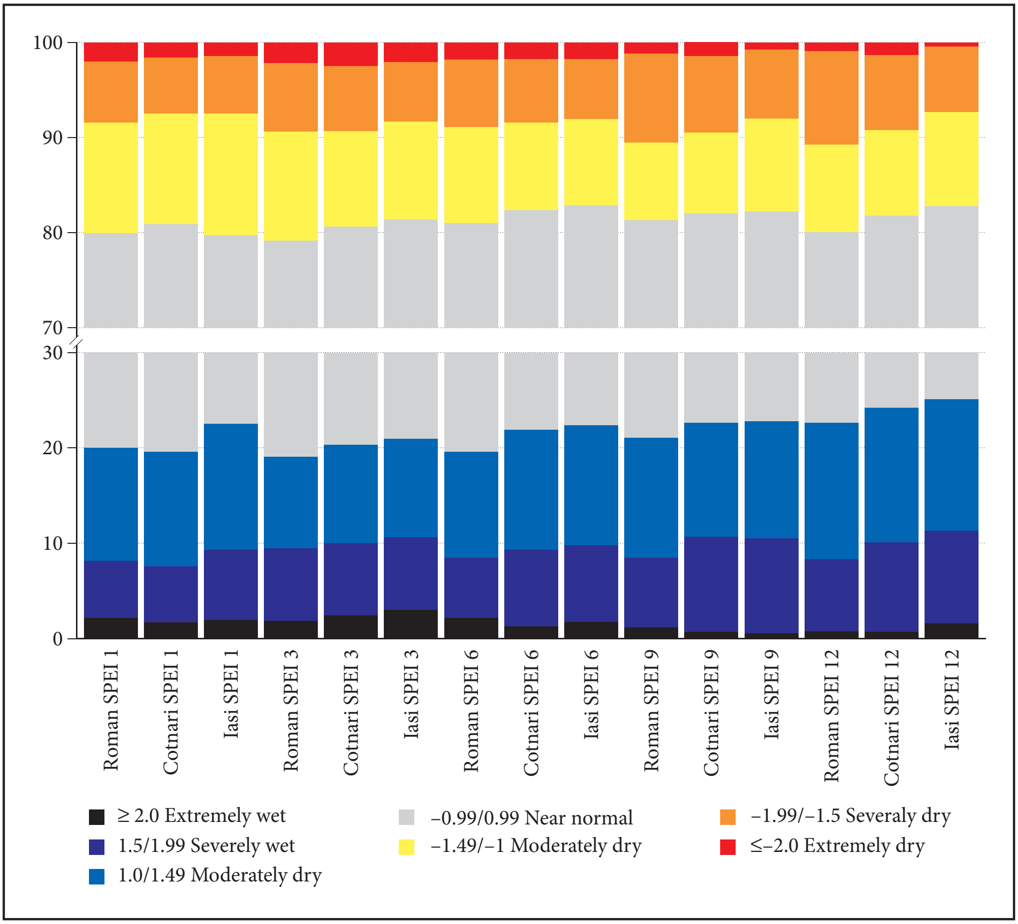


Figure 2: Percentage distribution (0–100%) of monthly SPEI values (from 1 to 12) by classes (from extremely wet months to extremely dry months) for the Roman, Cotnari and Iaşi weather stations for the period 1961–2018.

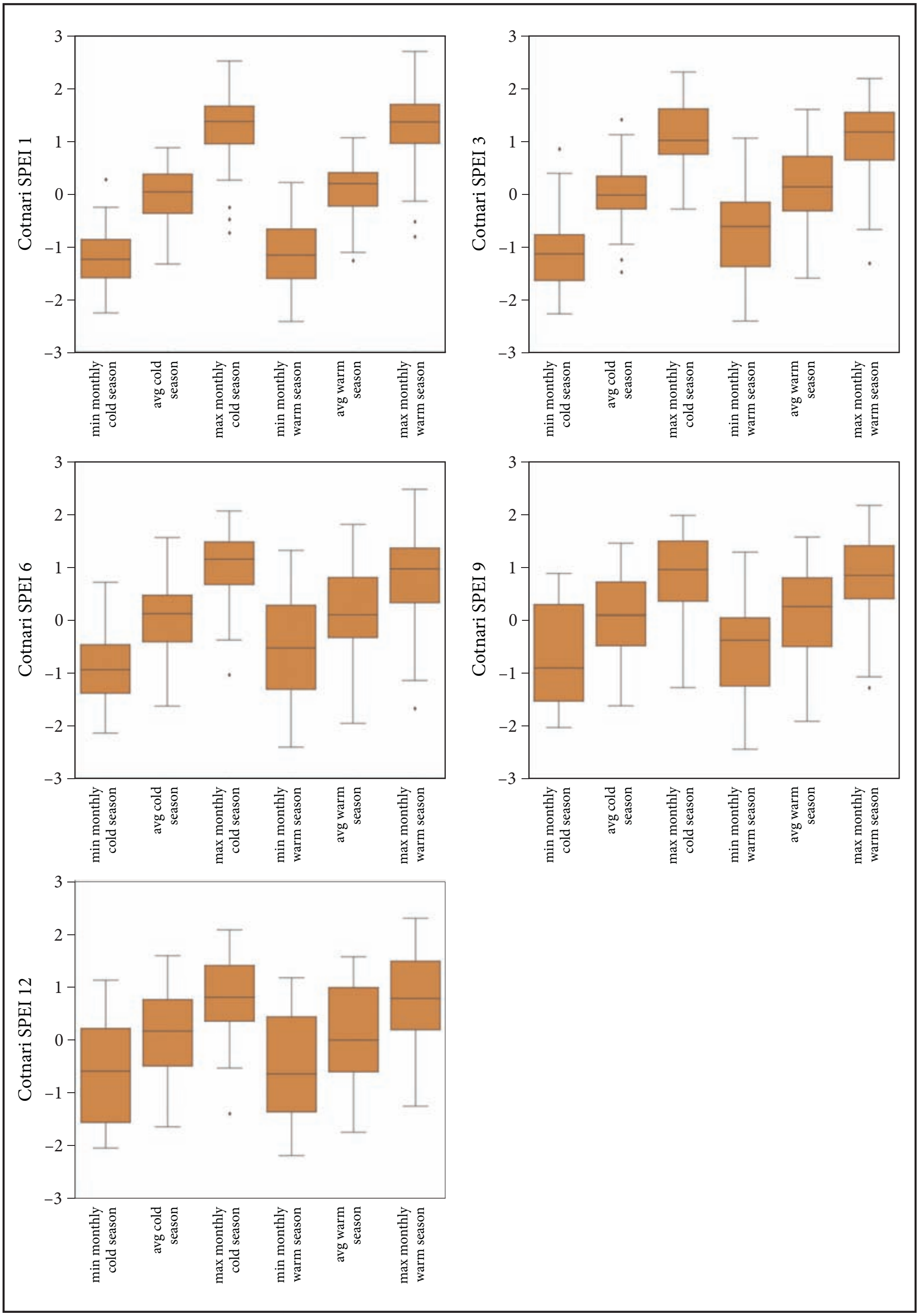


Figure 3: SPEI 1–12 parameter values (monthly minimum, mean, and maximum) by season (cold, warm) at the Cotnari weather station (1961–2018).

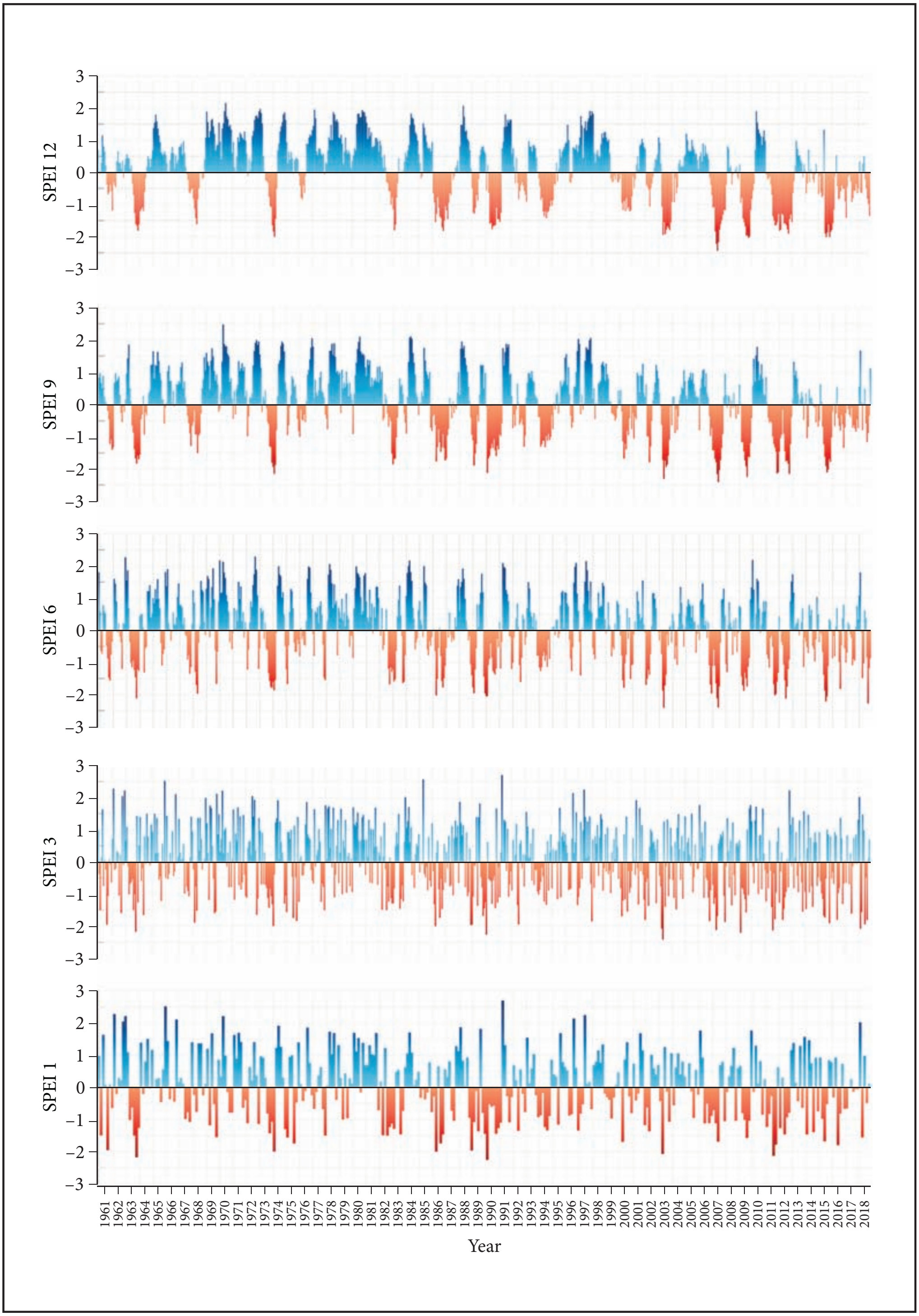


Figure 4: Multi-annual variation of monthly SPEI 1–12 values at the Cotnari weather station (1961–2018); blue – excess, red – deficit.

The variability of SPEI lacks a specific pattern for SPEI 1–3. Repetitive increases and decreases in SPEI become more obvious and orderly as we move from SPEI 1 to SPEI 12 in modelling and analysis. For shorter time frames (1–3 months), SPEI deviations from threshold 0 may indicate more frequent excessive humidity or, less frequently, severe drought. For longer intervals of averaging the monthly values of SPEI (9–12 months), the cumulative intervals with rainfall and water balance either strongly in excess or strongly deficient become more obvious (Figure 4).

It is obvious that periods of excess or rainfall deficit can turn into periods with water excess or water deficit. The 2007 warm season, which was deficient in precipitation, had a similar reflection in SPEI values. If we analyse separately only the SPEI 1–12 data of the last two decades, we observe an amplification of the water balance deficit parameters for all three stations. Torrential rains of a frontal nature of the warm seasons 2006, 2008, 2010, 2014, 2019 generated large accumulations of precipitation. These precipitations were not assimilated by the environmental components due to its torrential character. Therefore, the SPEI values, which take into account evapotranspiration, clearly indicate a deficit water balance for the last two decades (Figure 4).

Piticar et al. (2016) highlighted the sudden increase in the evapotranspiration reference value for the period 1981–2012 for weather stations in the Republic of Moldova, a territory in the immediate vicinity of the studied area and where climate, rainfall and water balance have many similarities. It is certain that the increase in evapotranspiration reference values after 1981 has left a very strong imprint on the investigated SPEI for Cotnari and surroundings.

The representation in figure 4 can be very useful for agronomists and viticulturists, to assess the amplitude and duration of the risk intervals and to predict or anticipate the size of the water surplus or deficit that various agricultural and viticultural crops may experience in the surveyed area (Potop 2011; Nedealcov et al. 2015; Apopei, Mihăilă and Bistricean 2020).

4.2. Validation of SPEI by NDVI

4.2.1 Temporal validation

NDVI values reflect the regime of climatic elements in the analysed interval: high values are specific to those days in the warm season with normal or surplus rainfall, and low values to those days in the cold season with rainfall deficit (Figure 4 and 5a).

The method of choosing satellite images for the months April–September was similar to that applied by Mihai et al. (2016), Angearu et al. (2020) or Dobri et al. (2021). The inter-seasonal dynamics for the analysed interval show a gait dependent on the meteorological particularities of each season and calendar year (Figure 5b). In the case of the analysis of the inter-annual course of the NDVI average values, we identified a minimum in 1987 (0.33) and a maximum in 2013 (0.53) – Figure 5b.

The value for the cold season in 1985 was calculated by averaging the monthly values for the months: (October 1984 + November 1984 + December 1984 + January 1985 + February 1985 + March 1985) / 6. Following this model, all NDVI values for the cold seasons from 1986 to 2020 were calculated, since cold seasons include months from two consecutive years.

4.2.2 Spatial validation

The cartographic products compare the two different meteorological moments: rainy and dry, both from the perspective of approaching the multi-annual mean variation (Figure 6), as well as from the perspective of the case study approach (Figure 7).

The spatial distribution of the NDVI index variation highlights the rainy and dry intervals, especially when we consider the values of the NDVI classes for the two analysed situations (Figure 6 and 7). For the two case studies, NDVI values ranged from 0.00 to 0.95. Values close to 0 showed exposed soils and those over 0.35 (up to 0.95) were specific to areas with forest vegetation or crops that benefited from an optimal rainfall amounts during the phenological development period.

In the case of multi-annual average variation, NDVI recorded values ranged from –0.85 to 0.89 (values below 0 have been excluded from the calculation). For generating the annual average there were years for which we had six satellite images available (1986) and years for which we had only two satellite images available (1985). The years considered according to time availability and correlation with the rainy time SPEI values were: 1984, 1985, 1988, 1991, 1997, 2005, 2006 and 2010. On the other hand, the years analysed

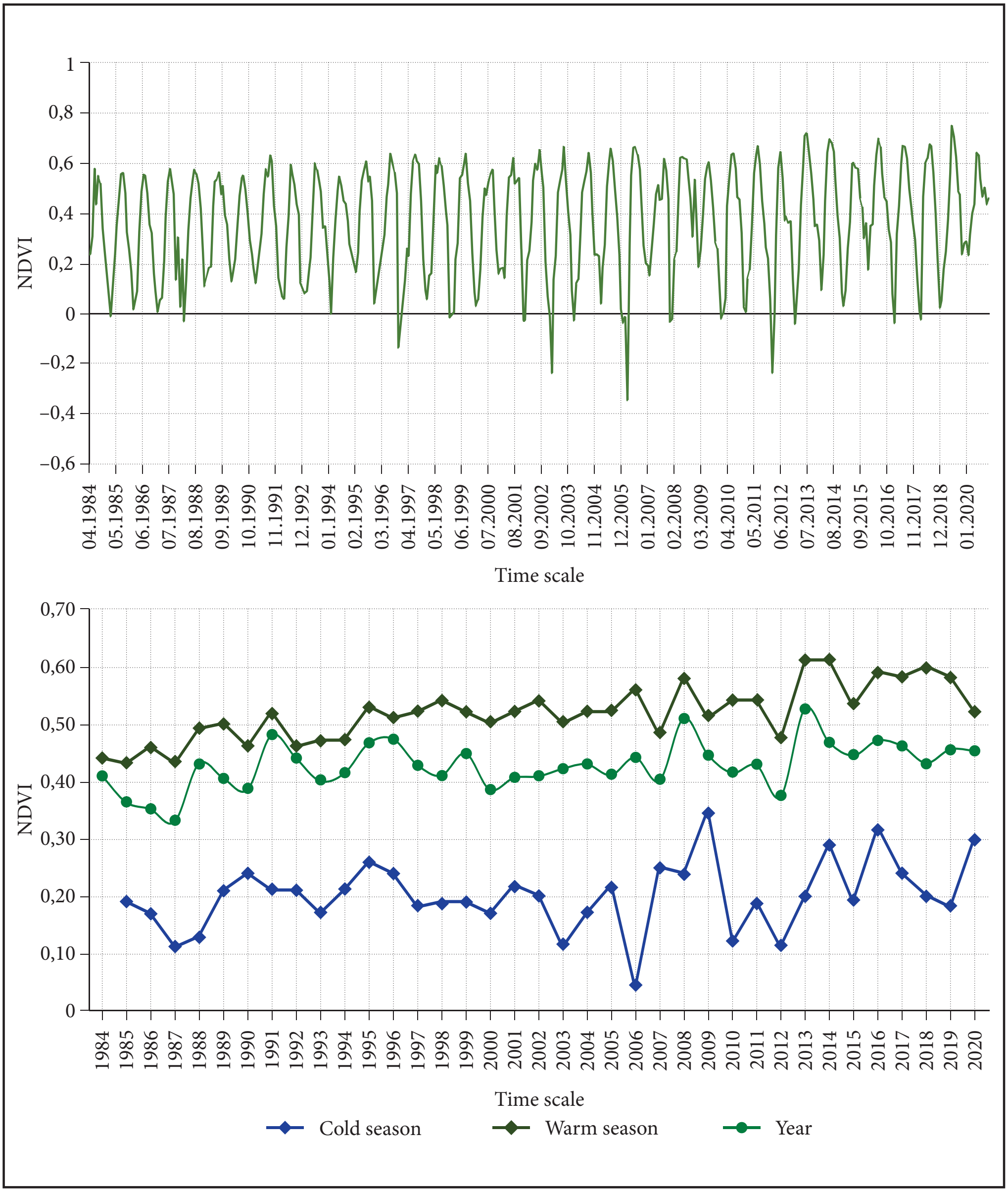
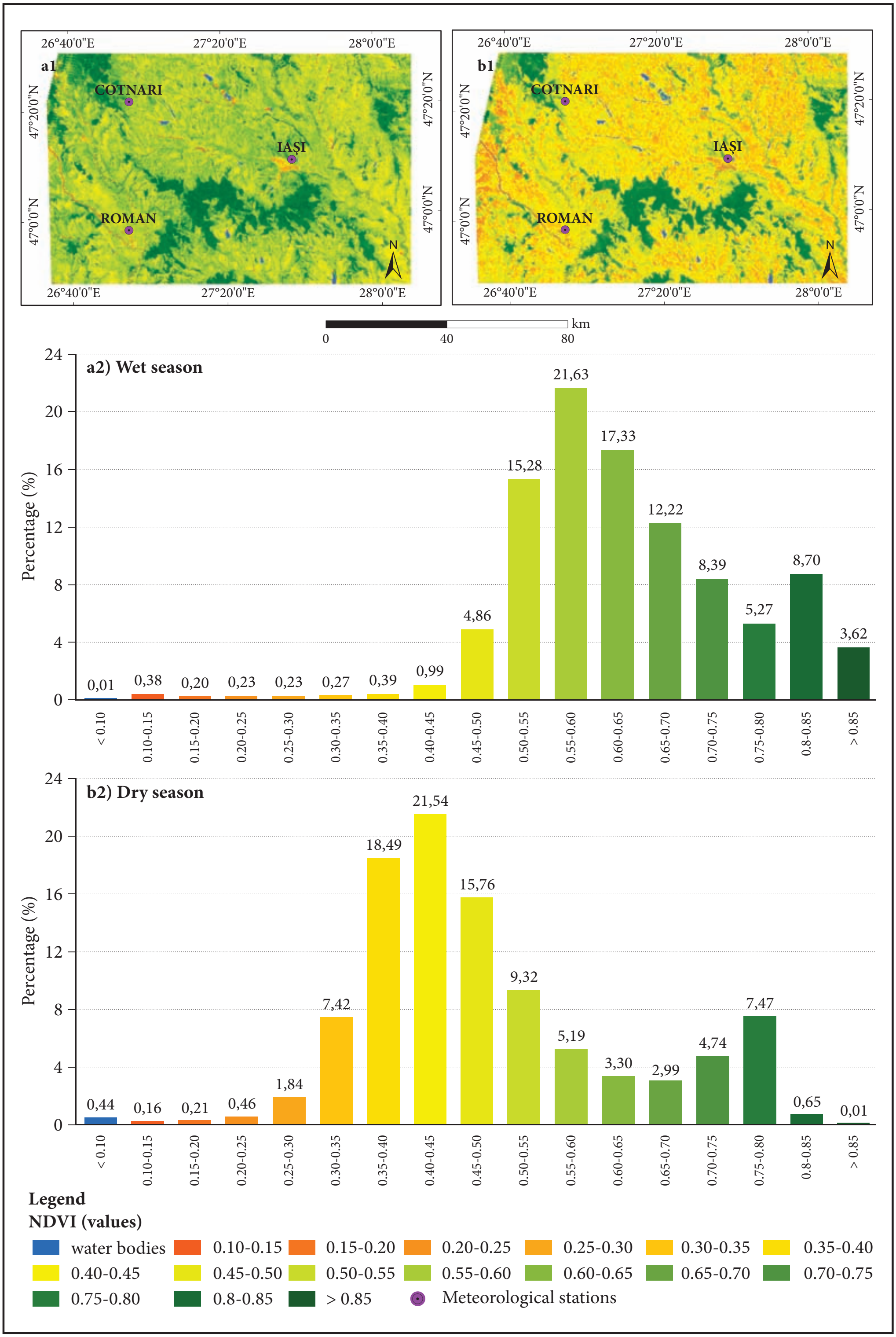


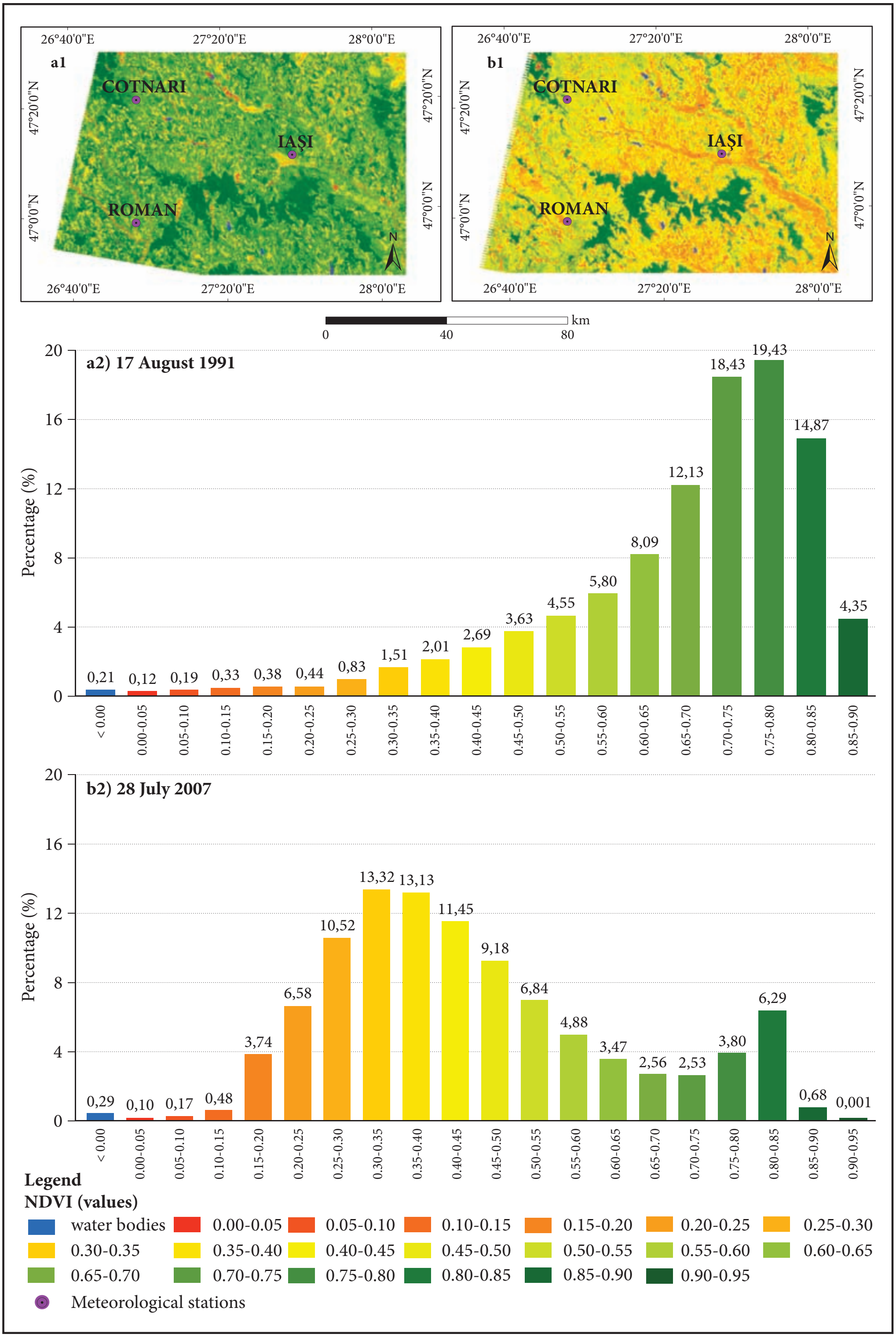
Figure 5: a) Changes in mean daily NDVI values from 1984 to 2020, b) Inter-annual trend of seasonal and annual NDVI values over the period 1984–2020.

Figure 6: Territorial distribution of NDVI in MP region: a1) wet season, b1) dry season. Histograms of NDVI values related to the surface of the surveyed area and to the two specific situations analysed: a2) wet season, b2) dry season. ➤ p. 53

Figure 7: Territorial distribution of NDVI in MP region: a1) 17 August 1991 – rainy weather and b1) 28 July 2007 – dry weather). Histograms of the NDVI value weights related to the surface of the surveyed area and to the two specific situations analysed a2) 17 August 1991, b2) 28 July 2007. ➤ p. 54



a1
b1
COTNARI
IAȘI
ROMAN
26°40'0"E
27°20'0"E
28°0'0"E
47°20'0"N
47°0'0"N
N
0
40
80
km
a2) Wet season
b2) Dry season
Percentage (%)
0,01
0,38
0,20
0,23
0,23
0,27
0,39
0,99
4,86
15,28
21,63
17,33
12,22
8,39
5,27
8,70
3,62
0,44
0,16
0,21
0,46
1,84
7,42
18,49
21,54
15,76
9,32
5,19
3,30
2,99
4,74
7,47
0,65
0,01
< 0.10
0.10-0.15
0.15-0.20
0.20-0.25
0.25-0.30
0.30-0.35
0.35-0.40
0.40-0.45
0.45-0.50
0.50-0.55
0.55-0.60
0.60-0.65
0.65-0.70
0.70-0.75
0.75-0.80
0.8-0.85
> 0.85
Legend
NDVI (values)
water bodies
Meteorological stations


26°40'0"E
27°20'0"E
28°0'0"E
47°20'0"N
47°0'0"N
a1
b1
COTNARI
IAŞI
ROMAN
N
0
40
80
km
a2) 17 August 1991
Percentage (%)
0,21
0,12
0,19
0,33
0,38
0,44
0,83
1,51
2,01
2,69
3,63
4,55
5,80
8,09
12,13
18,43
19,43
14,87
4,35
< 0.00
0.00-0.05
0.05-0.10
0.10-0.15
0.15-0.20
0.20-0.25
0.25-0.30
0.30-0.35
0.35-0.40
0.40-0.45
0.45-0.50
0.50-0.55
0.55-0.60
0.60-0.65
0.65-0.70
0.70-0.75
0.75-0.80
0.80-0.85
0.85-0.90
b2) 28 July 2007
Percentage (%)
0,29
0,10
0,17
0,48
3,74
6,58
10,52
13,32
13,13
11,45
9,18
6,84
4,88
3,47
2,56
2,53
3,80
6,29
0,68
0,001
< 0.00
0.00-0.05
0.05-0.10
0.10-0.15
0.15-0.20
0.20-0.25
0.25-0.30
0.30-0.35
0.35-0.40
0.40-0.45
0.45-0.50
0.50-0.55
0.55-0.60
0.60-0.65
0.65-0.70
0.70-0.75
0.75-0.80
0.80-0.85
0.85-0.90
0.90-0.95
Legend
NDVI (values)
water bodies
0.00-0.05
0.05-0.10
0.10-0.15
0.15-0.20
0.20-0.25
0.25-0.30
0.30-0.35
0.35-0.40
0.40-0.45
0.45-0.50
0.50-0.55
0.55-0.60
0.60-0.65
0.65-0.70
0.70-0.75
0.75-0.80
0.80-0.85
0.85-0.90
0.90-0.95
Meteorological stations

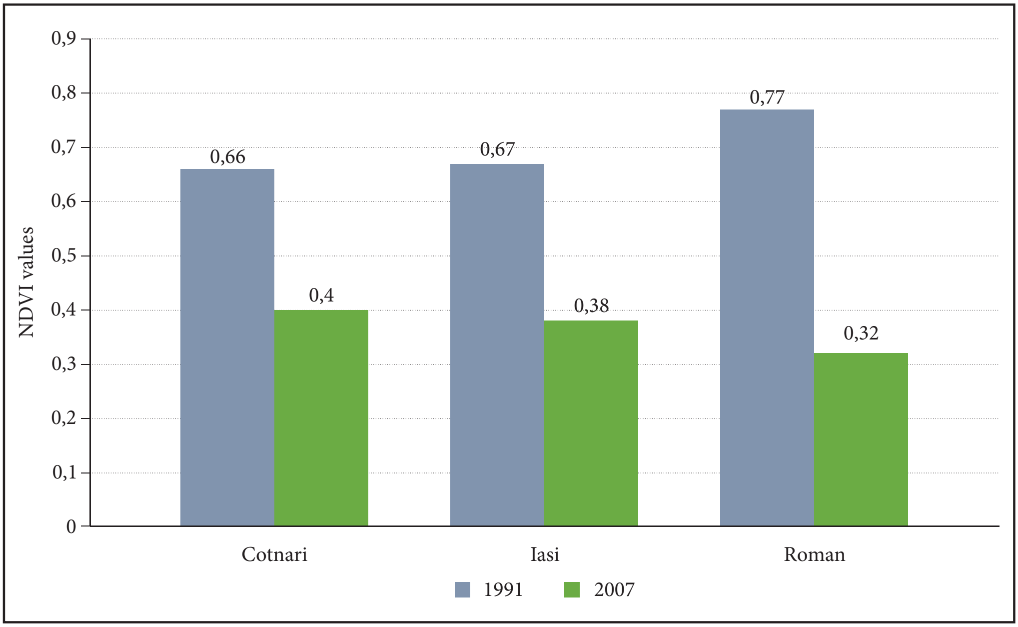


Figure 8: NDVI values for satellite scenes 1991 and 2007

for the dry time were also eight: 1986, 1990, 2000, 2007, 2009, 2011, 2015 and 2018. It turned out that the biggest differences in the value of NDVI were in Cotnari: 0.37 for dry time and 0.57 for rainy time. At the other two stations, the variations were smaller but still visible: 0.59 for rainy time and 0.44 for dry time in Iași, respectively 0.60 for rainy time and 0.48 for dry time in the case of Roman.

The obtained values complete, at least for the case of Roman, the meteorological and phenological picture specific to a site located in the meadow of a river where the rainfall contribution from the soil moisture reserve at the level of the terrace steps is felt. A similar situation was identified by Mihai et al. (2016). Moreover, the histogram analysis of the NDVI rainy-time map highlights the higher share of classes 0.50–0.55 (15.28%), 0.55–0.60 (21.63%) and 0.60–0.65 (17.33%). On the other hand, in the case of water scarcity, the NDVI histogram of the dry time map shows the higher share of classes 0.35–0.40 (18.49%), 0.40–0.45 (21.54%) and 0.45–0.50 (15.76%).

Next, we extracted the NDVI values of the three weather stations included in our study area, in order to observe if there are visible differences from a quantitative point of view. We found that the highest values of NDVI were recorded in 1991 at all 3 weather stations: 0.66 at Cotnari, 0.67 at Iași and 0.77 at Roman. In opposition, NDVI values from 2007 (0.40 at Cotnari, 0.38 at Iași and 0.32 at Roman) confirm the dry weather specific to this year (Figure 8).

4.3 SPEI trends after 1961

The variability and repeatability of the SPEI oscillations as shown in Figure 4 hide the negative trends of the SPEI. They are highlighted by applying the Mann-Kendall statistical test. In a region with a temperate climate, characterized by meteorological excesses, the knowledge of the climatic parameters trend and amplitude was of capital theoretical and practical importance (Mihăilă 2006; Tanasă 2011; Sfîcă 2015).

At SPEI 1, water balance trends indicate a downward evolution. The most pronounced decreases are specific to July and especially August, a month in which both the magnitude of the decrease and its statistical confidence becomes larger and stronger. Summers and springs became the time frame for the manifestation of SPEI depreciation, this decrease being imprinted on longer time intervals such as the warm seasons (April–September) and even on an average annual level (Table 3). October maintains the growth trends of SPEI, with relevant statistical significance.

Table 3: The 10-year trends of the evolution of SPEI 12 (1961–2018) highlighted by the Mann-Kendal in Roman, Cotnari and Iași (blue – positive trend, red – negative trend). Non-significant trends are not presented.

Period	Roman SPEI 1 MKt S/ Ss	Cotnari SPEI 1 MKt S/ Ss	Iasi SPEI 1 MKt S/ Ss	Roman SPEI 3 MKt S/ Ss	Cotnari SPEI 3 MKt S/ Ss	Iasi SPEI 3 MKt S/ Ss	Roman SPEI 6 MKt S/ Ss	Cotnari SPEI 6 MKt S/ Ss	Iasi SPEI 6 MKt S/ Ss	Roman SPEI 9 MKt S/ Ss	Cotnari SPEI 9 MKt S/ Ss	Iasi SPEI 9 MKt S/ Ss	Roman SPEI 12 MKt S/ Ss	Cotnari SPEI 12 MKt S/ Ss	Iasi SPEI 12 MKt S/ Ss
January										–0.15+	–0.21*	–0.18*	–0.15+	–0.21*	–0.21**
February											–0.25**	–0.19*	–0.12+	–0.20**	–0.19**
March					–0.15+						–0.22*	–0.17+	–0.12+	–0.18*	–0.17*
April				–0.12+	–0.17*	–0.14+		–0.15*	–0.15*		–0.19*	–0.16+	–0.17*	–0.23**	–0.21*
May					–0.15*	–0.17*		–0.18**	–0.17*		–0.15+		–0.19*	–0.28**	–0.24**
June					–0.16+			–0.18*	–0.16+			–0.13+	–0.17*	–0.23**	–0.22*
July		–0.19*	–0.16+		–0.18*	–0.15+	–0.17+	–0.22*	–0.18*	–0.16*	–0.16*	–0.18*	–0.14+	–0.21*	–0.20*
August	–0.18*	–0.20*	–0.18*	–0.18*	–0.24**	–0.21*	–0.22*	–0.25**	–0.24**	–0.22*	–0.28**	–0.24**	–0.18*	–0.24**	–0.22**
September				–0.21*	–0.25**	–0.22*	–0.22*	–0.22**	–0.21**	–0.20*	–0.26**	–0.22**	–0.15+	–0.20*	–0.18*
October	0.20*	0.17*	0.16*				–0.15+	–0.19*	–0.18*	–0.17*	–0.25**	–0.20*	–0.18+	–0.23*	–0.19*
November								–0.20*	–0.19+	–0.15+	–0.22*	–0.19*	–0.16+	–0.21*	–0.19*
December				0.16+					–0.17+	–0.17+	–0.22*	–0.20*	–0.17+	–0.24**	–0.22**
Annual		–0.07*	–0.07*		–0.11*	–0.10*	–0.10*	–0.15*	–0.15**	–0.14*	–0.21**	–0.19**	–0.17*	–0.22**	–0.22**
Winter									–0.10+	–0.16*	–0.24***	–0.20***	–0.17**	–0.22***	–0.21***
Spring		–0.09*	–0.09*		–0.15*	–0.13+		–0.14+	–0.13+		–0.20*	–0.16*	–0.17*	–0.24**	–0.22**
Summer	–0.12*	–0.16**	–0.14**	–0.15*		–0.18*	–0.16*	–0.21**	–0.18*	–0.15*	–0.18*	–0.18*	–0.17+	–0.23**	–0.21**
Autumn							–0.17*	–0.21*	–0.18*	–0.18*	–0.23**	–0.20**	–0.17+	–0.22*	–0.18*
Oct – Mar					0.08**			–0.10*	–0.11*	–0.16**	–0.24***	–0.20***	–0.17**	–0.22***	–0.20***
Apr – Sep	–0.10*	–0.12**	–0.11*	–0.15*		–0.16**	–0.016*	–0.19**	–0.18**	–0.14*	–0.21**	–0.17*	–0.17*	–0.23**	–0.22**

[Ss = Statistical significance; MKt = Mann-Kendall test; S = Slope; + = $p < 0.1$, the statistical link is significant (Ss, 85% confidence), * = $p < 0.05$, the statistical link is significant (Ss, 95% confidence), ** = $p < 0.01$, the statistical link is significant (Ss, 99% confidence); *** = $p < 0.001$, the statistical link is highly significant (Ss, 99.9% confidence)]

For SPEI 3, in Cotnari, the water balance worsens in 7 months of the year, from April to September, the decrease of SPEI value was accentuated and statistically significant. In Roman, and especially in Iași, the situation is similar. The springs, summers and years as a whole have declining SPEI values. Only at Cotnari, throughout the period October–March 1961–2018, the values of SPEI 3 increased slightly, imprinting a trend of improving the water balance in the cold season.

From the mediation level SPEI 6 to that of SPEI 12, the trends of precipitation quantities and water balance from 1961–2018 acquire a similar arealographic contour for the 3 stations (Table 3).

Considering only SPEI 6–12, the water balance indicates an intensity (with increasing statistical representativeness) of the water deficit (Table 3). Water shortages for environmental components increased over the analysed period and will most likely increase in the future.

According to our results, SPEI values in the vegetation season in Cotnari indicate the accentuation of the water deficit in the period 1961–2018, when the SPEI values that showed statistical significance ranged between –0.12 ($p < 0.01$) for SPEI 1 and –0.23 ($p < 0.01$) for SPEI 12. Also, the annual values of SPEI in Cotnari decreased during the analysed period from –0.07 ($p < 0.05$) for SPEI 1 to –0.22 ($p < 0.01$) for SPEI 12.

In 2011, Potop highlighted for a territory located east of our study area (for the Republic of Moldova and for the period 1955–2009) through SPI and SPEI the tendency of increased intensity of droughts during the summer months. The same author noted the high rate of increase in the evapotranspiration reference value for the summer season.

The fact that the decreasing trends of SPEI 12 are statistically significant for all the analysed time units, it is a warning sign, which should warn those responsible for the management of water resources in the considered area, so that in the future, water shortages in the Cotnari area and NE Romania can be controlled.

The results obtained by us are in agreement with those obtained on a larger scale (the territory between the Carpathians and the Dniester) for the period 1961–2012 by Mihăilă and Tanasă (2013), Mihăilă et al. (2017) and for Europe by Kingston et al. (2015) and Dukat et al. (2022).

Through SPEI, we have presented the depreciation of the involutive climatic context of the water balance for Cotnari and its surroundings in a complex and comprehensive manner, and the results obtained are consistent with those in the cited studies. Cumulative and amplified SPEI deficit for the 58 years analysed could be able to introduce many changes in the geographical landscape of the region (Mihăilă et al. 2017).

5 Conclusion

This study assesses the variability of the water balance in Cotnari and surroundings using SPEI (and NDVI) for the period 1961–2018.

The variability of the SPEI in the Cotnari area is characterized by extremes, oscillating between large surpluses and significant deficits. According to SPEI, between 57.2 and 61.4% of the months were normal in terms of water balance. Between 19.3 and 25.1% were water surplus months (extremely wet months were between 0.6 and 3% of cases) and between 17.1 and 20.8% were water deficit months (extremely dry months were between 0.4 and 2.43% of cases). SPEI showed extremely dry or wet intervals in both seasons across all averaging intervals (SPEI 1–12). Both extreme deficit and extreme surplus are more pronounced in the warm season of the year. SPEI ranged from –2.4 units to +2.7 units.

The links between NDVI and SPEI become stronger as SPEI reaches extreme values (above 1.5 units or below –1.5 units). The claim that vegetation always responded to water surplus, or deficit episodes as indicated by SPEI through NDVI values is supported by satellite images averaged for water surplus (29 scenes) and water deficit (23 scenes), as well as satellite scenes from August 1991 and July 2007 (selected for SPEI extremes).

SPEI trends become clearer, more pronounced and with increasing statistical confidence for the entire investigated area as the reference interval increases from SPEI 1 to SPEI 12. The water balance indicates a decrease in available water resources during the analysed interval (1961–2018).

6 References

Angearu, C. V., Ontel, I., Boldeanu, G., Mihăilescu, D., Nertan, A., Crăciunescu, V., Catană, S. et al. 2020: Multi-temporal analysis and trends of the drought based on MODIS data in agricultural areas, Romania. Remote Sensing 12-23. DOI: https://doi.org/10.3390/rs12233940

Apopei, L. M., Mihăilă, D., Bistricean, P. I. 2020: Thermo-hydrometric arguments in the demonstration of foehnal circulation in Cotnari, Romania. Geobalcanica, Proceedings 2020. Ohrid. DOI: https://doi.org/10.18509/GBP.2020.25

Bandoc, G., Prăvălie, R. 2015: Climatic water balance dynamics over the last five decades in Romania's most arid region, Dobrogea. Journal of Geographical Sciences 25. DOI: https://doi.org/10.1007/s11442-015-1236-1

Bannari, A., Morin, D., Bonn, F., Huete, A. R. 1995: A review of vegetation indices. Remote Sensing Reviews 13-1,2. DOI: https://doi.org/10.1080/02757259509532298

Beguería, S., Vicente-Serrano, S. M., Reig, F., Latorre, B. 2014: Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. International Journal of Climatology 34. DOI: https://doi.org/10.1002/joc.3887

Bordun, C., Nertan, A. T., Cimpeanu, S. M. 2018: Evolution of vegetation fraction cover in agricultural areas affected by prolonged droughts in the south regions of Romania. Agriculture for Life, Life for Agriculture Conference Proceedings.

Boroneant, C., Ionita, M., Brunet, M., Rimbu, N. 2011: CLIVAR-SPAIN contributions: seasonal drought variability over the Iberian Peninsula and its relationship to global sea surface temperature and large scale atmospheric circulation. WCRP OSC: Climate Research in Service to Society, Denver.

Chavez, J. P. S. 1996: Image-based atmospheric corrections – revisited and improved. Photogrammetric Engineering and Remote Sensing 62-9.

Cheval, S. 2015: The standardized precipitation index – an overview. Romanian Journal of Meteorology 12-1,2.

Cotea, V. D., Ciubotaru, M., Barbu, N. N., Cotea, V. V., Magazin, G. P., Grigorescu, C. C. 2006: Podgoria Cotnari / Cotnari vineyard. București.

Dascălu, S. I., Gothard, M., Bojariu, R., Birsan M. V., Cică, R., Vintilă, R., Adler, M. J. et al. 2016: Drought-related variables over the Bârlad basin (Eastern Romania) under climate change scenarios. Catena 141. DOI: https://doi.org/10.1016/j.catena.2016.02.018

Dobri, R. V., Sfîcă, L., Amihăesei, V. A., Apostol, L., Țîmpu, S. 2021: Drought extent and severity on arable lands in Romania derived from normalized difference drought index (2001–2020). Remote Sensing 13-8. DOI: https://doi.org/10.3390/rs13081478

Dragotă, C. S., Mărculeț, C., Mic, E. L., Grofu, A. 2012: Mapping dryness time-scales in the curvature Carpathians and Subcarpathians (Romania) by the standardized precipitation index. Romanian Journal of Geography 56-2.

Dukat, P., Bednorz, E., Ziemblińska, K., Urbaniak, M. 2022: Trends in drought occurrence and severity at mid-latitude European stations (1951–2015) estimated using standardized precipitation (SPI) and precipitation and evapotranspiration (SPEI) indices. Meteorology and Atmospheric Physics 134-20. DOI: https://doi.org/10.1007/s00703-022-00858-w

Hakam, O., Baali, A., El Kamel, T., Ahouach, Y., Azennoud, K. 2022: Comparative evaluation of various drought indices (DIs) to monitor drought status: A case study of Moroccan Lower Sebou basin. Kuwait Journal of Science 49-3. DOI: https://doi.org/10.48129/kjs.13911

Jianqing, Z., Jinlong, H., Buda, S., Lige, C., Yanjun, W., Tong, J., Fischer, T. 2016: Intensity, area and duration analysis of droughts in China 1960–2013. Climate Dynamics 48. DOI: https://doi.org/10.1007/S00382-016-3066-Y

Kendall, M. G. 1975: Rank correlation methods. London.

Kingston, D. G., Stagge, J. H., Tallaksen, L. M., Hannah, D. M. 2015: European-scale drought: Understanding connections between atmospheric circulation and meteorological drought indices. Journal of Climate 28. DOI: https://doi.org/10.1175/JCLI-D-14-00001.1

Mann, H. B. 1945: Nonparametric tests against trend. Econometrica 13-3. DOI: https://doi.org/10.2307/1907187

Mihai, L., Stancalie, A., Sporea, A., Sporea, D., Nertan, A., Mihailescu, D. 2016: Drought vegetation monitoring using in situ and satellite data, in the Caracal plain of Romania. Romanian Reports in Physics 68-2.

Mihăilă, D. 2006: Câmpia Moldovei-studiu climatic. Suceava.

Mihăilă, D., Bistricean, P. I., Lazurca, L. G., Briciu, A. E. 2017: Climatic water deficit and surplus between the Carpathian Mountains and the Dniester River (1961–2012). Environmental Monitoring and Assessment 189. DOI: https://doi.org/10.1007/s10661-017-6253-3

Mihăilă, D., Briciu, A. E. 2012: Actual climate evolution in the NE Romania. Manifestations and consequences, 12th International Multidisciplinary Scientific GeoConference, SGEM Conference Proceedings, 4. Albena.

Mihăilă, D., Tanasă, I. 2013: The characteristics of the atmospheric precipitating during the hot season of the year in the Plateau of Suceava. Present Environment & Sustainable Development 7-2.

Milanović, M., Micić, T., Lukić, T., Nenadović, S. S., Basarin, B., Filipović, D., Tomić, M. et al. 2019: Application of Landsat-derived NDVI in monitoring and assessment of vegetation cover changes in Central Serbia. Carpathian Journal of Earth and Environmental Sciences 14-1. DOI: https://doi.org/10.26471/cjees/2019/014/064

Morar, C., Lukić, T., Basarin, B., Valjarević, A., Vujičić, M., Niemets, L., Telebienieva, I. et al. 2021: Shaping sustainable urban environments by addressing the hydro-meteorological factors in landslide occurrence: Ciuperca Hill (Oradea, Romania). International Journal of Environmental Research and Public Health 18-9. DOI: https://doi.org/10.3390/ijerph18095022

Neadealcov, M., Răileanu, V., Sîrbu, R., Cojocariu, R. 2015: The use of standardized indicators (SPI and SPEI) in predicting droughts over the Republic of Moldova territory. Present Environment & Sustainable Development 9-2. DOI: https://doi.org/10.1515/pesd-2015-0032

Ontel, I., Irimescu, A., Boldeanu, G., Mihailescu, D., Angearu, C. V., Nertan, A., Craciunescu, V. et al. 2021: Assessment of soil moisture anomaly sensitivity to detect drought spatio-temporal variability in Romania. Sensors 21-24. DOI: https://doi.org/10.3390/s21248371

Pascoa, P., Gouveia, C., Russo, C. A., Bojariu, R., Vicente-Serrano, M. S., Trigo, M. R. 2020: Drought impacts on vegetation in Southeastern Europe. Remote Sensing 12-13. DOI: https://doi.org/10.3390/rs12132156

Patriche, C. V. 2009: Modele statistice aplicate în climatologie. Iași.

Piticar, A. 2013: Studii privind schimbările climatice recente din nord-estul României. Ph.D. thesis, Universitatea Babeș-Bolyai. Cluj-Napoca.

Piticar, A., Mihăilă, D., Lazurca, L. G., Bistricean, P. I., Puțuntică, A., Briciu, A. E. 2016: Spatiotemporal distribution of reference evapotranspiration in the Republic of Moldova. Theoretical and Applied Climatology 124-3. DOI: https://doi.org/10.1007/s00704-015-1490-2

Pörtner, H. O., Roberts, D. C., Tignor, M., Poloczanska, E. S., Mintenbeck, K., Alegría, A., Craig, M. et al. 2022: Climate change 2022 – impacts, adaptation and vulnerability. Working Group II contribution to the sixth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, New York. DOI: https://doi:10.1017/9781009325844

Potop, V. 2003: Repartiția spațială a secetelor cu grad diferit de intensitate pe teritoriul Republicii Moldova, Proceedings of the Symposium 'GIS', no. 9, Annals of the University »Alexandru Ioan Cuza«, Tom XLIX, s.IIc., Geography. Iași.

Potop, V. 2011: Evolution of drought severity and its impact on corn in the Republic of Moldova. Theorethical and Applied Climatology 105-3,4. DOI: https://doi.org/10.1007/s00704-011-0403-2

Prăvălie, R., Sîrodoev, I., Peptenatu, D. 2014: Detecting climate change effects on forest ecosystems in Southwestern Romania using Landsat TM NDVI data. Journal of Geographical Sciences 24. DOI: https://doi.org/10.1007/s11442-014-1122-2

Roşca, C. F. 2020: Variabilitatea climatică şi efectele induse asupra utilizării terenurilor în Câmpia Română (Sectorul Jiu-Olt). Ph.D. thesis, Universitatea Babeş-Bolyai. Cluj-Napoca.

Rouse, J. W., Haas, H., Schell, J. A., Deering, D. W. 1973: Monitoring vegetation systems in the Great Plains with ERTS. Paper presented at the Third ERTS Symposium. Internet: https://ntrs.nasa.gov/api/citations/19740022614/downloads/19740022614.pdf (3. 6. 2021).

Rouse, J. W., Haas, R. H., Schell, J.A., Deering, D. W., Harlan, J. C. 1974: Monitoring the vernal advancements and retrogradation (greenwave effect) of natural vegetation. NASA/GSFC Final Report, NASA, Greenbelt, MD. Internet: https://ntrs.nasa.gov/api/citations/19730017588/downloads/19730017588.pdf (12. 6. 2021).

Sandu, I. 2008: Clima României. Bucharest.

Sen, P. K. 1968: Estimates of the regression coefficient based on Kendall's Tau. Journal of the American Statistical Association 63-324. DOI: https://doi.org/10.1080/01621459.1968.10480934

Sfîcă, L. 2015: Clima Culoarului Siretului şi a regiunilor limitrofe. Ph.D. thesis, Universitatea Alexandru Ioan Cuza Iaşi.

Sfîcă, L., Ichim, P., Apostol, L., Ursu, A. 2018: The extent and intensity of the urban heat island in Iași city, Romania. Theoretical and Applied Climatology 134. DOI: https://doi.org/10.1007/s00704-017-2305-4

Spinoni, J., Antofie, T., Barbosa, P., Bihari, Z., Lakatos, M., Szalai, S., Szentimrey, T. et al. 2013: An overview of drought events in the Carpathian Region in 1961–2010. Advances in Science and Research 10. DOI: https://doi.org/10.5194/asr-10-21-2013

Stagge, J. H., Tallakse, T. L., Gudmundsson, L., Van Loon, A. F., Stahl, K. 2015: Candidate distributions for climatological drought indices (SPI and SPEI). International Journal of Climatology 35-13. DOI: https://doi.org/10.1002/joc.4267

Tănasă, I. 2011: Clima Podişului Sucevei – fenomene de risc, implicații în dezvoltarea durabilă. Ph.D. thesis, Universitatea Ștefan cel Mare, Suceava.

Tucker, C. J. 1979: Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment 8-2. DOI: https://doi.org/10.1016/0034-4257(79)90013-0

Vicente-Serrano, S. M., Beguería, S., López-Moreno, J. I. 2010: A multi-scalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. Journal of Climate 23-7. DOI: https://doi.org/10.1175/2009JCLI2909.1

Vicente-Serrano, S. M., Beguería, S., Lorenzo-Lacruz, J., Camarero, J. J., López-Moreno, J. I., Azorin-Molina, C., Revuelto, J. et al. 2012: Performance of drought indices for ecological, agricultural, and hydrological applications. Earth Interactions 16. DOI: https://doi.org/10.1175/2012EI000434.1

Weier, J., Herring, D. 2000: Measuring Vegetation (NDVI & EVI). Nasa Earth Observatory. Washington DC.

World Meteorological Organization 2012: Standardized Precipitation Index User Guide. WMO 1090. Geneva. Internet: https://www.droughtmanagement.info/literature/WMO_standardized_precipitation_index_user_guide_en_2012.pdf (5. 10. 2023).

World Meteorological Organization 2018: Guide to Instruments and Methods of Observation. Volume I – Measurement of Meteorological Variables. WMO 8. Geneva. Internet: https://community.wmo.int/en/activity-areas/imop/wmo-no_8 (5. 10. 2023).

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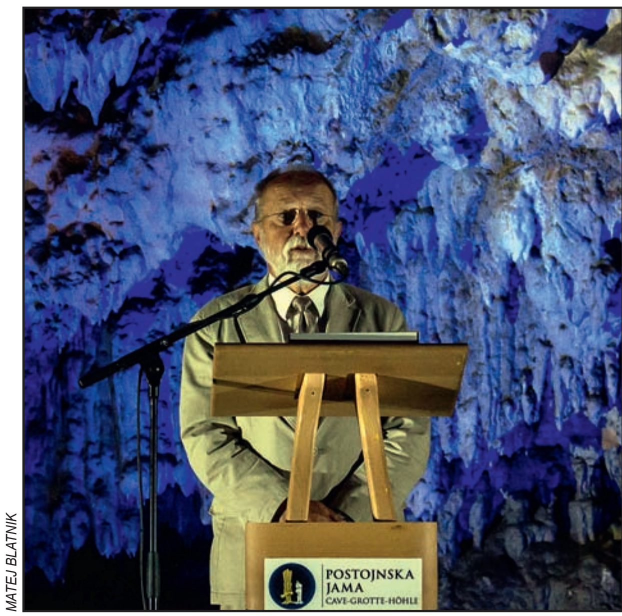
RESEARCH WORK AND CONTRIBUTION OF ANDREJ KRANJC TO GEOGRAPHY AND KARSTOLOGY

Nataša Ravbar



Andrej Kranjc during his welcoming speech at the celebration of the 50th anniversary of the International Union of Speleology in Postojna Cave on June 19th, 2015.

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Nataša Ravbar[1]

Research work and contribution of Andrej Kranjc to geography and karstology

ABSTRACT: Andrej Kranjc was one of the leading geographers of his generation at the national and international level. His research covers a wide range of topics related to karst geomorphology, speleology, and hydrology, as well as the history of karstology and karst terminology. This article presents his fruitful and active research activities, his contribution to geography, and his role and importance to karstology. His research and publications were honoured by his appointment as a member of the Slovenian Academy of Sciences and Arts. Through his scientific, professional, and educational work, Kranjc has had a lasting impact on Slovenian geography and has contributed significantly to the establishment of karstology in the professional community and among the general public. In addition, his work led to many important initiatives, such as the International Karstological School and the Doctoral study programme Karstology. It is also thanks to him that Slovenia is recognised as a karst country and is among the world leaders in karstology.

KEYWORDS: Andrej Kranjc, physical geography, karstology, speleology, research work

Raziskovalno delo in prispevek Andreja Kranjca h geografiji in krasoslovju

POVZETEK: Andrej Kranjc je bil eden vodilnih geografov svoje generacije na nacionalni in mednarodni ravni. Njegove raziskave zajemajo širok spekter tem, povezanih s kraško geomorfologijo, speleologijo in hidrologijo ter zgodovino krasoslovja in kraško terminologijo. V članku predstavljamo njegove plodne in aktivne raziskovalne dejavnosti, njegov prispevek h geografiji ter njegovo vlogo in pomen za krasoslovje. Za njegove raziskave in objave je bil počaščen z imenovanjem za člana Slovenske akademije znanosti in umetnosti. Kranjc je s svojim znanstvenim, strokovnim in pedagoškim delom trajno zaznamoval slovensko geografijo ter pomembno prispeval k uveljavitvi krasoslovja v strokovni in širši javnosti. Njegovo delo je pripeljalo do številnih pomembnih pobud, kot sta Mednarodna krasoslovna šola in Doktorski študijski program Krasoslovje. Tudi po njegovi zaslugi je Slovenija prepoznana kot kraška država in je med vodilnimi v svetu na področju krasoslovja.

KLJUČNE BESEDE: Andrej Kranjc, fizična geografija, krasoslovje, speleologija, raziskovalno delo

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[1] Research Centre of the Slovenian Academy of Sciences and Arts, Karst Research Institute, Postojna, Slovenia
natasa.ravbar@zrc-sazu.si (https://orcid.org/0000-0002-0160-1460)

1 Introduction

Slovenian academic Prof. Dr. Andrej Kranjc (1943–2023) is one of the most prominent karst researchers at national and the international level, recognised for his achievements in the field of karst geomorphology and hydrology, speleology, karstological terminology and the history of karstology. Although he was a geographer specialising in physical geography, he was primarily a speleologist and karstologist who authored numerous scientific, professional, and popular articles. He was a long-time researcher at the ZRC SAZU Karst Research Institute in Postojna, a member of the Slovenian Academy of Sciences and Arts, and professor emeritus of karstology at the University of Nova Gorica.

This article is dedicated to the life, work and successful research career of Prof. Dr. Andrej Kranjc. In addition to a brief biography, his fruitful and active research activity, his contribution to geography and his role and importance in karstology, which was marked by his strong but friendly character, are highlighted.

2 Research and professional work

Andrej Kranjc was born in Ljubljana on November 5th, 1943 (Savnik 1982). He started caving at the age of 15, and the first non-tourist cave he visited was Matjaževa jama under Šmarna gora hill near Ljubljana. He joined the speleological section of the Železničar Mountaineering Club, where he got acquainted with geologist Dušan Novak, academic Prof. Dr. Jože Bole and academic Prof. Dr. Boštjan Kiauta. Initially, he was most attracted to cave biology, so much so that he wanted to study biology and specialise in the study of cave biota. However, he was also attracted to travel, so he changed his mind shortly before entering university and decided to study geography and archaeology (Ravbar 2014). While still a student, he became an employee of the Karst Research Institute ZRC SAZU in Postojna, where he worked until his retirement in 2010 (Mulec et al. 2023).


FRANCE HABE (© ANDREJ KRANJC ARCHIVES)

Figure 1: Andrej Kranjc in Jama v Grapi in 1971.

He graduated from the Faculty of Arts in Ljubljana in 1971, earned a master's degree in 1977 and a doctorate in 1987. The content of the bachelor's, master's and doctoral theses was a study of karst, supervised by academic Prof. Dr. Ivan Gams. In 1972, he participated in a two-month specialisation course in speleology in Moulis (France) under the supervision of Dr. Alain Mangin, where he became familiar with regional karstology (Ravbar 2023). He then devoted his scientific work to speleology and karst research (Figure 1).

At the beginning of his work at the Karst Research Institute ZRC SAZU he helped to survey caves and later dealt with physical speleology and karst geomorphology. His dissertation dealt with recent fluvial sediments in caves (Kranjc 1986a). He was less concerned with theoretical issues than with regional karstology, karst hydrology, ecological issues, protection and conservation of karst and caves, and karstological terminology. In later years he devoted more time to the history of karstology, especially to the historical significance of Slovenian karst (https://www.sazu.si/clani/andrej-kranjc).

He also dealt with flooding in karst areas and published several regional speleological and karstological studies. He paid special attention to the Škocjan Caves and their protection, the history of karst research and the development of karstology. He edited several monographs, served on editorial boards of national and foreign journals, and was editor of the central karstological journal Acta Carsologica, listed in the Scientific Citation Index, for nearly two decades. He was invited to lecture at universities or conferences on several occasions (Figure 2). His scientific and professional bibliography represents an important contribution to the knowledge of Slovenian karst, to the development of karstology and its terminology. An evaluation of his work can be found in the following chapters.

3 Contribution to geography

Andrej Kranjc's research work covers a wide range of content related to karst geomorphology and hydrology. His main professional articles have been published in Acta Carsologica, Acta geographica Slovenica

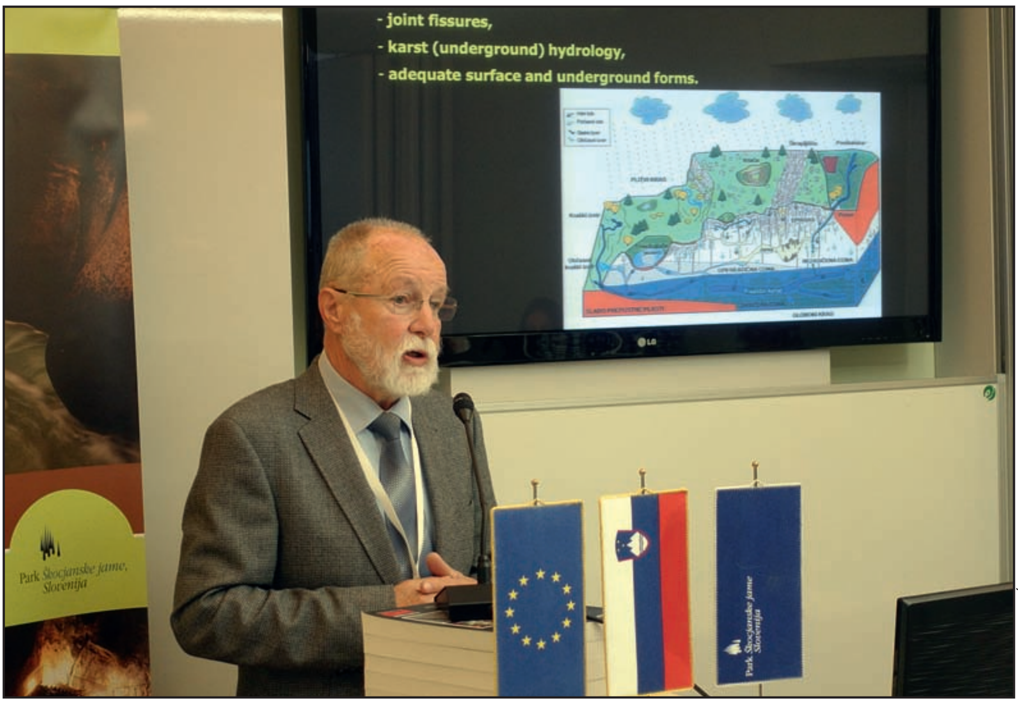

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Figure 2: Kranjc as a keynote speaker at the international conference SOS Proteus, organized on the occasion of the 250th anniversary of the taxonomic description of *Proteus anguinus* in the Škocjan Caves Park in 2018.

(Geografski zbornik), Geografski vestnik (Geographical Bulletin), Planinski vestnik, Proteus, and smaller contributions are collected in Naše jame and in the French journals Karstologia and Spelunca. He also frequently presented the results of his work at national and foreign congresses and symposia. His bibliography lists more than 1,400 units (https://bib.cobiss.net/bibliographies/si/webBiblio/bib301_20230324_093725_00986.html).

3.1 Karst geomorphology and hydrology

His earlier research on karst and caves was connected with the creation of the Basic speleological map of Slovenia, which was carried out in the period 1972–1978 within the framework of the Karst Research Institute ZRC SAZU. The map was gradually prepared for the whole of Slovenia in order to encourage further systematic discovery of caves, more detailed speleological research and study of hydrological, geomorphological, and geological features of karst (Habič, Kranjc and Gospodarič 1973). By surveying the caves, a lot of information and data on the geomorphological evolution of the karst landscape were obtained. With this work, the authors contributed mainly to the subsequent improvement of knowledge about the karst surface, speleogenesis, and hydrology (Habič 1968; Gospodarič 1976; Gospodarič and Habič 1976; Janež et al. 1997).

In his master's thesis on the study of karst in Ribniška Mala gora, Kranjc analyzed the factors affecting the development of karst (Figure 3), especially underground. He compared the underground karst formations and determined the stages of karst and cave development depending on the direction and type of previous water drainage. He concluded that the vertical bifurcation between the Kolpa and Krka rivers is a relatively recent phenomenon and that the reason for this is the karst nature associated with the subsidence of the studied region (Kranjc 1981b).

In his early work he devoted himself mainly to the study of fluvial sediments in caves. In these works, he placed great emphasis on observing and measuring the transport of sediments. Similar studies had already been carried out abroad (e.g., Renault 1968), but in Slovenia, this type of work was considered groundbreaking. It determined the origin and role of fluvial sediments in speleogenesis. In the case of the Reka River, he dealt with the transport of solid particles through the karst underground of the Škocjan Caves and Kačna Cave (Kranjc 1982c; 1986b). He described how much of it is suspended load and how much is bedload in the form of sand and gravel. On this basis, he gave an estimate of erosion intensity. He also observed and compared the coarse suspension load of the Pivka, Nanoščica and Lokva rivers (Kranjc 1982a). He found that the suspended sediment load depends on the geological conditions in the catchment area of the river and the given hydrological conditions. These works formed the basis for later studies on speleogenesis and cave sediments (e.g., Gams 1983; Čar and Gospodarič 1984; Habič et al. 1989; Slabe 1995; Mihevc 2001; Zupan Hajna 2002).

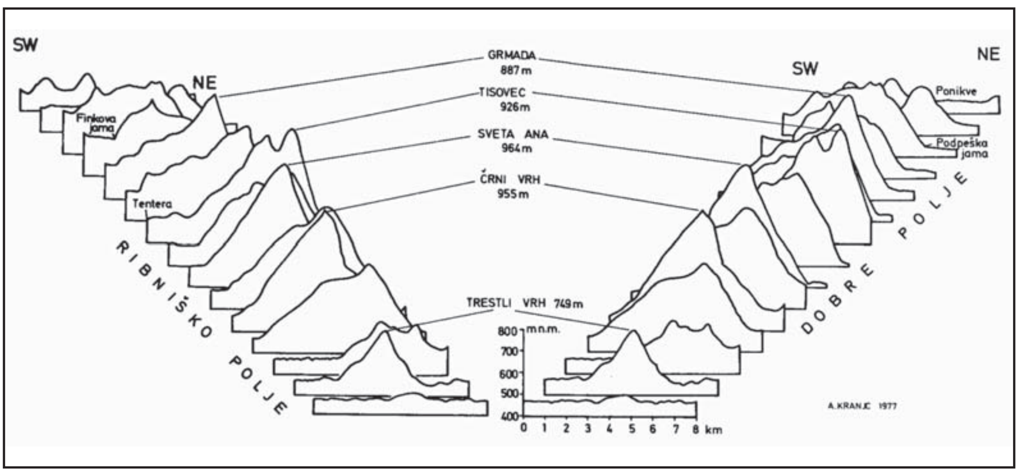

Figure 3: Cross-sections of peaks and slopes of the Mala gora Mountain (Kranjc 1981b).

Such studies have also proved useful for water use plans. An example is a study of contact karst at the transition from volcanic to carbonate rocks in the Ljubija River catchment, where he investigated suspension loading and related problems (Kranjc 1979b). In addition, he conducted petrographic, granulometric, morphometric, and other analyzes of sediments in the Babja jama Cave near Most na Soči and defined sedimentation processes in the cave (Kranjc 1981c). He also studied cave sediments in other caves, such as the Leška planina Shaft (Kranjc and Malečkar 1981).

He was also concerned with temperature measurements in caves, weathering of flowstone and the dynamics of dripstone fall (Kranjc 1974; 1983a; 1999; Kranjc and Opara 2002). He observed acid rain and its influence on underground karst processes. Using Postojna Cave as an example, he found that no accelerated corrosion processes are observed in the cave because the acidic water is neutralized on its way through the underground (Kogovšek and Kranjc 1988; 1989).

In addition, he devoted much of his work to the flooding of karst poljes and along sinking rivers. He described the flooding areas of Kočevje Polje, floods in Cerknica Polje, and along the Reka and Pivka rivers (Kranjc and Lovrenčak 1981; Kranjc 1981a; 1985a; 1985b; Kranjc and Mihevc 1988). These articles discuss

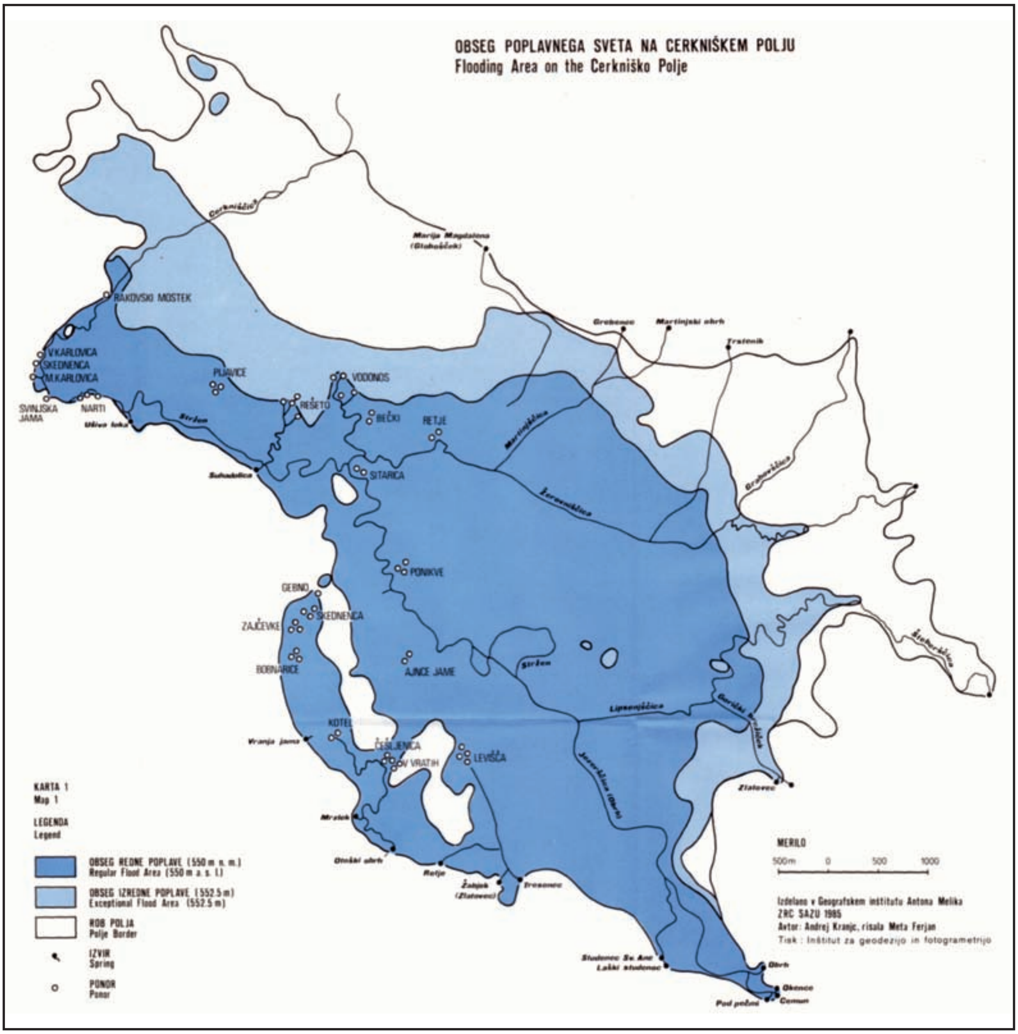

Figure 4: The map of the extent of floods in Cerknica Polje (Kranjc 1985a).

in detail the mechanism and characteristics of floods, as well as hydrological and pedological characteristics of the studied areas. The impact of floods on the life and activities of the population is given special attention. In the case of Cerknica Polje, the emphasis is on the evaluation of historical sources and plans for drainage, land reclamation, and the creation of a permanent lake (Figure 4). The work has been useful for much further research (Smrekar 2000) and, in particular, for the subsequent identification of inundation areas within the poljes and intermittent lakes for the purposes of ephemeral flood mapping (Ravbar et al. 2021). Within the framework of flood research, Kranjc has also been involved in the evaluation of regulatory and melioration measures, as well as in the assessment of damage caused by floods.

3.2 Regional karstology and protection initiatives

Kranjc also studied the geomorphology of various karst regions. He devoted much attention to the Lower Carniola Karst and published the results of his earlier karstological and speleological studies in a booklet Dolenjski kraški svet (Kranjc 1990a; Figure 5). More detailed studies include, for example, the study of the karst of Kočevje Polje (Kranjc 1972b), the karst in the vicinity of Velike Lašče, in which he describes the shallow dolomitic karst, and others (Kranjc and Kogovšek 1987; Kogovšek and Kranjc 1992). He also published numerous cave descriptions (Kranjc 1972c; 1979a; 1982d; 2001) and papers dealing mainly with the Alpine karst (Kenda and Kranjc 1978; Kranjc 1979a; 1982b; 2004a), karst caves types near the Triglav Mountain, and particularly ice caves (Kranjc 1976). He wrote a short paper on karst in Canada and several works on karst in southern China (Kranjc 1983b; Kogovšek et al. 1999).

In the later years of his research activity, Kranjc devoted himself to ecological issues, conservation of karst and its resource exploitation (Kranjc 1990b; 1992; 2002c; 2005). As part of his international activities, he was mainly active in the field of tracing techniques. Between 1992 and 1995, extensive research on contamination transport in karst took place on the Trnovo-Banjšice and Nanos plateaus. Based on field work, various tracers and models were tested. Kranjc summarised the results of this research in a special monograph (Kranjc 1997c). He also participated in various activities of COST projects on hydrogeological aspects

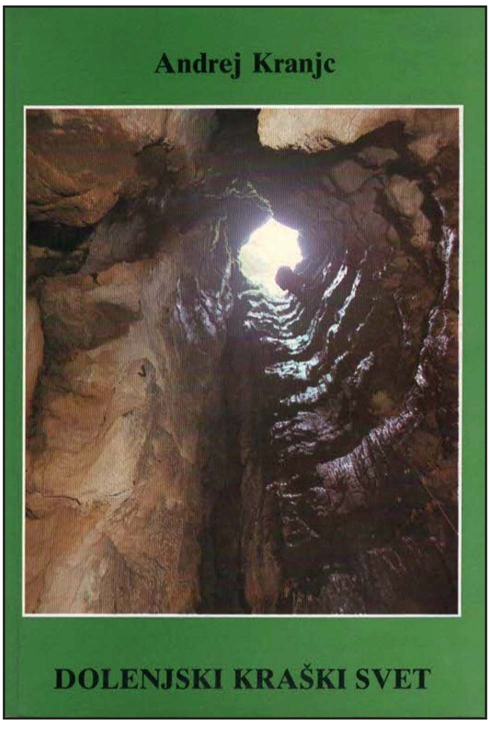

Figure 5: Kranjc is the author of numerous books, of which the booklet Dolenjski kraški svet (Karst of Lower Carniola) is noteworthy (Kranjc 1990a).

of groundwater protection in karst areas and on mapping of vulnerability and risk for protection of carbonate aquifers. Using the Škocjan Caves and Lunan Stone Forest as examples, he devoted considerable attention to the protection and management of the karst natural and cultural heritage (Kranjc and Liu 2001).

3.3 History of karstology and karst terminology

Kranjc also engaged in the history of karstology and speleology (Kranjc 1997a) and wrote articles on Slovenian speleology, which had a broader character (Kranjc 2002a). He was a good connoisseur of the works of Janez Vajkard Valvasor, especially the geomorphological, karstological and speleological contents in his work Slava Vojvodine Kranjske (The Glory of the Duchy of Carniola). He also studied the works of Baltazar Hacquet, whose Oryctographia Carniolica he considered a continuation or improvement of the Valvasor's Slava (Kranjc 1990c; 2006). He also processed the contributions of others who dealt with karstology, e.g., Freyer, Kircher, Martel, or the contributions of Habe, Gams, and others to the development of karstology (e.g., Kranjc 1997b; 1997d; 2002b; 2013; 2020).

Kranjc also dealt with the history of deforestation and reforestation in the Dinaric Karst (Kranjc 2009b; 2012). He contributed to karstological terminology and discussed the origin of the names *Kras* and *Dinara*, as well as terms such as *karst*, *siga*, *estavelle*, *doline*, and *tiankeng* (Kranjc 1972a; 1980; Mikoš et al. 2002; Kranjc 2009a; 2011; Kranjc and Panisset Travassos 2018). Kranjc was also the author of numerous encyclopedia articles. Among others, he contributed extensive geographic descriptions of the Dinaric Karst (Kranjc 2004b).

4 Strengthening karstology

In addition to his substantial contribution to science, he has promoted karst in many activities and roles. Throughout his service, Andrej Kranjc was employed at the ZRC SAZU Karst Research Institute (Figure 6). Over time, he progressed from assistant to scientific advisor, which he became in 1995. Between 1988 and 1995, he was the director of the Institute, but he does not remember this period very fondly due to constant financial uncertainty (Ravbar 2014).

Andrej Kranjc loved to travel. In his everyday life he was torn between Ljubljana and Inner Carniola Region, where, besides the working environment, the karst and the caves irresistibly fascinated him. He was especially attracted by the first-time experience or discovery, the beauty and tranquilly. According to the records in the Cave Registry (2023), he contributed records of about 150 caves and participated in the exploration of almost 200 caves. However, he probably visited and explored even more caves, because cave registers were not always kept. He claimed to have visited at least 600 Slovenian caves, and in total, including caves in other parts of the world, he had visited between 1,000 and 1,200 caves, of which he was very proud (Ravbar 2014). In addition to his professional commitments, he often took long trips with his family in his private life.

As a travel enthusiast, he visited various karst areas on six continents. He was an excellent connoisseur of karst all over the world, especially Chinese karst. Traveling with him was always stimulating. He looked forward to every trip, never grumbled, and brought a positive spirit to the team. He admired the beauty of nature, the hospitality of the locals and the deliciousness of the food, even when the trip was very tiring.

Kranjc was one of the first to see the perspective of Slovenian karstology in the international context. With the support of the Slovenian National Commission for UNESCO, he was the initiator of the world-famous International Karstological School (IKS), which for three decades has been the largest annual meeting of karstologists in the world (https://iks.zrc-sazu.si/en). The IKS is dedicated to a specific topic each year and has provided a wide range of relevant contributions to science. Every year there are between 100 and 150 participants, often over 200 from many countries around the world. In total, more than a thousand people from 63 countries attended the event (Mulec et al. 2023).

In addition, Kranjc always unselfishly shared his extensive expertise with the operators of tourist caves, landscape and regional parks, and other initiatives. For many years, he was the chairman of the Škocjan Caves Expert Council and worked closely with the administrators of Postojna Cave. From 2009 to 2013, he was a member of the academic committee of the UNESCO International Research Centre on Karst,

Figure 6: Kranjc (fourth from left) with his wife Maja Kranjc and his colleagues Janja Kogovšek, Tadej Slabe and Stanka Šebela from the Karst Research Institute in China in 1999.

based in Guilin, China, assisting it in conducting a number of academic exchanges and providing ideas and suggestions for long-term development.

Kranjc has held numerous leading positions in the field of geographical and karstological publications. Since 1989 he has been a member of the editorial board of the central Slovenian karstological journal Acta Carsologica. Between 1993 and 2010 he was its editor-in-chief, later co-editor (Gabrovšek and Ravbar 2023). Under his editorship, the journal experienced an upswing, gained international recognition, and the number of published papers increased. In the 1990s, the electronic edition of Acta Carsologica was introduced, an important step that allowed unlimited and even remote access to all articles. As a result, Acta Carsologica was included in the Web of Science and Scopus databases in 2006 (Gabrovšek and Ravbar 2015). However, Andrej Kranjc was also editor-in-chief (1991–1993) of the central Slovenian geographical journal Geografski vestnik (Geographical Bulletin) and a member of the editorial boards of numerous national and international (from Brazil, Egypt, France, Italy, China, Hungary, Germany, Poland, Russia, and Slovakia) scientific and professional journals in the fields of karstology, speleology, and environmental protection.

Kranjc has been a member of several international professional associations, including the Karst Commission of the International Geographical Union, which he chaired from 2008 to 2016, and several other commissions of the International Geographical Union (e.g., the Commission on Degradation and Desertification and the Commission on the History of Geography). He also served as vice president of the Slovenska Matica (Slovenian Society) for Natural Sciences from 2018 to 2022. In addition, he was a member of the Commission on the History of Speleology of the International Speleological Union, the Karst Commission of the International Association of Hydrogeologists, the Working Groups on Caves and Karst of the World Commission on Protected Areas of the World Conservation Union, the International Association for Quaternary Research, the French Karstological Association (Association Française de Karstologie), and others.

In 1998, he was elected assistant professor of physical geography at the Faculty of Arts in Ljubljana, where he taught karst geography until 2000 (Ogrin 2019). In 2008 he was elected full professor and a year later professor emeritus of karstology at the University of Nova Gorica. He supervised a number of theses and six dissertations by doctoral students from around the world (Ravbar 2007; Ćalić 2009; Lučić 2009; Panisset Travassos 2011; Breg Valjavec 2012; Griffiths 2020). He was also a member of the Senate of the University of Nova Gorica.

Thanks to the vision and perseverance of Andrej Kranjc, the Postgraduate Study Programme of Karstology was established in 2001, the only comprehensive study programme in karstology in the world and the only one in which the student receives the title of Doctor of Science in the field of karstology. The study programme was initially established at the Faculty of Humanities in Koper. Since 2003, the Doctoral study programme Karstology has been conducted under the auspices of the University of Nova Gorica (then Polytechnic), of which Kranjc was the director. The Doctoral study programme Karstology has been recognised as a UNESCO chair since 2014 (https://www.ung.si/en/schools/graduate-school/programmes/3KR). Nearly thirty doctoral students from around the world have already completed the Programme (Mulec et al. 2023).

Kranjc was awarded several times for his achievements. Of particular note are the Golden Plaque and the Anton Melik Prize of the Association of Slovenian Geographers, which he received in 2004 and 2011, respectively. He also received the Prešeren Award for Students, the Order of the Knight of the Academic Palm (Chevalier dans l'Ordre des Palmes Académiques) in 1997, the Award for Research Achievements in the Development and Strengthening of the Identity of Slovenes in Slovenia, which he was the first to receive in 1998, and others.

In 1995 he was elected associate member and in 2001 full member of the Slovenian Academy of Sciences and Arts (SAZU). From 2008 to 2014 he was its secretary general and from 2014 to 2017 its vice president. At SAZU, he also served as chairman of the Council for Environmental Protection. In March 2015, he was appointed a member of the European Academy of Sciences and Arts. In this capacity he has strongly promoted and strengthened karstology.

Kranjc was also a great specialist of international karst literature, which is not surprising, since books were another passion of his. He often told that he had books practically everywhere at home. He had inherited many of them from his father-in-law, but he always found it difficult to resist the temptation to buy another book. He was also an avid postcard collector. His collection included more than 250,000 pieces, which he carefully catalogued. He also collected stamps with karst and cave motifs.

Andrej was modest by nature, he never put himself in the limelight. His personality was characterised above all by openness, thoughtfulness and kindness. He was a man of enormous energy and willpower. Above all, he avoided conflict. In his work he was always precise and thorough. He never boasted, emphasised his many positions and honours, or underlined his accomplishments in any way. He was not only an outstanding scientist, but also a patient teacher and a wonderful colleague. He believed in young people and, was always very supportive.

5 Conclusion

In the last quarter of the 20th century and in the first two decades of the 21st century, Andrej Kranjc had a strong influence on Slovenian geography and contributed to spreading the reputation of Slovenia as a karst country and as a leader in karstology as a science. At the beginning of his research activity he was engaged in physical speleology and karst geomorphology. Then he turned to the study of regional karstology and karst hydrology, which led him to issues of karst protection and conservation. In later years he devoted more time to the history of karstology, especially the historical significance of Slovenian karst and karst terminology. With his research and professional work Andrej Kranjc has contributed to increasing Slovenia's competitiveness and innovation in the field of natural heritage protection.

Kranjc's work has left an indelible mark on the generations of geographers and karst researchers he has inspired, supported, and influenced, and from whom we have learned about karst, as well as on future generations. He has paved the way for us, pointed out directions for future research, and hinted at others as well. This article rounds out his scholarly work by recalling Andrej's contribution to geography and karstology, and introducing the reader to the person and work of our esteemed colleague.

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6 References

Breg Valjavec, M. 2012: Geoinformatic methods for the detection of former waste disposal sites in karstic and nonkarstic regions (case study of dolines and gravel pits). Ph.D. thesis, University of Nova Gorica. Nova Gorica.
Cave Registry, 2023. Cadastre of caves of the Karst Research Institute ZRC SAZU and Speleological Association of Slovenia. Postojna, Ljubljana.
Čar, J., Gospodarič, R. 1984: O geologiji krasa med Postojno, Planino in Cerknico. Acta Carsologica 12.
Ćalić, J. 2009: Uvala: contribution to the study of karst depressions (with selected examples from Dinarides and Carpatho-Balkanides). Ph.D. thesis, University of Nova Gorica. Nova Gorica.
Gabrovšek, F., Ravbar, N. 2015: 60 years of Acta Carsologica: Past, present, future. Acta Carsologica 44-3. DOI: https://doi.org/10.3986/ac.v44i3.4250
Gabrovšek, F., Ravbar, N. 2023: In memoriam. Andrej Kranjc (1943–2023). Acta Carsologica 52-1. DOI: https://doi.org/10.3986/ac.v52i1.13434
Gams, I. 1983: Škocjanski kras kot vzorec kontaktnega krasa. Mednarodni simpozij »Zaščita Krasa ob 160-letnici turističnega razvoja Škocjanskih jam« Sežana.
Gospodarič, R. 1976: Razvoj jam med Pivško kotlino in Planinskim poljem v kvartarju. Acta Carsologica 7.
Gospodarič, R., Habič, P. 1976: Underground water tracing: Investigations in Slovenia 1972– 1975. Postojna.
Griffiths, P. 2020: Managing karst in Coastal British Columbia, Canada: Systems and implementation results. Ph.D. thesis, University of Nova Gorica. Nova Gorica.
Habič, P. 1968: Kraški svet med Idrijco in Vipavo. Prispevek k poznavanju kraškega reliefa. Ljubljana.
Habič, P., Knez, M., Kogovšek, J., Kranjc, A., Mihevc, A., Slabe, T., Šebela, S., Zupan Hajna, N. 1989: Škocjanske jame speleological review. International journal of speleology 18-1,2.
Habič, P., Kranjc, A., Gospodarič, R. 1973: Osnovna speleološka karta Slovenije. Naše jame 15.
Janež, J., Čar, J., Habič, P., Podobnik, R. 1997: Vodno bogastvo visokega krasa. Ranljivost kraške podzemne vode Banjšic, Trnovskega gozda, Nanosa in Hrušice. Idrija.
Kenda, I., Kranjc, A. 1978: Jama pod Rdečo skalo (Mangrtska jama). Planinski vestnik 78.
Kogovšek, J., Kranjc, A. 1988: Opazovanje kislosti padavin v Postojni v letih 1985–1987. Geografski vestnik 60.
Kogovšek, J., Kranjc, A. 1989: Vpliv kislih padavin na procese v Postojnski jami. Acta Carsologica 18.
Kogovšek, J., Kranjc, A. 1992: Intenzivnost zakrasevanja v dolomitnem krasu (na primeru Lašč). Geografski vestnik 64.
Kogovšek, J., Kranjc, A., Slabe, T., Šebela, S. 1999: South China Karst 1999, Preliminary research in Yunnan. Acta Carsologica 28-2. DOI: https://doi.org/10.3986/ac.v28i2.495
Kranjc, A. 1972a: Estavela – inversac?. Naše jame 14.
Kranjc, A. 1972b: Kraški svet Kočevskega polja in izraba njegovih tal. Geographica Slovenica 13.
Kranjc, A. 1972c: Pološka jama in njen pomen pri raziskovanju slovenskega alpskega podzemlja. Planinski vestnik 72.
Kranjc, A. 1974: Jama Skednevnica. Primer mehanskega razpadanja sige. Proteus 36.
Kranjc, A. 1976: Tipi kraških votlin v Triglavskem pogorju. Acta Carsologica 7.
Kranjc, A. 1979a: Jama Srnica (Labirint pod Kaninom). Planinski vestnik 79.
Kranjc, A. 1979b: Kras v povirju Ljubije. Geografski vestnik 51.
Kranjc, A. 1980: Siga: prispevek k slovenskemu kraškemu imenoslovju. Geografski vestnik 52.
Kranjc, A. 1981a: Poplavni svet na Kočevskem polju. Geografski zbornik 21.
Kranjc, A. 1981b: Prispevek k poznavanju razvoja krasa v Ribniški Mali gori. Acta Carsologica 9.
Kranjc, A. 1981c: Sedimenti iz Babje jame pri Mostu na Soči. Acta Carsologica 10.
Kranjc, A. 1982a: Erozija v porečju Pivke. Geografski vestnik 54.
Kranjc, A. 1982b: Jama pod ledenikom. Planinski vestnik 82.
Kranjc, A. 1982c: Prod iz Kačne jame. Naše jame 23/24.
Kranjc, A. 1982d: Rupa na Brodu. Dolenjski kras, 49/50.
Kranjc, A. 1983a: Dinamika odpadanja sige v Golobji luknji. Predjama. Acta Carsologica 11.
Kranjc, A. 1983b: Kras v Kanadi. Geografski vestnik 55.
Kranjc, A. 1985a: Cerkniško jezero in njegove poplave. Geographica Slovenica 25.
Kranjc, A. 1985b: Poplavni svet ob Pivki. Ljudje in kraji ob Pivki 2. Postojna.

Kranjc, A. 1986a: Recentni fluvialni jamski sedimenti, njihovo nastajanje in vloga v speleogenezi. Ph.D. thesis, Univerza v Ljubljani. Ljubljana.
Kranjc, A. 1986b: Transport rečnih sedimentov skozi kraško podzemlje na primeru Škocjanskih jam. Acta Carsologica 14/15.
Kranjc, A. 1990a: Dolenjski kraški svet. Novo mesto.
Kranjc, A. 1990b: Jamski turizem na Krasu – med najstarejšimi turističnimi panogami. Primorje: zbornik 15. zborovanja slovenskih geografov, Portorož, 24.–27. oktobra 1990. Ljubljana.
Kranjc, A. 1990c: Valvasor in kraško podzemlje. Valvasorjev zbornik: ob 300-letnici izida Slave vojvodine Kranjske. Ljubljana.
Kranjc, A. 1992: Degradacija kraškega podzemlja. Geographica Slovenica 23.
Kranjc, A. 1997a: Karstology and speleology in Slovenia: from the history of karst and cave science to their perspectives. Annales. Series historia naturalis 7-11.
Kranjc, A. 1997b: The significance of E. A. Martel for speleology in Slovenia. International Journal of Speleology 26-3,4. DOI: http://dx.doi.org/10.5038/1827-806X.26.3.2
Kranjc, A. 1997c: Tracer hydrology 97: Proceedings of the 7th International Symposium on Water Tracing, Portorož, Slovenia, 26th – 31th May 1997. Rotterdam.
Kranjc, A. 1997d: Vloga slovenskih geografov v sodobnih raziskavah krasa. Geografski vestnik 69.
Kranjc, A. 1999: Speleothem fall (an example of a sudden stalactite collapse in Škocjanske jame). Acta Carsologica 28-1.
Kranjc, A. 2001: Podpeška jama: k odkritjem onstran sifonov. Naše jame 43.
Kranjc, A. 2002a: Anthron Society (Postojna 1889–1911), the beginning of organised speleology in Slovenia. Acta Carsologica 31-2. DOI: https://doi.org/10.3986/ac.v31i2.397
Kranjc, A. 2002b: Pomen H. Freyerja in Deželnega muzeja v Ljubljani za speleologijo. Zbornik za zgodovino naravoslovja in tehnike 15/16.
Kranjc, A. 2002c: The history of karst resources exploitation: An example of iron industry in Kranjska (Slovenia). Theoretical and applied karstology 15.
Kranjc, A. 2004a: Ice and alpine caves in Slovenia in older literature (17th to 19th century). Acta Carsologica 33-1. DOI: https://doi.org/10.3986/ac.v33i1.315
Kranjc, A. 2004b: Dinaric karst. Encyclopedia of Caves and Karst Science. New York, London.
Kranjc, A. 2005: Some large dolines in the Dinaric karst. Cave and Karst Science 32-2,3.
Kranjc, A. 2006: Baltazar Hacquet (1739/40–1815), the Pioneer of Karst Geomorphologists. Acta Carsologica 35-2. DOI: https://doi.org/10.3986/ac.v35i2-3.544
Kranjc, A. 2009a: An example of karst terminology evolution: From »Dolina« to »Tiankeng« Zhongguo Yanrong 28-2.
Kranjc, A. 2009b: History of deforestation and reforestation in the Dinaric Karst. Geographical Research 47-1. DOI: https://doi.org/10.1111/j.1745-5871.2008.00552.x
Kranjc, A. 2011: The origin and evolution of the term »karst« Procedia – Social and Behavioral Sciences 11. DOI: https://doi.org/10.1016/j.sbspro.2011.05.170
Kranjc, A. 2012: Dinaric Karst: an example of deforestation and desertification of limestone terrain. Deforestation around the world. Rijeka.
Kranjc, A. 2013: Ivan Gams – karstologist. Acta geographica Slovenica 53-1. DOI: https://doi.org/10.3986/AGS53101
Kranjc, A. 2020: Teorija hidrofilacij Atanazija Kircherja: prva znanstvena razlaga presihanja Cerkniškega jezera. Življenje in tehnika 71-5.
Kranjc, A., Kogovšek, J. 1987: Kam teče Predvratnica. Naše jame 29.
Kranjc A., Lovrenčak, F. 1981: Poplavni svet na Kočevskem polju. Geografski zbornik 21.
Kranjc, A., Liu, H. 2001: Lunan »Shilin« (Stone Forest) human impact and protection of (eventual) World Heritage Site (Yunnan, China). Acta Carsologica 30-1.
Kranjc, A., Malečkar, F. 1981: Brezno pri Leški planini: dopolnilne raziskave. Naše jame 23/24.
Kranjc, A., Mihevc, A. 1988: Poplavni svet ob Notranjski Reki. Geographica Slovenica 28.
Kranjc, A., Opara, B. 2002: Temperature Monitoring in Škocjanske jame Caves. Acta Carsologica 31-1. DOI: https://doi.org/10.3986/ac.v31i1.399
Kranjc, A., Panisset Travassos, L. E. 2018: On the origin of the name Dinara. Acta Carsologica 47-1. DOI: https://doi.org/10.3986/ac.v47i1.7021

Lučić, I. 2009: Povijest dinarskog krša na primeru Popova polja. Ph.D. thesis, University of Nova Gorica. Nova Gorica.

Mihevc, A. 2001: Speleogeneza divaškega krasa. Ljubljana. DOI: https://doi.org/10.3986/9789610503224

Mikoš, M., Kranjc, A., Matičič, B., Müller, J., Rakovec, J., Roš, M., Veselič, M., Brilly, M. 2002: Hidrološko izrazje. Acta hydrotechnica 20.

Mulec, J., Slabe, T., Šebela, S., Zupan Hajna, N., Knez, M., Čeligoj Biščak, J. (eds.) 2023: 75 let Inštituta za raziskovanje krasa. Ljubljana.

Ogrin, D. (ed.) 2019: Razvoj geografije na Slovenskem – 100 let študija geografije na Univerzi v Ljubljani. Ljubljana.

Panisset Travassos, L. E. 2011: The cultural importance of karst and caves. Ph.D. thesis, University of Nova Gorica. Nova Gorica.

Ravbar, N. 2007: Vulnerability and risk mapping for the protection of karst waters in Slovenia. Ph.D. thesis, University of Nova Gorica. Nova Gorica.

Ravbar, N. 2014: Interview with Andrej Kranjc. Acta Carsologica 43-1. DOI: https://doi.org/10.3986/ac.v43i1.900

Ravbar, N. 2023: In memoriam: Professeur Andrej Kranjc. Karstologia 81.

Ravbar, N., Mayaud, C., Blatnik, M., Petrič, M. 2021: Determination of inundation areas within karst poljes and intermittent lakes for the purposes of ephemeral flood mapping. Hydrogeological Journal 29. DOI: https://doi.org/10.1007/s10040-020-02268-x

Renault, P. 1968: Contribution à l'étude des actions mécaniques et sédimentologiques dans la spéléogenèse. Annales de spéléologie 23-3.

Savnik, R. 1982: Kranjc, Andrej. Primorski slovenski biografski leksikon: 8. snopič Kacin–Križnar, 2. knjiga. Gorica.

Slabe, T. 1995: Cave rocky relief and its speleogenetical significance. Ljubljana.

Smrekar, A. 2000: Cerkniško polje kot primer poseljenega kraškega ranljivega območja. Geographica Slovenica 33-1.

Zupan Hajna, N. 2002: Origin of fine-grained carbonate clasts in cave sediments. Acta Carsologica 31-2. DOI: https://doi.org/10.3986/ac.v31i2.392

CULINARY TOURISM IN NATURAL PROTECTED AREAS: THE CASE OF THE CUXTAL ECOLOGICAL RESERVE IN YUCATAN, MEXICO

Ana Laura González-Alejo, Christoph Neger

Variety of locally produced chilies used in different dishes of the cuisine of the Cuxtal Ecological Reserve.

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Ana Laura González-Alejo[1], Christoph Neger[2]

Culinary tourism in natural protected areas: The case of the Cuxtal Ecological Reserve in Yucatan, Mexico

ABSTRACT: The Cuxtal Ecological Reserve is located in the urban periphery of Merida. This reserve represents an element of tourist interest due to the diversity of tourist resources, although these have not been recognized yet. In addition, most of the local population has traditional culinary knowledge, which is little explored from a tourist perspective. This article proposes to identify the culinary resources of the reserve to elaborate a culinary map. The study is based on in-depth interviews with residents to assess their culinary knowledge, visitor surveys, and the field´s traditional food and agricultural product mapping. The results show that it has the potential to develop culinary tourism. Gastronomy can play an important role in boosting the local economy and conserving culinary identity among the inhabitants under the pressure of ultra-processed food from Merida.

KEYWORDS: culinary tourism, culinary mapping, food mapping, natural protected areas, Yucatan, Cuxtal, Mexico

Kulinarični turizem na naravnih zavarovanih območjih: primer ekološkega rezervata Cuxtal na Jukatanu v Mehiki

POVZETEK: Ekološki rezervat Cuxtal leži na mestnem obrobju Meride. Ta rezervat je turistična zanimivost zaradi raznolikosti turističnih virov, čeprav ti kot takšni še niso bili prepoznani. Poleg tega ima večina lokalnega prebivalstva tradicionalno kulinarično znanje, ki je s turističnega vidika slabo raziskano. V članku predlagamo opredelitev kulinaričnih virov rezervata, da bi izdelali kulinarični zemljevid. Študija temelji na poglobljenih intervjujih s prebivalci, s katerimi smo ocenili njihovo kulinarično znanje in tradicionalne metode. Rezultati kažejo, da ima rezervat potencial za razvoj kulinaričnega turizma. Gastronomija ima lahko pomembno vlogo pri spodbujanju lokalnega gospodarstva in ohranjanju kulinarične identitete prebivalcev pod pritiskom predelane hrane iz Meride.

KLJUČNE BESEDE: kulinarični turizem, kulinarično kartiranje, kartiranje hrane, naravna zavarovana območja, Jukatan, Cuxtal, Mehika

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[1] Postdoctoral researcher of the National Council of Science and Technology, Institute of Geography, National Autonomous University of Mexico, Mexico City, Mexico
analgleza@comunidad.unam.mx (https://orcid.org/0000-0003-3446-8093)

[2] Institute of Geography, National Autonomous University of Mexico, Mexico City, Mexico
neger@geografia.unam.mx (https://orcid.org/0000-0001-5210-5005)

1 Introduction

Recent studies have shown the importance of gastronomy and food and their relationship with tourism. They revealed that the gastronomic experience could enhance the regional attraction of a tourist destination (Quan and Wang 2004; Andersson, Mossberg and Therkelsen 2017). Other studies affirm that food tourism contributes to the diversification of rural economies through the mobilization of local actors (Bessière 1998), the integration of sustainable supply chains, and the promotion of employment and economic growth for complementary sectors and the supply chain itself (Eastham 2019). In the opposite direction, some research has revealed that globalization and the massification of tourism tend to homogenize the food supply of tourist destinations so that the promotion of traditional gastronomy linked to the host territory can contribute to the rescue of heritage local gastronomy and the reactivation of the value chain associated with it (Kumar 2019) whether they are agricultural, livestock, craft or service activities. From an environmental perspective, implementing agrotourism activities in peri-urban spaces can counteract the negative impacts of urban sprawl (Yang, Cai and Sliuzas 2010). In the last two decades, gastronomic heritage has gained momentum as a trigger for tourism activity (Reyes-May et al. 2019). Mexico, as a holder of a world-renown gastronomic and cultural diversity, has not been immune to this trend. In 2014, the Mexican government recognized the cultural value of traditional gastronomy and created the »National Gastronomy Promotion Policy« to strengthen the gastronomic value chain of traditional Mexican cuisines.

In addition, currently, there is a growing concern for the preservation and conservation of the environment, which has had an impact on new trends in tourism, especially verified through new segments that seek experiences more linked to nature, culture, indigenous communities, and adventure (Salcedo and San Martín 2012). In the case of Mexico, the Protected Natural Areas have positioned themselves as attractive spaces for the development of these alternative tourism segments (Comisión Nacional de Áreas Naturales Protegidas 2018) due not only to their outstanding natural and cultural wealth but also because of the economic benefits they bring to local communities (Briedenhann and Wickens 2004).

In general, the promotion of tourism activities has been subject to various criticisms, mainly due to the inequity in the distribution of benefits that tend to be concentrated in a small number of destinations or tourism service providers (Briedenhann and Wickens 2004). Yucatan and Mérida, in particular, have a strong touristic vocation, placing them as a destination of national tourist importance (Lara and García 2016). Between 2008 and 2018, Yucatan experienced average annual growth rates of up to 4.3% in visitor arrivals, 3.8% in the employed population in the sector, and an average annual growth of 9.4% in the sector´s economic output (Paz and Quiñones 2021).

The Cuxtal Ecological Reserve (CER), located to the south of the urban periphery of the city of Mérida in Yucatán, has characteristics of tourist interest that have not been recognized or valued at the local level. On the contrary, it has been under the threat of urban growth in sensitive ecological and cultural conservation areas. The lack of knowledge of the city's population regarding the existence of this reserve contributes to its degradation (Hernández-Cuevas et al. 2019), so tourism planning strategies could contribute to valuing natural and cultural resources available in this critical natural reservoir for its use and preservation (Martorell 2003).

In this context, the objective of this work is to recognize the culinary resources of the CER for the promotion of sustainable tourism in this area of ecological interest for the city of Mérida, Yucatán, through a culinary mapping strategy that allows integrating the tourist and culinary offer of Cuxtal to that of Mérida, the leading tourist destination in the state of Yucatán. This could result in social and economic benefits for the local population and in the rescue and preservation of its natural heritage and culture through its enhancement.

2 Theoretical background: the concept of culinary tourism

2.1 Food as a central resource in tourism development

The following subchapter introduces central concepts related to culinary tourism and culinary mapping, and the second subchapter to the implementation of culinary tourism in natural protected areas. Together, they provide the theoretical underpinning for the research carried out in this work. Within tourism, food consumption is so vital that it represents up to a third of the expenditure made by tourists worldwide (Quan and Wang 2004). Despite its obvious importance, for a long time there was little academic interest in the relationship between tourism and food. It was not until 1998 that Lucy M. Long defined, for the first time, the concept of culinary tourism as a way of intentionally experiencing other cultures through food (Long 1998; Kumar 2019). Since then, interest in this perspective has been growing, and today it constitutes a line of research that defines different characteristics of tourism activity linked to food through other concepts and perspectives. Gastronomic tourism (Hjalager and Richards 2002), cooking tourism, culinary tourism, food tourism (Hall and Mitchell 2002), and gourmet tourism are just some concepts that help to study these particularities. Currently, food is considered an integral part of tourist activity and has been considered, by some, as a differentiating element for tourist destinations (Kumar 2019). The growing process of globalization has impacted tourism and gastronomy due to the standardizing and homogenizing effects that threaten traditional food cultures and affect the local population nutritionally (Hall and Mitchell 2002). Tourism, in this case, can play a fundamental role in promoting traditional cuisines and local food production since these strategies help differentiate tourist destinations within a highly competitive market.

Culinary tourism is a subcategory of food tourism analysis. These categories are defined according to the level of interest that tourists have in food. Gourmet tourism is the first level of interest. In this, the visitors to a particular destination state that their main interest is tasting food in restaurants, markets, or routes designed for that purpose. On the contrary, in culinary tourism, visitors consider food an essential part of the experience, but they do not travel exclusively for this purpose. According to Beer, Ottenbacher and Harrington (2012), this type of tourist values the excellent quality of traditional and local food. For Du Rand, Booysen and Atkinson (2016), this type of visitor also appreciates contact with local cultures and learning about the food and customs of certain social groups, which implies a transfer of knowledge concerning the people, culture, traditions, and identity of the place visited.

Recent years have seen an increased interest in studying culinary tourism from a geographical viewpoint, due to its important spatial implications, both considering the influence of geographic aspects of a place or a region that influence culinary tourism, and culinary tourism's impact in local and regional societies and environments. This interest is shown for instance in a growing number of publications in specialized geographical journals, such as Tourism Geographies (Hashimoto and Telfer 2006; Spilková and Fialová 2013), Journal of Cultural Geography (Nelson 2016), GeoJournal of Tourism and Geosites (Marek and Wiśniewska 2021), and Acta geographica Slovenica (Razpotnik Visković and Komac 2021; Topole et al. 2021).

Other research has also identified the need for the development of quality tourism that integrates the preservation of natural and cultural resources, as well as the development and improvement of the living conditions of the community through strategies such as branding, certification and labeling (Ledinek Lozej and Razpotnik Visković 2022; Logar 2022; Razpotnik Visković and Logar 2022) to create a competitive identity within the market. Logar (2022) found that while there are market opportunities and promotion of local products, the impacts, in the case of the brand »Babica in Dedek« in Slovenia, were sectorally limited. Other theoretical principles, such as that of neo-endogenous development, could be useful for promoting integration strategies that favor rural development processes within the territories and that give importance to the geographical, productive, cultural and institutional proximities of the spaces that enable local actors to address global challenges through territorial governance processes.

In Mexico, there has also been a growing interest in protecting and promoting traditional and popular culture through patrimonialization. In 2010, Mexican cuisine was distinguished with the registration to the representative list of the Intangible Cultural Heritage of Humanity of UNESCO, which implies the commitment of the State to guarantee the protection of this cultural asset. The theoretical and conceptual approaches concerning gastronomy and tourism in Mexico have focused on the analysis of this heritage narrative, in most cases, and the study of tourist preferences about the gastronomic offer (Acle-Mena, Santos-Díaz and Herrera-López 2020). Contreras and Medina (2021) warned that, although Mexico currently has fifteen food Designations of Origin, they have not been articulated to comprehensive dynamics of tourism and gastronomic development. Along the same lines, Castillo et al. (2018) identified that the strategies for promoting gastronomic heritage in Mexico are insufficient and poorly articulated.

Culinary mapping is a methodology that can be beneficial in this regard for diagnosing, planning, and managing tourism activity related to food. Du Rand, Booysen, and Atkinson (2016) consider places of gastronomic interest, which include factories, shops, markets, restaurants, fields, events, festivals, and other types of facilities used for gastronomic purposes, in addition to the cultural and culinary heritage expressed in routes, books or cookbooks.

As a tourism planning tool, culinary mapping involves collecting, recording, analyzing, synthesizing, and visualizing information to describe the culinary resources, networks, and usage patterns of a specific group in a given area (Booysen and Du Rand 2019). According to Du Rand, Booysen, and Atkinson (2016), areas of gastronomic interest can be considered, which include factories, shops, markets, restaurants, fields, events, festivals, and other types of facilities used for gastronomic purposes, in addition to the cultural and culinary heritage expressed in routes, books or cookbooks. For such purposes, Geographic Information Systems (GIS) are the best way to visualize and analyze geographic information in different categories of food products in a given area. According to the bibliographic search realized for this work, this kind of spatial perspective of food tourism has not yet been explored in Mexico.

2.2 Culinary tourism in natural protected areas and its relationship to sustainability

An aspect that has recently gained increased attention is the relationship of culinary tourism to sustainable development and its application in areas of unique natural and cultural value, such as natural protected areas. In these areas, one of the main objectives of tourism, both in Mexico and the world, is preserving natural and cultural heritage while promoting improvement in the quality of life of the people who inhabit them (Cruz 2008). Many of the natural areas and ecological conservation spaces were created without considering the impacts they would cause on local communities that, by belonging to any of these areas, are prevented from carrying out many of the economic activities that gave them sustenance (Eagles and McCool 2002). For this reason, culinary tourism is positioned as one of the socioeconomic development options for local communities within ecological conservation areas without compromising biodiversity and ecological balance (Eagles and McCool 2002).

In this sense, culinary tourism can be a tool aiding to sustainable development. The notion of sustainable development arose in the late 1980s and early 1990s, in the context of the publication of the World Commission on Environment and Development's report Our common future in 1987 and the United Nations Conference for Environment and Development in 1992 (Zimmermann 2016). Sustainable development was defined broadly as a kind of development that meets / … / »the needs of the present without compromising the ability of future generations to meet their own needs.« (World commission on … 1987, 11). Later on, more elaborate conceptualizations were established, also more directly related to tourism, trying to obtain social and environmental benefits while avoiding tourism's potential negative outcomes (Hunter and Green 1995). UNEP and WTO (2005) defined twelve specific goals for sustainable tourism: 1) economic viability, 2) local prosperity, 3) employment quality, 4) social equity, 5) visitor fulfillment, 6) local control, 7) community wellbeing, 8) cultural richness, 9) physical integrity, 10) biological diversity, 11) resource efficiency, and 12) environmental purity. These clearly relate to culinary tourism in many ways, for example, by calling for fostering local, small-scale tourism establishments that purchase locally, use ingredients and energy in an efficient manner and reproduce their traditional gastronomic culture as part of their area's cultural heritage. Also the most influential conceptualization of sustainable development, the 17 Sustainable Development Goals of the UN's Agenda 2030 (Sachs et al. 2019), can be related to culinary tourism, for instance, by promoting sustainable consumption and production patterns, as well as sustainable agriculture.

Thus, sustainable development has been a central theme in recent studies regarding sustainable development. Authors like Sims (2009), Beer, Ottenbacher and Harrington (2012), and Jiménez, López-Guzmán and González (2016), affirm that the promotion of culinary tourism also has a positive impact on the sustainability and preservation of local culture. Razpotnik Visković and Komac (2021) even argued that sustainability is one of four elemental aspects that define the triangle food-territory-tourism that characterizes gastronomic tourism and Sorcaru (2019) proposed to include culinary tourism in local sustainable development strategies.

Sims (2009), in a study carried out in two natural parks in the United Kingdom, found that local food and drink contribute to the sustainability of tourism and agricultural activity by promoting sustainable practices to attract visitors. According to the author, buying and consuming local products prevents the food that tourists buy within the natural area from having to be transported from other regions or countries, which ultimately reduces the carbon footprint produced by the activity. Tourism perspectives focused on sustainability, such as Integral Rural Tourism, understand that the best form of tourism is one where benefits are achieved in the protection of the environment without disfavoring economic development and that, in turn, benefits the local economy without harming the communities themselves. This is how culinary tourism can be a strategy that compensates for the reduction in income due to restrictions on other economic activities (Hjalager and Johansen 2013). A more recent study by Topole et al. (2021) identifies the reduction of transport of food by consuming locally, sustainable transport options to get to destinations, waste management and recycling, and suitability to disadvantaged groups, e.g. persons with disabilities, as important aspects of sustainability in culinary tourism.

According to the Global Adventure Tourism Report (2013, cited in Comisión Nacional de Áreas Naturales Protegidas 2018), the tourism market linked to nature destinations is growing at approximately 20% annually at the international level. In the Mexican case, although the number of tourist visits increases yearly, a lack of diversification of tourist activity has been identified, focusing on sun and beach destinations. The international tourism market, for its part, demands new formats with a greater diversification of experiences with an offer of increasingly personalized services (Lopes 2018).

Stanford (2006; cited in Lópes 2018) warned of the profound changes in the profile of modern tourism, such as greater autonomy in planning trips by tourists, the growing concern for the environment, the appreciation of nature activities, the desire for interaction with the local population and the acquisition of much more authentic experiences linked to the enhancement of local heritage. According to Hjalager and Johansen (2013), surveys applied to visitors to natural parks in the United States found that up to 81% of tourists would have liked to try food of local origin and would have been willing to pay a higher price for this experience. This paper explores the conditions for fostering culinary tourism in the research area of CER where this topic has not been studied so far but that shows a high potential for connecting tourism and activities related to food. The following chapter gives a short overview of the general geographic conditions of this area.

3 Study area

The CER is located in the south of the municipality of Mérida, in Yucatán (Figure 1). It occupies an area of 10,757 km^2, representing 12% of the total municipal area of Mérida. It was declared a Natural Protected Area in the category of Zone Subject to Ecological Conservation in 1993 due to its strategic importance for the region because of the environmental services it provides, especially its transcendental function as a water collector (Ayuntamiento de Mérida 2017).

The CER contains nine towns belonging to the municipality of Mérida. According to the 2021 population census of the Instituto Nacional de Estadística y Geografía of México, in Yucatán, 525,092 people speak an indigenous language, mainly Mayan; at CER, it is spoken by 7162 inhabitants. The restrictions imposed by the declaration as an Ecological Reserve have prevented the development of productive activities that could transgress land-use regulations. It is estimated that up to 75% of the population that lives in the CER commute outside of it to perform paid work, mainly in the city of Mérida, which puts at risk the rescue and preservation of the knowledge that the local population has regarding the sustainable use of plants, animals and other resources of gastronomic value that exist in the reserve.

4 Methodology

The present study focuses on a case study to exemplify the application of culinary mapping in the context of studying tourism activities related to food. This was carried out in the CER, presented in the previous chapter, consisting of three field visits during the year 2021 as well as working with online research tools. The following list describes the main methods applied for data acquisition and their subsequent analysis:

- **Mapping in the field**: To identify the main tourist and gastronomic resources in the CER, tours were conducted throughout the entire road network within the reserve. The points of interest were georeferenced in the GPS Gaia mobile application to form a spatial database, which was then processed in ArcGIS to create a culinary map of the area. A protocol was established for each resource identified, which included photographs and a short note. This involved a total tour of 69 km to visit all communities within the reserve, as well as tourism-related attractions throughout the area. In addition to visually registering potential tourism resources and documenting them with photos, shop vendors, food service providers, and other locals present during the visits were contacted to find out more about the tourism and culinary resources present and their potential use by tourists. This provided part of the information added in the notes in the protocol. Furthermore, additional relevant information obtained via these informal talks was noted down in a research diary and was integrated into the interpretation of the results.

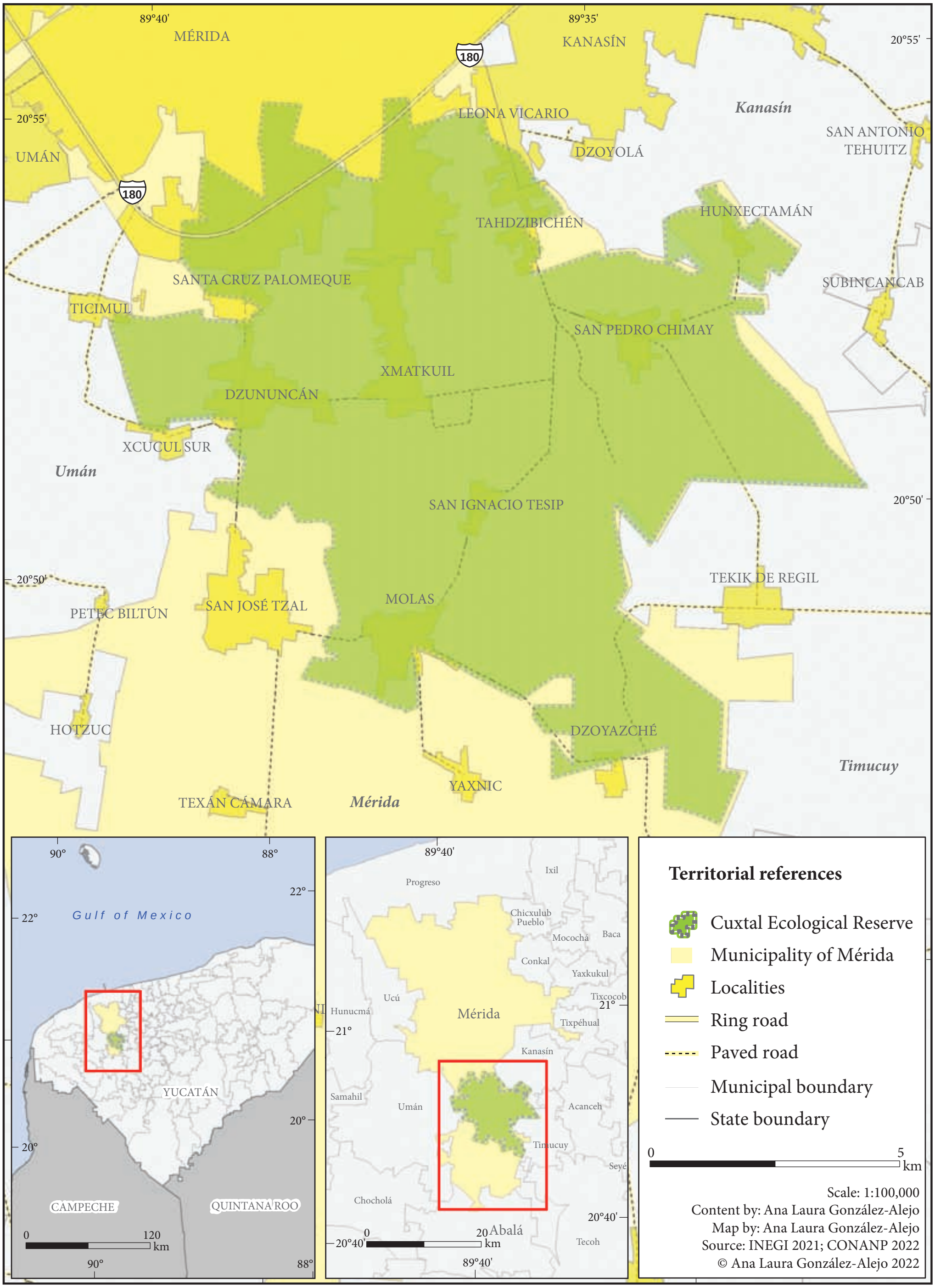

Figure 1: Location of the Cuxtal Ecological Reserve.

- **In-depth interviews**: In order to better analyze and interpret the results, and to avoid overlooking any important tourist and gastronomic resources and related aspects, in-depth interviews with three officials of the Cuxtal reserve, with five tourism service providers located in the inner city of Merida from where most tours to the surrounding tourism areas start, and with ten traditional cooks (nine women and one man) inside the reserve were made. They lasted between half an hour and two hours and were guided by a set of previously defined questions, that was adapted for each kind of interviewee. The results were coded to enable a systematic textual analysis of the main themes and aspects talked about in these interviews.
- **Online survey**: An additional, secondary method to better interpret the results was applying an online survey. Ninety-four tourists who had visited the reserve for tourist purposes were identified and sent an electronic survey (using the Google Forms tool) via Instagram to find out their interest in local cuisine. The questions were related to the respondents' general knowledge of the reserve and its touristic and culinary resources, specific aspects of the stay (such as main motive for visiting, transport mode, spending, etc.), and their satisfaction with the services found within the reserve and their general perception of tourism development in the area. We searched for contacts on Twitter and Facebook, too, but could not find relevant posts dealing specifically with the Cuxtal reserve. In general, the acquisition of information at this point of the research was limited to online sources due to the current state of the COVID-19 pandemic and restrictions for fieldwork. Fifty-eight persons answered the questions. The selection of interviewees via social networks might have been selective to some degree, as these tools are less used by elderly people. However, as confirmed by the interviews with local experts, most visitors coming to the reserve are young people and young adults.

5 Results

5.1 Resource mapping

The methodology described in the previous chapter brought about a detailed culinary mapping of the CER, which is presented in the following paragraphs of subchapter 5.1. Additional information obtained through this research is contained in subchapters 5.2 and 5.3, which aid in interpreting this culinary map, including the main tourist activities other than culinary tourism implemented in the reserve and the general tourist profile.

The direct identification of tangible culinary resources was carried out through fieldwork. They were georeferenced with the help of GIS tools and classified and integrated into a spatial database. The identified products include food sales establishments, backyard gardens, cooking workshops, and handicrafts associated with local production (Figure 2). Thirty-four gastronomic products were found in the CER associated with the local culinary culture: street stalls (9), home-style eateries (6), informal food stalls (5), production sites of sauces and jams (3), restaurants (2), honey production (2), a stand to sell tortillas (1), a bakery (1), traditional female cooks (5) and also a Biopark where traditional cooking classes are given to school children.

Due to the number of visits and their promotion on social media, the two restaurants are the most representative food establishments of the CER. They offer local gastronomic food and attract tourists with high purchasing power. The Santa Cruz Palomeque restaurant is located inside a 17th-century henequen hacienda, which currently serves as a hotel spa. The second restaurant, called Tío Charly, offers local and exotic dishes in a country setting inside the CER; they are visited by tourists and day visitors, especially residents from Mérida's urban area. The home-style eateries and the street food stalls offer local gastronomy, such as *panuchos* (deep-fried tortilla stuffed with refried black beans and topped with chopped cabbage), *tortas* (traditional sandwiches), *salbutes* (deep-fried tortilla topped with lettuce, avocado, pulled chicken or turkey, tomato and pickled red onion), and different preparations of pork meat, in addition to the popular *cochinita pibil* (slow-roasted pork dish that is cooked in a ground oven). These establishments are preferentially located in the road corridor leading to the CER.

The local culinary options are distributed in practically all the towns of the CER. They are particularly concentrated in Colonia Plan de Ayala Sur, Dzoyaxché, Dzununcán, San Pedro Chimay, and Molas. Regarding locally prepared products, Molas stands out, where you can buy locally produced sauces and

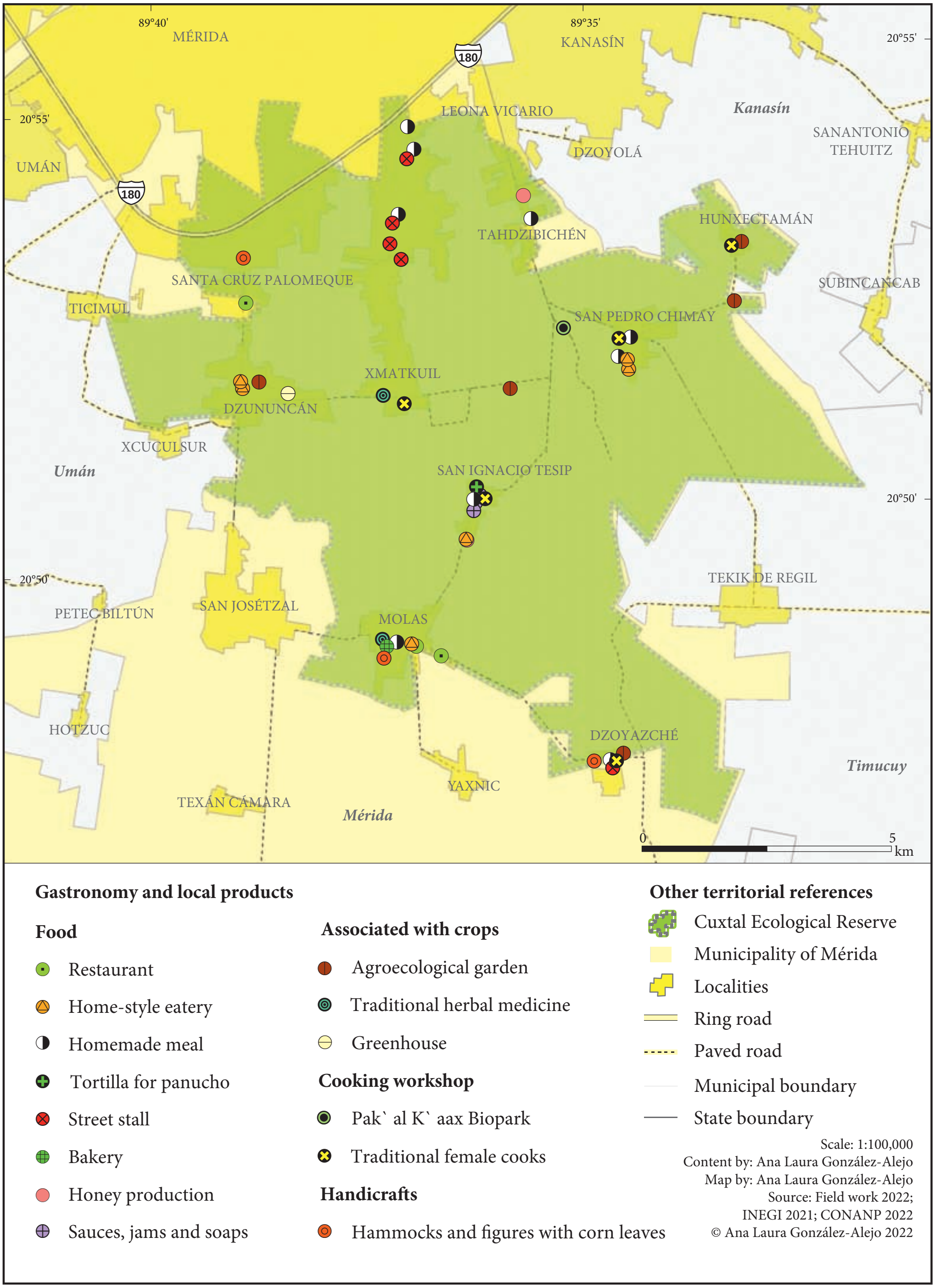

Figure 2: Cuxtal Ecological Reserve: culinary resources.

jams, as well as honey from the *Melipona* bees, a genus native to the Yucatan Peninsula and which comes from apiaries that are found inside the reserve.

In San Pedro Chimay, within the Biopark, in addition to visits and environmental education workshops, traditional cooking courses of the region are offered, which also constitutes a vital tourist resource for the reserve. Hunxectamán, the smallest in terms of population and the furthest away in terms of accessibility, stands out for its agroecological production of regional varieties of tomato and pumpkin, essential ingredients of Yucatecan gastronomy. The presence of a traditional female cook also stands out. Likewise, other towns have family gardens, known in Yucatan as *solares mayas*, which are traditional backyard production systems where families grow a variety of trees, shrubs, and herbaceous species for different purposes, be they food, ornamental, medicinal, agroforestry, and even fodder. These family production spaces are also used for raising chickens and the Mexican creole hairless pig, that is traditional of the Yucatan Peninsula. The recovery of the Rosapa'ak tomato crop, or kidney tomato, stands out, which was identified in a backyard garden of Dzoyaxché. This type of tomato has a great cultural value for the inhabitants of the Yucatan Peninsula since it is the raw material for representative recipes of regional gastronomy, such as *pan de cazón* (dogfish shark, refried black beans and spiced tomato sauce with *habanero* using layered tortillas), *pibipollos* (seasoned chicken covered in corn dough and wrapped in banana leaves and baked in an underground oven), and some varieties of *tamales* (corn dough with a filling that can be either savory or sweet, wrapped in a banana leaf or corn husk and steamed). Currently, it is considered that this tomato is in danger because other commercial varieties of tomato have monopolized the market.

In the CER, the production of fruit trees, vegetables, and animal husbandry was identified for self-consumption and commercialization through the *Círculo 47* government program (Figure 3). The program intends to promote agricultural activity under agroecological precepts that help improve the economic conditions of the rural populations of Mérida. The participating reserve producers produce chili, corn, pumpkin, tomato, orange, guava, papaya, eggs, pork, lamb, goat, rabbit, chicken, and turkey, and elaborate products such as honey, propolis, and *tortilla*.

The production inside the reserve is used for preparing traditional foods, from drinks such as *pozole* (corn-based drink cooked with calcium hydroxide; note: it is very different from the dish called *pozole* in central Mexico), *atole de masa* (corn-based drink cooked with calcium hydroxide to which different flavors are added, which can be fruits or seeds), and *atole de pinole* (drink made from ground corn, cocoa, cinnamon, and sugar); to foods that come from farming and hunting, such as local preparations of iguana, deer, and rabbit (the latter is usually prepared in a *pipian sauce* made from ground pumpkin seeds). A traditional element of the local cuisine that comes from backyard gardens is the herb chaya (*Cnidoscolus chayamansa*). It is used to prepare *empanadas* (fried pastries from corn dough with a savory filling), *panuchos*, broths, and even cakes. Sweet dishes are made from locally grown fruits and vegetables such as papaya, pumpkin, and cucumber.

In addition to the essential traditional culinary knowledge that the population possesses, the CER also has agricultural activities linked to local gastronomic activity. The preparation of *tortas de lechón* (a piece of bread cut in half similar to a sandwich filled with a sucking pig) in Molas stands out, where the Mexican creole hairless pig is raised in backyard gardens and cooked in a traditional oven outside the house. It is sold on weekends on the patio of a private place where people from other locations and Mérida go. In the same way, in San Ignacio Tesip, the traditional preparation of *cochinita pibil* is carried out in a grounded oven, which is also marketed among the local population and those from the city of Merida who come intending to taste it on weekends.

5.2 Tourism activities in the reserve

Incipient tourist activity was documented in the protected area. In the first place, bird watching can be indicated, a practice the residents carry out in Dzoyaxché; the celebration of *Pok ta pok* matches (traditional Mayan ball game) in the town of San Pedro Chimay where young people practice this sport and make exhibitions for tourists in San Pedro Chimay. This sport has a world championship in which teams from Yucatan and other locations in Mexico, Belize, and Guatemala participate. Many of the players of the Yucatan team that engages in these world games are from the CER.

Also, efforts are made to attract the attention of tourists so that they can carry out participatory observation in activities such as beekeeping Abeja Planet, in San Ignacio Tesip, a company that shows the process

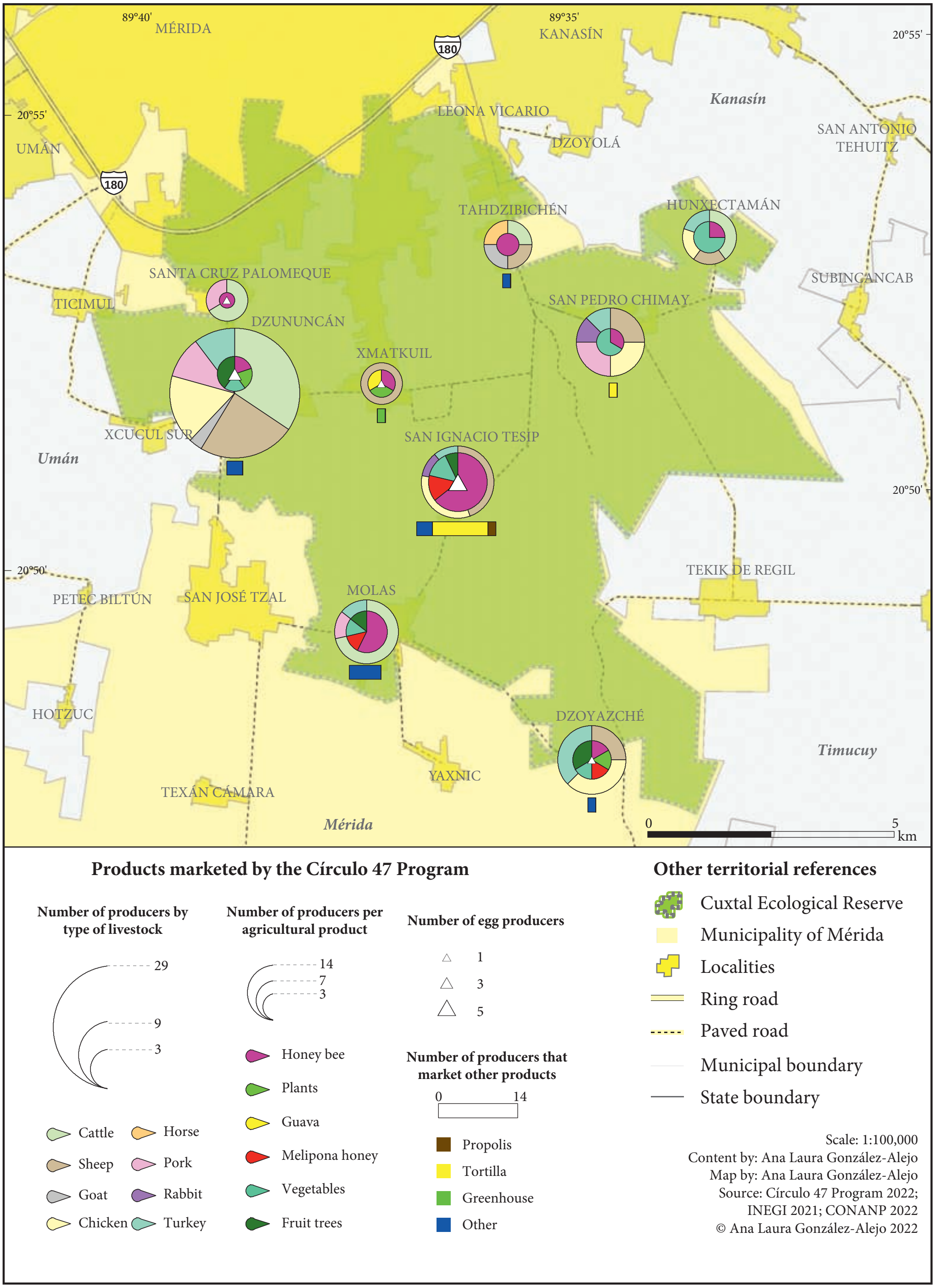

Figure 3: Agroecological products marked by the *Circle 47 Program*.

of collecting, processing, and packaging honey whose origin comes from bees that visit different native plants. There is also the possibility of observing and participating in the weaving of hammocks carried out in the homes of Dzoyaxché.

Weddings are also held in old haciendas that prospered around the henequen industry in the 19th century. The sites that register the highest number of events are Santa Cruz Palomeque, San Antonio Tahdzibinchén, and San Pedro Chimay. The offers of these places are aimed at a sector of the regional and national population with very high purchasing power. Despite this diversity of options for putting tourist activity into practice, the most frequent reason for traveling to the CER is to visit the Dzoyaxché hacienda, where swimming pools are open to the general public.

5.3 Tourist profile

A survey was conducted on 58 tourists who registered their visit on the Instagram application through the hashtags #cuxtal #dzoyaché #reservaecológicacuxtal #cuxtaleando. An electronic form was sent to 94 people, of which 58 sent their answers. Of the total responses, a little more than half were people whose ages ranged between 30 and 44 years, followed by visitors between 18 and 29 years (40%); based on this evidence, it can be affirmed that the majority of those who arrive at the CER are relatively young people.

The geographical origin of the interviewees indicates a majority whose point of origin is the municipality of Mérida (75%), with a relatively minor component of visitors who live in Mexico City. The means of transport used to get to Cuxtal were predominantly private cars (71% of the total); a smaller proportion (19%) used public transportation, and only 7% arrived through a tourist tour purchased in Mérida.

Tourists expressed interest in experiencing locally sourced food (58.1%) when asked what types of food they would like to see offered within the ecological reserve. As to the reasons why they choose to consume certain types of food during their visit to the CER, 22.6% indicated the taste, while 22.6% mentioned that the experimentation of local products and recipes is a motivation to food consumption during the visit to the reserve.

During the time of stay in the CER, it stands out that the tourists generally visited the reserve for a short time. 60.7% spent only between 1 and 3 hours, while 21.4% of those surveyed stayed between 4 and 6 hours. Only 17.9 % of those who responded to this survey made it at least on an overnight stay in the reserve. Among the reasons for returning to the reserve, tourists mentioned proximity to Mérida (13.8%), nature (13.8%), recreational activities, and the beauty of the place with 10.3% of the opinions, respectively.

The study found that there were differences in spending habits and food preferences based on age and gender. The results showed that people between the ages of 18 and 29 spent less money than those between the ages of 45 and 60. Additionally, younger women tended to prefer healthy foods, while the older group preferred local cuisine. Age and gender are important factors to consider when classifying tourists based on their food interests. It has been observed that different age groups prefer different types of food. By taking this into account, it would be possible to create targeted offers and marketing strategies to attract the right audience for various food options available in the CER.

6 Discussion

The main contribution of this article is the advancement of culinary tourism and of developing a culinary mapping approach that is suitable for a protected natural area. This is the first application of this type of culinary mapping study in Mexico. The approach helps identify spatial differences within the study area and highlights places that are particularly suitable for culinary tourism. It also identifies areas that have potential in terms of their resources but have not yet incorporated culinary tourism activities. The study combines mapping with in-depth interviews with local actors and a survey with tourists, which provides additional progress to this type of research. This study adds to previous work on culinary tourism and expands the scope of this type of research. The spatial identification of culinary resources allows the integration of gastronomy into regional economic and tourist circuits. It also helps with territorial management and planning for economic and tourist diversification strategies. This is achieved through the mobilization of local actors and promotion of employment, which promotes the cultivation of traditional ingredients and preserves local culture.

The research findings indicate that tourists are interested in traditional gastronomy and the local origin of food. This trend is consistent with other studies conducted in natural areas (Sims 2009; Beer, Ottenbacher and Harrington 2012; Hjalager and Johansen 2013; Fernandes and Richards 2021), where tourists have identified deficiencies in the provision and quality of food services within their reserves. In the case of natural areas with established tourist activity, such as the Mols Bjerge and Skjern Aadal reserves in Denmark, Hjalager and Johansen (2013) found that tourists demand higher quality food, beverages, and culinary experiences, particularly with regard to the origin of the ingredients. The experience gained in such areas highlights the need to integrate the gastronomic and productive offerings with other tourist attractions and actors (Du Rand, Booysen and Atkinson 2016).

Due to the current climate emergency, new trends around gastronomic tourism and sustainability have emerged. Authors such as Sims (2009) and Bertella (2020) point out that tourism activity should not continue to depend on food imports and an unsustainable industrial food system. On the contrary, tourism should be more linked to its local environment to stimulate tourism destinations' sustainable economic and environmental development (Zhang, Chen and Hu 2019). Other perspectives on rural development, such as neo-endogenous development, allow us to glimpse territorial linkage strategies that integrate multilevel actors who intend to build collective decision-making processes for the benefit of spaces. This perspective is especially relevant when applied to goods with great historical and sociocultural value, such as traditional foods (Martínez 2023).

In the case of the CER, the identification of small producers of traditional crops of local gastronomy and of cooks who know the culinary use of these ingredients allows the revitalization of agricultural activity and the preservation of agrobiodiversity and the food culture in the CER. In addition to the above, tourists are offered an authentic and sustainable gastronomic experience that differentiates it from other tourist destinations where the conditions to link local production, sustainability, culture, and traditional gastronomy do not exist. In this sense, other studies highlight the importance of incorporating local gastronomy as a way of differentiating the tourist destination (Karim and Chi 2010), especially among a growing number of tourists who travel for gastronomic reasons (López-Guzmán and Sánchez 2012; Contreras and Medina 2021).

The analysis in the CER allows us to recognize a series of advantages for other tourist destinations where this type of proposal has been implemented: The existence of many natural and cultural tourist attractions within the reserve, extensive gastronomic knowledge of the people who live there, and a group of agroecological producers currently integrated under the name of *Círculo 47* that sell fresh food within the reserve. The scarcity of producers and the little connection between them has been one of the main disadvantages that other gastronomic and culinary tourist destinations have faced, where this problem has been identified as a limitation to be faced (Fernandes and Richards 2021).

According to Zhang, Chen, and Hu (2019), tourists' consuming locally sourced food also reduces the carbon footprint generated by transporting goods to tourist destinations. However, for Rinaldi (2017), tourists exert significant pressure on ecosystems, water, and natural resources. Contreras and Medina (2021) suggest that globalization and food homogenization are the main threats to cultural and food identity in various tourist destinations in Mexico and the world. As experienced in the fieldwork, the communities within the CER are affected, in an increasingly visible way, by a diet that depends more and more on ultra-processed products and less on natural and traditional foods. From a social perspective, excluded local communities, as in the case of the inhabitants of the CER, also threaten the culture and preservation of priority crops and knowledge for the Mayan culture in the face of food homogenization.

7 Conclusions

The culinary mapping applied to a territory such as the CER allows it to glimpse the potential for the development of alternative tourist activities that complement the regional offer, in addition to promoting the diversification of the benefits of tourism to other social and economic actors that inhabit this reserve. As verified, local gastronomy can play a fundamental role in integrating tourism with the agroecological practice that contributes to economic reactivation and the recovery and preservation of knowledge by the local population.

The urban expansion of Mérida, which permanently threatens the territory of the reserve, also represents a risk for the local population who see their lifestyles modified, particularly due to the influence that urban eating patterns may have on the people of the CER that, as it was found in fieldwork, have traditional knowledge of gastronomic value. In this sense, planning the tourist activity can contribute to preserving the resources and culinary practices among the population and valorizing the natural, ecological and cultural resources that sustain it.

The mapping of culinary resources allows planning and managing alternative tourism strategies that integrate the CER within the state and regional tourism offers. Food tourism associated with the gastronomic and agroecological offer represents a viable option within an ecological preservation area with severe degradation problems due to the urban growth of the city of Mérida on this critical natural reservoir. With these strategies, local supply chains are also strengthened, which favors the local population.

8 References

Acle-Mena, R., Santos-Díaz, J., Herrera-López, B. 2020: La gastronomía tradicional como atractivo turístico de la ciudad de Puebla, México. Revista de Investigación, Desarrollo e Innovación 10-2.

Andersson, T., Mossberg, L., Therkelsen, A. 2017: Food and tourism synergies: Perspectives on consumption, production and destination development. Scandinavian Journal of Hospitality and Tourism 17-1. DOI: https://doi.org/10.1080/15022250.2016.1275290

Ayuntamiento de Mérida 2017: Modificación del Programa de Manejo de la Zona Sujeta a Conservación Ecológica Reserva Cuxtal, Yucatán, México. Mérida.

Beer, C., Ottenbacher, M., Harrington, R. 2012: Food tourism implementation in the black forest destination. Journal of Culinary Science and Technology 10-2. DOI: https://doi.org/10.1080/15428052.2012.677601

Bertella, G. 2020: Re-thinking sustainability and food in tourism. Annals of Tourism Research 84. DOI: https://doi.org/10.1016/j.annals.2020.103005

Bessière, J. 1998: Local development and heritage: Traditional food and cuisine as tourist attractions in rural areas. Sociologia Ruralis 1-38.

Booysen, I., Du Rand, G. 2019: Culinary mapping: A gastronomic tourism planning tool. The Routledge Handbook of Gastronomic Tourism. London, New York.

Briedenhann, J., Wickens, E. 2004: Tourism routes as a tool for the economic development of rural areas – vibrant hope or impossible dream? Tourism Management 25-1. DOI: https://doi.org/10.1016/S0261-5177(03)00063-3

Castillo, E., Santoyo, V., Muñoz, M., Rodríguez, B. 2018: Patrimonio gastronómico y desarrollo local en dos Pueblos Mágicos de México. Revista Iberoamericana de Viticultural, Agroindustria y Ruralidad 5-15.

Comisión Nacional de Áreas Naturales Protegidas 2018: Marco Estretégico de Turismo Sustentable en Áreas Naturales Protegidas de México. Mexico City.

Contreras, D., Medina, X. 2021: Turismo gastronómico, productos agroalimentarios típicos y denominaciones de origen. Posibilidades y expectativas de desarrollo en México. Journal of Tourism and Heritage Research 4-1.

Cruz, J. 2008: Turismo active na parte natural da Serra da Estrela. Criação de rotas temáticas Master´s Thesis, Universidade da Beira Interior. Covilhã.

Du Rand, G. E., Booysen, I., Atkinson, D. 2016: Culinary mapping and tourism development in South Africa´s Karoo region. African Journal of Hospitality, Tourism and Leisure 5-4.

Eagles, P., McCool, S. 2002: Planning for tourism in national parks and protected areas: Principles and concepts. Tourism in National Parks and Protected Areas: Planning and Management. London. DOI: https://doi.org/10.1079/9780851995892.0071

Eastham, J. 2019: Sustainable supply chains in gastronomic tourism. The Routledge Handbook of Gastronomic Tourism. New York.

Fernandes, C., Richards, G. 2021: Developing gastronomic practices in the Minho region of Portugal. Acta geographica Slovenica 61-1. DOI: https://doi.org/10.3986/AGS.9370

Hall, M., Mitchell, R. 2002: Tourism as a force for gastronomic globalization and localization. New York.

Hashimoto, A., Telfer, D. J. 2006: Selling Canadian culinary tourism: Branding the global and the regional product. Tourism Geographies 8-1. DOI: https://doi.org/10.1080/14616680500392465

Hernández Cuevas, F., Bracho Illescas, A. V., Loanca Rodríguez, K. G., Manus Gómez, M. P. 2019: Contingent valuation of the hydric resource: the case of the Ecological Reserve of Cuxtal, Yucatán. Revista Interamericana de Ambiente y Turismo 15-1. DOI: https://doi.org/10.4067/s0718-235x2019000100014

Hjalager, A., Johansen, P. H. 2013: Food tourism in protected areas – sustainability for producers, the environment and tourism? Journal of Sustainable Tourism 21-3. DOI: https://doi.org/10.1080/09669582.2012.708041

Hjalager, A., Richards, G. 2002: Tourism and gastronomy. The Routledge Handbook of Gastronomic Tourism. New York. DOI: https://doi.org/10.4324/9781315147628

Hunter, C., Green, H. 1995: Tourism and the environment: A sustainable relationship? London.

Instituto Nacional de Estadística y Geografía 2021: Censo de Población y Vivienda 2020.

Jiménez, J., López-Guzmán, T., González Santa-Cruz, F. 2016: Gastronomy and tourism: Profile and motivation of international tourism in the city of Cordoba, Spain. Journal of Culinary Science and Technology 14-4. DOI: https://doi.org/10.1080/15428052.2016.1160017

Karim, S., Chi, C. 2010: Culinary tourism as a destination attraction: An empirical examination of destinations' food image. Journal of Hospitality Marketing & Management 19-6. DOI: https://doi.org/10.1080/19368623.2010.493064

Kumar, S. 2019: Gastronomic tourism: A theoretical construct. The Routledge Handbook of Gastronomic Tourism. New York.

Lara, I., García, C. 2016: Determinación del índice de competitividad del destino turístico: Mérida. Casos de Investigación Turística Aplicada en México. Tuxtla Gutiérrez.

Ledinek Lozej, Š., Razpotnik Visković, N. 2022: Branding, labeling and certification. Geographical and anthropological insights. Acta geographica Slovenica 62-2. DOI: https://doi.org/10.3986/AGS.11265

Logar, E. 2022: Place branding as an approach to the development of rural areas: A case study of the brand »Babica in Dedek« from the Škofja Loka Hills, Slovenia. Acta geographica Slovenica 62-2. DOI: https://doi.org/10.3986/AGS.10883

Long, L. 1998: Culinary tourism: A folkloristic perspective on eating and otherness. Southern Folklore 55-3.

Lópes, T. 2018: Valorização do turismo na natureza na gestão de áreas naturais periurbanas. Ph.D Thesis, Universidad de Lisboa. Lisbon.

López-Guzmán, T., Sánchez, S. M. 2012: La gastronomía como motivación para viajar. Un estudio sobre el turismo culinario en Córdoba. Pasos. Revista de Turismo y Patrimonio Cultural 10-5. DOI: https//doi.org/10.25145/j.pasos.2012.10.072

Marek, A., Wiśniewska, A. 2021: Culinary tourism in Lower Silesia (Poland) in 2014–2017. GeoJournal of Tourism and Geosites 34-1. DOI: https//doi.org/10.30892/gtg.34130-641

Martínez, L. E. 2023: Food patrimonialization in rural-urban territories in Mexico from neo-endogenous development. Cuadiernu 11.

Martorell, A. 2003: Cultural routes: Tangible and intangible dimensions of cultural heritage. Proceedings of the 14th ICOMOS General Assembly and International Symposium: Place, memory, meaning: Preserving intangible values in monuments and sites. Victoria Falls.

Nelson, V. 2016: Peru's image as a culinary destination. Journal of Cultural Geography 33-2. DOI: https://doi.org/10.1080/08873631.2016.1153269

Paz, R., Quiñonez, A. 2021: Preámbulo. Evolución económica del turismo en Yucatán 2006–2018. Península 16-2.

Quan, S., Wang, N. 2004: Towards a structural model of the tourist experience: An illustration from food experiences in tourism. Tourism Management 25-3. DOI: https://doi.org/10.1016/S0261-5177(03)00130-4

Razpotnik Visković, N., Komac, B. 2021: Gastronomy tourism: A brief introduction. Acta geographica Slovenica 61-1. DOI: https://doi.org/10.3986/AGS.10258

Razpotnik Visković, N., Logar, E. 2022: Certification, labelling and branding in tourism research: systematic review. Acta geographica Slovenica 62-2. DOI: https://doi.org/10.3986/AGS.10858

Reyes-May, O., Rodríguez-Cih, J., Alonzo-Báez, W., Pérez-Dzib, C. 2019: Las cantinas de Yucatán: Turismo y cultura gastronómica. Progessio. Perspectivas científicas del Poniente de Yucatán. Mexico City.

Rinaldi, C. 2017: Food and gastronomy for sustainable place development: a multidisciplinary analysis of different theoretical approaches. Sustainability 9-10. DOI: https://doi.org/10.3390/su9101748

Sachs, J., Schmidt-Traub, G., Mazzucato, M., Messner, D., Nakicenovic, N., Rockström, J. 2019: Six transformations to achieve the Sustainable Development Goals. Nature Sustainability 2. DOI: https://doi.org/10.1038/s41893-019-0352-9

Salcedo, M. P., San Martin, F. 2012: Turismo y sustentabilidad: Paradigma de desarrollo entre lo tradicional y lo alternative. Gestión y Estrategia 41.

Sims, R. 2009: Food, place and authenticity: Local food and the sustainable tourism experience. Journal of Sustainable Tourism 17-3. DOI: https://doi.org/10.1080/09669580802359293

Sorcaru, I. A. 2019: Gastronomy tourism – A sustainable alternative for local economic development. Annals of »Dunarea de Jos« University of Galati 1. Economics and Applied Informatics 25-1. DOI: https://doi.org/10.35219/eai1584040912

Spilková, J., Fialová, D. 2013: Culinary tourism packages and regional brands in Czechia. Tourism Geographies 15-2. DOI: https://doi.org/10.1080/14616688.2012.726268

Stanford, D. 2006: Responsible tourism, responsible tourist: What makes a responsible tourist in New Zealand? Ph.D Thesis, Victoria University of Wellington. Wellington.

Topole, M., Pipan, P., Gašperič, P., Geršič, M., Kumer, P. 2021: Culinary events in the Slovenian countryside: Visitors' motives, satisfaction, and views of sustainability. Acta geographica Slovenica 61-1. DOI: https://doi.org/10.3986/AGS.7617

UNEP, WTO 2005: Making tourism more sustainable. A guide for policy makers. Paris.

World commission on environment and development 1987: Our common future: Brundtland report. Oxford.

Yang, Z., Cai, J., Sliuzas, R. 2010: Agro-tourism enterprises as a form of multi-functional urban agriculture for peri-urban development in China. Habitat International 34-4. DOI: https://doi.org/10.1016/j.habitatint.2009.11.002

Zhang, T., Chen, J., Hu, B. 2019: Authenticity, quality, and loyalty: Local food and sustainable tourism experience. Sustainability 11-12. DOI: https://doi.org/10.3390/su11123437

Zimmermann, F. 2016: Nachhaltigkeit wofür? Von Chancen und Herausforderungen für eine nachhaltige Zukunft. Was ist Nachhaltigkeit – eine Perspektivenfrage? Berlin.

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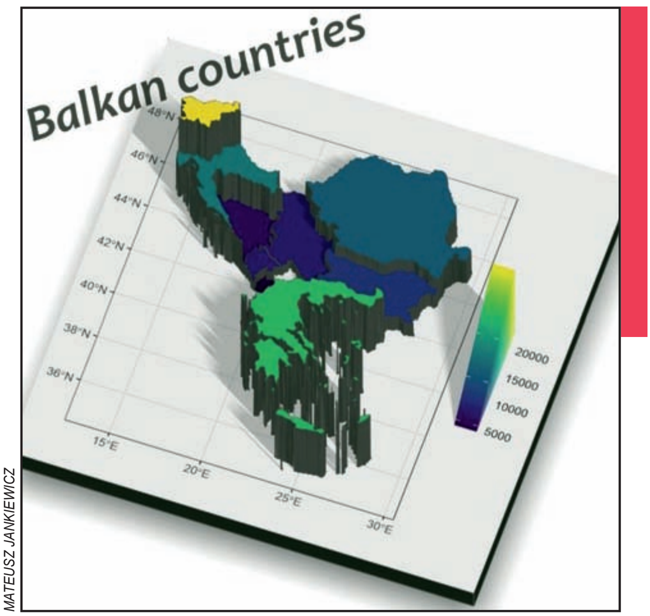
ECONOMIC GROWTH IN THE BALKAN AREA: AN ANALYSIS OF ECONOMIC β-CONVERGENCE

Tomasz Grodzicki, Mateusz Jankiewicz



3D spatial differentiation of GDP per capita in Balkan countries.

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Tomasz Grodzicki[1], Mateusz Jankiewicz[1]

Economic growth in the Balkan area: An analysis of economic β-convergence

ABSTRACT: The Balkan countries undergoing the transition must advance their economies to be more competitive. The aim of this paper is to analyse economic growth with a primary focus on the analysis of economic convergence in the Balkan region in the period of 1997–2020. The research analyses the following Balkan economies: Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Greece, Montenegro, North Macedonia, Romania, Serbia, and Slovenia. This study applies Gross Domestic Product (GDP) as a measure of economic growth and is based on the neoclassical economic growth model: the Solow's convergence concept. The results show that the Balkan countries experienced economic convergence with a speed of 1.82% in the cross-sectional model and 7.87% in the panel data model. It means that the initially less developed economies noted higher economic growth than those richer.

KEYWORDS: Balkan countries, economic growth, β-convergence, geography

Gospodarska rast na Balkanu: analiza gospodarske β-konvergence

POVZETEK: Balkanske države v tranziciji morajo za večjo konkurenčnost izboljšati svoja gospodarstva. Namen tega prispevka je analizirati gospodarsko rast s poudarkom na analizi ekonomske konvergence na Balkanu med letoma 1997 in 2020. Raziskava analizira gospodarstva naslednjih držav: Albanije, Bosne in Hercegovine, Bolgarije, Hrvaške, Grčije, Črne Gore, Severne Makedonije, Romunije, Srbije in Slovenije. Kot merilo gospodarske rasti je uporabljen bruto domači proizvod (BDP), analiza pa temelji na neoklasičnem modelu gospodarske rasti – tj. Solowovem konceptu konvergence. Rezultati kažejo, da je hitrost ekonomske konvergence balkanskih držav znašala 1,82 % v presečnem modelu in 7,87 % v modelu s panelnimi podatki. To pomeni, da so na začetku manj razvite države doživljale višjo gospodarsko rast kot bogatejše.

KLJUČNE BESEDE: balkanske države, gospodarska rast, β-konvergenca, geografija

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[1] Nicolaus Copernicus University in Toruń, Faculty of Economic Sciences and Management, 87-100 Toruń, Poland
t.grodzicki@umk.pl (https://orcid.org/0000-0001-7819-2127), m.jankiewicz@umk.pl (https://orcid.org/0000-0002-4713-778X)

1 Introduction

The studies on economic growth have been widely elaborated in the literature. The idea of real convergence has gained momentum in economic theory since the early 1950s. It is an economic phenomenon that concerns the process of equalization of the level of economic indicators (often economic growth measured by Gross Domestic Product (GDP) per capita) of various economies to a common average. The economic convergence hypothesis is based on the existence of certain mechanisms through which the process of equalizing wealth levels between different economies exists (Rey and Le Gallo 2009; Sachs and Warner 1995; Yin, Zestos and Michelis 2003). With the idea of economic convergence comes the so-called catch-up effect, meaning that less developed economies achieve a higher (faster) economic growth than richer countries (Amable 1993; Bourdin 2015; de la Fuente 1995).

The convergence process should be at the heart of the political debate as it generates numerous positive aspects with the main one, which is decreasing the gap between the rich and the poor (it creates more middle-income class). One may also ask a different question: what would happen without convergence? What would be the problems that countries lagging behind should address? The biggest issue here would be growing disparities which would induce brain drain and brain waste (better opportunities in the rich economies so the poor ones would 'lose' human capital, very often talented and well-educated), which could cause many structural problems in the long term. There are also many other factors that the poorest economies should work on, like i.e., improving the quality of institutions, education, investing in infrastructural projects, etc. Unfortunately, economic convergence cannot be taken for granted as there are many cases of the existence of the opposite scenario, which is called economic divergence (Broadberry 2013; Palier, Rovny and Rovny 2018; Petrakos, Kallioras and Anagnostou 2011; Pritchett 1997; Upchurch 2012). This results in the opposite effect of the catch-up one: the relative level of development in the richest units is higher than in the poorest ones. It implies growing disparities in the economic wealth of countries.

Previous studies on economic development and growth in the Balkan, which according to the historians, consists of eleven countries: Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Greece, Kosovo, Montenegro, North Macedonia, Romania, Serbia, and Slovenia (Crampton 2002) and Western Balkan (Bosnia and Herzegovina, Croatia, Kosovo, Montenegro, North Macedonia, Serbia) regions imply that some particular problems need to be addressed. One of them is demography which is strongly affected by emigration (Baldwin-Edwards 2004; King and Oruc 2019; Malaj and de Rubertis 2017; Petreski et al. 2017). Balkan countries have experienced the so-called brain drain: many people leave these countries for better economic conditions (Bartlett et al. 2016). There are also cases of underemployment and brain waste, meaning that people also accept working in a different sector, often requiring fewer skills than they used to work back home (Uvalic 2008; 2011). In addition, there is also an issue of depopulation and regional peripheralization in the Balkans (Borsi and Metiu 2015; Lukić et al. 2012; Lulle 2019; Mickovic et al. 2020).

Hence, economic security is a key challenge that Balkan economies, especially Western Balkans, must address to advance their economies and be more competitive (Zeneli 2014). Problems with poverty, unemployment, and inequalities need to be resolved. These economies should focus on accelerating socioeconomic reforms, modernization, and institutional transformation as a remedy. Moreover, deeper regional cooperation and integration with the EU market are called to allow them to catch up with technologies and the level of marked-oriented institutions. This all would positively result in their economic development. In addition, the Balkan economies should work on: (1) their remittances to be more oriented to investment instead of personal consumption; (2) building more business zones and improving their business environment, tackling corruption, and increasing government effectiveness, especially the rule of law so they can attract the Foreign Direct Investment (FDI); (3) fostering the process of automation and digitalization since domestic enterprises are usually far from the competitive market in comparison to foreign firms (Jushi et al. 2021; Nedić et al. 2020; Ziberi and Alili 2021).

Since not all Balkan countries are a member of the European Union (EU), it is interesting to see if EU membership might also be a factor that fosters economic development. An exciting research approach was offered by Velkovska (2021), who used the Kuznets curve approach and found that being an EU member correlates to lower income inequality, so it implies better redistribution efforts rather than in the case of being outside the EU. Moreover, in all Balkan countries, the results showed that the Kuznets curve is flatter at starting stages of economic growth, with income inequality decreasing at later stages of economic development.

This paper, therefore, focuses on an important research gap on economic growth, and in particular the concept of convergence, in the Balkan area. Hence, it is vital to formulate the following research question: Did the Balkan countries converge over time in terms of economic growth? The presented literature analysed the potential problems that the Balkan countries need to work on in order to develop their economies; from now on, the question is whether these countries converge, meaning if they are getting more and more similar in terms of economic growth.

2 Data and methods

Data used in this research concern the GDP per capita levels and come from the World Bank database (https://data.worldbank.org/). The World Bank database contains information about various macroeconomic indicators across all countries. Among these indicators are such that characterise economic, social and environmental conditions of territorial units. The analysis is conducted for 10 Balkan countries in the years 1997–2020 (excluding Kosovo due to a lack of data before 2008). The period 1997–2020 is the longest available period at the moment.

The analysis in this research is based on the convergence concept created by Solow (1956) on the grounds of the neoclassical economic growth model. In particular, β-convergence cross-sectional and panel data models are estimated. This allows for checking the presence of the catching-up effect of wealthier economies on poorer ones (Barro and Sala-i-Martin 1992).

The cross-sectional Ordinary Least Squares (OLS) β-convergence model is estimated and verified in the first step of the investigation. The general form of the absolute convergence model is as follows (Arbia 2006):

$$\frac{\mathrm{T}}{\quad} \tag{1}$$

where $GDP_{0,i}$ and $GDP_{T,i}$ denote the Gross Domestic Product per capita levels in the first and the last year of analysis, respectively, α and β are the structural parameters of the model, but εi denotes the random component. The parameter β signalizes whether the convergence process occurs. Negative and significantly different from 0 estimate of β points out that the absolute convergence is said to be favored by the data. This denotes that poorer countries grow faster than rich ones and also that they all converge to the same *steady-state* level of GDP per capita (Arbia 2006).

Based on the model (1), the speed of convergence and *half-life* time as fundamental convergence characteristics can be appointed. Speed of convergence (b) evidences the level of inequalities between units reduced in one year. *Half-life* time statistic (t_{hl}) shows what time is needed to mitigate current inequalities by half. Statistics b and t_{hl} are calculated as follows (Arbia 2006; Ben-David 1996):

$$\frac{\quad}{\quad} \tag{2}$$

$$\frac{\quad}{\quad} \tag{3}$$

where β – as above, T – difference between the last and the first year of investigation.

The β-convergence model estimated based on the cross-sectional data has some disadvantages that cause an increase in interests of convergence models based on the panel data. Firstly, this is the approach which does not show full dynamic of the cross-country distribution of GDP per capita because of considering GDP levels only in two extreme years of the investigation. In this approach, countries seek to the same *steady-state* level. Panel data models allow including individual characteristics of territorial units (individual effects) that cause differentiation of the *steady-state* level (similarly as the conditional convergence).

Moreover, in the cross-sectional OLS regression, it is not possible to include the variable describing the technological progress. In panel data models, the differentiation of constant allows taking into account the differences in technology (Chambers and Dhongde 2016). The technological progress can also include the time variable which cannot be implemented to the cross-sectional models.

Therefore, the next part of the research contains the economic convergence analysis based on the β-convergence panel data model. In panel data models, time between the first and the last years of the research is not omitted such as in the cross-sectional OLS model. The dynamics in the whole period is taken into account. The advantage of this approach is the availability of including the technological differences between countries in the form of individual effects. Moreover, panel data models help correct the bias generated by omitted variables and heterogeneity in the classical cross-sectional regression (Arbia, Basile and Piras 2005). The general form of the model is as follows:

(4)

where $GDP_{i,t}$ and $GDP_{i,t-1}$ are the GDP *per capita* level in time *t*–1 and *t* respectively, $\alpha, \beta, \varepsilon_{i,t}$ – as above. Model (4) can be equivalently written as:

(5)

In this case, the convergence occurs if the estimate of the 1+β is from interval 0,1 and is statistically significant. For the panel data model, the speed of convergence is evaluated using the following formula:

(6)

Whereas *half-life* statistic is evaluated the same as in the cross-sectional approach – using formula (3). The speed of convergence evaluated based on the panel β-convergence model is higher than this evaluated considering cross-sectional data. This is the result of presence of short-term fluctuations between extreme years of the research. Moreover, including the individual effects induces an upward bias in the estimate of convergence coefficient. This is the result of the differentiation of *steady-state* levels to which countries seek with the same speed. The convergence to individual equilibrium is faster than to common *steady-state* level. Model (5) is the first-order autoregressive model, so the stationarity of the response and explanatory processes is required. In order to check the presence of the unit root in the processes, the test proposed by Levin, Lin, and Chu (2002) is used. This is one of the tests dedicated to panel data. The alternative hypothesis of this test is that the unit root is absent in the processes.

The quality of each model is verified with adequate diagnostic tests. In the cross-sectional model, homoscedasticity and normality of model residuals are required. Therefore, this research applies tests proposed by White (1980) to verify the homoscedasticity of residuals, and Doornik and Hansen (2008) to check the consistency of the residuals' distribution with the normal distribution. In panel data models, the most desirable characteristic is the lack of the residuals' serial autocorrelation. This is verified with the test proposed by Arellano and Bond (1991).

Finally, the switching β-convergence panel data model is estimated to check whether the convergence in the groups of EU and non-EU countries occurs. The model is as follows:

(7)

where $GDP^{1}_{i,t-1}$ and $GDP^{2}_{i,t-1}$ are values of GDP per capita in the first and the second regime, respectively. The first regime relates to EU countries and in the second regime non-EU countries belong.

The absolute β-convergence model considered in this research has a few limitations that are necessary to point out. Firstly, the differences in the population growth rates and savings rates between countries are not included. In the light of the Solow's (1956) neoclassical growth model, these processes significantly influence the economic convergence. Moreover, the assumption about the common steady-state level can be wrong because of the differences in the individual characteristics of countries. However, Balkan countries are quite homogenous, so in this research the common steady-state level is admissible. Other limitation, unrelated with the concept of the convergence, is time range of the study. The newest available data of GDP levels in the World Bank Database came from 2020. Therefore, the impact of COVID-19 pandemic on the convergence process is not able to discuss.

3 Results

Figure 1 shows the tendencies of the GDP per capita level in selected countries in the period of 1997–2020. A continuous upward trend in the GDP per capita level characterizes most countries from 1997 to 2020. The exception is Greece, where an increasing tendency was observed only until 2007. Next, the financial crisis dated in the years 2007–2009 caused a considerable decrease in GDP per capita to the level from the first year of analysis. In the years 2012–2019, values of the considered process in Greece were at a similar level. Short-term negative changes in the economic growth associated with the financial crisis could be observed in Croatia, Montenegro, Romania, and Slovenia. In 2020 GDP per capital level in some of the countries (Croatia, Greece, Montenegro, North Macedonia, Romania and Slovenia) slightly decreased compared to its level from the previous year. It could be the first consequence of the COVID-19 pandemic, which started in 2019.

Table 1 shows values of GDP per capita in the extreme years of the study and its growth rate in the period of 1997–2020. In 1997 the highest level of considered process was noted in Greece (16,972.72 USD). However, due to instability in its tendency, the growth rate of GDP in the selected period was only 1.88%. Other countries showed a much higher growth rate concerning economic growth. The consequence of this situation is that Slovenia's GDP per capita at the end of the considered period was higher than Greece's. The lowest level of GDP per capita in both years was observed in Albania. Simultaneously, one of the highest growth rates was noted there. It is worth noticing that two countries (Greece and Slovenia) were initially characterized by a much higher GDP per capita than the others.

Figure 2 presents the spatial differentiation of GDP per capita in four chosen years of an investigation. The years 1997 and 2020 are chosen as two extreme years of the research. In turn, 2004 is the year

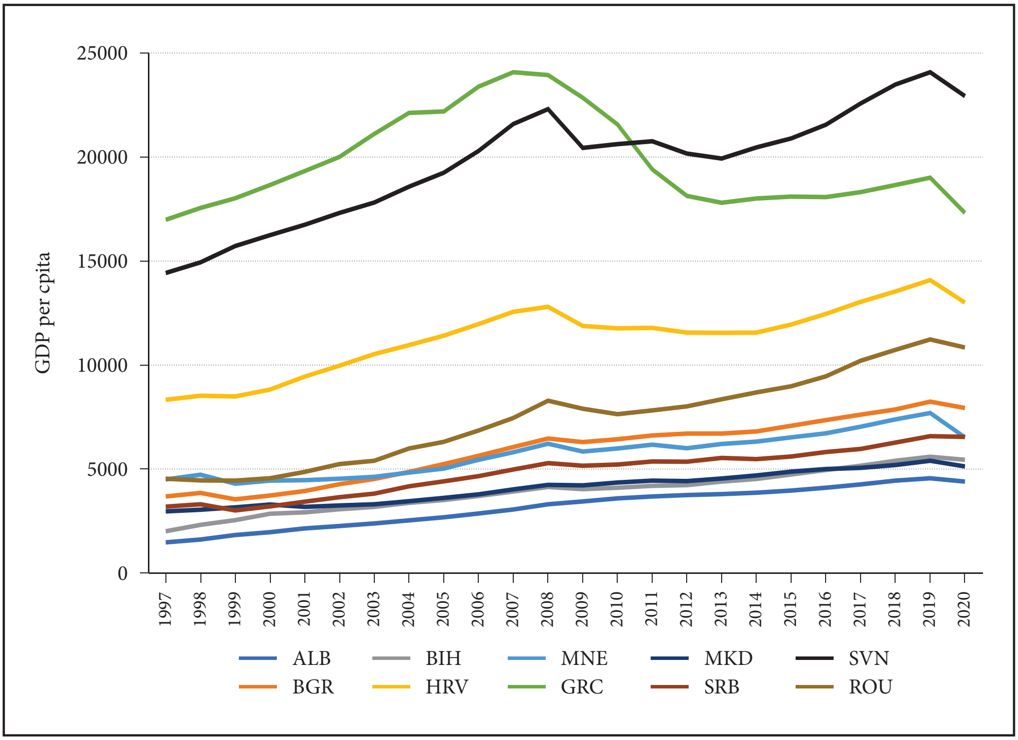


Figure 1: Tendencies of the GDP per capita level in Balkan countries in the years 1997–2020.
Note: ALB – Albania, BGR – Bulgaria, BIH – Bosnia and Herzegovina, HRV – Croatia, MNE – Montenegro, GRC – Greece, MKD – North Macedonia, SRB – Serbia, SVN – Slovenia, ROU – Romania.

of Slovenia's accession to the EU structures, and 2012 is the first year of the economic slowdown after the recovery from the financial crisis between 2008 and 2009. Due to a small number of territorial units, countries are divided into two groups. The first group contains states with GDP per capita values below the median, and the second – the others. The spatial differentiations of the considered process are almost the same in every presented year. Only Bulgaria and Montenegro changed groups from 2004 onwards compared with the first year of research. Bulgaria moved to the group of countries with higher GDP per capita, differently than Montenegro. Moreover, most of countries in the EU (Croatia, Greece, Romania, and Slovenia) characterise higher than median level of GDP per capita in the whole analysed period.

Figure 3 shows the dependence between GDP per capita in the first year of investigation and its growth rate in the period of 1997–2020. The negatively sloped regression line shows that lower economic growth rates characterized countries with a higher level of GDP per capita in 1997. Based on the relationship shown in Figure 3, we can suppose that the economic convergence between selected countries occurs.

The supposition about economic convergence can also be formulated based on the maps in Figure 4. The map on the left presents the GDP per capita level in Balkan countries in 1997, whereas the map on the right shows its growth rate in the period of 1997–2020. Countries with a higher level of GDP per capita in 1997 had, on average, a lower growth rate.

The first step of the investigation contains the analysis of β-convergence based on the cross-sectional data. Models were estimated in two periods: (1) 1997–2019 and (2) 1997-2020. The choice of periods is associated with the start of the COVID-19 pandemic and its impact on the convergence process.

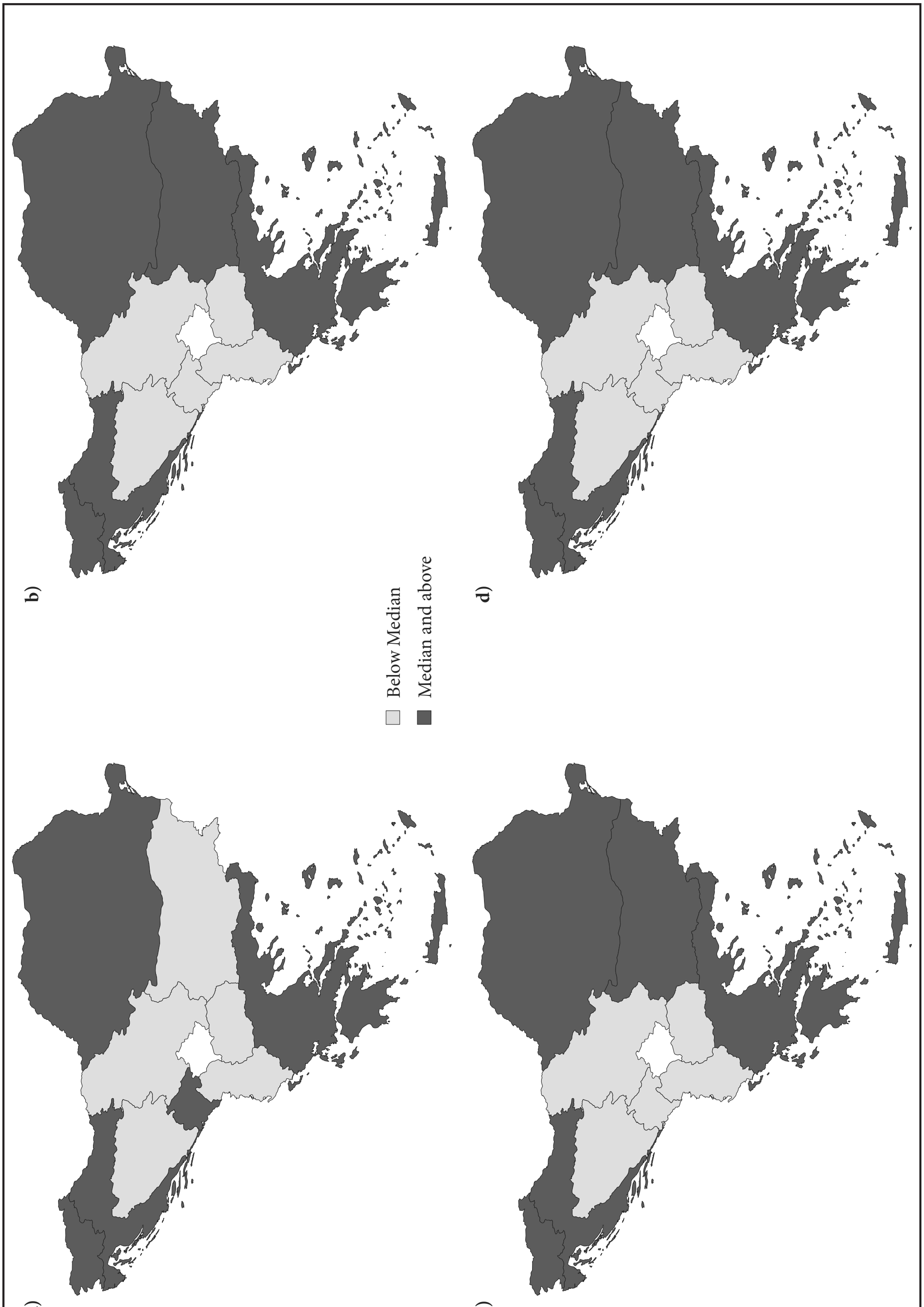
Table 2 presents the results of the estimation and verification of cross-sectional β-convergence models in periods 1997–2019 and 1997–2020. In both cases, parameter β is negative and statistically significant. It is caused by the GDP per capita level in selected Balkan countries to converge to the same steady-state level. Values of statistic b show that in one year, inequalities in the considered process are reduced by 1.68% and 1.82% based on the data from the period 1997–2019 and 1997–2020, respectively. It implies that half of the current inequalities will be reduced in almost 41 and 38 years, respectively. Both models have desirable characteristics that refer to homoscedasticity and normality of residual distribution. Changes in the GDP per capita in 2020 caused a slight acceleration of the convergence process based on the cross-sectional data approach.

Table 3 contains the results of the estimation and verification of panel data β -convergence models in the periods 1997–2019 and 1997–2020. Analysis was preceded by testing the unit root presence in the GDP per capita panel data using the Levin-Lin-Chu (LLC) test. For both periods, values of test statistics allowed us to reject the zero hypothesis about unit roots in the formation of GDP per capita level. Therefore, the results of the model's estimation can be considered reliable. The parameter estimate (1 + β) is less than one in both models, and the parameter is statistically significant. It causes economic convergence between Balkan countries, based on data from 1997–2020. The panel data approach shows that inequalities in the

Table 1: GDP per capita levels in extreme years of the analysis and its growth rate.

Country	GDP per capita (constant 2015 USD)		
	1997	2020	Growth rate
Albania (ALB)	1464.30	4390.06	199.81%
Bulgaria (BGR)	3674.93	7920.91	115.54%
Bosnia and Herzegovina (BIH)	2001.18	5433.15	171.50%
Croatia (HRV)	8322.96	12986.24	56.03%
Montenegro (MNE)	4486.78	6512.62	45.15%
Greece (GRC)	16972.72	17292.63	1.88%
North Macedonia (MKD)	2954.52	5115.92	73.16%
Serbia (SRB)	3180.51	6540.72	105.65%
Slovenia (SVN)	14415.78	22915.15	58.96%
Romania (ROU)	4526.06	10828.45	139.25%

Figure 2: The spatial differentiation of GDP per capita in Balkan countries in the years 1997 (a), 2004 (b), 2012 (c), and 2020 (d). ➤ p. 98


a)
b)
c)
d)
Below Median
Median and above

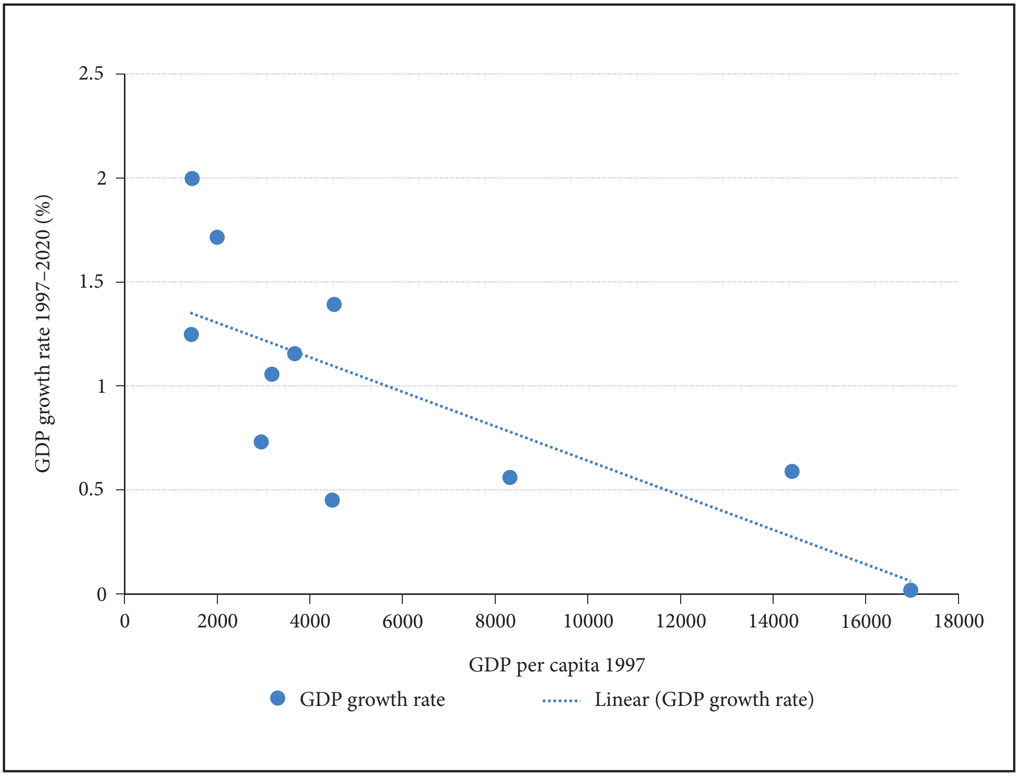


Figure 3: The dependence between GDP per capita in 1997 and its growth rate in the period of 1997–2020.

Table 2: The results of estimation and verification of cross-sectional β-convergence models.

Parameter	1997–2019			1997–2020		
	Estimate	t-Statistics	p-value	Estimate	t-Statistics	p-value
α	3.39	5.99	≤ 0.05***	3.52	5.36	≤ 0.05***
β	–0.32	–4.79	≤ 0.05***	–0.34	–4.41	≤ 0.05***
			Diagnostics			
R^2		0.74			0.71	
White test		0.91 (0.64)			1.43 (0.49)	
D-H test		0.32 (0.85)			0.32 (0.85)	
b		0.02			0.02	
t_{hl}		41.32			38.06	

Notes: (1) D-H denotes Doornik and Hansen normality test; (2) Numbers in brackets refer to p-values of tests statistics;*** – parameter statistically significant at the 1%.

GDP per capita level can be reduced faster than in the cross-sectional approach. The time needed to reduce current inequalities by half decreased to about 7 and 9 years in the period of 1997–2019 and 1997–2020, respectively. Speed-up of the convergence process refers to increasing inequalities between units which are reduced in one year to 9.43% and 7.87%, respectively. The results of the Arellano-Bond test point out the lack of second-order autocorrelation in the models' residuals.

Compared to the models based on the cross-sectional data, changes in the GDP per capita level in 2020 slightly cause inhibition of the convergence process. Conclusions based on the panel data approach are more reliable due to consideration of changes in the whole period, not only in two extreme years of the analysis. The inhibition of economic convergence between Balkan countries is connected with the first

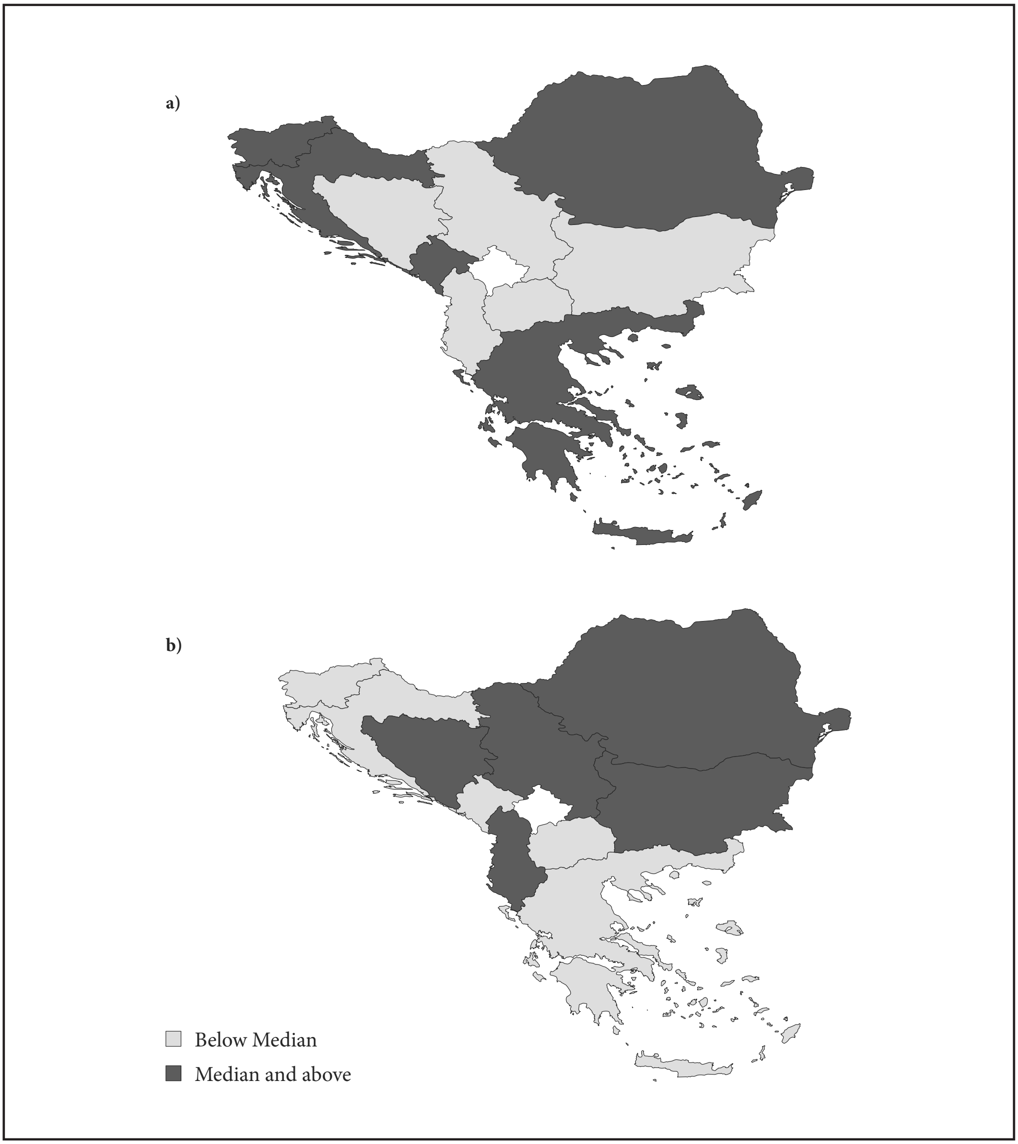


Figure 4: The spatial differentiations of GDP per capita level in 1997 (a) and its growth rate in the period of 1997-2020 (b).

negative results of the COVID-19 pandemic, which are observable for some of the considered countries, especially since this breakdown appeared after a continuous upward trend visible for the previous few years.

Table 4 presents the results of estimation and verification of switching panel data β-convergence models. They consider two separate regimes of countries. The first regime contains Balkan countries that belong to the European Union. In the second group non-EU countries are included. In the period of 1997–2019 the estimates of parameters $1 + \beta^1$ and $1 + \beta^2$ have similar values 0.98 and 0.95, respectively, and they are statistically significant. Values of parameters below one testify that the convergence process occurs in both groups of countries. It is worth noting that the process speeds up considering data in the period of 1997–2020. The time needed to reduce existing inequalities by half falls from nearly 32 to nearly 28 years and from 14 to 11 years for EU and non-EU countries, respectively. It is the opposite situation than for the whole area, where the convergence slowed down adding one year to the investigation. The relatively large difference between speed of convergence in the first and the second period in case of non-EU Balkan countries is caused by the most negative effects of the COVID-19 pandemic in the countries with the highest level of GDP per capita, e.g. Montenegro. This causes that units can become more similar in the shorter time.

Moreover, the half-life time statistics is higher in the analysis with regimes. This can result from share the whole area into more homogenous groups. High similarity of units and relatively stable differences in time between them cause that the time needed to become more and more similar is longer.

Table 3: The results of estimation and verification of panel data β -convergence models.

Parameter	1997–2019			1997–2020		
	Estimate	z-Statistics	p-value	Estimate	z-Statistics	p-value
a	0.81	0.79	0.43	0.68	0.78	0.44
$1+\beta$	0.91	7.62	≤ 0.05***	0.92	9.19	≤ 0.05***
Diagnostics						
A-B(1) test		–2.10 (0.04)			–2.21 (0.03)	
A-B(2) test		–0.40 (0.69)			–0.70 (0.48)	
b		0.09			0.08	
t_{hl}		7.35			8.81	

Note: A-B(*n*) refers to Arellano and Bond *n*-order autocorrelation test; *** – parameter statistically significant at the 1%.

Table 4: The results of estimation and verification of switching panel data β-convergence models.

Parameter	1997–2019			1997–2020		
	Estimate	z-Statistics	p-value	Estimate	z-Statistics	p-value
a^1	0.23	4.15	≤ 0.05***	0.25	4.22	≤ 0.05***
a^2	0.43	5.04	≤ 0.05***	0.53	5.88	≤ 0.05***
$1+\beta^1$	0.98	166.50	≤ 0.05***	0.98	152.60	≤ 0.05***
$1+\beta^2$	0.95	93.43	≤ 0.05***	0.94	86.49	≤ 0.05***
Diagnostics						
b^1		0.02			0.02	
t^1_{hl}		31.75			27.80	
b^2		0.05			0.06	
t^2_{hl}		14.40			11.20	

Note: *** – parameter statistically significant at the 1%. Number 1 is related to the EU countries, number 2 is related to the non-EU countries.

4 Discussion

Fortunately, in this study, the process of economic convergence in the Balkans in 1997–2019 and 1997–2020 occurred with the speed of: (i) for cross-sectional data 1.68% and 1.82%, respectively, (ii) for panel data 9.43% in 1997-2019 and 7.87% in 1997–2020. Hence, there is no agreement on what should be a reference point for the speed of convergence. Some indicate an average rate of convergence of around 2% per year in a cross-sectional approach (Barro et al. 1991; Barro and Sala-i-Martin 1992); others emphasize that there is no 'natural' rate of convergence and deny the existence of the previously mentioned 2% rate of convergence (Abreu, De Groot and Florax 2005; Arbia, Le Gallo and Piras 2008; Mur, López and Angulo 2010). However, numerous studies confirm that the convergence rate for the panel data should be higher – accounting for 5.6% (Barro and Sala-i-Martin 1995), around 6% (Islam 1995), or even 10% (Caselli, Esquivel and Lefort 1996).

Próchniak and Witkowski (2013) analysed 25 European transition countries, including the Balkans, from 1960 to 2009. The results indicated the β-convergence in the group of all considered countries conditioned by economic growth factors occurred with the speed of 1.5–2.0% percent annually. In a different study, the rate of convergence for the Balkans was 2.6% in 1989–1993 and 2.2% in 1994–2005 (El Ouardighi and Somun-Kapetanovic 2007). Another study proved that from 2004 to 2013, the Western Balkans and the EU converged (GDP per capita) at 2.17% (Siljak and Nagy 2018). This study confirms that the Balkan countries are converging in economic terms, which is a positive sign. However, the speed of convergence is different depending on the data applied in the research. For cross-sectional data, the process results are below expectations of 2% as Barro and others (1991) indicated. However, the panel data model shows optimistic outcomes of around 8–9% convergence speed per annum.

Hence, it is difficult to decide which approach should be chosen for the analysis (therefore this paper applied both). One can argue that a panel estimate of convergence is preferable. The idea of convergence is defined as a dynamic concept, which may be difficult to capture with cross-sectional analysis (Das 2002).

Policymakers should therefore focus on addressing the issue of economic growth in the Balkan countries since their convergence level – although is sufficient, it is definitely not extraordinary. Thus, these countries should focus on foster the factors of economic growth, which include: quality institutions (property rights, dependable legal system, honest government, competitive market, political stability), creating new incentives for growth (better conditions for doing business, more efficient spending on R&D), and factors of production including: human and physical capital, organization, technological knowledge (Cowen and Tabarrok 2021; Helpman 2009). Nevertheless, it is important to underline that non-EU Balkan countries converge faster than the EU Balkan ones. This is an optimistic prognostic, especially taking into consideration their EU aspiration and candidate or potential candidate status.

5 Conclusion

The paper researched an essential economic growth phenomenon, the β-convergence model, in the Balkans in the periods of 1997–2019 and 1997–2020. The results from cross-sectional β-convergence models showed an economic convergence process between Balkan countries with speeds ranging from 1.68% to 1.82% in the analysed periods. Considering panel data, the results imply that the convergence process not only exists but is also much faster. The speed of the convergence process accounts for 9.43% in 1997–2019 and 7.87% in 1997–2020.

The results clearly proved the existence of economic convergence in the Balkan economies. It indicates that the countries with an initially lower level of economic growth are on the way to catching up with these wealthier economies at the starting point. The pace of the catching-up process is not impressive, so although the convergence process occurs, its results imply that there is still a long way ahead for the poorer economies to catch up.

Further research on this topic may include the more developed comparative analysis between the convergence of the EU and non-EU members within the Balkans, using, e.g., the club-convergence approach. It would also be an explorative topic to know whether the Balkans' economies converge with the remaining EU economies and their average. Moreover, the conditional convergence will be considered. Finally, as new data will be published, the research may focus on the COVID-19 impact on economic convergence in the Balkans.

6 References

Abreu, M., De Groot, H. L. F., Florax, R. J. G. M. 2005: A meta-analysis of β-convergence: the legendary 2%. Journal of Economic Surveys 19-3. DOI: https://doi.org/10.1111/j.0950-0804.2005.00253.x

Amable, B. 1993: Catch-up and convergence: a model of cumulative growth. International Review of Applied Economics 7-1. DOI: https://doi.org/10.1080/758528250

Arbia, G. 2006: Spatial econometrics: statistical foundations and applications to regional convergence. Heidelberg. DOI: https://doi.org/10.1007/3-540-32305-8

Arbia, G., Le Gallo, J., Piras, G. 2008: Does evidence on regional economic convergence depend on the estimation strategy? Outcomes from analysis of a set of NUTS2 EU regions. Spatial Economic Analysis 3-2. DOI: https://doi.org/10.1080/17421770801996664

Arbia, G., Basile, R., Piras, G. 2005: Using spatial panel data in modelling regional growth and convergence. ISAE Working Paper 55. DOI: https://doi.org/10.2139/ssrn.936321

Arellano, M., Bond, S. 1991: Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. The Review of Economic Studies 58-2. DOI: https://doi.org/10.2307/2297968

Baldwin-Edwards, M. 2004: Sustainable development and emigration: The contemporary Balkans and the European Union. SEER: Journal for Labour and Social Affairs in Eastern Europe 7-1.

Barro, R. J., Sala-i-Martin, X. 1992: Convergence. Journal of Political Economy 100-2. DOI: https://doi.org/10.1086/261816

Barro, R. J., Sala-i-Martin, X., Blanchard, O. J., Hall, R. E. 1991: Convergence across states and regions. Brookings Papers on Economic Activity 1991-1. DOI: https://doi.org/10.2307/2534639

Barro, R. J., Sala-i-Martin, X. 1995: Economic growth. Cambridge, London.

Bartlett, W., Uvalic, M., Durazzi, N., Monastiriotis, V., Sene, T. 2016: From university to employment: Higher eduation provision and labour market needs in the Western Balkans. Synthesis Report. Brussels.

Ben-David, D. 1996: Trade and convergence among countries. Journal of International Economics 40-3,4. DOI: https://doi.org/10.1016/0022-1996(95)01405-5

Borsi, M. T., Metiu, N. 2015: The evolution of economic convergence in the European Union. Empirical Economics 48. DOI: https://doi.org/10.1007/s00181-014-0801-2

Bourdin, S. 2015: National and regional trajectories of convergence and economic integration in Central and Eastern Europe. Canadian Journal of Regional Science 38-1.

Broadberry, S. 2013: Accounting for the great divergence. Economic History Working Papers 184-13.

Caselli, F., Esquivel, G., Lefort, F. 1996: Reopening the convergence debate: A new look at cross-country growth empirics. Journal of Economic Growth 1-3.

Chambers, D., Dhongde, S. 2016: Convergence in income distributions: Evidence from a panel of countries. Economic Modelling 59. DOI: https://doi.org/10.1016/j.econmod.2016.07.019

Cowen, T., Tabarrok, A. 2021: Modern Principles: Macroeconomics. New York.

Crampton, R. J. 2002: The Balkans since the Second World War. London. DOI: https://doi.org/10.4324/9781315843209

de la Fuente, A. 1995: Catch-up, growth and convergence in the OECD. CEPR Discussion Papers 1274.

Das, T. K. 2002: Convergence across Indian States: Cross-sectional and panel estimations. South Asia Economic Journal 3-2. DOI: https://doi.org/10.1177/139156140200300207

Doornik, J. A., Hansen, H. 2008: An omnibus test for univariate and multivariate normality*. Oxford Bulletin of Economics and Statistics 70-1. DOI: https://doi.org/10.1111/j.1468-0084.2008.00537.x

El Ouardighi, J., Somun-Kapetanovic, R. 2007: Do Balkan countries have a European future? An analysis of real economic convergence 1989-2005. South East European Journal of Economics and Business 2-2. DOI: https://doi.org/10.2478/v10033-007-0002-4

Helpman, E. 2009: The mystery of economic growth. Cambridge. DOI: https://doi.org/10.2307/j.ctv1c5cx4v

Islam, N. 1995: Growth empirics: A panel data approach. The Quarterly Journal of Economics 110-4. DOI: https://doi.org/10.2307/2946651

Jushi, E., Hysa, E., Cela, A., Panait, M., Voica, M. C. 2021: Financing growth through remittances and foreign direct investment: Evidences from Balkan Countries. Journal of Risk and Financial Management 14-3. DOI: https://doi.org/10.3390/jrfm14030117

King, R., Oruc, N. 2019: Editorial Introduction: migration in the Western Balkans – trends and challenges. Journal of Balkan and Near Eastern Studies 21-1. DOI: https://doi.org/10.1080/19448953.2018.1532682
Levin, A., Lin, C. F., Chu, C. S. J. 2002: Unit root tests in panel data: asymptotic and finite-sample properties. Journal of Econometrics 108-1. DOI: https://doi.org/10.1016/S0304-4076(01)00098-7
Lukić, T., Stojsavljević, R., Đurđev, B., Nagy, I., Đerčan, B. 2012: Depopulation in the Western Balkan countries. European Journal of Geography 3-2.
Lulle, A. 2019: Balkans and Baltics: on migration as a factor of regional peripheralization. Journal of Balkan and Near Eastern Studies 21-1. DOI: https://doi.org/10.1080/19448953.2018.1532684
Malaj, V., de Rubertis, S. 2017: Determinants of migration and the gravity model of migration-application on Western Balkan emigration flows. Migration Letters 14-2.
Mickovic, B., Mijanovic, D., Spalevic, V., Skataric, G., Dudic, B. 2020: Contribution to the analysis of depopulation in rural areas of the Balkans: case study of the municipality of of Niksic, Montenegro. Sustainability 12-8. DOI: https://doi.org/10.3390/su12083328
Mur, J., López, F., Angulo, A. 2010: Instability in spatial error models: An application to the hypothesis of convergence in the European case. Journal of Geographical Systems 12. DOI: https://doi.org/10.1007/s10109-009-0101-0
Nedić, V., Despotović, D., Cvetanović, S., Djukić, T., Petrović, D. 2020: Institutional reforms for economic growth in the Western Balkan countries. Journal of Policy Modeling 42-5. DOI: https://doi.org/10.1016/j.jpolmod.2020.04.002
Palier, B., Rovny, A. E., Rovny, J. 2018: European disunion? Social and economic divergence in Europe, and their political consequences. Welfare Democracies and Party Politics: Explaining Electoral Dynamics in Times of Changing Welfare Capitalism. Oxford. DOI: https://doi.org/10.1093/oso/9780198807971.003.0011
Petrakos, G., Kallioras, D., Anagnostou, A. 2011: Regional convergence and growth in Europe: Understanding patterns and determinants. European Urban and Regional Studies 18-4. DOI: https://doi.org/10.1177/0969776411407809
Petreski, M., Petreski, B., Tumanoska, D., Narazani, E., Kazazi, F., Ognjanov, G., Jankovic, I. et al. 2017: The size and effects of emigration and remittances in the Western Balkans. A forecasting based on a Delphi Process. Comparative Southeast European Studies 65-4. DOI: https://doi.org/10.1515/soeu-2017-0044
Pritchett, L. 1997: Divergence, big time. Journal of Economic Perspectives 11-3. DOI: https://doi.org/10.1257/jep.11.3.3
Rey, S. J., Le Gallo, J. 2009: Spatial analysis of economic convergence. Palgrave Handbook of Econometrics. London. DOI: https://doi.org/10.1057/9780230244405_27
Próchniak, M., Witkowski, B. 2013: Real β-convergence of transition countries. Eastern European Economics 51-3. DOI: https://doi.org/10.2753/EEE0012-8775510301
Sachs, J. D., Warner, A. M. 1995: Economic convergence and economic policies. National Bureau of Economic Research Working Paper 5039. DOI: https://doi.org/10.3386/w5039
Solow, R. M. 1956: A contribution to the theory of economic growth. The Quarterly Journal of Economics 70-1. DOI: https://doi.org/10.2307/1884513
Siljak, D., Nagy, S. G. 2018: The effects of the crisis on the convergence process of the Western Balkan countries towards the European Union. Society and Economy 40-1. DOI: https://doi.org/10.1556/204.2018.40.1.7
Upchurch, M. 2012: Persistent economic divergence and institutional dysfunction in post-communist economies: An alternative synthesis. Competition & Change 16-2. DOI: https://doi.org/10.1179/1024529412Z.0000000008
Uvalic, M. 2008: Integrating the Balkans with the European Union. The EU and the Economies of the Eastern European Enlargement. Heidelberg. DOI: https://doi.org/10.1007/978-3-7908-2034-8_5
Uvalic, M. 2011: Which development model for the Balkans? Reflections on the twenty years of transition (1989-2009). The Adriatic Balkan Area from Transition to Integration. Napoli.
Velkovska, I. 2021: Is there a link between income inequality and economic growth in the Balkans? Testing the Kuznets hypothesis. Revija za socijalnu politiku 28-2. DOI: https://doi.org/10.3935/rsp.v28i2.1764
White, H. 1980: A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. Econometrica 48-4. DOI: https://doi.org/10.2307/1912934

Yin, L., Zestos, G. K., Michelis, L. 2003: Economic convergence in the European Union. Journal of Economic Integration 18-1.
Zeneli, V. 2014: Economic development in the Western Balkans: On the road to competitive market economies? Connections 13-4.
Ziberi, B., Alili, M. Z. 2021: Economic growth in the Western Balkans: A panel analysis. South East European Journal of Economics and Business 16-2. DOI: https://doi.org/10.2478/jeb-2021-0015

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DETERMINING THE LENGTHS OF MILES AND NUMERICAL MAP SCALES FOR VOLUME VII OF THE GRAPHIC COLLECTION ICONOTHECA VALVASORIANA

Marina Viličić, Emilia Domazet, Martina Triplat Horvat

A section of a panoramic view of Wagensberg, which is included in Volume VII of the graphic collection of the *Iconotheca Valvasoriana* (Sig. VZ VII, 110) and in Valvasor's *Die Ehre des Hertzogthums Crain*, Book XI. The graphic author is Andreas Trost, the publisher is Johann Weichard Valvasor.

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UDC: 528.915:76”1685”

Marina Viličić[1], Emilia Domazet[2], Martina Triplat Horvat[3]

Determining the lengths of miles and numerical map scales for Volume VII of the graphic collection Iconotheca Valvasoriana

ABSTRACT: This article presents the procedure for determining numerical scales based on the graphic scales drawn to process the graphic material in Volume VII of the Valvasor collection. To calculate the numerical scales, the miles drawn on the maps and their lengths in relation to one degree of the meridian were studied. A total of 22 different miles were drawn on the maps studied, of which the German mile was the most common. After calculating the numerical scales, it was found that the largest scale of the maps examined was 1:220,000 and the smallest was 1:11,200,000.

KEYWORDS: *Iconotheca Valvasoriana*, graphic scale, length of miles, numerical scale, Valvasor, Metropolitan Library of the Archdiocese of Zagreb

Določanje dolžin milj in številčnih kartografskih meril v sedmem zvezku grafične zbirke Iconotheca Valvasoriana

POVZETEK: Avtorice v članku preučujejo grafično gradivo v sedmem zvezku Valvasorjeve zbirke, pri čemer predstavijo postopek določanja številčnih meril na podlagi vrisanih grafičnih meril. Za izračun številskih meril so preučile milje, narisane na zemljevidih, in njihove dolžine v razmerju do ene stopinje poldnevnika. Na preučevanih zemljevidih je bilo vrisanih skupno 22 različnih milj, med katerimi je bila najpogostejša nemška milja. Po izračunu številčnih meril so avtorice ugotovile, da je bilo največje uporabljeno merilo 1 : 220.000, najmanjše pa 1 : 11.200.000.

KLJUČNE BESEDE: *Iconotheca Valvasoriana*, grafično merilo, dolžina milj, številčno merilo, Valvasor, Metropolitanska knjižnica Zagrebške nadškofije

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[1] University of Zagreb, Facutly of Geodesy, Zagreb, Croatia
marina.vilicic@geof.unizg.hr (https://orcid.org/0000-0003-4312-4073)

[2] Metropolitan Library of the Archdiocese of Zagreb, Croatian State Archives, Zagreb, Croatia
edomazet@arhiv.hr (https://orcid.org/0000-0002-4851-3951)

[3] Geomatika d. o. o., Trilj, Croatia
martina.triplat.horvat@geomatika.hr (https://orcid.org/0000-0002-8304-7474)

1 Introduction

After being kept in various institutions for several centuries, the Valvasor graphic collection is now in the Metropolitan Library of the Archdiocese of Zagreb of the Croatian State Archives in Zagreb. The collection is the result of a private project by Johann Weichard Valvasor (slo. *Janez Vajkard Valvasor*), a Slovenian polymath, collector and owner of a copperplate engraving workshop, who collected 7,935 prints and bound them in 18 volumes (Abaffy 2004). To this day, the collection has been partially preserved in its original form, only Volume IV has been lost over time (Magić 2012).

Valvasor's personal interest and knowledge of cartography led him to collect valuable cartographic and topographic works, vedute and maps of most European countries and cities, and to include them in Volume VII of the graphic collection. Although most of the maps are from the 17th century, the volume also contains copies of maps from the 16th century. The volume contains editions by famous European cartographers, topographers and publishers such as the Dutch families Visscher and Blaeu, works by Georg Matthaeus Vischer from Vienna, etc. The majority of the city vedute were published by the Nuremberg publisher Paulus Furst and his successors. As far as the accuracy of his maps and vedute is concerned, Valvasor's works are in no way inferior to the works of the aforementioned publishers. Worth mentioning here is the unique copy of the oldest map of northern Croatia by the Jesuit Stjepan Glavač from 1673 (Magić, Pelc and Abaffy 2016).

The research for this article was conducted using a facsimile of Volume VII of the Valvasor collection. A verification of the original map with a facsimile was conducted as part of Viličić's dissertation (Viličić 2019) on the map of Stjepan Glavač. For the purposes of this study, an additional verification of the preservation of the dimensions of the maps published in the facsimile was performed on some selected maps. This comparison showed that the facsimile of the maps was made in the actual dimensions because there were

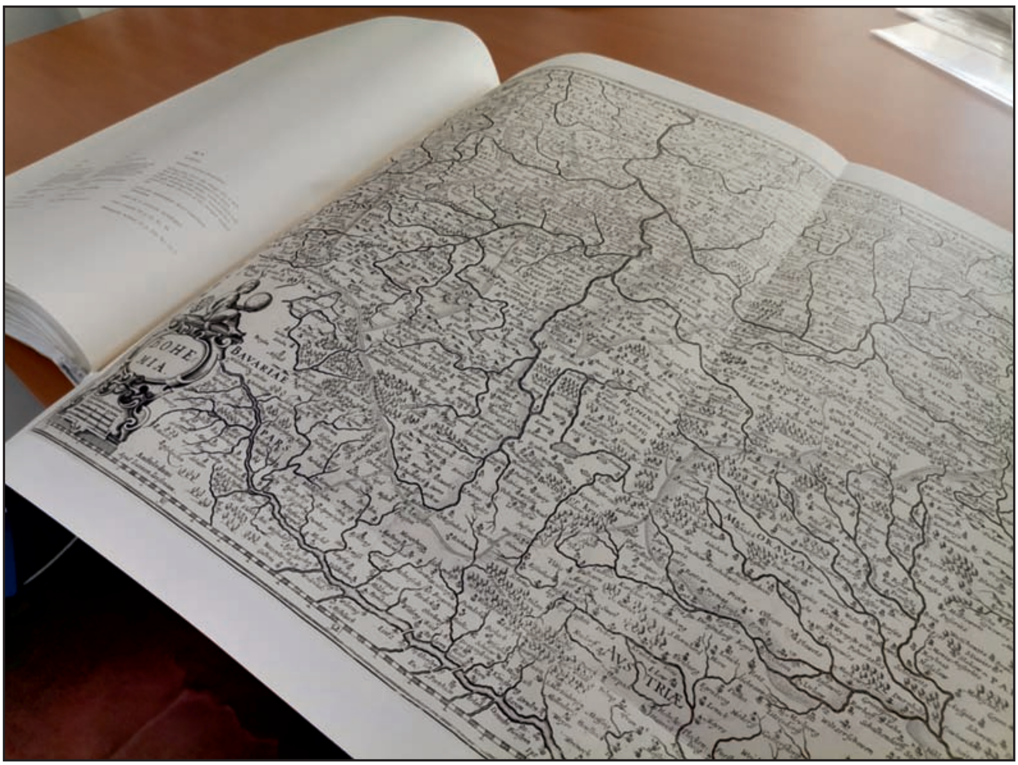

Figure 1: Layout of Volume VII of the graphic collection of the *Iconotheca Valvasoriana*.

no changes in the dimensions of the map. The facsimile edition project began in 2002, and in 2010 a facsimile edition of all 17 volumes of the Valvasor collection was published in cooperation with the Slovenian Academy of Sciences and Arts (Franc 2011, https://www.zg-nadbiskupija.hr/mobile.aspx?id=4935). The *Iconotheca Valvasoriana* (Figure 1) was published by the Janez Vajkard Valvasor Foundation at the Slovenian Academy of Sciences and Arts in Ljubljana. The co-publisher was the Archdiocese of Zagreb, Metropolitana Library, which provided the originals for the preparation of a facsimile edition (Gostiša 2004).

Since no one has yet dealt with the calculation of the scales for the maps contained in Volume VII of the Valvasor graphic collection, this article aims to fill this gap by presenting the procedure for determining the numerical map scale using graphic scales based on the facsimile edition.

1.1 Literature review

For recalculating measurements expressed in old measures, the literature (Riccioli 1661; 1672; Belostenec 1740; Anonymus 1798; von Alberti 1957; Vlajinac 1968; Herkov 1977; Mušnjak 1982; Kretschmer 1986; Viličić and Lapaine 2016) dealing with the lengths of the old linear measures was examined. In the previous literature, there are works that deal with a similar topic, such as Krejčí and Cajthaml (2009) who used an approximation for the length of the Moravian Mile, as they did not know its reliable length. Viličić and Lapaine (2016) calculated the length of the Croatian Mile using the graphic scales on the analysed maps. Jupp (2017) deals with the standardization of the length of the Chinese unit li. In his calculation, the author used the knowledge that the Earth was considered a sphere in Europe at that time, and to calculate the length he used the radius of a sphere with the same centre and surface as the WGS84 ellipsoid.

In the analysed literature there are several approaches to determine the numerical scale of the map. Mušnjak (1982) showed the calculation of the numerical scale in three different ways: by applying a graphic scale, by using a degree grid of latitude, and by comparing it with a map of the same area but with a different scale. Beineke (2001) explains the determination of scale using two methods: direct determination of scale using an old map and indirect determination of scale by comparison with modern maps. Krejčí and Cajthaml (2009) determined the numerical scale of Muller's map of Moravia in several ways: by using a graphical scale bar, by measuring distances between towns, by measuring the map frame, and by using MapAnalyst software. Rajaković, Kljajić and Lapaine (2014) determined the scale of the Mercator map of *Sclavonia, Croatia, Bosnia cum Dalmatiae parte* using the scale bar in German and Italian Miles. Jupp (2017) used the digitized facsimiles to determine the scale by calculating the ratio between the size of the scan points and the average pixel size. In addition to using the graphical scale to calculate the numerical scale, Viličić and Lapaine (2023) determined the scale of the Glavač map by applying the calculated amount of the radius-to-scale ratio obtained after determining the map projection and latitude of the standard parallel of the Glavač map. In addition to Krejčí and Cajthaml (2009), there are examples of other articles in which the MapAnalyst software tool was used to calculate the numerical scale (e.g., Bower 2009; Cajthaml 2009; Bitelli and Gatta 2012; Selvi and Bekiroglu Keskin 2019).

2 Materials and methods

2.1 Materials

Volume VII of the graphic collection of the *Iconotheca Valvasoriana* (Figure 1) contains 46 maps, including map sheets by Georg Matthaeus Vischer: Upper Austria of 1669 and Styria of 1678. However, other graphic representations refer to vedute. Within Volume VII maps are marked with the signature VZ VII and the ordinal number of its occurrence within the volume. Of the total number of maps illustrated in Volume VII of the Valvasor collection, only 35 maps have a graphic scale, which was used to calculate the approximate numerical scale. In addition, the article contains a list of the miles drawn on the analysed maps and their lengths (Table 4). Since some miles are not listed in the contemporary literature (e.g., von Alberti 1957), it was necessary to find them in the literature published at the time of the publication of the maps analysed or to obtain them by calculation in relation to the other mile drawn on the map.

2.2 Methods

For maps with drawn graphic scales (Table 1) whose length is denoted in miles, an approximate numerical scale was calculated. Before calculating the scale, it was necessary to research how the mile lengths were expressed, whether they were divided into meridian degrees, walking hours, etc. This information was obtained by consulting the literature (Riccioli 1661; 1672; Belostenec 1740; Anonymus 1798; von Alberti 1957; Vlajinac 1968; Herkov 1977; Mušnjak 1982; Kretschmer 1986; Viličić and Lapaine 2016), calculating from the ratio to a mile of known length, or, in the best case, by specifying the data with the graphic scale plotted on the map. When length was expressed as a proportion of the meridian degree, it was necessary to express that length in today's metric system of units and to determine for each map when it was published. To obtain the desired length, it was first determined whether the Earth to which the fraction of the meridian degree refers was considered a sphere or an ellipsoid at that time, and then the possible dimensions of the Earth at that time and the length of the meridian degree were converted to today's metric system of units (Chapter 3.1 and Table 2).

For the calculation of the approximate numerical scale in Table 5 (Chapter 3.3), the values of each author for the radius of the Earth's sphere and the length of one degree of the meridian were used, which are given in Table 2. Table 5 shows the calculated numerical scales in relation to different values of the Earth's radius and the average numerical scale calculated from these scales.

In calculating the numerical scale of the map, the concept of approximate scale (Table 5) is used because it should be taken into account that the ellipsoid and the sphere cannot be mapped onto a plane without distortion, so the scale cannot have the same value at every point on the map and different scales exist in different parts of a map (Frančula 2000; Robinson et al. 2017). Moreover, it is difficult to determine with certainty the exact numerical scale, i.e. the main scale, since the exact length of those miles (Chapter 3.2) and the dimensions of the Earth at that time are not known (at that time there were several surveys of the Earth, Table 2).

The entire process of determining the approximate numerical scale of the map from the graphic scale was divided into the following steps (Figure 2):

1. Defining the main aim: calculating the numerical map scales for Volume VII of *Iconotheca Valvasoriana*,
2. Analyzing the time frame, i.e. the year and/or the century in which the map was published,
3. Determining whether the geographic coordinates on the map are defined on a sphere or an ellipsoid,
4. Determining the possible dimensions of the Earth at that time,
5. Reading the length of the graphic scale from the maps and the units in which the length of a mile is expressed,
6. Determining the possible length of a mile at that time (checking in the literature, calculating in relation to a mile of known length or on the map),
7. Converting the length of the mile into today's metric system of units, and
8. Calculating the approximate numerical scale of the map.

On the analysed maps (Table 1), graphic scales are expressed by the length of a given mile. Herkov (1977) states that some miles have had different lengths throughout history, some have not changed, and some have remained unknown. Since measurements have changed over time, Mušnjak (1982) points out that when recalculating measurements expressed in old measurements, it is necessary to know the year in which the map was made and the area in which it was made. For this reason, before calculating the numerical scale of the map, it was necessary to study and calculate the lengths of the miles of that time, expressed as part of a degree of the meridian, an hour of walking, the number of steps, etc.

In the following, using the example of Figure 3 and expressions 1–3, we showed how to calculate the length of a mile (*Milliaria Gallica*) when its length is not known, for example, when the part of the mile in one degree of the meridian is unknown and the length of the second mile (*Milliaria Germanica*) drawn on the map is known as the 15th part of a meridian degree.

The numerical scale M is a map scale which can be given in terms of a ratio or fraction (Frančula, Lapaine and Jazbec 2020). In the form of a fraction, we write it as:

$$\overline{\qquad}, \qquad\qquad 100{,}000 \qquad\qquad (1)$$

where n is the total number of miles read from the graphic scale, d is the length of the entire length of the graphic scale on the map in centimetres (Figure 3), l is the length of one mile in centimetres, L is the part of a mile in a degree of the meridian (Table 4) and k is the length of a degree of the meridian in kilometres given by each author (Table 2).

Table 1: List of analysed maps from the graphic collection of the *Iconotheca Valvasoriana* with information about the signature, the title of the map, the year of creation, the name of the author and other remarks (Gostiša 2004). If the data for individual maps are not known, the fields in the table are left blank.

Signature	Title of map	Year	Author	Remark
VZ VII, 5	*Nova totius REGNI POLONIAE… Exacta Delineato…*	1685	Guillaume Le Vasseur de Beuplan	Hollstein (Paas 1994) dates the map to around 1685.
VZ VII, 7	*NOVA TOTIVS GERMANIAE DESCRIPTO*	1631	Willem Blaeu	Copy according to W. Blaeu's map from 1631.
VZ VII, 12	*NOVA hactenus… SCLAVONIAE et CROATIAE…*	1673	Stjepan Glavač	
VZ VII, 13-24	*Archiducatus Austr[iae Superioris Geographica Descriptio facta Anno 1667]*	1669	Georg Matthäus Vischer	The map was completed in 1667 and printed in 1669.
VZ VII, 25-36	*Stijriae Ducatus Fertilissim[i Nova Geographica Descriptio…]*	1678	Georg Matthäus Vischer	
VZ VII, 37	*KARSTIA, CARNIOLA, HISTRIA et WINDORVM MARCHIA*	1589	Gerhard Mercator	The map was first published in Mercator's 1589 set entitled *Italiae, Sclavoniae et Graeciae tabule geografice*.
VZ VII, 38	*Celsissimo ac… GUIDOBALDO Archiep*	1666	Franciscus Dückher	
VZ VII, 39	*Erzhertzogthum Kärnten*	1688	Johann Weichard Valvasor	This map was published in Valvasor's work from 1688.
VZ VII, 40	*CARNIOLIA KARSTIA HISTRIA et WINDORVM MARCHI…*	1684	Johann Weichard Valvasor	It is assumed that the map was created in 1684.
VZ VII, 41	*CROATIA*	1684	Johann Weichard Valvasor	It is assumed that the map was created in 1684.
VZ VII, 42	*CARNIOLIA KARSTIA HISTRIA et WINDORVM MARCHIA*	1681	Johann Weichard Valvasor	The map was also printed in the work *Carniolia antiqua et nova* by J. L. Schönleben.
VZ VII, 45	*REGNI HVNGARIAE Superioris, et maximae partis Inferioris…*	1682	Johann Alwxander Reiner	
VZ VII, 46	*TVRCICVM IMPERIVM*	1634–1663	Willem and Joan Blaeu	The map appears in the atlases of Willem and Joan Bleau between 1634–1663.
VZ VII, 47	*NOVA ITALIAE DELINEATIO*	1631	Willem and Joan Blaeu	The map appears in the atlases by Willem and Joan Blaeu from 1631, and is based on the 1617 map of Italy by G. A. Magini.
VZ VII, 48	*MAGNAE BRITANNIAE et HIBERNIAE Nova DESCRIPTIO*	1629		The map is probably a copy of W. Blaeu's 1629 map.
VZ VII, 49	*NAMVRICVM COMITATVS*	1647	Cornelis Danckerts	The map is a copy of the Willem and Joan Blaeu map, for example, in 1647.
VZ VII, 50	*VTRIVSQVE BVRGVNDIAE, tum Ducatus tum Comitatus, DESCRIPTIO*	1634–1663	Willem Blaeu	The map appears in the atlases by Willem and Joan Blaeu between 1634 and 1663.
VZ VII, 51	*LUTZENBURGENSIS DUCATUS VERISS. DESCRIPT.*	1579	Jacques Surhon	This is a copy of the map published in Ortelius' *Theatrum orbis terrarum* from 1579.
VZ VII, 52	*STIRIA Steyrmarck*	1649		The map appears in the atlases by Willem and Joan Blaeu, for example in *Theatrum orbis terrarium, sive, Atlas Novus*, Amsterdam, 1649, part 1, no 5.

VZ VII, 53	*POLONIA Regnum, et SILESIA Ducatus*	1634		The map was created around 1634 according to the map by W. Grodecki.
VZ VII, 54	*TRANSYLVANIA Sibenburgen*	1595		The template for this map was Mercator's 1595 map of Transylvania.
VZ VII, 55	*MORAVIAE NOVA ET POST OMNES PRIORES ACCURATISSIMA DELINEATIO*	1664	Johann Amos Komensky	The template for this map was issued by Claes Jansz Visscher's father in 1621.
VZ VII, 56	*SILESIA DVCATVS*	1579	Martin Helwig	The map was created according to a map from Ortelius' 1579 *Theatrum orbis terrarum*. Ortelius used Helwig's map of Silesia from 1561 as a template.
VZ VII, 57	*SCLAVONIA, CROATIA, BOSNIA cum DALMATIAE PARTE*	1589	Mercator	Mercator's map was first published in Mercator's set entitled *Italiae, Sclavoniae et Graeciae tabule geographice* in 1589.
VZ VII, 58	*BOHEMIA*		Publisher: Joannes Janssonius	
VZ VII, 59	*TABULA GERMANIAE emendata recens…*			
VZ VII, 60	*BELGII REGNII accuratissima Tabula*		Nicolaes I Visscher	
VZ VII, 61	*BELGIUM FOEDERATUM emendate auctum et novissime editum,…*		Nicolaes I Visscher	
VZ VII, 62	*Novissima et accuratissima XVII PROVINCIARUM GERMANIAE INFERIORIS Delineatio*			
VZ VII, 63	*DUCATUS GELDRIA et ZUTPHANIA Comitatus*			A reduced copy of Visscher's large map of Gelderland.
VZ VII, 64	*GALLIA Vulgo LA FRANCE,..*			
VZ VII, 65	*Totius FLUMINIS RHENI Novissima DESCRIPTIO…*			
VZ VII, 67	*Totius Regni HUNGARIAE Maximaeque Partis DANUBII FLUMINIS… Delineatio*		Nicolaes I Visscher	
VZ VII, 68	*AUSTRIA, HUNGARY AND THE NEIGHBOURING AREAS*	1674	Antonio Francesco Lucini	
VZ VII, 69	*NOVANET ACCURATA TOTIUS… REGNI HUNGARIAE DESCRIPTIO*	1682	Corneo	

If a mile with an unknown length is denoted by *a* and a mile with a known length is denoted by *b*, and following the expression 1, the expression for calculating the fraction *M* is:

(2)

After equating both expressions, we obtain the ration of the known mile l_b to an unknown mile l_a:

(3)

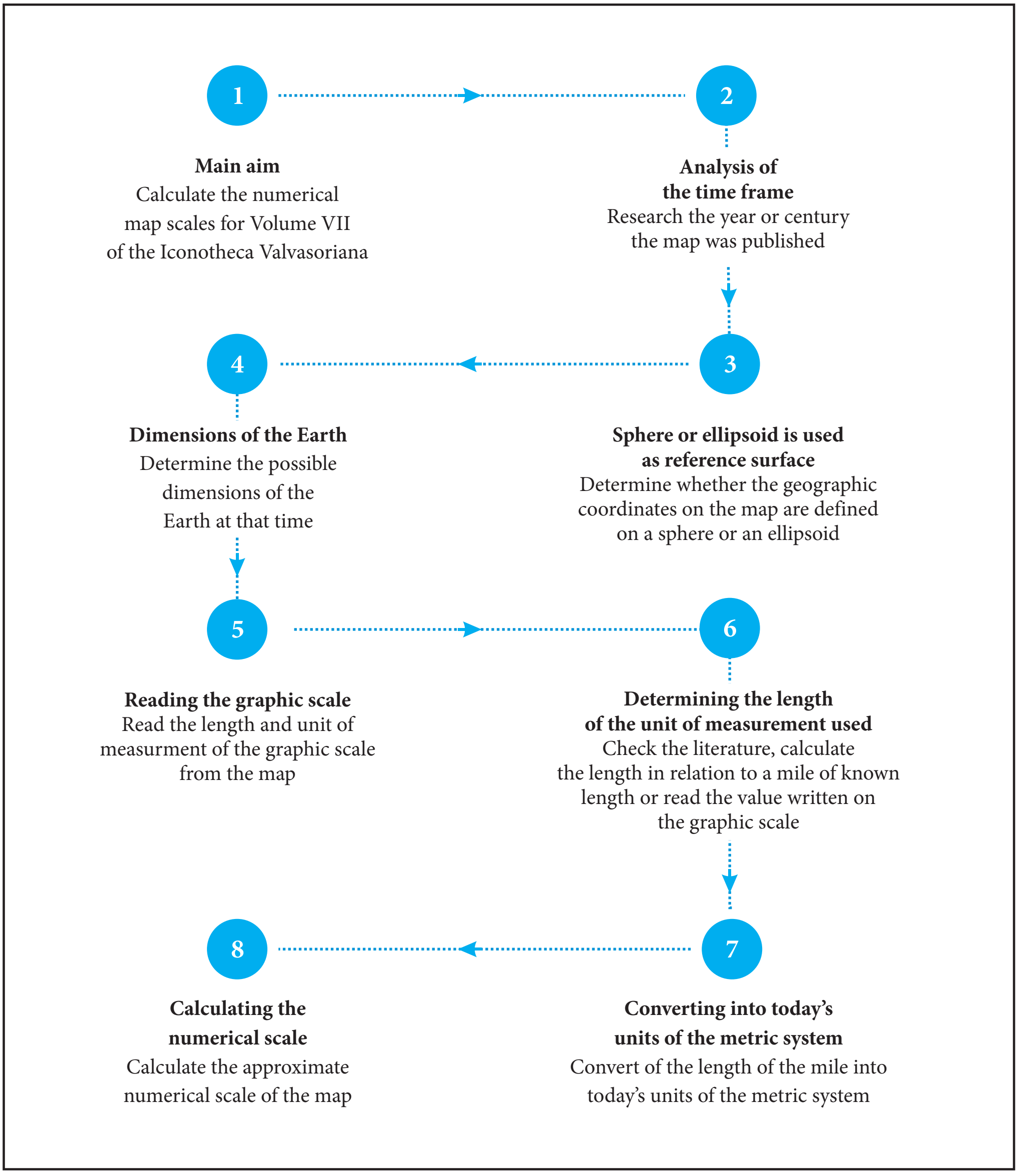

Figure 2: Research flow chart.

Figure 3: Display of the graphic scale on the map VZ VII, 50 with additional explanations of the graphic scale.

From the graphical scale, it was measured that 10 Gallic Miles (*Milliaria Gallica*) are 7.5 cm and 8 German Miles (*Milliaria Germanica*) are 8 cm. The known variables are $n_a = 10$, $d_a = 7.5$ cm, $n_b = 8$, $l_b = 1/15$, $d_b = 8$ cm, and the unknown variable is l_a. Using expression (3), it is established that one Gallic Mile l_a is equal to 0.75 German Miles, i.e. one Gallic Mile is 1/20 of the degree of the meridian.

On the maps of that time, it is difficult to determine the exact numerical scale with certainty because the lengths of these miles were expressed as a proportion of the meridian degree or a walking hour, and the exact radius of the Earth sphere at that time is not known in today's metric system of units. In determining the numerical scale of the map, the average numerical scale for various radii of the Earth sphere was first calculated, and then the obtained scale value was rounded to the nearest whole number, every 100,000 if the scale was smaller than 1,000,000, or every 10,000 if the scale was larger than 1,000,000; e.g., if the calculated scale was 4,449,280, the rounded value would be 4,500,000.

3 Results

3.1 Shape and dimensions of the Earth at the time of the publication of the maps

Volume VII of the graphic collection *Iconotheca Valvasoriana* dates from 1685, and the earliest known dating of a map within this collection refers to the map *Lutzenburgensis Ducatus Veriss. Descript*. (Sig VZ VII, 51) by Jacques Surhon, and the map *Silesia Dvcatvs* (Sig VZ VII, 56) by Martin Helwig from 1579. The last known dating of a map within this collection refers to the map *Erzhertzogthum Kärnten* by Valvasor (Sig VZ VII, 39) from 1688.

Table 2: Chronologically ordered values for the radius of the Earth's sphere and the length of one degree of the meridian, listed by Viličić and Lapaine (2023). The period given in the table covers the time of publication of the maps in Volume VII of Valvasor's graphic collection.

Year	1528	1602	1645	1668/1670
Author	Jean Fernel	Tycho Brahe	Riccioli	Jean Picard
Length of one degree of the meridian *k* [km]	111.232	111.282	120.658	111.212
Radius of the Earth's sphere *R* [km]	6371	6376	6917	6372

Accordingly, the published maps can be dated to the period from 1579 to 1688, i.e., from the end of the 16th century to the end of the 17th century. Since it was not until the end of the 17th century that Isaac Newton and Christiaan Huygens, with their theoretical deduction from mechanics, concluded that the Earth should have the shape of a rotating ellipsoid flattened at the poles (Solarić and Solarić 2016), it can be assumed that the Earth was considered a sphere at the time these maps were made.

Since there have been several attempts to determine the size of the Earth throughout history, which differed significantly based on the method of determination, it is important to consider the possible known values of the radius of the Earth's sphere at that time.

Viličić and Lapaine (2023) studied the possible radii of the Earth's sphere at the time of publication of the 1673 Glavač map, which is also part of the Valvasor collection, and whose publication date coincides with the dating of other maps in the collection.

Since the values determined by Snellius were published in 1729, 100 years after his death and after revisions by Petrus van Musschenbroek, later than the maps from Volume VII of the graphic collection, Snellius' value was not considered in the calculation. The results obtained earlier were published by Snellius in 1617 in the work *Eratosthenes Batavus*, but he made some errors in his first measurements (Lapaine and Frančula 1998). In this article the values of Blaeu's measurement were also not further analysed because they are not known and the only known fact is that the measured length of one meridian degree on the coast of the North Sea differed by 60 fathoms compared to more accurate Picard's measurement that followed more than 50 years later (Stevenson 1914; Lapaine and Frančula 1998; Luminet 2014). In addition, the arc length measured by Norwood is not known exactly. The measured length was about 550 m too long, but this was the best approximation made in England at that time (Laughton 2020). Since the value of Riccioli's radius differs considerably from the values of other authors, his value should be taken with caution. Piccard's value for the length of the 1° meridian followed almost at the end of the 17th century, so his value should be considered only for maps made after the publication of his length. Table 2 lists the known lengths of the 1° meridian that were used to calculate the approximate numerical scale and these values are from the time when the analysed maps were created.

3.2 Determination of lengths of miles on the analysed maps

Considering the period in which the analysed maps were published, the lengths of the miles drawn on the graphic scales are described below. Since miles are easier to interpret in relation to another mile, they are described with at least one additional mile drawn on the maps.

German Mile and Great Italian Mile

Viličić and Lapaine (2016) studied the length of the German Mile (*Milliaria Germanica*), on Glavač's map of 1673. The authors found that one German Mile was equal to four Italian Miles (*Milliaria Italica*), which corresponds to the ratios of the two miles marked on the map VZ VII, 57. Herkov (1977) concluded that the Italian Mile has not changed over the centuries and that it is equal to 1/60 of a meridian degree. Riccioli (1672) also gives the same value for the length of the Italian Mile, although it should be noted that his work was published at a time when most of the maps in the analysed graphic collection were produced.

In their works authors (Riccioli 1672; Herkov 1977; Viličić and Lapaine 2016) use the term Italian Mile for 1/60 degree of the meridian. Since there were two types of Italian Miles on the maps of the Valvasor collection, the suggestion by Herkov (1977) and Mušnjak (1982) was followed and a distinction between the miles was introduced: the Great Italian Mile (1/60 degree of the meridian) and the Small Italian Mile (1/75 degree of the meridian).

Small, Medium and Large German Mile *(Milliarium Commune, Maiusculum* and *Magnum)*

Vischer's map of Upper Austria from 1669 consists of map sheets (Sig VZ VII, 13-24), where on sheet Sig VZ VII, 23, three graphic scales of the *Scala Milliarium* are drawn (Figure 4).

A review of the literature revealed no information about these miles or their length. To solve the problem, the 1678 map of Styria by the same author was consulted. On the sheet Sig VZ VII, 33 three miles are marked, the length of which is given in walking hours (Figure 5).

Herkov (1977) states that in Germany a walking hour was calculated as 3710 m or 2000 geometric steps, so the lengths for 1.5, 2, and 2.5 walking hours were calculated using this value (Table 3).

A review of the literature revealed that Riccioli (1672) listed three types of German miles, calling them *Germanica Parua* (1/18 degrees of the equator), *Medicora* (1/15 degrees of the equator), and *Magna* (1/12 degrees of the equator). Herkov (1977) also noted that there were three German miles in the 16th century: Large (1/12 of a degree of the equator, 9275 m), Medium (1/15 of a degree of the equator, 7402 m), and Small (1/18 of a degree of the equator, 6183 m), whose values are very similar to the mile lengths calculated by the walking hours in Table 3.

It follows that Riccioli's (1672) *Germanica Parua* would be a Small German Mile, corresponding to the *Commune* mile; *Germanica Medicora* would be a Medium German Mile, corresponding to the *Maiusculum* mile; and *Germanica Magna* would be a Large German Mile, corresponding to the *Magnum* mile from the map sheets Sig VZ VII, 13-24.

Figure 4: Representation of the graphic scales on the map sheet Sig VZ VII, 23.

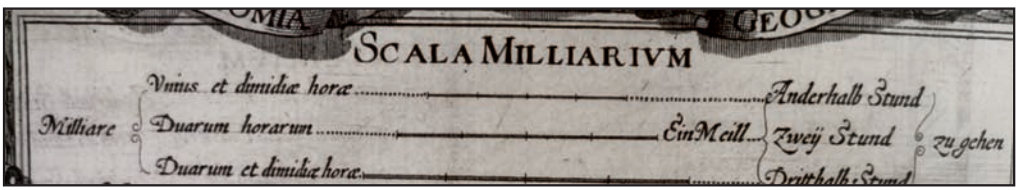

Figure 5: Representation of the graphic scales on the map sheet Sig VZ VII, 33.

Table 3: Length of a walking hour in meters calculated for the map Sig VZ VII, 25-36.

Walking hour	Length [m]
1.5 hours (*Vnius et dimidiae horae = Anderhalb Stund*)	5565
2 hours (*Duarum horarum = Zweij Stund*)	7420
2.5 hours (*Duarum et dimidiae horae = Dritthalb Stund*)	9275

Small, Medium and Large German Mile *(Milliarium Parva, Communia* and *Magna)*

In Volume VII of the Valvasor collection, another map (Sig VZ VII, 58) is also marked with three miles – *Scala Milliarium continens Magna, communia and parua*. It was necessary to investigate to which miles the miles indicated on the graphic scale of the map refer. The investigations have shown that they are German miles. Following the terminology used by Herkov (1977), we have given these miles the same English designations Small, Medium and Large German Miles, but with different Latin designations and different lengths than the German miles mentioned above.

A review of the literature revealed that Riccioli (1672) listed several lengths of the German Mile (*Germanica*) as a part of a degree of the equator: *Minima* (15 ½), *Parua* (13 ⅔), *Mediocria* (12 ½), *Magna* (10 ⅔) and *Maxima* (9 ½).

By applying expression (2), the read and measured values from the graphic scales (see Table 5) and for Riccioli's (1672) proportions of the German miles mentioned above, it was shown that *Milliarium Magna* on the map corresponds to the length of Riccioli's German mile *Germanica Magna* and is marked as Large German Mile. *Milliarium parua* on the map corresponds to Riccioli's German mile *Germanica Parua* and is marked as Small German Mile. *Milliarium communia* corresponds to Riccioli's *Germanica Mediocria* mile and is marked as Medium German Mile.

Small Italian and German Mile

On the map Sig VZ VII, 47, the *Milliaria Italica communia* is drawn next to the German Mile (*Milliaria Germanica communia*). From the measured and read mile values, and the application of expression (3), it was found that one *Milliaria Germanica communia* corresponds to five *Milliaria Italica communia*. Applying expression (3) for the read values and assuming that the German Mile is 1/15 of the meridian degree, the Italian Mile is 1/75 of the meridian degree. Based on the Mušnjak (1982) statement that there are two Italian miles: the Small Italian Mile (1/75 degree of the meridian) and the Great Italian Mile (1/60 degree of the meridian), the *Milliaria Italica communia* would correspond to the Small Italian Mile.

Moscow, Polish, Ukrainian and German Miles

According to Riccioli (1672), the Moscow Mile (*Milliaria Moscovitica*) is 1/80 of a degree of the meridian, while for the Polish Mile (*Milliaria Polonica cummunia*) he does not give its proportion, but the values *Pedes* and *seu Passus*. The ratio between the German and Moscow Mile from the map Sig VZ VII, 5 confirms Riccioli's value (1672).

The ratio between the German and Polish Mile from the map Sig VZ VII, 5 confirms the value (von Alberti 1957, 248) that one Polish Mile corresponds to 1/20 of a meridian degree.

No data were found in the evaluated literature on the length of the Ukrainian Mile (*Milliaria Ucrenica*), therefore its length was calculated from the ratio to the German Mile on the map Sig VZ VII, 5 and it was found that one Ukrainian Mile corresponds to 1/12.5 degrees of the meridian.

Croatian and German Mile

On the map Sig VZ VII, 12 the Croatian Mile is marked. Viličić and Lapaine (2016) examined the length of the Croatian Mile on this map and on several maps where the Croatian Mile is also shown. They found that the Croatian Mile corresponds to 1/10 of a degree of the meridian.

Hungarian and German Mile

On the maps Sig VZ VII, 45 and Sig VZ VII, 67 next to the German Mile (*Milliaria Germanica*), the Hungarian Mile (*Milliaria Hungarica*) is drawn. From the literature it is obvious that there were several types of Hungarian miles at the time of the publication of this map. For example, Viličić and Lapaine (2016) cite maps where one Hungarian Mile corresponds to 1/10 of a degree of the equator. Riccioli (1661) cites sources stating that one Hungarian Mile is equal to 1/14 of the length of one degree of the equator. Using the lengths of the German and Hungarian Miles read from the maps Sig VZ VII, 45 and Sig VZ VII, 67, the expression (3) and the length of the German Mile of 1/15 degree of the meridian, the calculated length of the Hungarian

Mile is 1/12 of the meridian degree. The calculated value matches the ratio of Hungarian and German Miles given in Anonymus (1798), for a German Mile of 1/15 meridian degree.

Small and Large English Mile in relation to the German Mile

On the map Sig VZ VII, 48, next to the German Mile (*Milliaria Germanica communia*), the *Milliar Anglica parva* and *Milliaria Anglica Communia* are drawn. Using the German Mile and expression (3), it was calculated that one German Mile corresponds to four *Milliar Anglica parva* and about three *Milliaria Anglica Communia*. If the German Mile is 1/15 of a meridian degree, then *Milliar Anglica parva* is 1/60 of a meridian degree, and if rounded, *Milliaria Anglica Communia* is 1/50, which agrees with Riccioli's (1672) data on the length of these miles. After reviewing the literature (Riccioli 1672; Herkov 1977), it was found that the values of these miles do not agree with the value of the English Mile given by Mušnjak (1982) in her work. In order to facilitate the distinction between these miles, the terms Large and Small English Mile were introduced.

Gallic and German Mile

On the maps Sig VZ VII, 49, VZ VII, 60, VZ VII, 61, VZ VII, 62, VZ VII, 64 and VZ VII, 65 the *Germanica Communia* and the *Gallica Communia* miles are marked. From the values read from the map, applying expression (3) and for the value of the German Mile of 1/15 degree of the meridian, it follows that the Gallic Mile is 1/20 of the degree of the meridian. The value for the Gallic Mile corresponds to the value given by Herkov (1977) and Riccioli (1672).

Table 4: Summary of the length of the mile in relation to the degree of the meridian.

Mile	Number of miles in one degree meridian
German Mile (*Milliaria Germanica, Milliaria Germanica communia, Milliaria Germanica Com, Gemeene Duytsche Mylen, Leghe Germanica, Scala Germanica, Scala Milliarium)*	15
Small German Mile (*Milliarium Commune)*	18
Medium German Mile (*Milliarium Maiusculum)*	15
Large German Mile (*Milliarium Magnum)*	12
Small German Mile (*Milliarium Parua)*	13 2/3
Medium German Mile (*Milliarium Communia)*	12 1/2
Large German Mile (*Milliarium Magna)*	10 2/3
Italian Mile (*Milliaria Italica, Scala Italica)*	60
Small Italian Mile (*Milliaria Italica communia)*	75
Polish Mile (*Milliaria Polonica cummunia)*	20
Ukrainian Mile (*Milliaria Ucrenica)*	12.5
Moscow Mile (*Milliaria Moscovitica)*	80
Croatian Mile (*Milliaria Croatica)*	10
Hungarian Mile (*Milliaria Hungarica, Milliaria Hungarica communia, Scala Hungarica)*	12
Small English Mile (*Milliar Anglica parva)*	60
Large English Mile (*Milliaria Anglica Communia)*	50
Gallic Mile (*Miliaria Gallica Communia Milliaria Gallica)*	20
Large Mile (*Milliaria magna)*	15
Small Mile (*Milliaria minora)*	20
Franch Mile (*France Mylen)*	20
Geographical Mile (*Comunia Geographica)*	15
Moravian Mile (*Milliarium Moravica)*	12

Table 5: Representation of the measured and read values of mile lengths from the maps, and the calculated numerical scales with respect to different values of the Earth's radius with the final approximate (average and rounded) numerical scale of the analysed maps. Because Riccioli's radius differs considerably from the values of the other authors, his value was not taken to calculate the final scale.

Sig VZ, VII	Mile length	Numerical scales according to different values of the Earth's radius				Average numerical scale	Approximate numerical scale
		Jean Fernel (1528)	Tycho Brahe (1602)	Riccioli (1645)	Jean Picard (1668/1670)		
5	20 *Milliaria Polonica cummunia* = 2.5 cm *15 Milliaria Germanica* = 2.5 cm *10 Milliaria Ucrenica* = 2 cm *80 Milliaria Moscovitica* = 2.5 cm	1:4,449,280	1:4,451,280	1:4,732,060	1:4,448,480	1:4,449,680	1:4,500,000
7	*30 Milliaria Germanica* = 6.4 cm	1:3,476,000	1:3,477,563	1:3,770,562	1:3,475,375	1:3,476,313	1:3,500,000
12	*5 Milliaria Croatica* = 19.3 cm *7 Milliaria Germanica* = 18.0 cm	1:288,273	1:288,402	1:312,701	1:288,221	1:288,298	1:300,000
13-24	*Scala Milliarium:* *Commune* = 5 cm *Maiusculum* = 6.6 cm *Magnum* = 8.4 cm		Using *Milliarium Commune* – 1:463,750 Using *Milliarium Maiusculum* – 1:436,471 Using *Milliarium Magnum* – 1:441,667 (mile lengths are calculated as an hour of walking)		1:447,296	1:450,000	
25-36	*Scala Milliarium, Milliare:* *Vnius et dimidiae horae* = *Anderhalb Stund zu gehen* = 3.5 cm *Duarum horarum* = *Zweij Stund zu gehen* = 4.7 cm *Duarum et dimidiae horae* = *Dritthalb Stund zu gehen* = 5.9 cm		Using *Vnius et dimidiae horae* – 1:636,000 Using *Duarum horarum* – 1:631,489 Using *Duarum et dimidiae* – 1:628,814		1:632,101	1:630,000	
37	*14 Milliaria Italica communia* = 4.2 cm	1:494,364	1:494,587	1:536,258	1:494,276	1:494,409	1:500,000
38	*5 Scala Miliarium* = 7 cm	1:529,676	1:529,914	1:574,562	1:529,581	1:529,724	1:530,000
39	*4 Milliaria Germanica Com* = 4.9 cm	1:605,344	1:605,616	1:656,642	1:605,235	1:605,399	1:600,000
40	*3 Milliaria germanica communia* = 4.3 cm	1:517,358	1:517,591	1:561,200	1:517,265	1:517,405	1:520,000
41	*4 Milliaria germanica* = 4 cm *3 Milliaria Croatica* = 5 cm	1:704,469	1:704,786	1:764,167	1:704,343	1:704,533	1:700,000
42	*3 Milliaria germanica communia* = 4.4 cm	1:505,600	1:505,827	1:548,445	1:505,509	1:505,645	1:500,000
45	*5 Milliaria Hungarica* = 6.2 cm *5 Milliaria Germanica* = 7.6 cm	1:603,923	1:604,195	1:655,101	1:603,814	1:603,977	1:600,000
46	*50 Milliaria Germanica communia* = 3.3 cm	1:11,235,556	1:11,240,606	1:12,187,677	1:11,233,535	1:11,236,566	1:11,200,000
47	*150 Miliaria Italica communia* = 7.5 cm *28 Miliaria Germanica communia* = 7 cm	1:2,966,187	1:2,967,520	1:3,217,547	1:2,965,653	1:2,966,453	1:3,000,000
48	*15 Milliaria Germanica Communia* = 4.4 cm *60 Milliar Anglica parva* = 4.4 cm *50 Milliaria Anglica Communia* = 4.6 cm	1:2,491,362	1:2,492,482	1:2,702,485	1:2,490,914	1:2,491,586	1:2,500,000
49	*3 Miliaria Germanica Communia* = 10 cm *4 Miliaria Gallica Communia* = 10 cm	1:222,464	1:222,564	1:241,316	1:222,424	1:222,484	1:220,000

50	*10 Milliaria Gallica* = 7.5 cm *8 Milliaria Germanica* = 8 cm	1:741,547	1:741,880	1:804,387	1:741,413	1:741,613	1:740,000
51	*3 Milliaria magna, quorum XV.* = 5.4 cm *4 Milliaria minora, quorum XX. Gradum efficiunt* = 5.3 cm	1:415,857	1:416,044	1:451,097	1:415,782	1:415,894	1:420,000
52	*2 Milliaria Germanica* = 3.5 cm	1:423,741	1:423,931	1:459,650	1:423,665	1:423,779	1:420,000
53	*40 Milliaria Germanica* = 4.7 cm	1:6,311,035	1:6,313,872	1:6,845,844	1:6,309,901	1:6,311,603	1:6,300,000
54	*6 Milliaria Germanica communia* = 6.4 cm	1:695,200	1:695,513	1:754,113	1:695,075	1:695,263	1:700,000
55	*Scala Milliarium:* *7 Comunia Geographica* = 10.85 cm *7 Moravica* = 11.9 cm	1:511,836	1:512,066	1:555,210	1:511,744	1:511,882	1:510,000
56	*8 Milliaria Germanica communia* = 6.2 cm	1:956,834	1:957,265	1:1,037,918	1:956,662	1:956,920	1:960,000
57	*5 Milliaria Germanica* = 4 cm *20 Milliaria Italica* = 4 cm	1:926,933	1:927,350	1:1,005,483	1:926,767	1:927,017	1:930,000
58	*Scala Milliarium continens:* *4 Magna* = 3.2 cm *4 communia* = 3.6 cm *4 parua* = 4 cm	1:813,893 – 1:1,303,500	1:814,259 – 1:1,304,086	1:882,863 – 1:1,413,961	1:813,746 – 1:1,303,266	1:813,966 – 1:1,303,617	1:810,000 – 1:1,300,000
59	*15 Milliaria Germanica communia* = 4 cm	1:2,780,800	1:2,782,050	1:3,016,450	1:2,780,300	1:2,781,050	1:2;800,000
60	*6 Milliaria Germanica communia* = 5.4 cm *8 Milliaria Gallica communia* = 5.4 cm	1:823,941	1:824,311	1:893,763	1:823,793	1:824,015	1:820,000
61	*6 Milliaria Germanica communia* = 7.2 cm *8 Milliaria Gallica communia* = 7.2 cm	1:617,956	1:618,233	1:670,322	1:617,844	1:618,011	1:620,000
62	*8 Milliaria Germania com: Gemeene Duytstche Mylen* = 6.4 cm *10 Milliaria Gallica communia. Uren Gaens* = 6 cm	1:926,933	1:927,350	1:1,005,483	1:926,767	1:927,017	1:930,000
63	*3 Gemeene Duytstche Mylen van 15 in een Graet* = 6.6 cm *4 France Mylen oste Uren Gaens* = 6.6 cm	1:337,067	1:337,218	1:365,630	1:337,006	1:337,097	1:340,000
64	*30 Milliaria Gallica communia* = 6.9 cm *25 Milliaria Germanica communia* = 7.65 cm	1:2,420,721	1:2,421,809	1:2,625,857	1:2,420,286	1:2,420,939	1:2,400,000
65	*8 Milliaria Germanica com: Gemeene Duytstche Mylen* = 6.5 cm *10 Milliaria Gallica communia. Uren Gaens* = 6.1 cm	1:912,205	1:912,615	1:989,507	1:912,041	1:912,287	1:900,000
67	*15 Milliaria Germanica communia* = 5.1 cm *12 Milliaria Hungarica communia* = 5.1 cm	1:2,181,020	1:2,182,000	1:2,365,843	1:2,180,627	1:2,181,216	1:2,200,000
68	*10 Scala di Leghe Germanica* = 6.8 cm *40 Scala millaria Italica* = 6.8 cm	1:1,090,510	1:1,091,000	1:1,182,922	1:1,090,314	1:1,090,608	1:1,100,000
69	*5 Schala Hungarica* = 7.2 cm *6 Schala Germanica* = 7.4 cm *24 Schala Italica* = 7.4 cm	1:584,751	1:585,014	1:634,304	1:584,646	1:584,804	1:600,000

Large and Small Mile (Miliaria magna and Miliaria minora)

On the map Sig VZ VII, 51, the miles of *Miliaria magna* and *Miliaria minora* are marked with an additional explanation about the length of these miles: »*Milliaria magna, quorum XV., minora quorum XX. Gradum efficiunt*« (eng. »The degree consists of 15 large or 20 small miles«), which clearly determines the length of these miles in the degree of the meridian and does not require additional insight into the literature.

French and German Mile

On the map Sig VZ VII, 63 the length of the French Mile (*France Mylen*) is calculated from the ratio to the German Mile (*Gemeene Duytstche Mylen*), which is indicated on the map as 1/15 degree of the meridian (*van 15 in een Graet*). The length of a French Mile calculated this way is 1/20 of a meridian degree.

Geographic and Moravian Mile

On the map Sig VZ VII, 55, the Geographic Mile (*Comunia Geographica*) and the Moravian Mile (*Morauica*) are marked. According to Riccioli (1672) the Moravian Mile (*Morauica*) is 1/12 degree of the meridian, and according to Herkov (1977) the Geographic Mile is 1/15 degree of the meridian.

Since the denominators of the scales resulting from the application of the Moravian and Geographic Miles differ by about 67,000, it is assumed that an error occurred in drawing the graphic scale on the map.

3.3 Calculation of an approximate numerical scale with the analysed maps

Using the mile lengths in relation to the meridian degree (Table 4), the measured values of mile lengths given in Table 5, and expressions (1), numerical scales were calculated for various values of the Earth's radius (see Table 5). These numerical scales in Table 5 are the average values using all drawn miles on each map. Using these values, the average numerical scale was determined and finally rounded to the nearest integer.

4 Discussion

Determining the numerical scale from the graphic scale of older maps requires prior research on the lengths of miles at the time the map was published. Only one map (Sig VZ VII, 51) has the length of a mile written, which was not the case for the other maps. It was thus necessary to conduct research on mile lengths, which are fundamentally linked to the shape of the Earth (Beineke 2001). The period of publication of the maps also had to be considered (Mušnjak 1982). Because the lengths of most miles have changed throughout history and a review of contemporary literature provides general information about the length of a mile for a large historical period, it is advisable to research the literature published at the time, such as Riccioli (1661; 1672), Anonymus (1798) in this article.

As described in Chapter 3.1, the published maps date from the end of the 16th to the end of the 17th century. Based on the period in which the maps were published, literature from this approximate period (Riccioli 1661; 1672; Belostenec 1740; Anonymus 1798) and literature that mentions the length of miles in this period (von Alberti 1957; Vlajinac 1968; Herkov 1977; Mušnjak 1982; Kretschmer 1986; Viličić and Lapaine 2016) were selected. The research revealed that the mile lengths were expressed as a proportion of the meridian degree (Table 4) and at the time the maps were published, the Earth was considered a sphere with several possible dimensions (Table 2).

In total, 22 different miles were mapped on the evaluated maps, of which the Ukrainian Mile and the Small, Medium and Large German Miles (*Milliarium Commune, Maiusculum* and *Magnum*) were not found in the evaluated literature.

Among the analysed maps, the German Mile is the most common, occurring on 30 maps with seven different names. On two other maps the German Mile is mapped, but under the names of Large, Small and Medium German Mile (Table 4). Mušnjak (1982) states that the German mile includes the names *Milliaria Germanica* and *Milliaria Germanica communia* (*Milliaria Germanica Com*). The name *Gemeene Duytsche*

Mylen is also connected with the German Mile, because it is noted on the map that this mile is 1/15 degree of the meridian, which corresponds to the length of the German Mile. From the relationship between *Leghe Germanica* and *Milliaria Italica* and the relationship between *Scala Germanica* and *Scala Italica*, it was concluded that the names *Leghe Germanica* and *Scala Germanica* correspond to the length and concept of the German Mile. The term *Scala Milliarium* is also associated with the concept of the German Mile, since on the map Sig VZ VII, 38 the type of mile could not be determined with certainty (Figure 6). The problem of the length of the *Scala Milliarium* was solved by considering the mile most frequently drawn on the analysed maps and the measurement of the distance between the cities.

Since miles with similar names are not necessarily the same miles, such miles must always be considered together with the miles with which they are plotted on the map (e.g., the Large and the Small German Mile are plotted on the maps Sig VZ VII, 13-24 and VZ VII, 58 with similar names but different lengths).

Of the miles drawn, the Croatian Mile has the largest proportion of the meridian degree, while the largest number of miles shown is between 1/10 and 1/20 of the meridian degree (Figure 7).

Errors in the lengths of the graphic scale were found on several copies of the maps. Thanks to the remaining miles on the map, the most probable lengths of the graphic scales could be calculated (Sig VZ VII, 48 and VZ VII, 51).

For the map Sig VZ VII, 57, the measurements show that one German Mile corresponds to four Italian Miles. Rajaković, Kljajić and Lapaine (2014) calculated the scale of a copy of this map from the Novak collection (Mercator 1630) using the graphic scales in miles. Mušnjak (1982) did the same for a copy of this map from the Croatian archives (Sig A II – 4 inv No 32). The authors obtained the same values as in this article. After the conducted research, the authors did not find any other studies with which they could compare their results. On the maps where one mile is marked (e.g., Sig VZ VII, 37, VZ VII, 46 and VZ VII, 47), the authors made a rough check by using a digital copy of those maps in online galleries (e.g. Yale Library, https://library.yale.edu/; Old Maps Online, https://www.oldmapsonline.org/; Geographicus Rare Antique Maps, https://www.geographicus.com/). In other maps (Sig VZ VII, 38 and VZ VII, 40), where only one mile is drawn, the authors measured the distances between the cities.

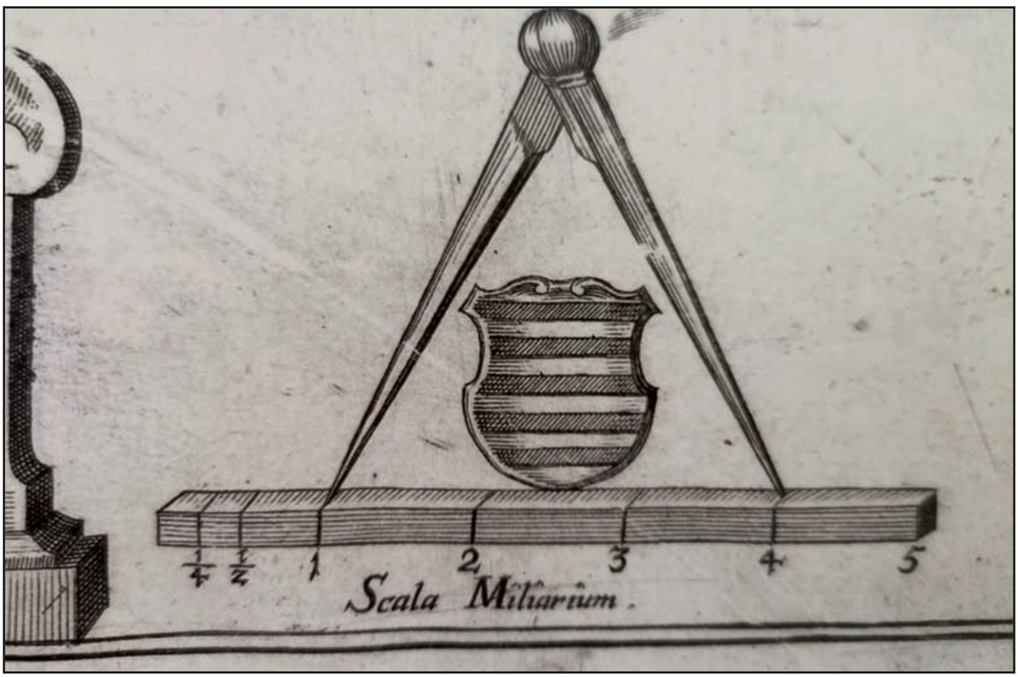

Figure 6: Representation of the graphic scale on the map Sig VZ VII, 38.

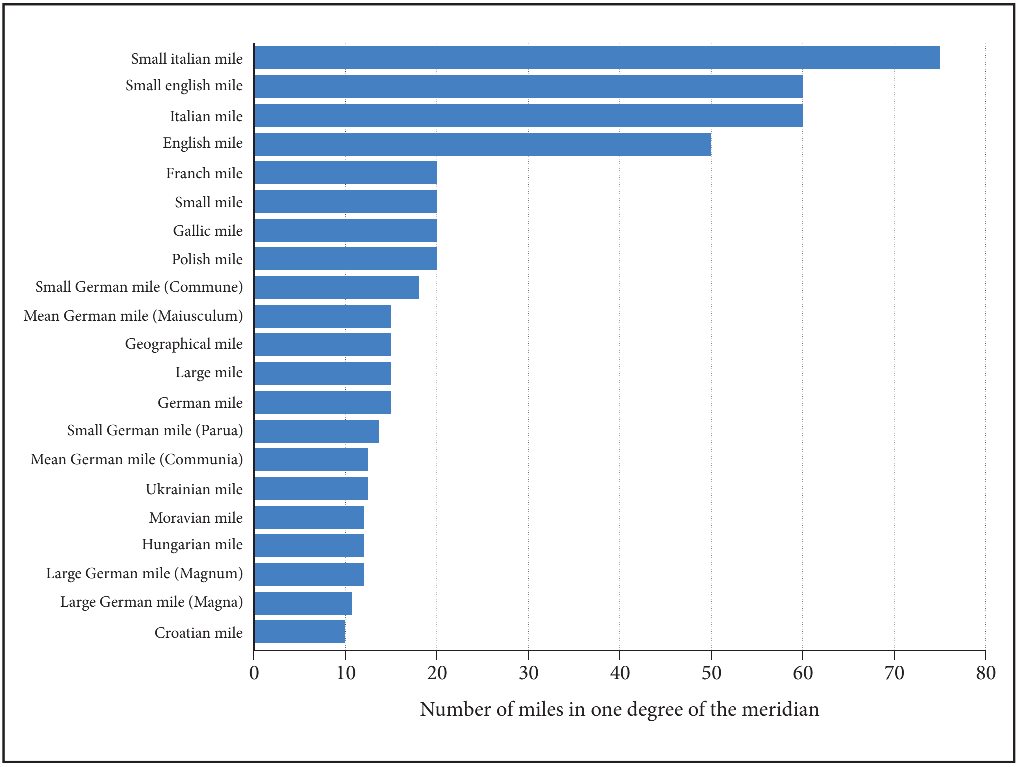

Figure 7: Plot of the range of proportions of each mile in a meridian degree.

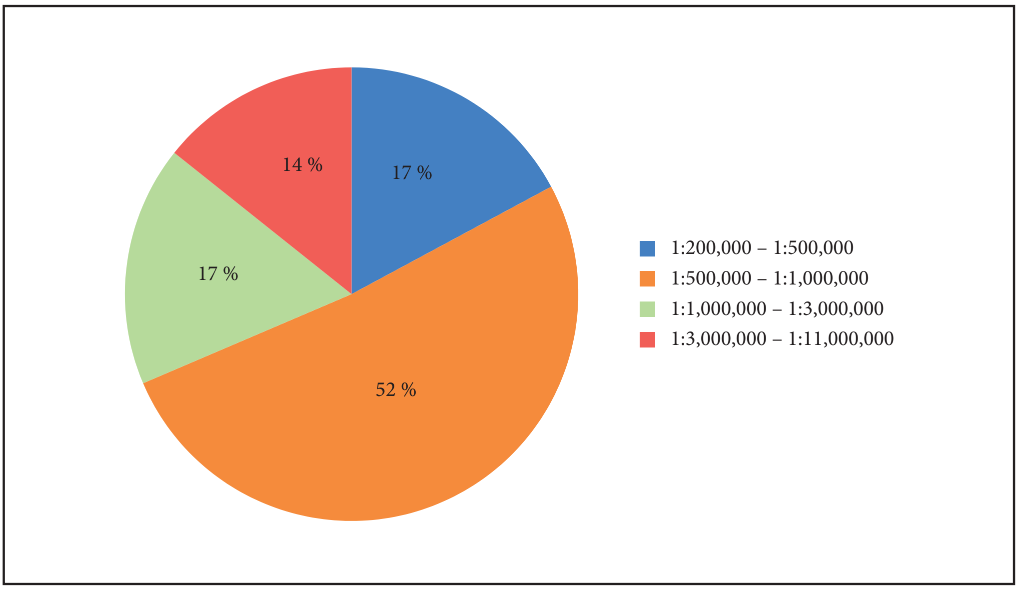

Figure 8: Proportions of the scales of the analysed maps.

It should be noted that calculating the scale based on the distance between cities is not a good method of calculation, since errors in the placement of cities were very common at that time, and the distances measured in this way are affected by the deformations of the map projection.

After calculating the numerical scales, it was found that the largest scale of the studied maps is 1:220,000 and the smallest is 1:11,200,000. Figure 8 shows that more than half of the maps have a scale of 1:500,000 to 1:1,000,000.

In addition to using the graphic scale to determine map scale, a map grid can also be used (14 maps in this graphic collection), the use of which requires knowledge of map projections. The determination of the numerical scale is also possible for the maps that have neither a drawn map grid nor a graphic scale (five maps in this graphic collection). For such maps, it is first necessary to research in which map projection the map was created, which requires individual consideration of each map. In such cases, many authors use programs that compare old maps with modern maps (e.g., MapAnalyst). This is not a bad approach, but it requires additional independent testing and great caution, as well as additional knowledge of transformations and map projections.

5 Conclusion

The processing of the cartographic material of Volume VII of the Valvasor graphic collection requires, among other descriptive data, the determination of mathematical elements – the numerical scale of the map. Since these data were not previously available, a numerical scale for the 35 maps in this collection was determined using the facsimile edition of Volume VII (Gostiša 2004) and the expression (1). The scale was determined by reading the graphic scale and converting the length of the graphic scale, expressed in miles, to the present system of units of measurement.

Since the length of the mile has changed throughout history, research had to be done on the length of the mile at the time the map was published, while converting the length of a mile to today's system of units required research on the dimensions and shape of the Earth at that time.

Since the length of the mile was expressed as a fraction of a meridian degree or a walking hour, and the exact radius of the Earth sphere at that time is not known in today's metric system of units, it is difficult to determine the exact numerical scale. Therefore, the average numerical scale for different radii of the Earth's sphere was first calculated and then the scale value was rounded to the nearest integer.

The research conducted has shown that in order to determine the length of a mile, it is not advisable to use only contemporary encyclopaedias (e.g., von Alberti 1957) that list mile lengths, but it is necessary to research literature going back to the time when the maps were published and/or literature that analyses mile lengths in specific historical periods in more detail.

For future research, it is planned to use the map grid to determine the scale of the remaining maps from Volume VII and to use the map grid to independently verify the previously determined numerical scales with the graphic scale. Since a possible error in drawing the graphic scale in Moravian Miles was found during this research (Sig VZ VII, 55), we could not confirm the length of the Moravian Mile given in the literature (Riccioli 1672). For future research, it is suggested to examine other literature and maps outside Volume VII that date from a similar period and have a graphic scale in Moravian Miles, as well as maps with graphic scales in the Ukrainian Mile and the Small, Medium and Large German Miles (*Milliarium Commune, Maiusculum* and *Magnum*) to confirm the lengths calculated in this article.

6 References

Abaffy, M. 2004: Starije grafičko gradivo u knjižnicama, muzejima i arhivima: Neki problemi obrade, čuvanja i restauriranja na primjeru Valvasorove grafičke zbirke Nadbiskupije Zagrebačke. Zbornik radova Konzerviranje i restauriranje papira 4: Grafički materijal. Ludbreg, Zagreb.

Anonymus 1798: Institutiones arithmeticae in usum gymnasiorum et scholarum grammaticarum, per Regnum Hungariae, et provincias eidem adnexas. Budae, library »Juraj Habdelić«, Zagreb. Sig. 2556, Vol 1–3.

Beineke, D. 2001: Verfahren zur Genauigkeitsanalyse für Altkarten. Ph.D. thesis, Studiengang Geodäsie und Geoinformation Universität der Bundeswehr München. Neubiberg.

Belostenec, I. 1740: Gazophylacium, seu latino-illyricorum onomatum aerarium, selectioribus synonimis, … Typis Joannis Baptistaw Weitz. Inclyti Regni Croatiae Typographi. Zagreb. Internet: http://books.google.hr/books?id=LssGAAAAQAAJ&printsec=frontcover&hl=hr&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false (22. 9. 2023).

Bitelli, G., Gatta, G. 2012: Georeferencing of an XVIII century technical map of Bologna (Italy). e-Perimetron 7-4.

Bower, D. 2009: The accuracy of Robert Saxton's survey and map of Manningham, dated 1613. The Cartographic Journal 46-2. DOI: https://doi.org/10.1179/000870409X459833

Cajthaml, J. 2009: Detailed analysis of the Müller's map of Bohemia. Proceedings of the 24th International Cartographic Conference ICC 2009. Santiago de Chile. Internet: https://icaci.org/files/documents/ICC_proceedings/ICC2009/html/nonref/25_7.pdf (20. 9. 2023).

Frančula, N. 2000: Kartografske projekcije. Skripta, Geodetski fakultet Sveučilišta u Zagrebu. Zagreb.

Frančula, N. Lapaine, M., Jazbec, I. P. 2020: Dictionary of Cartography. Zagreb.

Gostiša, L. (ed.) 2004: Iconotheca Valvasoriana. Volume VII. Ljubljana, Zagreb.

Herkov, Z. 1977: Prinosi za upoznavanje naših starih mjera za dužinu i površinu, nastavak. Zbornik Odsjeka za povijesne znanosti Zavoda za povijesne i društvene znanosti Hrvatske akademije znanosti i umjetnosti 8. Internet: https://hrcak.srce.hr/83646 (21. 9. 2023).

Jupp, D. L. 2017: Projection, scale, and accuracy in the 1721 Kangxi maps. Cartographica 52-3. DOI: https://doi.org/10.3138/cart.52.3.2016-0004

Krejčí, J., Cajthaml, J. 2009: Müller's maps of the Czech lands and their analysis. Acta Geodaetica et Geophysica Hungarica 44-1. DOI: https://doi.org/10.1556/AGeod.44.2009.1.4

Kretschmer, I. 1986: Maβsysteme, nichtmetrische. Lexikon zur Geschichte der Kartographie. Band 2. Wien.

Lapaine, M., Frančula, N. 1998: Glavačev rad na kartografiranju Hrvatske, Radovi Zavoda za znanstveni rad HAZU Varaždin, radovi posvećeni 85. obljetnici Andre Mohorovičića. Varaždin.

Laughton, J. K. 2020: Norwood, Richard. Dictionary of National Biography, 1885–1900, Volume 41. Internet: https://en.wikisource.org/wiki/Dictionary_of_National_Biography,_1885-1900/Norwood,_Richard (18. 4. 2023).

Luminet, J. P. 2014: Blaeu, Willem Janszoon. Biographical Encyclopedia of Astronomers. New York. DOI: https://doi.org/10.1007/978-1-4419-9917-7_9230

Magić, V. 2012: Metropolitanska knjižnica u Zagrebu: Vodič / The Metropolitan Library in Zagreb: Guide. Zagreb.

Magić, V., Pelc, M., Abaffy, M. (eds.) 2016: Cimelia Metropolitana. The History and Treasures of the Zagreb Archdiocese Library. Zagreb.

Mercator, G. about 1630: *Sclavonia, Croatia, Bosnia cum Dalmatiae parte*, Collection Novak (Sign. ZN-Z-XVII- MER-1630?-1).

Mušnjak, T. 1982: Mjerila na starim zemljopisnim kartama. Arhivski vjesnik 25-1.

Paas, J. R. (ed.) 1994: Hollstein's German Engravings, Etchings and Woodcuts 1400–1700. Volume XXXVIII: Jacob von Sandrart. Roosendaal.

Rajaković, M., Kljajić, I., Lapaine, M. 2014: Map projection reconstruction of a map by Mercator. Cartography from Pole to Pole: Selected Contributions to the XXVIth International Conference of the ICA. Berlin, Heidelberg. DOI: https://doi.org/10.1007/978-3-642-32618-9_3

Riccioli, G. B. 1661: Geographiae et Hydrographiae Reformatae Libri Duodecim. Haeredis Victorij Benatij. Bologna. Internet: https://books.google.hr/books?id=AkI_1g-eg48C&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false (18. 4. 2023).

Riccioli, G. B. 1672: Geographiae et Hydrographiae Reformatae Nuper Recognitae, & Auctae. Libri Duodecim. Typis Ioannis LaNoù. Venice. Internet: https://books.google.hr/books?id=bipRAAAAcAAJ&printsec=frontcover&hl=hr&source=gbs_ge_summary_r&cad=0#v=onepage&q=Stadias%20micus%20seu&f=false (18. 4. 2023).

Robinson, A. H., The Committee on Map Projections 2017: Choosing a World Map. Choosing a Map Projection. Lecture Notes in Geoinformation and Cartography. Cham. DOI: https://doi.org/10.1007/978-3-319-51835-0_2

Selvi, H. Z., Bekiroglu Keskin, G. 2019: A cartographic analysis of Matrakci Nasuh's miniatures. The Cartographic Journal 56-4. DOI: https://doi.org/10.1080/00087041.2018.1532703

Solarić, M., Solarić, N. 2016: Boškovićeva i Maireova trigonometrijska mreža pri određivanju duljine dijela meridijanskog luka Rim-Rimini. Ruđer Bošković i geoznanosti. Zagreb.

Stevenson, E. L. 1914: Willem Janszoon Blaeu, 1571–1638: A sketch of his life and work. New York. Internet: https://archive.org/details/willemjanszoonblstev/page/20/mode/2up (28. 8. 2023)

Viličić, M. 2019: Kartografska analiza karte Stjepana Glavača iz 1673. godine. Ph.D. thesis, Sveučilište v Zagrebu, Geodetski fakultet. Zagreb.

Viličić, M., Lapaine, M. 2016: The Croatian mile on old maps. Cartography and Geoinformation 15-25.

Viličić, M., Lapaine, M. 2023: Determining the scale and map projection of Stjepan Glavač's map from 1673. International Journal of Cartography. DOI: https://doi.org/10.1080/23729333.2022.2140003

Vlajinac, M. 1968: Речник наших старих мера – у току векова 3 (Rečnik naših starih mera – u toku vekova 3). Beograd.

von Alberti, H. J. 1957: Mass und Gewicht: geschichtliche und tabellarische Darstellungen von den Anfängen bis zur Gegenwart. Berlin.

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WHAT IS HAPPENING WITH FREQUENCY AND OCCURRENCE OF THE MAXIMUM RIVER DISCHARGES IN BOSNIA AND HERZEGOVINA?

Slobodan Gnjato, Igor Leščešen, Biljana Basarin, Tatjana Popov

LAZAR MIHAJLOVIĆ

Štrbački buk (Una River).

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Slobodan Gnjato[1], Igor Leščešen[2], Biljana Basarin[2], Tatjana Popov[1]

What is happening with frequency and occurrence of the maximum river discharges in Bosnia and Herzegovina?

ABSTRACT: In this study, we explored the frequency and occurrence rate of maximum river discharges in the Una and Sana rivers, to understand hydrological variations amidst climate change. We categorized maximum discharges into severe (Una River M1 > 98.2 m^3/s; Sana River M1 > 118.2 m^3/s) and extreme (Una River, M2, > 123.4 m^3/s; Sana River M2 > 246.4 m^3/s) events, and identified trends in these events, crucial for assessing environmental impacts. Our findings reveal a nuanced pattern: both rivers experience an increase in severe events from 58 to 55 and 56 to 54 days return period respectively, indicating complex hydrological dynamics. The trends underscore the significant shifts in annual event occurrences, the evolving nature of river systems and underscore the necessity for adaptive management strategies.

KEYWORDS: Hydrology, maximum discharges, Una River, Sana River, Cox-Lewis test, trend, Bosnia and Herzegovina

Frekvenca in pojavnost največjih rečnih pretokov v Bosni in Hercegovini

POVZETEK: Članek proučuje frekvenco in stopnjo pojavnosti največjih pretokov bosanskih rek Une in Sane, kar omogoča boljše razumevanje hidroloških sprememb kot posledic podnebnih sprememb. Največji pretoki so razdeljeni v dve kategoriji, močno povečane pretoke (Una: M1 > 98,2 m^3/s; Sana: M1 > 118,2 m^3/s) in izjemne pretoke (Una: M2 > 123,4 m^3/s; Sana: M2 > 246,4 m^3/s), pri čemer so določeni trendi njihove pojavnosti, ki so ključni za proučevanje okoljskih vplivov. Izsledki raziskave kažejo, da se pri obeh rekah pojavnost močno povečanih pretokov povečuje, saj se povratna doba med njimi krajša (z 58 na 55 dni pri Uni in s 56 na 54 dni pri Sani), kar priča o zapleteni hidrološki dinamiki. Trendi razkrivajo pomembne spremembe v letni pojavnosti teh dogodkov ter opozarjajo na spreminjajočo se naravo rečnih sistemov in potrebo po prilagoditvenih strategijah upravljanja.

KLJUČNE BESEDE: hidrologija, največji pretoki, Una, Sana, Cox-Lewisov test, trend, Bosna in Hercegovina

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[1] University of Banja Luka, Faculty of Natural Sciences and Mathematics, Banja Luka, Bosnia and Herzegovina
slobodan.gnjato@pmf.unibl.org (https://orcid.org/0000-0002-7186-4872),
tatjana.popov@pmf.unibl.org (https://orcid.org/0000-0001-6836-276X)

[2] University of Novi Sad, Faculty of Sciences, Novi Sad, Serbia
igorlescesen@yahoo.com (https://orcid.org/0000-0001-9090-2662), biljana.basarin@dgt.uns.ac.rs (https://orcid.org/0000-0002-2546-3728)

1 Introduction

Regarded among the most destructive natural hazards, flood events feature extremely high-water stages which cause flooding of areas in a variety of settings (Blöschl 2022). Moreover, they are the most frequent natural hazards impacting 1.6 billion people globally, with a mean of 163 occurrences per year (Centre for … 2020). As such, they have the potential to induce sudden and severe devastation in the environment and harmful effects on society in multiple ways (Kuntla, Saharia and Kirstetter 2022). The rising tendency in the damages induced by flood events is primarily caused by intense deforestation of river valleys, enhanced economic activities (i.e., increased wealth) in flood-risk areas, and climate change (Ionita and Nagavciuc 2021). More frequent and intense occurrences of extreme events (i.e., floods, droughts and storms) over the past few decades have proven to be related to the negative effects of global warming which has accelerated the water cycle (Chagas, Chaffe and Blöschl 2022; Wang and Liu 2023). Not only does climate change affect the principal components of the climate system but affects the processes that cause floods to form on the land surface as well (Tarasova et al. 2023). Hence, as a consequence of the growth in flood events on a global scale, there has been a proliferation of research tackling the problem of climate change impacts on these extreme hydrological events (Arnell and Gosling 2016; Hodgkins et al. 2017; Majone et al. 2022; Speight and Krupska 2021; Tabari 2020). Given the identified changes in the timing of floods throughout the year, it has been shown that snowmelt-generated floods are becoming less common in colder areas, whereas convective events are increasing in frequency at the expense of synoptic events (Blöschl et al. 2019; Chegwidden, Rupp and Nijssen 2020; Tarasova et al. 2023). Furthermore, besides meteorological and hydrological processes, watershed shape or size is a principal factor influencing flooding variations (Sharma, Wasko and Lettenmaier 2018). Smaller basins commonly experience changes similar to those in precipitation, although larger catchments may be more dominated by other warming-related changes (i.e., reduction of soil moisture and snowmelt; Hirabayashi et al. 2021). Overall, flood events in various areas of the Northern Hemisphere are primarily controlled by extreme precipitation events (Alifu et al. 2022). Thus, monitoring alterations in the frequency and severity of flooding is crucial for developing adequate adaptation and mitigation strategies given that future global floods are influenced by climate warming (Asadieh and Krakauer 2017).

Many European rivers have been impacted by extreme high streamflow events since the last decade of the 20th century, which resulted in damages worth billions of euros (Fischer and Schumann 2021), while extreme hydrological events are anticipated to increase even more in terms of frequency and severity (Paprotny et al. 2018). Over the last several years a substantial number of research on this issue has been carried out, where a majority of studies examined trends in flood events at the European level (Bertola et al. 2020; Blöschl et al. 2019; Brönnimann et al. 2022; Kemter et al. 2020; Tarasova et al. 2023). Overall findings suggest increased flood events in northwestern parts of Europe due to increased winter and autumn precipitation, whereas southeastern, central and eastern parts of Europe have experienced a reduction in flooding generally due to increased air temperatures and evaporation. Such results are also confirmed by various local and regional research in the southern (Vicente-Serrano et al. 2017), eastern (Venegas-Cordero et al. 2022), northern (Wilson and Hisdal 2013), central (Mudelsee et al. 2003; 2004; 2006) and western parts (Hannaford et al. 2021) of Europe. Studies on extremely high streamflows in southeastern Europe have also been carried out extensively during the past decade where authors usually employed either the regional flood frequency analysis method (Kavcic et al. 2014; Leščešen and Dolinaj 2019; Leščešen et al. 2022a) or different trend change methods (Pešić et al. 2023; Radevski et al. 2018; Tadić, Bonacci and Dadić 2016). Also, a substantial number of studies in the same region focused on the calculation of flood magnitude with a specific return period by applying a widely used flood frequency analysis (FFA) (Cerneagă and Maftei 2021; Leščešen et al. 2022a; Radevski and Gorin 2017; Tadić, Dadić and Barač 2013; Zabret and Brilly 2014). This method can provide vital knowledge about the hydrological behaviour of a river (Šraj and Bezak 2020), whilst the procedure fits various functions to data and extrapolates the tails of the distribution to assess the magnitude and probability of flood events (Leščešen et al. 2022a).

To this date, flood analysis in Bosnia and Herzegovina (BH) remains scarce and insufficiently covered. Many flood frequency analyses were produced for the period 1961–1990, mainly for project studies, and are not available publicly. However, recent studies in the form of research articles are extremely rare and treat either specific extreme events (Vidmar et al. 2016) or the extent of flooded areas using satellite and radar images (Ivanišević et al. 2022). Floods in BH are predominantly induced by humid air currents coming from the Atlantic or abrupt melting of snow that occurs late in the early winter/late spring period. In the 21st century and especially over the last decade the number of flooding events has substantially risen. The majority of flooding in BH has been occurring in the Sava River basin (76% of BH territory) on predominantly impermeable geological formations where the hydrographic network is well-developed (Gnjato et al. 2023). The most severe flood in recent history, which occurred in May of 2014, inflicted a significant portion of BH territory (> 50%) causing displacement of > 100,000 people with overall damage of 2 billion euros (Vidmar et al. 2016). Floods impacted mostly the northern and central parts of BH and were generally present in the lower areas of the major river basins (i.e., Una, Vrbas and Bosna). After 2014, major flood events occurred in 2018, 2019, 2021 and 2023 (see also reports at https://floodlist.com/tag/bosnia).

Frequency and occurrence rate of maximum river discharges are crucial for engineering practice since severe floods in BH are predicted to be generated more frequently as a result of climate change. Given the data availability, record length, and increased danger of flood risk, for this study, we chose to investigate two hydrological profiles in the Una River basin (Novi Grad and Prijedor). The major objective was to perform a comprehensive maximum discharge frequency and occurrence analysis for the Una and Sana Rivers covering the 60-year period, from 1961 to 2020. Furthermore, our targets were to identify trends in the extremely high discharges and to observe their seasonal features.

2 Material and methods

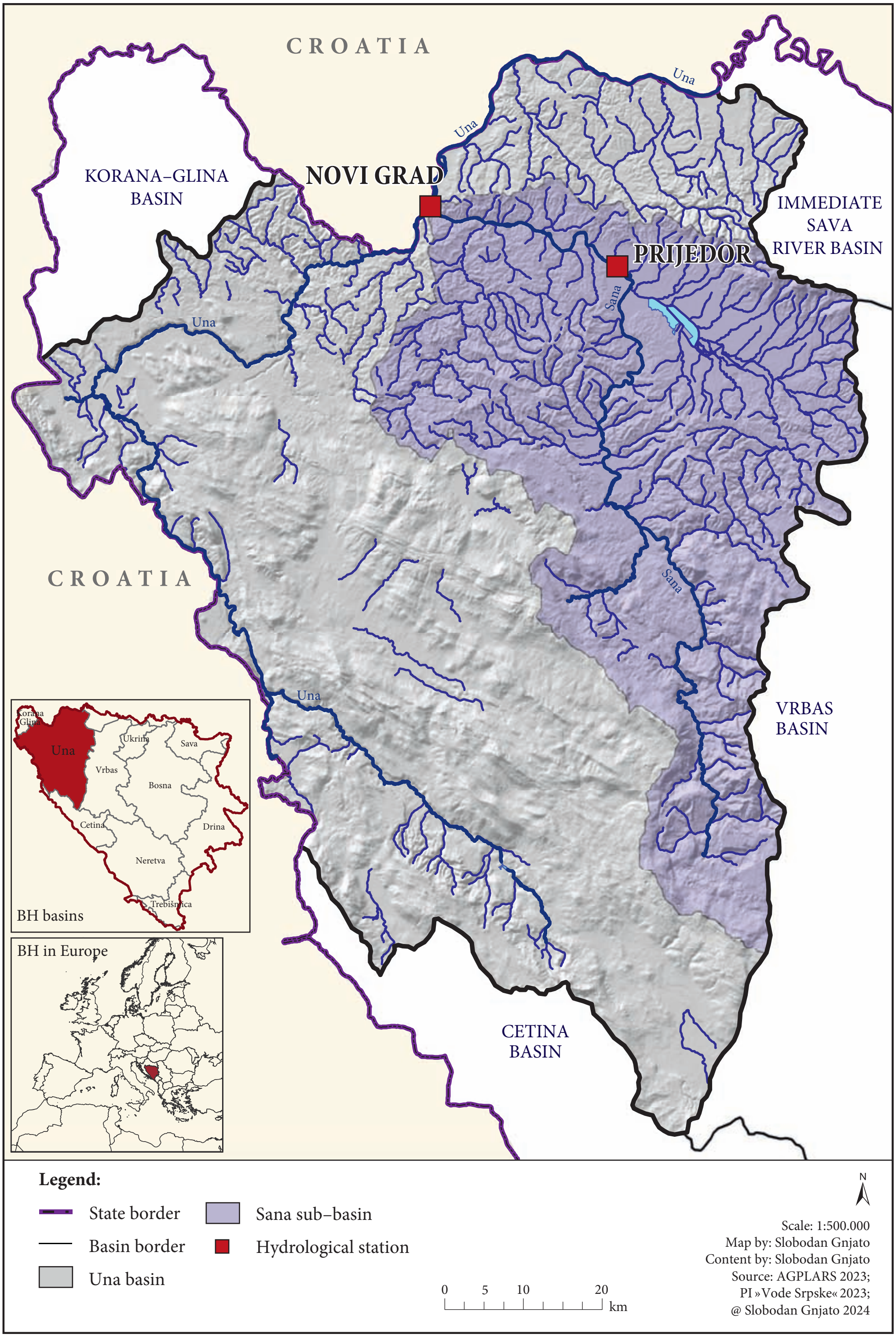
2.1 Study area

With an area of 9130 km^2 and a total river length of 210 km, the Una River basin is positioned in the northwestern part of BH (Figure 1). The source of the Una River consists of a large number of karst springs in the Dinaric Alps. Even though the main source is located in the Republic of Croatia, the river itself appears after a few kilometers in BH. The southern, western, and central parts of the Una basin are predominantly under the influence of karst as approximately 2/3 of the Una basin consists of karstified and significantly karstified areas with poorly developed surface river network (Gnjato 2022). Unlike the southern and central parts, the northeastern area of the watershed is a valley built from alluvial deposits. In this part, the river Una receives its largest right tributary, the Sana River (146 km of river length with an area of 3,782 km^2). The Una River has a characteristic hydrological regime, which is characterized by low summer and high spring flows. Also, extremely large winter flows are characteristic of this river. According to the classification of Ilešič (1948) the Una River, as well as most of the large tributaries of the Sava in BH, is characterized by the Posavina variant of the pluvio-nival water regime, determined by the highest discharges in April and March, and the minimum flows in August and September (Gnjato et al. 2021) The climate conditions in the basin change from the mountain in the southern parts of the basin to continental and moderate continental climate types in the central and northern parts, respectively.

2.2 Data

Input data for this research were obtained from the Hydrometeorological Service of the Republic of Srpska and they consist of the maximum discharges observed for each month for the Una River at Novi Grad station and Sana River at Prijedor station, spanning the interval from 1961 to 2020, as illustrated in Figure 2. The annual maximum discharge of a river is an important indicator of water availability and flood risk management (Higashino and Stefan 2019). It is known that not every high discharge value causes a flood but every flood is preceded by a high discharge value (Shiklomanov et al. 2007). Therefore, we chose to analyse monthly maximum discharges as a good indicator of potential floods. The data set had some missing values, mainly at Sana River the data was missing for the 1991–1994 period, while on Una River the data was missing for 1991, 1992, 2000, and 2001 (see Tables 1 and 2). Hydrological datasets frequently contain gaps, outliers, or incorrect data. If the issue of missing data is ignored it can lead to a reduction in the statistical power of the techniques used and even to incorrect conclusions about the study phenomenon (Łopucki et al. 2022). In order to assess the sensitivity of our study results to the presence or absence of data, we conducted a comprehensive sensitivity analysis by considering three hypothetical cases: (b1) where

Figure 1: Map of the Una River basin. ➤ p. 133


CROATIA
KORANA–GLINA
BASIN
NOVI GRAD
Una
Una
Una
Una
PRIJEDOR
Sana
Sana
IMMEDIATE
SAVA
RIVER BASIN
CROATIA
VRBAS
BASIN
CETINA
BASIN
Korana
Glina
Una
Ukrina
Sava
Vrbas
Bosna
Cetina
Drina
Neretva
Trebišnjica
BH basins
BH in Europe
Legend:
State border
Basin border
Una basin
Sana sub–basin
Hydrological station
N
Scale: 1:500.000
Map by: Slobodan Gnjato
Content by: Slobodan Gnjato
Source: AGPLARS 2023;
PI »Vode Srpske« 2023;
@ Slobodan Gnjato 2024
0 5 10 20
km

all missing months were assumed to have Magnitude 1 (M1) events, (b2) where all missing months were assumed to have Magnitude 2 (M2) events, and (b3) where all missing months were assumed to have no events (see chapter 2.3 for definition of M1 and M2 events). We applied this method to fill the missing data, utilizing the median value of discharges that are below the average maximum discharges for the whole period in case of b1, and in case of b2, we used the median of the discharge values above the maximum averages for the whole period (Tables 3 and 4). When analysing the results, it can be noticed that b2 has a slightly higher mean, lower standard error, and a slightly lower skewness compared to b1 and b3. Additionally, b2 has the highest median value. These factors indicate that b2 has the most stable and consistent results compared to b1 and b3. Therefore, based on these analyses, we can conclude that the b2 scenario is the best for both rivers. That is why, we decided to adopt b2 and fill all of our missing data with median of the values above the average maximum discharge for the whole period, 261.4 m^3/s for Sana River and 584.5 m^3/s for Una River. This approach provided a valuable insight into the potential impact of missing data on our findings. This sensitivity analysis enhances the reliability of our conclusions and underscores the importance of acknowledging the uncertainties associated with missing data in hydrological studies. Prevalence of significant inter-annual and interdecadal variability in the records of maximum streamflows in Europe has been reported (Kundzewicz et al. 2005).

The dataset was partitioned into two distinct categories: hydrological summer (April to September) primarily triggered by heavy precipitation, and hydrological winter (October to March) driven by a combination of precipitation and snowmelt. We emphasize the necessity of distinguishing between winter and summer maximum discharges due to their distinct meteorological and hydrological origins (Mudelsee et al. 2003; 2004; 2006). This delineation in our analysis serves the purpose of providing valuable explanations and insights into the patterns and determinants of extreme events. It is crucial to recognize that maximum discharges typically do not confine themselves to a specific season, making this differentiation imperative for a comprehensive understanding of flood dynamics.

2.3 Methods

To examine the rates of maximum river discharge occurrences over time and assess any notable alterations, we employed kernel estimation along with confidence bands. This approach utilized a Gaussian kernel function denoted as *K*, which assigned weights to observed extreme event dates, *T(i)*, where *i* ranged from 1 to *N* (representing the number of maximum discharges). It was used to estimate the occurrence rate, *λ*, at a given time *t* using the following formula (Equation 1):

. (1)

In order to determine the bandwidth (*h* = 20 years), we employed cross-validation, which seeks an optimal balance between bias and variance. To establish 90% confidence bands around *λ(t)*, we adopted a bootstrap resampling technique, repeating the procedure 5,000 times and calculating a 90th percentile-*t* confidence band. This methodical framework, integrating the nonstationary Poisson process and bootstrap confidence bands, was initially introduced by Mudelsee et al. (2003; 2004; 2006) for risk analysis in climatology and hydrology. Later works by Mudelsee (2014; 2020) provided detailed explanations of the nonstationary methodical framework in two comprehensive books. Furthermore, our study included a trend analysis. This analysis was conducted within a nonstationary framework, and we estimated time-dependent occurrence rates using advanced kernel techniques supported by the construction of bootstrap confidence bands (Mudelsee 2020).

To assess the significance of the occurrence rate estimation curves we applied Cox-Lewis test, a statistical test that was outlined by Mudelsee et al. (2004). This test focuses on extreme events, examining whether there is an upward or downward trend. Detected trends in occurrence rate were validated for the measured interval (1961–2020) using the statistical Cox-Lewis test. This test compares the null hypothesis H0: constant occurrence rate against H1: increasing occurrence rate.

Figure 2: The monthly maximum discharges of the Sana (a) and Una (b) rivers for 1961–2020. ➤ p. 135

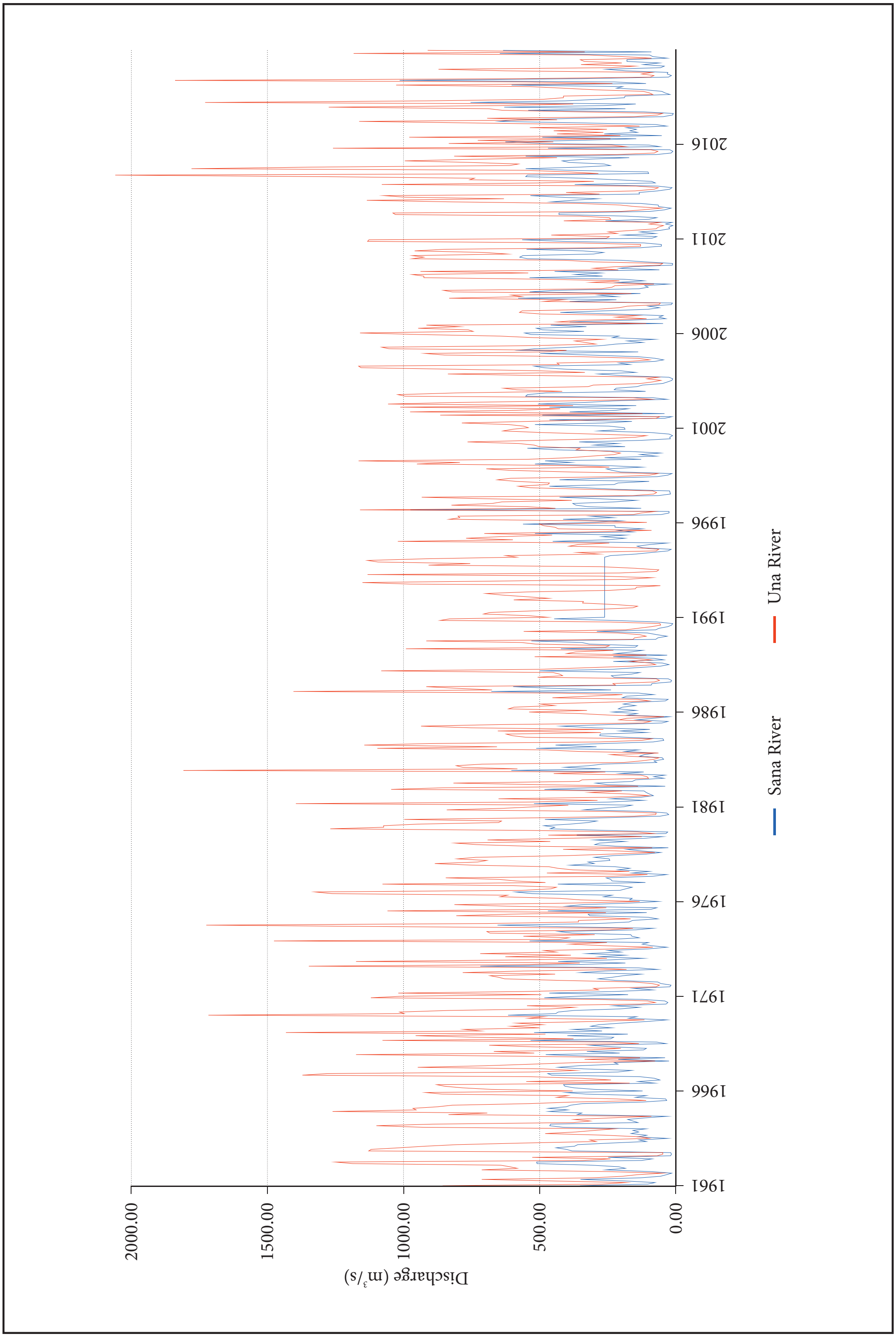

Una River
Sana River
Discharge (m³/s)
2000.00
1500.00
1000.00
500.00
0.00
1961
1966
1971
1976
1981
1986
1991
1996
2001
2006
2011
2016

Table 1: Monthly maximum discharge at the Sana River for 1961–2020.

Sana River (Prijedor station) Monthly maximum discharges (m3/s)												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1961	352	102	76	185	350	131	56	34	14	93	257	185
1962	210	310	509	511	125	86	248	19	16	18	381	402
1963	439	372	360	241	107	135	29	137	106	164	136	157
1964	109	414	463	459	139	157	176	113	32	362	345	467
1965	397	469	402	386	343	122	33	37	148	108	330	404
1966	122	298	374	407	412	77	139	58	78	131	456	470
1967	213	161	338	432	355	211	226	25	211	39	313	478
1968	206	326	118	108	237	315	35	70	534	240	228	398
1969	176	521	270	379	235	313	283	202	104	32	174	143
1970	616	441	432	374	204	133	229	35	29	40	124	483
1971	360	175	465	227	83	157	22	17	54	66	221	285
1972	234	193	127	350	259	65	137	718	367	185	432	242
1973	118	281	185	327	200	250	101	31	91	123	100	537
1974	234	134	161	165	380	431	146	82	421	655	291	172
1975	158	66	100	315	322	107	470	91	70	402	341	166
1976	63	170	160	265	233	529	589	205	183	160	205	433
1977	111	233	239	256	85	32	160	95	212	168	222	388
1978	300	322	242	244	300	229	108	55	126	181	27	221
1979	298	280	185	298	116	48	364	36	29	258	461	444
1980	484	389	322	290	481	252	57	26	33	101	338	280
1981	190	161	521	243	117	239	126	82	96	108	116	482
1982	311	38	251	294	159	147	43	81	39	205	118	604
1983	275	408	319	270	69	80	44	50	133	115	74	188
1984	137	512	291	441	260	83	44	47	186	279	278	106
1985	205	95	298	421	244	51	28	145	83	22	179	141
1986	233	144	211	197	147	193	159	38	28	197	181	80
1987	138	678	238	462	597	90	87	18	15	27	227	237
1988	163	132	500	231	147	56	24	49	229	43	80	229
1989	31	223	163	121	422	149	139	318	345	530	74	65
1990	31	69	105	290	74	61	29	15	11	68	229	447
1991						MISSING DATA						
1992						MISSING DATA						
1993						MISSING DATA						
1994		MISSING DATA		240	146	88	29	17	122	142	98	32
1995	452	252	186	271	183	517	156	212	122	223	223	561
1996	301	199	414	229	313	54	24	24	975	127	322	366
1997	378	226	144	282	427	65	19	21	23	212	333	464
1998	226	212	98	427	284	69	29	14	202	233	255	123
1999	252	517	383	480	127	261	70	131	55	166	434	545
2000	186	301	211	355	126	20	22	11	24	93	284	186
2001	189	245	517	265	161	464	40	14	490	41	390	219
2002	174	464	145	506	333	229	32	83	551	545	477	111
2003	226	219	142	122	48	30	14	11	24	195	285	147
2004	200	400	485	520	168	209	77	44	76	137	317	498
2005	138	578	520	383	273	219	120	178	76	233	209	531
2006	555	337	490	512	328	459	47	390	189	36	62	46
2007	229	424	266	102	60	101	16	12	390	218	579	215
2008	284	130	537	445	135	101	114	24	213	116	189	537
2009	269	371	274	445	60	207	155	12	11	113	199	545
2010	573	561	302	265	341	548	130	53	53	117	414	564
2011	87	70	194	74	131	57	23	26	11	37	13	258
2012	98	70	181	429	429	94	41	17	63	64	128	457
2013	383	285	427	534	133	135	67	22	13	67	371	75
2014	88	215	341	551	545	99	102	395	551	352	240	263
2015	392	417	335	171	551	72	17	10	22	469	58	99
2016	485	626	352	145	490	51	263	140	168	144	182	33
2017	73	333	650	582	355	47	11	9	119	542	185	630
2018	265	147	754	407	284	189	186	21	39	51	113	218
2019	195	603	109	226	1014	348	27	16	32	29	185	255
2020	56	42	120	60	179	179	31	84	96	646	89	634

Table 2: Monthly maximum discharge at the Una River for 1961–2020.

Una River (Novi Grad station)
Monthly maximum discharges (m^3/s)

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1961	856	270	181	449	713	307	195	142	47	254	713	582
1962	610	643	1187	1250	342	240	527	69	47	47	1128	1118
1963	1015	922	805	568	292	316	97	132	256	480	367	299
1964	225	930	1100	892	376	314	374	236	89	835	692	1261
1965	953	965	874	821	538	379	109	217	437	395	860	919
1966	379	677	785	849	878	169	549	238	344	530	1372	1280
1967	522	367	489	948	697	528	362	76	335	131	573	1174
1968	520	668	309	202	530	685	135	233	1077	376	737	956
1969	478	1432	715	779	499	606	489	584	292	115	541	484
1970	1717	998	1015	834	458	371	546	129	75	104	296	1120
1971	1006	494	1019	557	283	302	72	59	88	154	426	629
1972	651	682	443	782	557	181	304	1348	541	353	1174	546
1973	253	626	385	718	438	484	218	84	271	388	253	1476
1974	426	392	560	298	682	694	243	157	1015	1724	694	357
1975	357	165	300	806	606	257	1059	436	255	620	813	374
1976	132	348	426	645	617	1263	1325	565	458	438	595	1077
1977	478	587	648	845	229	104	473	170	378	433	466	747
1978	885	728	694	803	734	399	231	77	216	414	87	541
1979	731	809	461	691	407	125	468	82	140	546	1269	1073
1980	1073	948	651	640	998	481	151	74	71	247	841	634
1981	515	395	1395	530	287	651	239	100	169	317	198	1046
1982	856	138	496	816	355	344	100	106	128	448	259	1808
1983	581	782	806	712	189	126	80	61	174	239	63	357
1984	476	1096	657	1144	897	279	124	88	552	601	623	275
1985	653	266	753	936	643	120	92	208	180	43	240	353
1986	539	326	615	595	445	497	291	97	139	453	322	196
1987	439	1404	675	807	917	221	231	78	60	72	507	415
1988	426	450	1082	494	326	157	74	93	167	91	157	518
1989	108	401	367	229	991	258	244	515	567	917	157	151
1990	109	132	212	559	184	138	91	55	58	244	865	831
1991							MISSING DATA					
1992					MISSING DATA				56	976	1151	612
1993	184	87	275	1132	207	70	62	148	275	908	755	1094
1994	1132	916	584	625	280	361	72	62	143	392	361	244
1995	1021	598	770	646	454	703	326	89	431	MISSING DATA		
1996	106	326	832	793	800	156	127	75	1160	442	545	824
1997	675	639	382	696	933	159	81	70	85	312		
1998	469	464	584	655	605	223	95	65	387	605	696	244
1999	387	951	793	1165	545	392	312	227	203	240	366	351
2000							MISSING DATA					
2001		MISSING DATA		785	540	285	73	59	865	122	976	584
2002	425	1012	377	1057	800	398	89	156	994	1021	808	417
2003	584	632	322	303	130	86	54		63	474	837	334
2004	495	804	1156	1165	428	436	170	95	138	339	849	921
2005	483	401	1053	1080	517	294	331	371	271	520	646	942
2006	1160	744	762	946	793	916	108	434	364	107	221	138
2007	495	574	564	289	209	177	61	56	486	411	832	564
2008	605	163	820	853	273	234	223	80	312	207	480	925
2009	925	968	542	938	211	303	221	58	48	303	406	968
2010	925	968	618	703	959	853	273	129	129	356	1132	1127
2011	255	244	457	215	248	159	72	64	45	98	58	411
2012	238	244	351	1030	1039	199	122	54	149	203	351	821
2013	1135	631	995	1071	280	403	149	79	64	146	1080	495
2014	301	757	739	1286	2059	284	387	557	1779	1341	610	578
2015	757	995	745	436	814	219	79	65	92	1259	184	236
2016	834	450	727	240	979	203	436	266	448	253	536	133
2017	341	745	1163	436	693	154	67	49	356	637	687	1275
2018	646	377	1729	916	487	413	412	84	97	119	298	411
2019	535	1027	232	554	1839	562	94	80	125	87	627	872
2020	239	149	348	198	336	351	89	196	318	1184	335	911

Table 3: Sensitivity analysis results for Sana River.

Sana River (Prijedor station)												
B1	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
n	56.0	56.0	56.0	57.0	57.0	57.0	57.0	57.0	57.0	57.0	57.0	57.0
mean (m^3/s)	239.9	284.8	295.5	312.7	256.2	173.1	112.3	91.1	154.6	183.6	235.3	308.2
Standard error	18.1	21.5	20.6	17.7	22.3	17.5	14.9	16.0	23.7	20.6	16.6	23.4
Median (m^3/s)	207.8	248.5	268.2	289.9	218.5	134.8	73.8	45.8	96.0	143.0	221.7	256.7
Standard dev	135.5	161.0	154.1	133.4	168.4	132.4	112.4	121.0	179.1	155.3	125.6	176.7
Kurtosis	0.9	0.9	0.9	0.9	0.9	0.8	0.7	0.5	0.6	0.8	0.9	0.8
Skewness	0.9	0.6	0.7	0.1	1.8	1.4	2.1	3.1	2.3	1.6	0.5	0.2
Minimum	31.3	38.4	75.8	59.6	48.2	19.8	11.4	8.8	10.6	18.3	13.1	31.5
Max	616.1	677.8	754.0	582.0	1014.0	548.0	588.6	717.7	975.0	654.6	579.0	634.0
Quartile 1	153.3	167.8	181.9	226.4	134.5	75.4	29.1	20.4	31.5	67.7	134.0	170.0
Quartile 3	299.9	402.0	404.9	427.5	341.6	221.5	156.6	117.2	186.5	219.3	324.0	467.7
Range	584.8	639.4	678.2	522.4	965.8	528.2	577.2	708.9	964.4	636.4	565.9	602.5
B2	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
n	56.0	56.0	56.0	57.0	57.0	57.0	57.0	57.0	57.0	57.0	57.0	57.0
mean (m^3/s)	245.2	290.1	300.8	316.7	260.2	177.1	116.3	95.1	158.6	187.6	239.2	312.1
Standard error	18.0	21.2	20.2	17.3	22.2	17.7	15.4	16.6	23.9	20.7	16.6	23.1
Median (m^3/s)	227.5	261.4	268.2	289.9	240.6	134.8	73.8	45.8	96.0	143.0	227.2	261.4
Standard dev	134.6	158.8	151.4	130.6	167.6	133.8	116.2	125.2	180.6	156.2	125.1	174.7
Kurtosis	0.9	0.9	0.9	0.9	0.9	0.8	0.6	0.5	0.6	0.8	0.9	0.8
Skewness	0.8	0.5	0.7	0.1	1.8	1.3	1.9	2.8	2.2	1.5	0.4	0.2
Minimum	31.3	38.4	75.8	59.6	48.2	19.8	11.4	8.8	10.6	18.3	13.1	31.5
Max	616.1	677.8	754.0	582.0	1014.0	548.0	588.6	717.7	975.0	654.6	579.0	634.0
Quartile 1	153.3	167.8	183.9	237.8	134.5	75.4	29.1	20.4	31.5	67.7	134.0	170.0
Quartile 3	299.9	402.0	404.9	427.5	341.6	242.0	156.6	117.2	211.5	234.6	324.0	467.7
Range	584.8	639.4	678.2	522.4	965.8	528.2	577.2	708.9	964.4	636.4	565.9	602.5
B3	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
n	56.0	56.0	56.0	57.0	57.0	57.0	57.0	57.0	57.0	57.0	57.0	57.0
mean (m^3/s)	227.7	272.7	283.3	303.6	247.1	164.0	103.2	82.0	145.5	174.5	226.2	299.1
Standard error	19.8	23.4	22.6	19.6	23.4	18.2	15.1	16.0	24.1	21.3	18.0	24.8
Median (m^3/s)	207.8	248.5	268.2	289.9	218.5	126.2	56.4	36.6	80.8	128.9	221.7	256.7
Standard dev	147.9	174.8	169.3	147.7	177.0	137.7	113.8	120.7	182.1	160.5	135.5	187.5
Kurtosis	0.9	0.9	0.9	1.0	0.9	0.8	0.5	0.4	0.6	0.7	1.0	0.9
Skewness	0.6	0.4	0.4	−0.2	1.6	1.3	2.2	3.3	2.4	1.5	0.3	0.1
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max	616.1	677.8	754.0	582.0	1014.0	548.0	588.6	717.7	975.0	654.6	579.0	634.0
Quartile 1	120.9	141.6	156.3	226.4	126.8	65.3	28.6	17.0	28.4	61.1	117.3	146.1
Quartile 3	299.9	402.0	404.9	427.5	341.6	221.5	140.9	85.6	186.5	219.3	324.0	467.7
Range	616.1	677.8	754.0	582.0	1014.0	548.0	588.6	717.7	975.0	654.6	579.0	634.0

Table 4: Sensitivity analysis results for Una River.

Una River (Novi Grad station)												
B1	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
n	56.0	56.0	56.0	57.0	57.0	57.0	57.0	59.0	58.0	57.0	56.0	55.0
mean (m3/s)	555.4	581.8	633.8	690.2	559.4	333.2	234.6	173.4	323.8	420.8	542.9	640.3
Standard error	46.6	46.6	46.7	42.2	50.1	31.2	31.0	27.4	44.9	48.4	45.6	56.3
Median (m3/s)	505.0	612.0	633.0	715.0	508.0	289.5	150.0	89.0	209.5	354.5	543.0	571.0
Standard dev	348.4	348.5	349.6	318.3	378.1	235.5	234.2	210.5	341.8	365.3	341.1	417.4
Kurtosis	0.9	1.1	1.0	1.0	0.9	0.9	0.6	0.5	0.6	0.8	1.0	0.9
Skewness	0.7	0.2	0.5	–0.4	1.6	1.5	2.6	3.5	2.1	1.5	0.3	0.4
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max	1717.0	1432.0	1729.0	1286.0	2059.0	1263.0	1325.0	1348.0	1779.0	1724.0	1372.0	1808.0
Quartile 1	331.0	326.0	380.8	521.0	286.0	166.5	87.0	67.0	91.3	142.3	286.8	346.8
Quartile 3	776.3	835.8	805.3	898.0	748.8	405.5	315.5	202.0	398.0	522.5	768.3	945.5
Range	1717.0	1432.0	1729.0	1286.0	2059.0	1263.0	1325.0	1348.0	1779.0	1724.0	1372.0	1808.0
B2	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
n	56.0	56.0	56.0	57.0	57.0	57.0	57.0	59.0	58.0	57.0	56.0	55.0
mean (m3/s)	594.3	620.7	672.7	719.4	588.6	362.4	263.8	193.2	343.3	450.0	581.9	689.0
Standard error	42.0	41.6	40.9	36.7	47.1	30.2	31.7	28.7	44.6	46.8	41.2	50.0
Median (m3/s)	537.0	612.0	633.0	715.0	539.0	305.0	206.5	95.0	255.5	390.0	584.3	584.0
Standard dev	314.6	311.4	306.0	277.1	355.3	228.3	239.6	220.7	339.3	353.5	308.1	370.6
Kurtosis	0.9	1.0	0.9	1.0	0.9	0.8	0.8	0.5	0.7	0.9	1.0	0.8
Skewness	0.9	0.4	0.9	–0.1	1.9	1.5	2.2	3.0	2.0	1.5	0.4	0.6
Minimum	106.0	87.0	181.0	198.0	130.0	70.0	54.0	49.0	45.0	43.0	58.0	133.0
Max	1717.0	1432.0	1729.0	1286.0	2059.0	1263.0	1325.0	1348.0	1779.0	1724.0	1372.0	1808.0
Quartile 1	415.5	388.3	453.5	558.5	333.5	194.5	91.8	72.0	118.0	206.0	347.0	401.8
Quartile 3	776.3	835.8	805.3	898.0	748.8	481.8	365.0	222.0	439.8	584.0	768.3	945.5
Range	1611.0	1345.0	1548.0	1088.0	1929.0	1193.0	1271.0	1299.0	1734.0	1681.0	1314.0	1675.0
B3	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
n	56.0	56.0	56.0	57.0	57.0	57.0	57.0	59.0	58.0	57.0	56.0	55.0
mean (m3/s)	555.4	581.8	633.8	690.2	559.4	333.2	234.6	173.4	323.8	420.8	542.9	640.3
Standard error	46.6	46.6	46.7	42.2	50.1	31.2	31.0	27.4	44.9	48.4	45.6	56.3
Median (m3/s)	505.0	612.0	633.0	715.0	508.0	289.5	150.0	89.0	209.5	354.5	543.0	571.0
Standard dev	348.4	348.5	349.6	318.3	378.1	235.5	234.2	210.5	341.8	365.3	341.1	417.4
Kurtosis	0.9	1.1	1.0	1.0	0.9	0.9	0.6	0.5	0.6	0.8	1.0	0.9
Skewness	0.7	0.2	0.5	–0.4	1.6	1.5	2.6	3.5	2.1	1.5	0.3	0.4
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max	1717.0	1432.0	1729.0	1286.0	2059.0	1263.0	1325.0	1348.0	1779.0	1724.0	1372.0	1808.0
Quartile 1	331.0	326.0	380.8	521.0	286.0	166.5	87.0	67.0	91.3	142.3	286.8	346.8
Quartile 3	776.3	835.8	805.3	898.0	748.8	405.5	315.5	202.0	398.0	522.5	768.3	945.5
Range	1717.0	1432.0	1729.0	1286.0	2059.0	1263.0	1325.0	1348.0	1779.0	1724.0	1372.0	1808.0

As the sample size (n) increases, the test statistic, u, rapidly conforms to a standard normal distribution. Here, $T(i)$, where $i = 1, \ldots, n$, represents the extreme event dates, n denotes the data size, and [t1, t2] indicates the observation interval (Mudelsee 2020).

In our study, we analysed two categories of events based on different threshold levels. Initially, we set the threshold at the 30-year average maximum discharge (1961–1990) as that is the reference period most commonly applied by WMO, for both summer (April-September) and winter (October-March) seasons. Further, we classified maximum discharges into two magnitudes as follows: Magnitude 1 (M1), severe events – maximum discharge up to the threshold; and Magnitude 2, extreme events (M2) with all discharge values above the threshold (Table 1).

In terms of annual assessments, severe events (M1) along the Una River are characterized by flow rates up to 504.4 m^3/s, while extreme events (M2) are delineated by values surpassing this threshold. This distinction is similarly observed during the summer season, where M1 events are defined as those with flow rates up to 405.2 m^3/s, and M2 events are those exceeding this level. During the winter season, the delineation remains consistent, with M1 events being those with discharge values up to the threshold of 605.6 m^3/s, and M2 events being those exceeding this threshold.

Turning to the Sana River, annual M1 events are denoted by flow rates up to 224.9 m^3/s, with M2 events representing values surpassing this threshold (Table 5). In the summer, the threshold is set at 181.2 m^3/s, with M1 events defined below this threshold and M2 events above it (Table 5). Similarly, for the winter season, the threshold is established at 249.1 m^3/s, with M1 events identified as those falling below this threshold, and M2 events as those exceeding it (Table 5).

Table 5: Thresholds applied to define severe (M1) and extreme (M2) events.

River	Annual	Summer season	Winter season
Una	504.4 m^3/s	405.2 m^3/s	605.6 m^3/s
Sana	224.9 m^3/s	181.2 m^3/s	249.1 m^3/s

3 Results and discussion

3.1 Flood seasonality

Severe (M1) and extreme (M2) events on the Una and Sana rivers mainly occurred during the winter half of the year (October to March) while no annual maximum occurred during June (Figure 3). Seasonal variations significantly impact the occurrence of annual maximum discharges in the Una and Sana Rives. Winter maximums are predominantly observed in April, these events are primarily the result of snowmelt in the upper regions of the basin and rainfall in the lower areas.

An analysis of M1 and M2 events occurrences throughout each month over the span of 1961–2020 unveils pronounced seasonal fluctuations. Notably, the frequency of winter events displayed an upward trajectory from October (three events) through March (nine events), gradually waning as the year advanced. In contrast, the prevalence of summer floods peaked in May (six events), gradually waning as the summer season approached its conclusion in September (three events).

3.2 Seasonal flood frequency and occurrence rate

To assess the trends in the occurrence of the M1 and M2 events, this study applied the Cox and Lewis test to inspect these trends. The statistical analysis affirmed these outcomes at a 95% confidence level, as illustrated in Figures 4 and 5. When analysis of the frequency of M1 events was conducted the same conclusion can be made for both stations during the summer season, and that is that there is an increasing trend at Una River ($u = 0.704$; $p = 0.241$) and Sana River ($u = 0.772$; $p = 0.220$), but these trends are not statistically significant. The frequency of M1 events at Una River increased from the beginning of the period from $\lambda_{(t)} \approx 3.3611\ a^{-1}$ to $\lambda_{(t)} \approx 3.635\ a^{-1}$ at the end of the period, or at the beginning of the period, one event was occurring every 54 days, while at the end of the period on the event was occurring every 50 days. Similarly, at Sana River frequency increased from 3.362 a^{-1} to 3.660 a^{-1}, this coincides with the increased frequency of these events from 55 days to 50 days. The occurrence rate of the M1 events during the winter season on Una and Sana rivers is characterized by a slight increase by the year 1990 followed by a flattening of the trend line indicating that no significant changes occurred during the winter season. At Una River, the frequency of M1 events during the winter season changed for just five days from 56 ($\lambda_{(t)} \approx 3.289$ a^{-1}) to 51

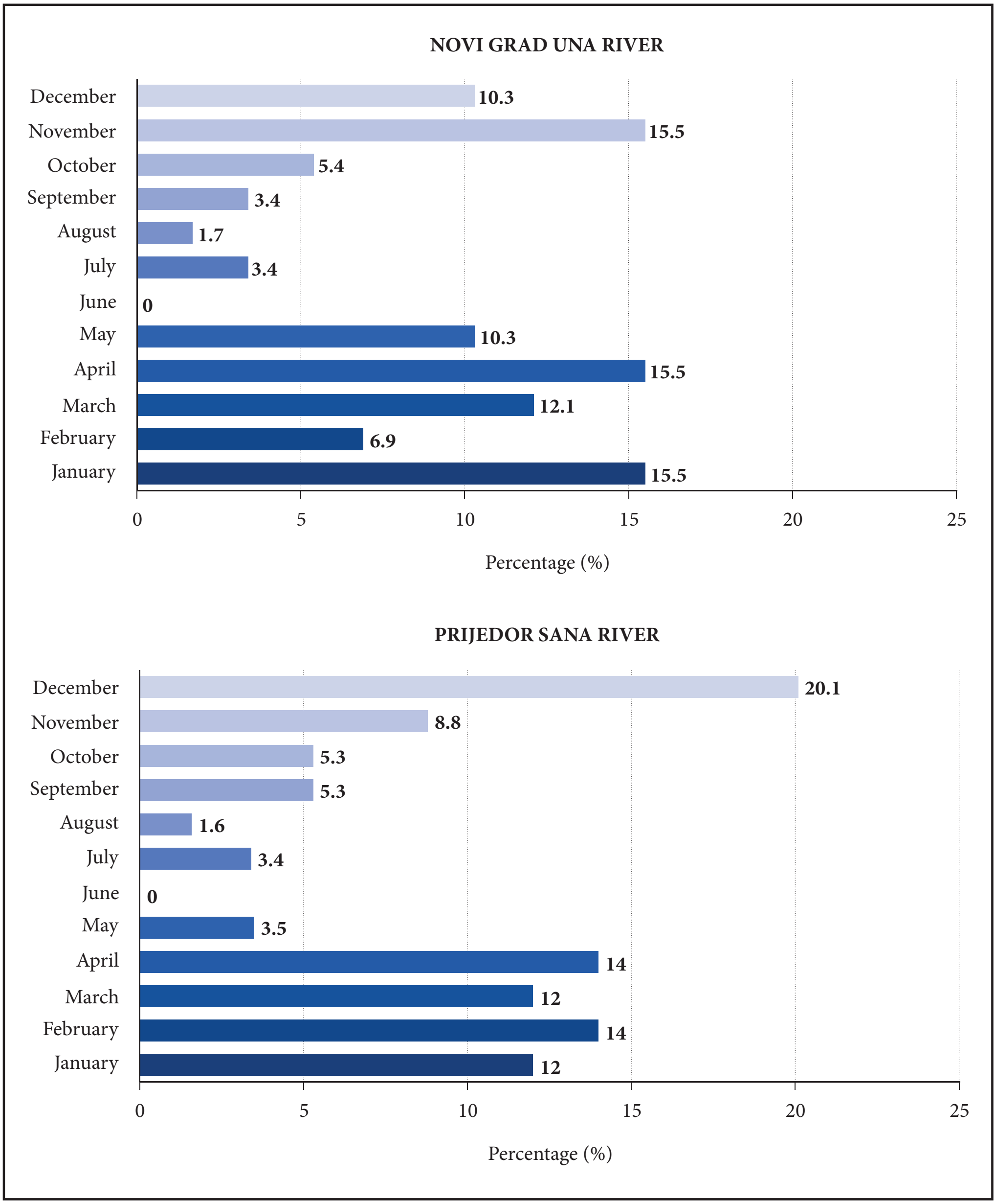


Figure 3: Percentage of annual maximum discharges per month for Una and Sana rivers.

day ($\lambda_{(t)} \approx 3.548\ a^{-1}$). Interestingly, on Sana River the decrease in the frequency of M1 events was observed during the winter season, at the beginning of the period it was 58 days ($\lambda_{(t)} \approx 3.165\ a^{-1}$), and at the end of the observed period 59 days ($\lambda_{(t)} \approx 3.112\ a^{-1}$).

During the observed period, the occurrence rate of the M2 events at Una River (Figure 4) shows a declining trend both during summer ($u = -0.819$; $p = 0.206$) and winter ($u = -0.799$; $p = 0.212$) but they were not statistically significant ($p < 0.05$). The frequency of summer M2 events on the Una River has exhibited a decrease over time. In the 1960s, the average frequency was approximately 68 days per event ($\lambda_{(t)} \approx 2.681\ a^{-1}$), while in 2020, it had extended to about 77 days per event ($\lambda_{(t)} \approx 2.406\ a^{-1}$). Similarly, during the winter season, a reduction in the frequency of M2 events was observed. At the start of the period, an event was expected approximately every 36 days ($\lambda_{(t)} \approx 2.692\ a^{-1}$), but by the end of the period, this frequency had decreased to one event every 76 days ($\lambda_{(t)} \approx 2.435\ a^{-1}$).

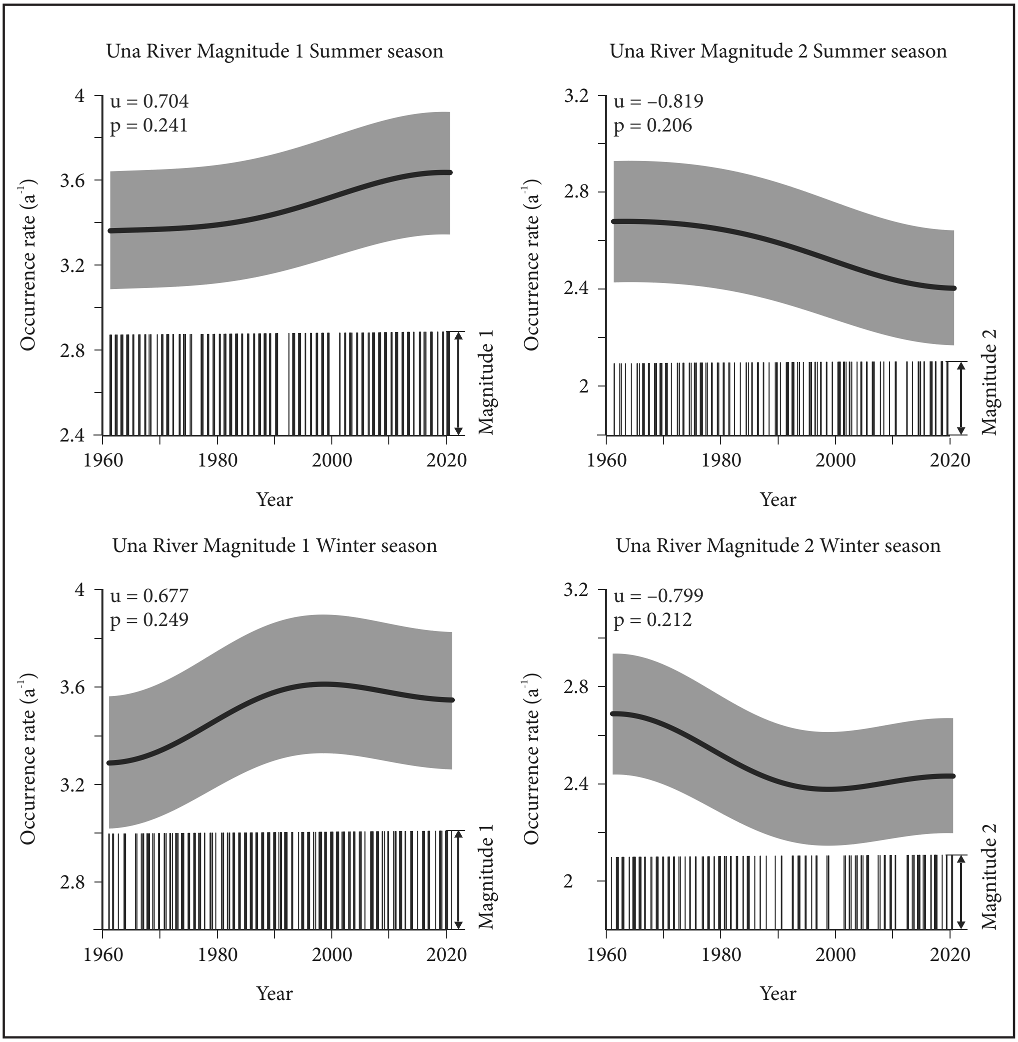


Figure 4: Occurrence rates (solid lines) of Una River monthly maximum discharge at Novi grad station for two magnitude classes with bootstrap 90% confidence band (shaded). Kernel estimation using a bandwidth of 20 years is applied to the flood dates with the Cox and Lewis test results for trend estimation (upper left-right corner of each graph).

The Sana River trends of the M2 events show that during summer season these events are decreasing ($u = –0.899$; $p = 0.184$) while during winter season a moderate increase can be observed ($u = –0.016$; $p = 0.493$) but this trend is not statistically significant ($p < 0.05$). The frequency of M2 events during summer season changed from 68 days ($\lambda_{(t)} \approx 2.681\ a^{-1}$) in 1961 to 77 in 2020 ($\lambda_{(t)} \approx 2.382\ a^{-1}$). Winter M2 events also changed, from 65 days ($\lambda_{(t)} \approx 2.817\ a^{-1}$) to 64 days ($\lambda_{(t)} \approx 2.870\ a^{-1}$).

In the latest Intergovernmental Panel on Climate Change (2023) report it is suggested that the assumption of stationary hydrology should be abandoned because of climate change and its effects that are likely to have a significant influence on the hydrological cycle. Consequently, several European Union (EU) countries have adopted modifications to their design standards, incorporating a precautionary approach that accounts for non-stationarity. That is why we applied the Cox-Lewis test which is expressly tailored to assess non-stationarity within the extremal component of the system responsible for generating a time series.

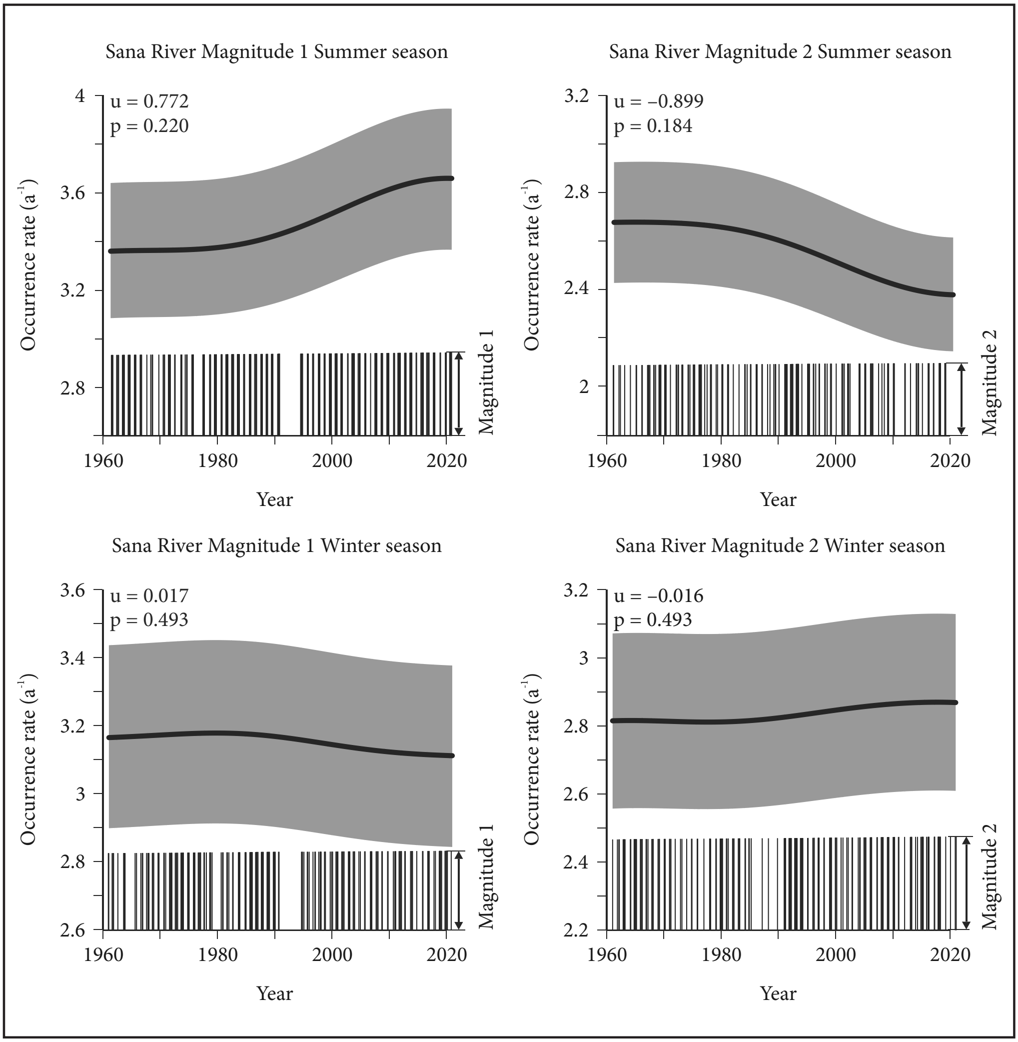


Figure 5: Occurrence rates (solid lines) of Sana River monthly maximum discharge at Prijedor station for two magnitude classes with bootstrap 90% confidence band (shaded). Kernel estimation using a bandwidth of 20 years is applied to the flood dates with the Cox and Lewis test results for trend estimation (upper left-right corner of each graph).

This aspect is particularly pertinent in hydroclimatic data analysis, as highlighted by Kundzewicz, Pińskwar and Brakenridge (2018). Results presented in Figures 4 and 5 imply that future changes in summer maximum discharge in the Una River basin mostly point to a rise in M1 events and to a decrease in the M2 events but these changes are not statistically significant. During the winter season, a similar increasing trend followed by a decrease in severe events is observed, while extreme events are showing an increase from the mid-1990s, but these changes are not statistically significant.

The analysis of seasonal data demonstrated that summer extreme events underwent more significant changes than winter events. When taking into account seasonal variations, winter and spring will become wetter due to a rise in precipitation by 20% caused mainly by higher temperatures (Myhre et al. 2019). These findings indicate that climate is the driving force behind the observed alterations in flood events as both winter and summer precipitations have also shown a statistically significant upward trend of precipitation over BH (Popov et al. 2017). According to the Clausius-Clapeyron relationship, there is an indication that the intensity of daily extreme precipitation escalates at a rate of approximately 7% for each 1 °C rise in air temperature (Mudelsee et al. 2004; Blöschl et al. 2019). This finding is further supported by empirical observations (Westra, Alexander and Zwiers 2013) and modeling experiments (O'Gorman 2015), both of which have rigorously examined the scaling hypothesis after the Clausius-Clapeyron equation across various spatial and temporal scales. Moreover, it's worth noting that cyclonic activity in Europe has seen an increase since the onset of the 21st century, leading to a heightened frequency of heavy rainfall events (Mikhailova, Mikhailov and Morozov 2012). For example, the highest one-day precipitation amount (Rx1day) trend has shown a statistically significant increase over most of the BH area during the winter period (October-March) (Leščešen et al. 2023). So, as the extreme precipitation in the region is increasing, it is expected that flooding in smaller basins could increase (Blöschl et al. 2019).

Consequently, alterations in these circulation patterns are anticipated to exert an influence on precipitation levels, thereby yielding substantial consequences for river discharge and water levels. There is a pressing need for further investigation to elucidate the intricate connections between circulation patterns, the frequency and scale of extreme hydrological events, and the geographical characteristics of the region. The findings of this study underscore the critical significance of meticulous scrutiny of shifts in flood behaviour when undertaking assessments for flood design and risk management (Petrow and Merz 2009). This analysis should be conducted again in the near future, to check if the seasonal change observed is a statistically significant change as the observation period is extended.

3.3 Annual flood frequency and occurrence rate

Further, we have analysed the occurrence and frequency of the M1 and M2 events at the annual time scale (Figure 6). Trend analysis of annual maximum discharges at Una River shows no statistically significant trends both for M1 ($u = 0.745$; $p = 0.228$) and M2 ($u = -0.802$; $p = 0.211$) events. Similarly, at the Sana River, no statistically significant trends were observed in both magnitudes, M1 events ($u = 0.612$; $p = 0.270$) and M2 events ($u = -0.675$; $p = 0.249$). This decrease in severe events is reported all over southeast Europe. A negative trend has been observed for major rivers in Serbia (Kovačević-Majkić and Urošev 2014; Leščešen et al. 2022a). Similarly, negative trends have been identified across the entirety of North Macedonia (Radevski et al. 2018). In Montenegro, the Morača River also exhibited a downward trend during the period from 1951 to 2010 (Burić, Ducić and Doderović 2016). In Slovenia, a reduction has been observed at the majority of hydrological gauges (Oblak, Kobold and Šraj 2021; Bezak, Brilly and Šraj 2016). Conversely, a negative trend has been reported in Croatia during the summer (Čanjevac and Orešić 2015). The trends in river flow observed in BH closely resemble the patterns identified in the southeastern part of Europe. Specifically, notable downward trend has been reported for rivers such as Bosna, Vrbas, Vrbanja and Sana (Gnjato et al. 2023).

The observed variations in these values provide valuable insights into the frequency of these events and the potential implications of long-term environmental changes. For the Una River, we observed an increase in the M1 events from 58 days ($\lambda_{(t)} \approx 6.320\ a^{-1}$) at the beginning of the investigated period to 55 days ($\lambda_{(t)} \approx 6.653\ a^{-1}$) at the end. This shift suggests a rise in the annual occurrence of M1 events over time, which may be indicative of changing hydrological conditions in the Una River basin. In contrast, the M2 events in the Una River exhibited a decreasing trend, decreasing from 64 days ($\lambda_{(t)} \approx 5.663\ a^{-1}$) at the outset to 69 days ($\lambda_{(t)} \approx 5.332\ a^{-1}$) by 2020. This reduction in the annual rate of occurrence for M2 events could signify a decrease in the frequency of more extreme events, raising questions about potential mitigating factors or environmental changes within the river's catchment area.

In the case of the Sana River, the findings revealed a rise in the M1 events, increasing from 56 days ($\lambda_{(t)} \approx 6.505\ a^{-1}$) in 1960 to 54 days ($\lambda_{(t)} \approx 6.779\ a^{-1}$) by 2020. This shift suggests a notable increase in the annual occurrence of M1 events, which could be related to a range of factors, including land use modifications, climate trends, or other environmental alterations. Interestingly, the M2 events in the Sana River decreased from 67 days ($\lambda_{(t)} \approx 5.478\ a^{-1}$) at the beginning of the period to 70 days ($\lambda_{(t)} \approx 5.185\ a^{-1}$) by 2020, indicating a significant decline in the frequency of more extreme events. This decline raises concerns about the potential impact of these extreme events on the river ecosystem, infrastructure, and local communities.

It is important to highlight several advantages and disadvantages of the presented study. On the positive side, the study contributes valuable insights into the patterns and trends of severe (M1) and extreme

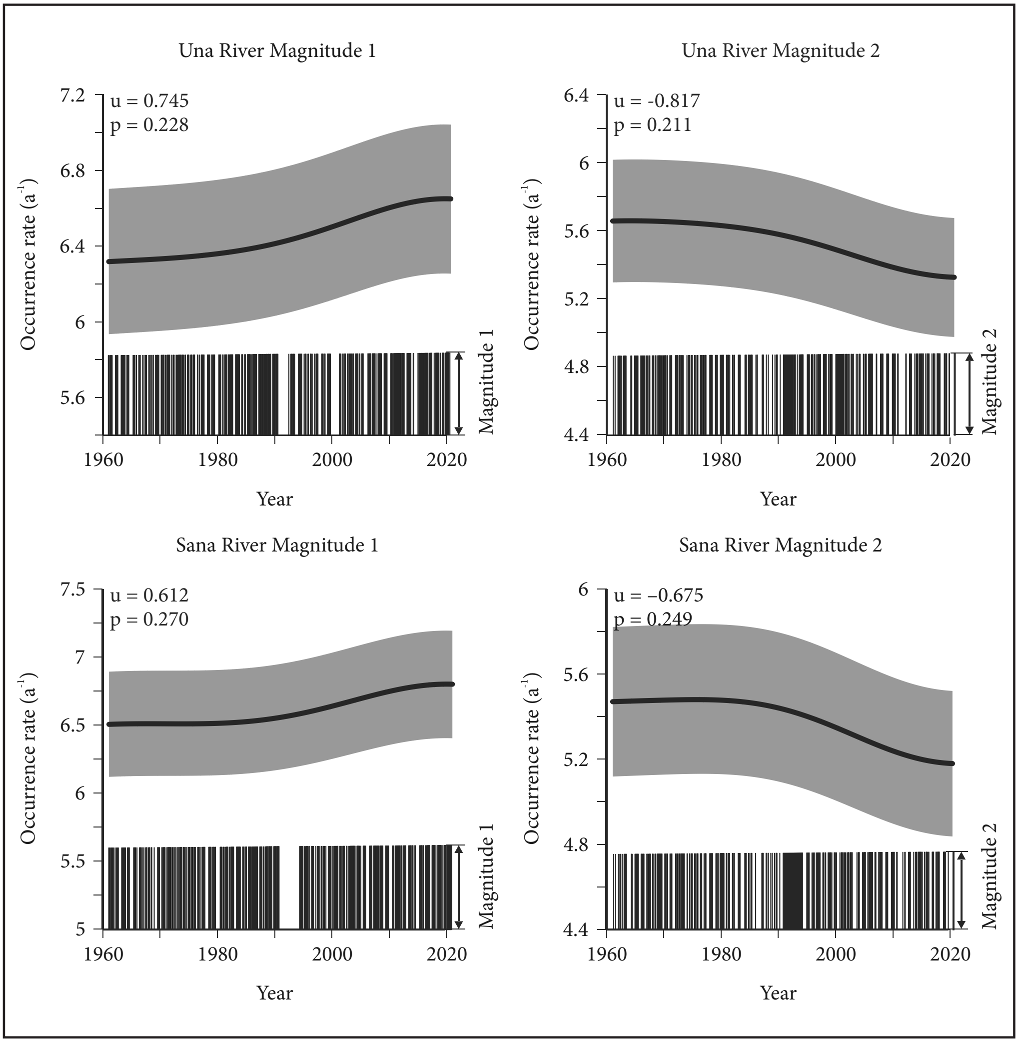


Figure 6: Occurrence rates of Annual Maximum Discharge (solid lines) of Una and Sana rivers for two magnitude classes with bootstrap 90% confidence band (shaded). Kernel estimation using a bandwidth of 20 years is applied to the maximum discharge data dates with the Cox-Lewis test results for trend estimation (upper left-right corner of each graph).

(M2) flood events, shedding light on their seasonal variations over a 60-year period. The use of sophisticated statistical methods, such as kernel estimation and trend analyses by means of the Cox-Lewis test, enhances the understanding of hydrological changes and allows for the identification of potential shifts in flood behaviour. Additionally, the inclusion of confidence bands in the results provides a measure of uncertainty, contributing to the robustness of the findings. However, some limitations exist. The absence of statistically significant trends in certain aspects of the data, particularly in M1 and M2 events during summer and winter, underscores the challenges in attributing observed changes solely to climate warming. Moreover, relying on a 30-year reference period for threshold determination may not fully capture the complexities of evolving climate patterns. Despite these limitations, the research serves as a foundation for future investigations and underscores the importance of continuous monitoring and analysis in the context of climate change impacts on flood events.

4 Conclusion

In this comprehensive analysis of severe (M1) and extreme (M2) events in the Una River basins, spanning from 1961 to 2020, we have unveiled critical insights into the dynamics of these extreme hydrological events in BH. Floods, regarded as one of the most destructive natural hazards worldwide, have exhibited intriguing seasonal variations and trends in this region. Our study highlighted the prevalence of winter maximum discharges, primarily occurring from October to March, while peak discharges are commonly observed in April due to snowmelt in the upper regions of the basin and rainfall in the lower areas. Conversely, summer maximum discharges peaked in May, diminishing as the summer season progressed. To assess trends in the occurrence of maximum discharges, we employed the Cox-Lewis test, revealing declining trends in the occurrence rate of Magnitude 2 events for both summer and winter seasons, though these were not statistically significant. Further, our findings suggest that future changes in summer and winter maximum discharges may indicate an increase in severe events, although these changes did not attain statistical significance.

Comparisons with neighbouring countries in Southeast Europe reveal a region-wide pattern of declining river discharges, similar to what we have observed in BH. However, extreme events exhibited a statistically significant increase in the Sana River, signalling a potential for more frequent extreme events in time to come.

Our study underlines the critical importance of ongoing monitoring and research into the intricate connections between climate change, circulation patterns, and flood behaviour. This comprehension is crucial for informed flood design and risk management strategies in a changing hydroclimatic landscape. By identifying non-stationarity in hydrology and emphasizing seasonal variations, our findings contribute to the broader understanding of the evolving nature of these hazards and the necessity for adaptive measures in BH and beyond. As flood events continue to pose significant threats to both human communities and the environment, proactive flood risk management strategies are essential on a global scale.

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5 References

Alifu, H., Hirabayashi, Y., Imada, Y., Shiogama, H. 2022: Enhancement of river flooding due to global warming. Scientific Reports 12. DOI: https://doi.org/10.1038/s41598-022-25182-6

Arnell, N. W., Gosling, S. N. 2016: The impacts of climate change on river flood risk at the global scale. Climatic Change 134-3. DOI: https://doi.org/10.1007/s10584-014-1084-5

Asadieh, B., Krakauer, N. Y. 2017: Global change in streamflow extremes under climate change over the 21st century. Hydrology and Earth System Sciences 21-11. DOI: https://doi.org/10.5194/hess-21-5863-2017

Bertola, M., Viglione, A., Lun D., Hall. J., Blöschl, G. 2020: Flood trends in Europe: are changes in small and big floods different? Hydrology and Earth System Sciences 24-4. DOI: https://doi.org/10.5194/hess-24-1805-2020

Bezak, N., Brilly, M., Šraj, M. 2016: Flood frequency analyses, statistical trends and seasonality analyses of discharge data: a case study of the Litija station on the Sava River. Journal of Flood Risk Management 9-2. DOI: https://doi.org/10.1111/jfr3.12118

Blöschl, G. 2022: Three hypotheses on changing river flood hazards. Hydrology and Earth System Sciences 26-19. DOI: https://doi.org/10.5194/hess-26-5015-2022

Blöschl, G., Hall, J., Viglione, A., Perdigão, R. A. P., Parajka, J., Merz, B., Lun, D. et al. 2019: Changing climate both increases and decreases European river floods. Nature 573. DOI: https://doi.org/10.1038/s41586-019-1495-6

Brönnimann, S., Stucki, P., Franke, J., Valler, V., Brugnara, Y., Hand, R., Slivinski, L. C. et al. 2022: Influence of warming and atmospheric circulation changes on multidecadal European flood variability. Climate of the Past 18-4. DOI: https://doi.org/10.5194/cp-18-919-2022

Burić, D., Ducić, V., Doderović, M. 2016: Poplave u Crnoj Gori krajem 2010. godine sa osvrtom na kolebanje proticaja Morače. Glasnik Odjeljenja prirodnih nauka 21.

Centre for Research on the Epidemiology of Disasters and United Nations Office for Disaster Risk Reduction 2020: The human cost of disasters: an overview of the last 20 years (2000-2019). Geneva, Brussels.

Cerneagă, C., Maftei, C. 2021: Flood frequency analysis of Casimcea river. IOP Conference Series: Materials Science and Engineering 1138. DOI: https://doi.org/10.1088/1757-899X/1138/1/012014

Chagas, V. B. P., Chaffe, P. L. B., Blöschl, G. 2022: Climate and land management accelerate the Brazilian water cycle. Nature Communications 13. DOI: https://doi.org/10.1038/s41467-022-32580-x

Chegwidden, O., Rupp, D. E., Nijssen, B. 2020: Climate change alters flood magnitudes and mechanisms in climatically-diverse headwaters across the northwestern United States. Environmental Research Letters 15. DOI: https://doi.org/10.1088/1748-9326/ab986f

Čanjevac, I., Orešić, D. 2015: Contemporary changes of mean annual and seasonal river discharges in Croatia. Hrvatski geografski glasnik 77-1. DOI: https://doi.org/10.21861/HGG.2015.77.01.01

Fischer, S., Schumann, A. H. 2021: Multivariate flood frequency analysis in large river basins considering tributary impacts and flood types. Water Resources Research 57-8. DOI: https://doi.org/10.1029/2020WR029029

Gnjato, S. 2022: Uticaj klimatskih promjena na proticaj rijeka u Bosni i Hercegovini. Ph.D. thesis, Univerzitet u Beogradu. Beograd.

Gnjato, S., Popov, T., Adžić, D., Ivanišević, M., Trbić, G., Bajić, D. 2021: Influence of climate change on river discharges over the Sava river watershed in Bosnia and Herzegovina. Idöjárás 125-3. DOI: https://doi.org/10.28974/idojaras.2021.3.5

Gnjato, S., Popov, T., Ivanišević, M., Trbić, G. 2023: Long-term streamflow trends in Bosnia and Herzegovina (BH). Environmental Earth Sciences 82-14. DOI: https://doi.org/10.1007/s12665-023-11040-9

Hannaford, J., Mastrantonas, N., Vesuviano, G., Turner, S. 2021: An updated national-scale assessment of trends in UK peak river flow data: how robust are observed increases in flooding? Hydrology Research 52-3. DOI: https://doi.org/10.2166/nh.2021.156

Higashino, M. Stefan, H.G. 2019: Variability and change of precipitation and flood discharge in a Japanese river basin. Journal of Hydrology: Regional Studies 21. DOI: https://doi.org/10.1016/j.ejrh.2018.12.003

Hirabayashi, Y., Alifu, H., Yamazaki, D., Imada, Y., Shiogama, H., Kimura, Y. 2021: Anthropogenic climate change has changed frequency of past flood during 2010-2013. Progress in Earth and Planetary Science 8. DOI: https://doi.org/10.1186/s40645-021-00431-w

Hodgkins, G. A., Whitfield, P. H., Burn, D. H., Hannaford, J., Renard, B., Stahl, K., Fleig, A. K. et al. 2017: Climate-driven variability in the occurrence of major floods across North America and Europe. Journal of Hydrology 552. DOI: https://doi.org/10.1016/j.jhydrol.2017.07.027

Ilešič, S. 1948: Rečni režimi v Jugolsaviji. Geografski vestnik 19.

Ionita, M., Nagavciuc, V. 2021: Extreme floods in the eastern part of Europe: Large-scale drivers and associated impacts. Water 13-8. DOI: https://doi.org/10.3390/w13081122

Intergovernmental Panel on Climate Change (IPCC) 2023: Climate change 2021 – The physical science basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge. DOI: https://doi.org/10.1017/9781009157896

Ivanišević, M., Savić, S., Pavić, D., Gnjato, S., Popov, T. 2022: Spatio-temporal patterns of flooded areas in the lower part of the Sana river basin (Bosnia and Herzegovina). Bulletin of the Serbian Geographical Society 102-2. DOI: https://doi.org/10.2298/GSGD2202067I

Kavcic, K., Brilly, M., Sraj, M. 2014: Regional flood frequency analysis in Slovenia. Geophysical Research Abstracts 16, EGU General Assembly. Vienna.

Kemter, M., Merz, B., Marwan, N., Vorogushyn, S., Blöschl, G. 2020: Joint trends in flood magnitudes and spatial extents across Europe. Geophysical Research Letters 47-7. DOI: https://doi.org/10.1029/2020GL087464

Kovačević-Majkić, J., Urošev, M. 2014: Trends of mean annual and seasonal discharges of rivers in Serbia. Journal of the Geographical Institute »Jovan Cvijic«, SASA 64-2. DOI: https://doi.org/10.2298/IJGI1402143K

Kundzewicz, Z. W., Graczyk, D., Maurer, T., Pińskwar, I., Radziejewski, M., Svensson, C., Szwed, M. 2005: Trend detection in river flow series: 1. Annual maximum flow. Hydrological Sciences Journal 50-5. DOI: https://doi.org/10.1623/hysj.2005.50.5.797

Kundzewicz, Z. W., Pińskwar, I., Brakenridge, G. R. 2018: Changes in river flood hazard in Europe: A review. Hydrology Research 49-2. DOI: https://doi.org/10.2166/nh.2017.016

Kuntla, S. K., Saharia, M., Kirstetter, P. 2022: Global-scale characterization of streamflow extremes. Journal of Hydrology 615. DOI: https://doi.org/10.1016/j.jhydrol.2022.128668

Leščešen, I., Basarin, B., Podraščanin, Z., Mesaroš, M. 2023: Changes in annual and seasonal extreme precipitation over southeastern Europe. Environmental Sciences Proceedings 26-1. DOI: https://doi.org/10.3390/environsciproc2023026048

Leščešen, I., Dolinaj, D. 2019: Regional flood frequency analysis of the Pannonian Basin. Water 11-2. DOI: https://doi.org/10.3390/w11020193

Leščešen, I., Šraj, M., Basarin, B., Pavić, D., Mesaroš, M., Mudelsee, M. 2022b: Regional flood frequency analysis of the Sava River in south-eastern Europe. Sustainability 14. DOI: https://doi.org/10.3390/su14159282

Leščešen, I., Šraj, M., Pantelić, M., Dolinaj, D. 2022a: Assessing the impact of climate on annual and seasonal discharges at the Sremska Mitrovica station on the Sava River, Serbia. Water Supply 22-1. DOI: https://doi.org/10.2166/ws.2021.277

Łopucki, R., Kiersztyn, A., Pitucha, G., Kitowski, I. 2022: Handling missing data in ecological studies: Ignoring gaps in the dataset can distort the inference. Ecological Modelling 468. DOI: https://doi.org/10.1016/j.ecolmodel.2022.109964

Majone, B., Avesani, D., Zulian, P., Fiori, A., Bellin, A. 2022: Analysis of high streamflow extremes in climate change studies: how do we calibrate hydrological models? Hydrology and Earth System Sciences 26-14. DOI: https://doi.org/10.5194/hess-26-3863-2022

Mikhailova, M. V., Mikhailov, V. N., Morozov, V. N. 2012: Extreme hydrological events in the Danube River basin over the last decades. Water Resources 39-2. DOI: https://doi.org/10.1134/S0097807812010095

Mudelsee, M. 2020: Statistical analysis of climate extremes. Cambridge. DOI: https://doi.org/10.1017/9781139519441

Mudelsee, M. 2014: Climate time series analysis: Classical statistical and bootstrap methods. Atmospheric and Oceanographic Sciences Library. Cham. DOI: https://doi.org/10.1007/978-3-319-04450-7

Mudelsee, M., Deutsch, M., Börngen, M., Tetzlaff, G., 2006: Trends in flood risk of the river Werra (Germany) over the past 500 years. Hydrological Sciences Journal 51. DOI: https://doi.org/10.1623/hysj.51.5.818

Mudelsee, M., Börngen, M., Tetzlaff, G., Grünewald, U. 2004: Extreme floods in central Europe over the past 500 years: Role of cyclone pat hway »Zugstrasse Vb«. Journal of Geophysical Research 109-D23. DOI: https://doi.org/10.1029/2004JD005034

Mudelsee, M., Börngen, M., Tetzlaff, G., Grünewald, U. 2003: No upward trends in the occurrence of extreme floods in central Europe. Nature 425. DOI: https://doi.org/10.1038/nature01928

Myhre, G., Alterskjær, K., Stjern, C. W., Hodnebrog, Ø., Marelle, L., Samset, B. H., Sillmann, J. et al. 2019. Frequency of extreme precipitation increases extensively with event rareness under global warming. Scientific Reports 9. DOI: https://doi.org/10.1038/s41598-019-52277-4

O'Gorman, P. A. 2015: Precipitation extremes under climate change. Current Climate Change Reports 1-2. DOI: https://doi.org/10.1007/s40641-015-0009-3

Oblak, J., Kobold, M., Šraj, M. 2021: The influence of climate change on discharge fluctuations in Slovenian rivers. Acta geographica Slovenica 61-2. DOI: https://doi.org/10.3986/AGS.9942

Paprotny, D., Sebastian, A., Morales-Nápoles, O., Jonkman, S. N. 2018: Trends in flood losses in Europe over the past 150 years. Nature Communications 9. DOI: https://doi.org/10.1038/s41467-018-04253-1
Pešić, A. M., Jakovljević, D., Rajčević, V., Gnjato, S. 2023: Extreme discharges trends in the rivers of the Balkan region – Examples from two adjacent countries (Bosnia & Herzegovina and Serbia). International Conference on Hydro-Climate Extremes and Society. Novi Sad
Petrow, T., Merz, B. 2009: Trends in flood magnitude, frequency and seasonality in Germany in the period 1951-2002. Journal of Hydrology 371-1-4. DOI: https://doi.org/10.1016/j.jhydrol.2009.03.024
Popov, T., Gnjato, S., Trbić, G., Ivanišević, M. 2017: Trends in extreme daily precipitation indices in Bosnia and Herzegovina. Collection of Papers - Faculty of Geography at the University of Belgrade 65-1. DOI: https://doi.org/10.5937/zrgfub1765005P
Radevski, I., Gorin, S. 2017: Floodplain analysis for different return periods of river Vardar in Tikvesh Valley (Republic of Macedonia). Carpathian Journal of Earth and Environmental Sciences 12-1.
Radevski, I., Gorin, S., Taleska, M., Dimitrovska, O. 2018: Natural regime of streamflow trends in Macedonia. Geografie 123-1. DOI: https://doi.org/10.37040/geografie2018123010001
Sharma, A., Wasko, C., Lettenmaier, D. P. 2018: If precipitation extremes are increasing, why aren't floods? Water Resources Research 54-11. DOI: https://doi.org/10.1029/2018WR023749
Shiklomanov, A. I., Lammers, R. B., Rawlins, M. A., Smith, L. C., Pavelsky, T. M. 2007: Temporal and spatial variations in maximum river discharge from a new Russian data set. Journal of Geophysical Research: Biogeosciences 112-G4. DOI: https://doi.org/10.1029/2006JG000352
Speight, L., Krupska, K. 2021: Understanding the impact of climate change on inland flood risk in the UK. Weather 76-10. DOI: https://doi.org/10.1002/wea.4079
Šraj, M., Bezak, N. 2020: Comparison of time trend- and precipitation-informed models for assessing design discharges in variable climate. Journal of Hydrology 589. DOI: https://doi.org/10.1016/j.jhydrol.2020.125374
Tabari, H. 2020: Climate change impact on flood and extreme precipitation increases with water availability. Scientific Reports 10. DOI: https://doi.org/10.1038/s41598-020-70816-2
Tadić, L., Bonacci, O., Dadić, T. 2016: Analysis of the Drava and Danube rivers floods in Osijek (Croatia) and possibility of their coincidence. Environmental Earth Sciences 75-18. DOI: https://doi.org/10.1007/s12665-016-6052-0
Tadić, L., Dadić, T., Barač, B. 2013: Flood frequency modelling of the Kopački rit Nature Park. Tehnički vjesnik 20-1.
Tarasova, L., Lun, D., Merz, R., Blöschl, G., Basso, S., Bertola, M., Miniussi, A. et al. 2023: Shifts in flood generation processes exacerbate regional flood anomalies in Europe. Communications Earth & Environment 4. DOI: https://doi.org/10.1038/s43247-023-00714-8
Venegas-Cordero, N., Kundzewicz, Z. W., Jamro, S., Piniewski, M. 2022: Detection of trends in observed river floods in Poland. Journal of Hydrology: Regional Studies 41. DOI: https://doi.org/10.1016/j.ejrh.2022.101098
Vicente-Serrano, S. M., Zabalza-Martínez, J., Borràs, G., López-Moreno, J. I., Pla, E., Pascual, D., Savé, R. et al. 2017: Extreme hydrological events and the influence of reservoirs in a highly regulated river basin of northeastern Spain. Journal of Hydrology: Regional Studies 12. DOI: https://doi.org/10.1016/j.ejrh.2017.01.004
Vidmar, A., Globevnik, L., Koprivšek, M., Sečnik, M., Zabret, K., Đurović, B., Anzeljc, D. et al. 2016: The Bosna River floods in May 2014. Natural Hazards and Earth System Sciences 16-10. DOI: https://doi.org/10.5194/nhess-16-2235-2016
Wang, X., Liu, L. 2023: The Impacts of climate change on the hydrological cycle and water resource management. Water 15. DOI: https://doi.org/10.3390/w15132342
Westra, S., Alexander, L. V., Zwiers, F. W. 2013: Global increasing trends in annual maximum daily precipitation. Journal of Climate 26-11. DOI: https://doi.org/10.1175/JCLI-D-12-00502.1
Wilson, D., Hisdal, H. 2013: Trends in floods in small Norwegian catchments – instantaneous vs. daily peaks. Geophysical Research Abstracts 15, EGU General Assembly. Vienna..
Zabret, K., Brilly, M. 2014: Hydrological regionalisation of flood frequency analyses in Slovenia. Acta hydrotechnica, 27-47.

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Unsolicited or invited original research articles and review articles are accepted. Articles and materials or sections of them should not have been previously published or under consideration for publication elsewhere. The articles should cover subjects of current interest within the journal's scope.

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1 Types of articles

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- Fridl, J., Urbanc, M., Pipan, P. 2009: The importance of teachers' perception of space in education. Acta geographica Slovenica 49-2. DOI: https://doi.org/10.3986/AGS49205
- Gams, I. 1994a: Types of contact karst. Geografia Fisica e Dinamica Quaternaria 17.
- Gams, I. 1994b: Changes of the Triglav glacier in the 1955-94 period in the light of climatic indicators. Geografski zbornik 34.
- Van Hall, R. L., Cammeraat, L. H., Keesstra, S. D., Zorn, M. 2016: Impact of secondary vegetation succession on soil quality in a humid Mediterranean landscape. Catena, In press. DOI: https://doi.org/10.1016/j.catena.2016.05.021 (25. 11. 2016).
- De Kerk, G. V., Manuel, A. R. 2008: a comprehensive index for a sustainable society: The SSI – The Sustainable Society Index. Ecological Economics 66-2,3. DOI: https://doi.org/10.1016/j.ecolecon.2008.01.029
- Perko, D. 1998: The regionalization of Slovenia. Geografski zbornik 38.
- Urry, J. 2004: The 'system' of automobility. Theory, Culture and Society 21-4,5. DOI: https://doi.org/10.1177%2F0263276404046059
- Yang, D. H., Goerge, R., Mullner, R. 2006: Comparing GIS-based methods of measuring spatial accessibility to health services. Journal of Medical Systems 30-1. DOI: https://doi.org/10.1007/s10916-006-7400-5

5.2 Citing books

- Cohen, J. 1988: Statistical power analysis for the behavioral sciences. New York.
- Fridl, J., Kladnik, D., Perko, D., Orožen Adamič, M. (eds.) 1998: Geografski atlas Slovenije. Ljubljana.
- Hall, T., Barrett, H. 2018: Urban geography. London. DOI: https://doi.org/10.4324/9781315652597
- Hall, C. M., Page, S. J. 2014: The geography of tourism and recreation: Environment, place and space. New York. DOI: https://doi.org/10.4324/9780203796092
- Luc, M., Somorowska, U., Szmańda, J. B. (eds.) 2015: Landscape analysis and planning. Springer Geography. Heidelberg. DOI: https://doi.org/10.1007/978-3-319-13527-4
- Nared, J., Razpotnik Visković, N. (eds.) 2014: Managing cultural heritage sites in southeastern Europe. Ljubljana. DOI: https://doi.org/10.3986/9789610503675

5.3 Citing chapters of books or proceedings

- Gams, I. 1987: A contribution to the knowledge of the pattern of walls in the Mediterranean karst: A case study on the N. island Hvar, Yugoslavia. Karst and Man, Proceedings of the International Symposium on Human Influence in Karst. Ljubljana.
- Hrvatin, M., Perko, D., Komac, B., Zorn, M. 2006: Slovenia. Soil Erosion in Europe. Chichester. DOI: https://doi.org/10.1002/0470859202.ch25
- Komac, B., Zorn, M. 2010: Statistično modeliranje plazovitosti v državnem merilu. Od razumevanja do upravljanja. Naravne nesreče 1. Ljubljana.
- Zorn, M., Komac, B. 2013: Land degradation. Encyclopedia of Natural Hazards. Dordrecht. DOI: https://doi.org/10.1007/978-1-4020-4399-4_207

5.4 Citing expert reports, theses, dissertations and institutional reports

- Breg Valjavec, M. 2012: Geoinformatic methods for the detection of former waste disposal sites in karstic and nonkarstic regions (case study of dolines and gravel pits). Ph.D. thesis, University of Nova Gorica. Nova Gorica.

- Holmes, R. L., Adams, R. K., Fritts, H. C. 1986: Tree-ring chronologies of North America: California, Eastern Oregon and Northern Great Basin with procedures used in the chronology development work including user manual for computer program COFECHA and ARSTAN. Chronology Series 6. University of Arizona, Laboratory of tree-ring research. Tucson.
- Hrvatin, M. 2016: Morfometrične značilnosti površja na različnih kamninah v Sloveniji. Ph.D. thesis, Univerza na Primorskem. Koper.
- Šifrer, M. 1997: Površje v Sloveniji. Elaborat, Geografski inštitut Antona Melika ZRC SAZU. Ljubljana.
- World commission on environment and development 1987: Our common future: Brundtland report. Oxford.

5.5 Citing online materials with authors

- Tiran, J. 2021: Slovenija se je v celoti odela v modro. Metina lista. Internet: https://metinalista.si/slovenija-se-je-v-celoti-odela-v-modro/ (3. 11. 2021).
- Davies, G. 2017: The place of data papers: Producing data for geography and the geography of data production. Geo: Geography and Environment. Internet: https://blog.geographyandenvironment.com/2017/09/27/the-place-of-data-papers-producing-data-for-geography-and-the-geography-of-data-production/ (8. 11. 2021).

5.6 Citing websites without authors (e.g. websites of projects and institutions)

Use in-text citations only. It is not necessary to include a citation in the reference list. The in-text citation should include the URL.

5.7 Citing publicly archived data (e.g. statistical data)

Use in-text citations only. It is not necessary to include publicly archived datasets in the reference list. The in-text citation should include the name of the dataset, the institution providing the data and the time frame of the data used.

When the data you cited were published as a report, add it to the reference list and use the following format:

- Popis prebivalstva, gospodinjstev, stanovanj in kmečkih gospodarstev v Republiki Sloveniji, 1991 – končni podatki. Zavod Republike Slovenije za statistiko. Ljubljana, 1993.
- Agriculture, forestry and fishery statistics. 2020 edition. Publications Office of the European Union. Luxembourg, 2020.

5.8 Citing geospatial data and cartographic materials

Geospatial data used in maps should be cited in the colophon on the map (see the Table and Figures section of the Authors' Guidelines). It is not necessary to include geospatial data in the reference list.

When cartographic materials are published as an independent monograph, add it to the reference list and use the following format:

- Buser, S. 1986: Osnovna geološka karta SFRJ 1 : 100.000, list Tolmin in Videm (Udine). Savezni geološki zavod. Beograd.
- Državna topografska karta Republike Slovenije 1 : 25.000, list Brežice. Geodetska uprava Republike Slovenije. Ljubljana, 1998.
- Franciscejski kataster za Kranjsko, k. o. Sv. Agata, list A02. Arhiv Republike Slovenije. Ljubljana, 1823–1869.
- The vegetation map of forest communities of Slovenia 1:400,000. Biološki inštitut Jovana Hadžija ZRC SAZU. Ljubljana, 2002.

5.9 Citing legal sources

Use in-text citation. It is not necessary to include a citation in the reference list. The in-text citation should include the title of legal document and the year.

5.10 In-text citation examples

All references in the reference list are cited in the text. In-text citations should include the last name of the author(s) or the name of the institution, and the year of publication. Separate individual citations by semicolons, arrange citations by year of publication, and separate the page information from author(s)' names and years by a comma; for example: (Melik 1955), (Melik, Ilešič and Vrišer 1963; Gams 1982a; Gams 1982b; World Commission on Environment and Development 1987). For references with more than three authors, cite only the first, followed by et al.: (Melik et al. 1956). Give page numbers only for direct quotations. Narrative citations: Perko (2016, 25) states: »Hotspots are …« or parenthetical citation (Kokole 1974, 7–8).

When citing online materials without authors, such as project or institutional websites, the URL should be included, for example: »The aim of the LABELSCAPE project is to develop mechanisms for integrating sustainability labels into tourism policy (https://labelscape.interreg-med.eu).«

When citing publicly archived data, such as statistical data, inform the reader in the text with the name of dataset, the time frame, and the institution that provides the data: »The 2000–2020 population data used in the analysis were provided by the Eurostat«. If the statistical data were published as a report, cite the document, e.g. (Popis prebivalstva … 1993).

When citing legal sources such as legislative acts, white papers, etc., you should provide (short formal) title and the year, for example: »… The European Commission's White paper on transport (2011) sets out ten strategic goals for a competitive and resource-efficient transport system: …«

5.11 Reference list

Arrange references alphabetically and then chronologically if necessary. Identify more than one reference by the same author(s) in the same year with the letters *a*, *b*, *c*, etc., after the year of publication: (1999a; 1999b). Use this format for indirect citations: (Gunn 2002, cited in Matei et al. 2014).

Include the Digital Object Identifier (DOI) in the reference if available. Format the DOI as follows: https://doi.org/… (for example: https://doi.org/10.3986/AGS.1812).

6 Tables and figures

Number all tables in the article uniformly with their own titles. The number and the text are separated by a colon, and the caption ends with a period. Example:

Table 1: Number of inhabitants of Ljubljana.

Table 2: Changes in average air temperature in Ljubljana (Velkavrh 2009).

Tables and figures must be indicated in the main text in parentheses, for example »(Table 1)«, or as a part of the sentence, for example »… as can be seen in the Table 1«.

Tables should contain no formatting and should not be too large; it is recommended that tables not exceed one page.

Upload figures to the OJS as separate files in digital form. If the files prepared cannot be uploaded using these programs, consult the editorial board (ags@zrc-sazu.si) in advance.

Number all figures (maps, graphs, photographs) in the article uniformly with their own titles. Example:

Figure 1: Location of measurement points along the glacier.

All graphic materials must be adapted to the journal's format. Illustrations should be exactly 134 mm wide (one page) or 64 mm wide (half page, one column), and the height limit is 200 mm.

To make anonymous peer review possible, include the name of the author(s) with the title of the illustration in the file metadata, but not in the article text.

Maps should be made in digital vector form with Corel Draw, Adobe Illustrator, or a similar program, especially if they contain text. They can exceptionally be produced in digital raster form with at least 300 dpi resolution, preferably in TIFF or JPG format. For maps made with *CorelDraw* or *Adobe Illustrator*, two separate files should be prepared; the original file (.cdr or .ai format) and an image file (.jpg format).

For maps made with ArcGIS with raster layers used next to vector layers (e.g., .tif of relief, airborne or satellite image), three files should be submitted: the first with a vector image without transparency together with a legend and colophon (export in .ai format), the second with a raster background (export in .tif format), and the third with all of the content (vector and raster elements) together showing the final version of the map (export in .jpg format).

Do not print titles on maps; they should appear in a caption.

Save colors in CMYK, not in RGB or other formats.

Use Times New Roman for the legend (size 8) and colophon (size 6). List the author(s), scale, source, and copyright in the colophon. Write the colophon in English (and Slovenian, if applicable). Example:

Scale: 1:1,000,000
Content by: Drago Perko
Map by: Jerneja Fridl
Source: Statistical Office of the Republic of Slovenia 2002
© 2005, ZRC SAZU Anton Melik Geographical Institute

Graphs should be made in digital form using *Excel* on separate sheets and accompanied by data.
Photos must be in raster format with a resolution of 600 dpi, preferably in .tif or .jpg formats.

Figures containing a screenshot should be prepared at the highest possible screen resolution (Control Panel\All Control Panel Items\Display\Screen Resolution). The figure is made using Print Screen, and the captured screen is pasted to the selected graphic program (e.g., *Paint*) and saved as .tif. The size of the image or its resolution must not be changed.

Examples of appropriate graphic data formats: see the templates of maps in cdr and mxd files (available at https://ags.zrc.sazu.si) for a full-page map in landscape layout and an example of the correct file structure (available at https://ags.zrc.sazu.si) for submitting a map created with *ESRI ArcGIS*.

SUBMISSION PREPARATION CHECKLIST

As part of the submission process, authors are required to check off their submission's compliance with all of the following items, and submissions may be returned to authors that do not adhere to these guidelines.

- I, the corresponding author, declare that this manuscript is original, and is therefore based on original research, done exclusively by the authors. All information and data used in the manuscript were prepared by the authors or the authors have properly acknowledged other sources of ideas, materials, methods, and results.
- Authors confirm that they are the authors of the submitting article, which is under consideration to be published (print and online) in the journal *Acta geographica Slovenica* by Založba ZRC, ZRC SAZU.
- All authors have seen and approved the article being submitted.
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- The journal policies and guidelines have been reviewed and followed.

- The metadata (title, abstract, key words, authors, affiliation, ORCiD, etc.) are provided in English (Slovenian authors must provide the metadata also in Slovenian language).
- The list of authors is complete. Failure to do so may result in co-authors not being listed on the article at publication.
- The submission is in Microsoft Word format and the document template was used (single-spaced text, 12-point font, no formatting except italics and bold).
- The article has been checked for spelling and grammar.
- Figures are not embedded in the Word file and are provided as a graphic file: editable vector format (e.g., cdr, ai) for maps and illustrations; tif for photographs; xlsx for graphs. The Word file includes only figure captions.
- Tables are placed in the Word file with text at the appropriate place.
- The reference list was prepared following the guidelines.
- All references in the reference list are cited in the text.
- Where available, URLs and DOI numbers for references are provided.
- Graphic files are in one .zip file.
- Authors agree that any costs of English proofreading are borne by the author(s). No additional costs are associated with the submission.
- The instructions for ensuring a double-blind review have been followed.

ACTA GEOGRAPHICA SLOVENICA EDITORIAL REVIEW FORM

This is a review form for editorial review (version 14) of an article submitted to the AGS journal.

This is an original scientific article.
(The article is original and the first presentation of research results with the focus on methods, theoretical aspects or a case study.)

- Yes
- No

The article follows the standard IMRAD/ILRAD scheme.

- Yes
- No

The article's content is suitable for reviewing in the AGS journal.
(The article is from the field of geography or related fields of interest, the presented topic is interesting for the readers of *Acta geographica Slovenica* and well presented. In case of negative answer add comments below.)

- Yes
- No

Editorial notes regarding the article's content.

The reference list is suitable (the author cites previously published articles with similar topics from other relevant geographic scientific journals).

- Yes, the author cited previously published articles on a similar topic.
- No, the author did not cite previously published articles on a similar topic.

Notes to editor-in-chief regarding previously published scientific work.

Is the language of the article appropriate and understandable?

RECOMMENDATION OF THE EDITOR
- The article is accepted and can be sent to the review process.
- Reconsider after a major revision (see notes).
- The article is rejected.

ACTA GEOGRAPHICA SLOVENICA REVIEW FORM

This is *Acta geographica Slovenica* review form (version 7).

1 RELEVANCE

Are the findings original and the article is therefore a significant one?
- yes
- no
- partly

Is the article suitable for the subject focus of the AGS journal?
- yes
- no

2 SIGNIFICANCE

Does the article discuss an important problem in geography or related fields?
- yes
- no
- partly

Does it bring relevant results for contemporary geography?
- yes
- no
- partly

What is the level of the novelty of research presented in the article?
- high
- middle
- low

3 ORIGINALITY

Has the article been already published or is too similar to work already published?
- yes
- no

Does the article discuss a new issue?
- yes
- no

Are the methods presented sound and adequate?

- yes
- no
- partly

Do the presented data support the conclusions?

- yes
- no
- partly

4 CLARITY

Is the article clear, logical and understandable?

- yes
- no

If necessary, add comments and recommendations to improve the clarity of the title, abstract, keywords, introduction, methods or conclusion:

5 QUALITY

Is the article technically sound? (If not, the author should discuss with the Editorial Board [ags@zrc-sazu.si] for assistance.)

- yes
- no

Does the article take into account relevant current and past research on the topic?

- yes
- no

Propose amendments, if no is selected:

Is the references list at the end of the article adequate?

- yes
- no

Propose amendments, if no is selected:

Is the quoting in the text appropriate?

- yes
- no
- partly

Propose amendments, if no is selected:
Which tables are not necessary?
Which figures are not necessary?

COMMENTS OF THE REVIEWER

Comments of the reviewer on the contents of the article:
Comments of the reviewer on the methods used in the article:

RECOMMENDATION OF THE REVIEWER TO THE EDITOR-IN-CHIEF

Please rate the article from 1 [low] to 100 [high] (this will NOT be presented to the author):
Personal notes of the reviewer to the editor-in-chief (this will NOT be presented to the authors):

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JOURNAL HISTORY

Acta geographica Slovenica (print version: ISSN: 1581-6613, digital version: ISSN: 1581-8314) was founded in 1952. It was originally named *Geografski zbornik / Acta geographica* (print ISSN 0373-4498, digital ISSN: 1408-8711). Altogether, 42 volumes were published. In 2002 *Geographica Slovenica* (ISSN 0351-1731, founded in 1971, 35 volumes) was merged with the journal.

Since 2003 (from Volume 43 onward), the name of the joint journal has been *Acta geographica Slovenica*. The journal continues the numbering system of the journal *Geografski zbornik / Acta geographica*.

Until 1976, the journal was published periodically, then once a year, twice a year from 2003, and three times a year since 2019.

The online version of the journal has been available since 1995. In 2013, all volumes of the magazine were digitized from the beginning of its publication to including 1994 .

All articles of the journal are available free of charge in digital form on the journal website http://ags.zrc-sazu.si.

Those interested in the history of the journal are invited to read the article »The History of *Acta geographica Slovenica*« in volume 50-1.

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