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Climate change, extreme heat, and outdoor thermal comfort in urban areas: Case of İzmir, Turkey

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Abstract

Recently, environmental problems, urban population growth, the expansion of urban areas, and climate-insensitive planning practices have significantly increased the effects of the climate crisis in urban areas. As cities' population increases, cities' vulnerability to disasters also increases. The negative effects of the climate crisis and global warming on both socio-economic and socio-ecological ecosystems vary at different scales. On the other hand, urbanization practices and the current spatial structure of Turkish cities reduce the resilience capacity of cities against the climate crisis and increase their vulnerability. When the environmental and social pressures of the climate crisis rise, hazards such as floods, extreme heat, and urban heat island (UHI) effects turn into disasters in cities. To prevent this, the effects of the climate crisis and the resilience capacity of existing urban structures should be well understood. This study focuses on extreme heat and the UHI effect, which is a critical socio-spatial problem. It is seen that the recent literature on climate change and extreme heat mostly focuses on UHI as an urban vulnerability and an effect of urban morphology, but previous studies partially cover morphological indicators. This study differs from many studies by relating local climate zone mapping with site-based study design and a comprehensive morphological dataset. The case study focuses on İzmir, Turkey; the relationship between outdoor temperature recordings and urban typo-morphological features is examined by using multivariate regression analysis. The findings correspond to the detection of the effective size of greening and the importance of ventilation for cooling in relatively high temperature climatic zones.

Keywords: climate change, urban heat islands, local climate zone, thermal comfort, İzmir, Turkey

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Introduction

In the recent era of climate crisis and environmental problems, urban population growth, urban sprawl, and conventional urban planning practices have exacerbated the effects of the climate crisis on urban areas. The negative effects of the climate crisis on socio-economic and socio-ecological ecosystems have emerged at different spatial scales. Heavy rainfall, droughts, extreme heat, and sea level rise occur in different urban areas of the world. Especially in dense urban areas, cities are more vulnerable to climate change-induced disasters such as floods and urban heat islands (UHIs) (Tapia, C. *et al.* 2017). The distribution of these impacts and their exposure levels are not equal among the urban population. Disadvantaged social groups, such as the elderly and disabled, are relatively more vulnerable to the impacts of the climate crisis in urban areas. Since 50.7 percent of the world's population resides in cities and 68.4 percent of them are expected to live in cities by 2050, the impacts of climate crisis on urban areas may be worse due to the rise of (especially disadvantaged) population that will be affected by climate crises in the upcoming years (He, H. *et al.* 2021).

Conventional urbanization practices, planetary urbanization, and the population rise

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of cities around the world make them more vulnerable to the effects of the climate crisis (Öztürk, S.P. and Tikik, M. 2022). Through the impacts of the climate crisis on socio-ecological systems in cities, hazards such as heavy rain, rise of sea level, and extreme heat turn into disasters. To prevent urban disasters, the impacts of the climate crisis in cities and their adaptive capacity should be well understood (Xu, L. *et al.* 2019). Relying on this understanding, climate crisis mitigation and adaptation policies should be developed and integrated into urban systems for more resilient and liveable cities.

In recent studies of climate crisis mitigation and adaptation, the concept of vulnerability provides a fundamental theoretical framework to understand the state of urban systems. The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as the degree to which a system is exposed to and copes with the adverse impacts of climate change. Since the concept of vulnerability is not a directly measurable concept, it is operationalised through a specific set of indicators. Recent literature defines vulnerability as the degree of three basic indicators: Exposure, sensitivity, and adaptive capacity (Weis, S.W.M. *et al.* 2016). When we examine the vulnerability of cities, sensitivity and adaptive capacity are the abilities of the urban systems to cope with climate-related hazards. Many measurable indicators may shape the sensitivity and adaptive capacity of urban systems. These indicators are the structural characteristics of the urban systems, such as macroform layout, green infrastructure, transportation network and traffic volumes, population distribution, etc. For instance, a more compact urban macroform and self-sufficient neighbourhood will help mitigate the urban heat island effect and thus reduce energy consumption demand. Sub-indicators such as building height, street width, sky view factor, and building density, amount of green space, land use diversity, and transportation system also affect the formation of urban heat islands and energy consumption demand (Urquizo, J. *et al*. 2017; Sakar, B. and Çalişkan, O. 2019; Öztürk, S.P. and Tikik, M. 2022; Zhou, L. *et al.* 2022; Xu, D. *et al.* 2023).

The UHI effect is one of the most fundamental urban hazards, depending on extreme heat and urban structure in cities that directly affects the liveability and outdoor thermal comfort (Urquizo, J. *et al*. 2017; Mansuroğlu, S. *et al*. 2021; Zhou, L. *et al.* 2022) and the quality of water, air, soil, and food (Tapia, C. *et al.* 2017; Todeschi, V. and Pappalardo, S.E. 2022). Typological and morphological sub-indicators of urban structure, such as land-use, building density, building height, street network, floor area ratio, and sky view factor, directly affect the degree of urban heat island formation (Tapia, C. *et al.* 2017; Urquizo, J. *et al*. 2017; Sakar, B. and Çalişkan, O. 2019; Öztürk, S.P. and Tikik, M. 2022; Zhou, L. *et al.* 2022).

There have been ongoing investigations to mitigate UHIs' effects, such as the use of afforestation, grassing, and permeable surfaces (Amani-Beni, M. *et al.* 2018), as well as higher sky view factors and wider air corridors (Sakar, B. and Çalişkan, O. 2019). Although green areas and wet surfaces are preferred urban elements for reducing air temperature of the urban areas, their spatial organization in continuity and sizes higher than 30–40 hectares is much more successful (Çubukçu, K.M. and Şentürk, Y. 2022). Creating green areas connected to water bodies such as seas and streams, protecting large water bodies, rainwater recycling, roof gardens, and medium-sized green areas are vital urban design elements to mitigate UHIs (Liu, H.-Y. *et al.* 2023).

To make an accurate decision-making in urban design strategies, it is necessary to comprehend the state of vulnerability and adaptive capacity of cities. Urban vulnerability relies on the context of the city, that is, the demographic, socio-economic, physical, environmental, and institutional characteristics that affect the adaptation capacity against the climate crisis (Kaya, Y. 2018). City-specific vulnerabilities and adaptive capacity make it necessary to design policies to combat and adapt to climate crisis impacts in a city-specific manner. Therefore, the first step in making cities more resilient to climate change is to identify city-specific socioeconomic and socio-ecological vulnerability levels (Xu, L. *et al.* 2019). There are recent approaches to assess the vulnerability level of cities considering the state of urban typo-morphology that may exacerbate the impacts of climate change. Extreme diurnal heat in cities is one of them under consideration (Maiullari, D. *et al*. 2021; Ling, T.-Y. 2022; Ahmed, I. *et al.* 2023; Lemonsu, A. *et al.* 2024). The urban heat island effect is also an important impact of the urban typo-morphology that increases climate change pressure on socio-ecological systems. Studies assessing the relationship between urban typo-morphology and the urban heat islands use various approaches consisting 'multivariate statistical causality models' (Urquizo, J. *et al*. 2017; Xu, L. *et al.* 2019; Wang, Q. *et al.* 2022; Zhou, L. *et al.* 2022), "vulnerability index" calculation (Marquez-Ballesteros, M.J. *et al.* 2019; Akbaba, S. 2020; Bibri, S.E. and Krogstie, J. 2021), urban fragility mapping' and 'simulation modelling' using such as ENVI-Met, EnergyPlus simulation, CEEM-U (Economy and Energy for Urban Microgrids), CityBes, ArcGIS, Insight220, Urban Block Generator Grasshopper /rhinoceros, City Energy Analyst programs (Kardinal Jusuf, S. *et al.* 2007; Asfour, O. 2022; Kolokotsa, D. *et al.* 2022) and 'remote sensing techniques' upon city-wide scale (Galdies, C. and Lau, H.S. 2020; Jain, S. *et al.* 2020; Buo, I. *et al.* 2021; Gadekar, K. *et al.* 2023).

Within the scope of UHIs and extreme heat in cities, there is a limited number of studies focusing on data collection by field study in cities (Urquizo, J. *et al*. 2017; Privitera, R. *et al.* 2018; Kuang, W. 2020; Zhou, L. *et al.* 2022). In addition, there is a lack of comprehensive studies that address local typological-morphological characteristics together with other urban factors and socio-ecological elements (wind speed generation of the urban fabric, density of traffic, green space types, etc.). The explanatory capacity of these studies is also limited due to low indicator datasets and lack of field study (Čeh, M. *et al.* 2018; Yu, Z. *et al.* 2020; Wang, Q. *et al.* 2022). In this context, detailed research is needed to decide which of these features is the most important indicator and to understand the effect of different indicator compositions (Sakar, B. and Çalışkan, O. 2019; Yu, Z. *et al.* 2020; Öztürk, S.P. and Tikik, M. 2022; Wang, Q. *et al.* 2022; Zhou, L. *et al.* 2022). This study differs in its field study based on multiple regression analysis. It focuses on the relationship between urban built environments and extreme heat that may cause urban heat islands (Lemonsu, A. *et al.* 2021; Ling, T.-Y. 2022).

The main argument of this study is that the relationship between urban typo-morphology and extreme outdoor heat must be in focus to design UHI mitigation strategies in cities, and there is a need for micro-spatial scale investigations to understand driving factors (Maiullari, D. *et al*. 2021; Ahmed, I. *et al*. 2023; Lemonsu, A. *et al.* 2024). This study investigates the effect of different features of the built environment on extreme outdoor heat and the impact on the potential configuration of UHIs in İzmir city. The effects on the configuration of extreme outdoor heat as a trigger of UHIs are examined through statistical analysis at close surrounding environments (500 m) of different building types. The unique value of this study is that it has a hierarchical spatial approach from meso- to micro-scale to have a deeper understanding of micro-scale spatial and environmental dynamics. It simulates the 'local climate zones' and continually focuses on 'high climatic zones' to discover prominent features that exacerbate extreme heat. Furthermore, this study aims to provide insights to examine the latent effects of the built environment on the configuration of extreme outdoor heat and UHIs.

Literature review

In recent studies on mitigating and preventing the impacts of the climate crisis, which is a socio-ecological phenomenon, it is seen that the concept of vulnerability provides a theoretical framework. The concept of vulnerability is the degree of three basic indicators: exposure, sensitivity, and adaptive capacity. Exposure is the degree to which a system is exposed to climate crisis-based events. Sensitivity is the degree of positive or negative impacts of the climate crisis on a system. Adaptive capacity is determined by local resources and conditions that limit or support a system's ability to adapt to the climate crisis (IPCC, 2021). When we examine the situation of cities against the climate crisis within the framework of vulnerability, urban disasters such as flooding, inundation, urban heat island, and extreme heat events are the substantial impacts that challenge the vulnerability of an urban system (Weis, S.W.M. *et al.* 2016; Tapia, C. *et al*. 2017; Xu, L. *et al.* 2019; Öztürk, S.P. and Tikik, M. 2022; Todeschi, V. and Pappalardo, S.E. 2022).

UHI is a phenomenon that makes cities vulnerable to climate crisis-based extreme heat, and it is where the cooling process of an urban area is much lower and slower than its nearby rural area, especially at night (Rajagopal, P. *et al.* 2023). Prevailing studies on urban heat islands and extreme heat mitigation are focused on urban environmental quality degradation, urban form, energy demand, urban environment materials, and urban planning policies (Gonzalez-Trevizo, M.E. *et al.* 2021; Karimi, A. *et al.* 2023). Previous studies of UHI have utilized multiple linear regression models and regression-based spatial mappings using Ordinary Least Square, Pearson R, Root Mean Square Error, Mean Bias Error, etc. Besides, the urban canopy model is used to model the relationship between the urban environment and atmospheric parameters (e.g., temperature, wind speed, and solar radiation) (Gonzalez-Trevizo, M.E. *et al.* 2021; Ren, C. *et al.* 2021; Karimi, A. *et al.* 2023). The heat retaining capacity of an urban area is related to the atmospheric parameters (e.g., diurnal temperature, wind speed, and solar radiation) and morphological characteristics of the area. Therefore, diurnal extreme heat events may increase the urban heat island effect caused by urban morphology. Since the temperature differences unfold not only between urban-rural but also within urban areas, it is important to analyse the local climate zones and their atmospheric and typo-morphological characteristics (Martilli, A. *et al.* 2020).

The local climate zone (LCZ) is a theoretical and practical framework to determine urban and rural areas with distinct land use-built types and land cover non-built types that may influence the UHI effect (Geletič, J. *et al.* 2016). These two characteristics consist of building density, building height, surface reflectance, surface roughness length, sky view factor, green spaces, soil and bare lands, water bodies, etc. To classify LCZ, the main methods are supervised manual classification, k-means clustering, remote sensing image classification, and GIS-based urban spatial clustering analysis (Milošević, D.D. *et al.* 2016; Xu, D. *et al.* 2023).

UHI controlling and mitigation studies mainly concentrate on the effects of urban green infrastructure. Urban vegetation, as a greening arrangement, is recommended as a vital strategy to decrease the effects of UHI as well as to control extreme air temperatures at both day and night. Vegetation for UHI mitigation is formed as parks, parklets, street trees, green refuges, green roofs, lawns, green building facades, etc. It is observed that urban green space is usually colder than the surrounding building environment, and its effect is called a 'park cold island' (PCI). Its cooling effect is mainly based on the effects of evapotranspiration and blocking shortwave radiation and providing shadow (Cui, F. *et al.* 2021; Rakoto, P.Y. *et al.* 2021; Wang, Y. *et al.* 2021; Han, D. *et al*. 2023). A case study evident that increasing green cover such as parks, parklets, and street trees up to 10 percent is the most appropriate strategy for UHI mitigation (Wang, Y. *et al.* 2021). It is claimed that the larger green spaces have a much more cooling effect than smaller ones (smaller than 40 ha) (Çubukçu, K.M. and Şentürk, Y. 2022). To succeed 1 °C decrease in outdoor temperature requires an increase in green cover up to 16 percent (Marando, F. *et al.* 2022). Besides, it is recommended that the increasing height-to-width (sky view factor > 0.2) greatly enhance the cooling effect of vegetation (Karimi, A. *et al.* 2023).

Relying on previous studies on UHI and extreme heat events in urban areas, it is vital to evaluate the contributors to the urban heat island effect. It is recommended that further studies focus on identifying 'local climate zones' and microclimates of urban areas, urban design features, and their impacts on UHI, extreme heat, and outdoor thermal comfort (Shi, Y. *et al.* 2019). Outdoor thermal comfort is an important indicator of the quality of urban life and liveability that must be considered in urban planning and design processes.

Study site and methodology

The study area is the city of İzmir, located in the Aegean region and the third largest city in Turkey. İzmir city has a population of 4,500,000 and a surface area of 12,012 km². İzmir's population density is 375 persons per km², and its building density is 15 buildings per km² in the central urban area. The metropolitan urban area has 30 districts, and the central urban area has 11 districts *(Figure 1).* İzmir city has a Mediterranean climate with hot and dry summers and mild and rainy winters. The average annual temperature is 17.3 °C. The annual maximum temperature is 40.5 °C, and the annual minimum temperature is -4.0 °C. The hot summer season is five months long from May to the end of September. Due to its population size and temperatures of up to 40 °C in hot summers, İzmir is an important case of climate crisis-sensitive urbanization.

The study has mainly two parts, one is local climate zones mapping to determine suburban areas with distinct land cover and typo-morphological characteristics. The second

Fig. 1. Central districts of İzmir with site measured points. *Source*: Authors' compilation.

part assesses the relationship between built environment features and diurnal outdoor heat records. The methodological approach of the first part is based on overlay mapping of these parameters in ArcGIS 10.8 using the spatial analysis overlay tool to create local climate zones. The second part relies on multi-variable regression analysis to measure the relationship between built environment features and diurnal outdoor heat within relatively 'high climatic zones' in SPSS using the regression tool. The site study focuses on different typo-morphological features in the 'high local climate zones' of İzmir. The study operationalizes the effects of the built environment on outdoor heat by using measurable indicators.

Within the context of first part of the study, the local climate zones of İzmir are mapped using eight indicators: 1) building heights, 2) building density, 3) street density, 4) arterial road density, 5) green space density, 6) aspect of solar radiation, 7) aspect of sea breeze exposure, 8) water bodies are used in ArcGIS 10.8. Subsequently, three climatic zones were identified, and zones with relatively high building density and low green areas and water bodies, as 'high urbanized' (LCZ 2 and LCZ 3), are selected for outdoor diurnal temperature recording.

The LCZ map was developed using GIS software of ArcGIS 10.8-based on spatial clustering analysis using weighted sum under the overlay tool of ArcMap 10.8 by ex-

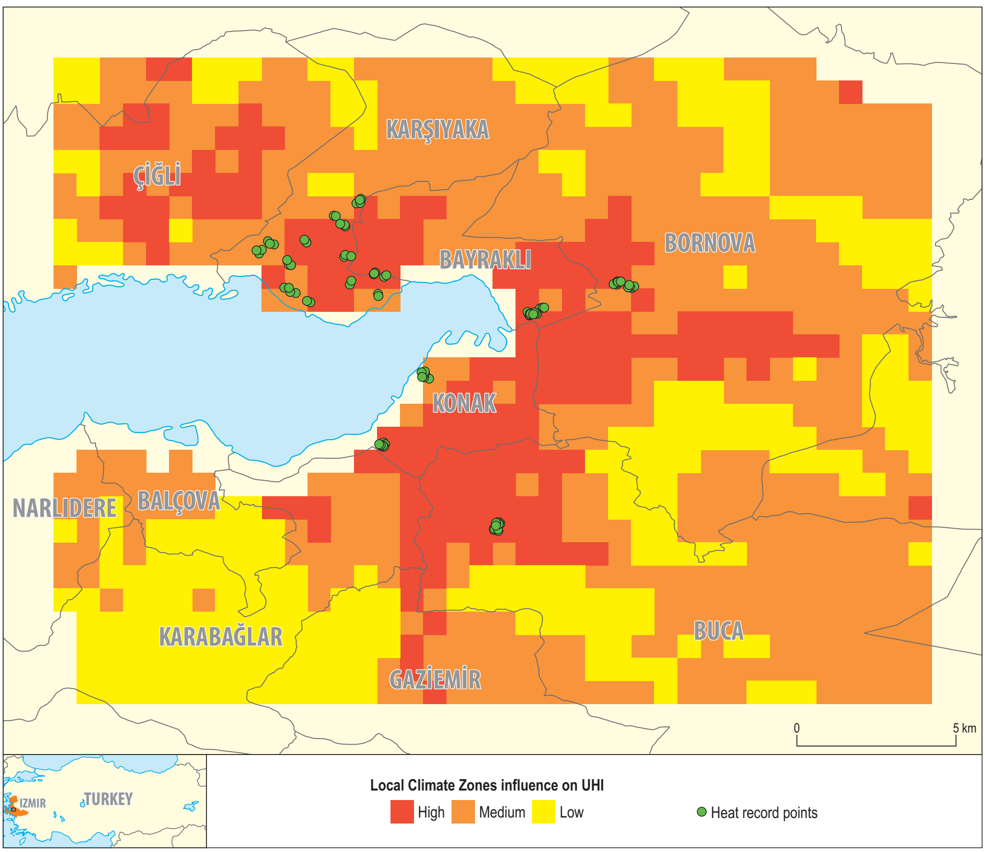

Fig. 2. Local climate zones and locations of temperature records. *Source*: Authors' compilation.

amining the eight indicators of İzmir city. These indicators are categorized into three categories as high, medium, and low using natural break classification. The indicators are combined by aggregating the indicators with equal weighting factors. The suburban areas that have the highest building density, lowest green space density, no water body, without direct sea breeze, and in the south-west direction with direct solar radiation are defined as high: LCZ 3. The suburban areas with medium building density, medium green space density, without direct sea breeze, without water body, and in the south-west direction are defined as medium: LCZ 2. Subsequently, the urban areas with the lowest building density, highest green space density, close to the water body, in the west direction with direct sea breeze, and without direct solar radiation are defined as low: LCZ 1 *(Figure 2).* The most populated urban areas correspond to LCZ 3, with the highest density and lowest green density. Within the scope of outdoor temperature recordings, the locations are indicated within 'high urbanized' zones, considering different morphological and atmospheric features as seen in *Figure 2*.

The second phase of the study seeks to identify built environment features associated with higher temperatures using multivariate regression analysis for site temperature recordings with sensors, and typo-morphological indicators. The study area is focused on LCZ 2 and LCZ 3 in the city centre, with red coloured, which are relatively the densest urbanized zones. Within these zones, diurnal outdoor temperature was recorded at 88 different locations with sensors, and 11 indicators of the built environment were collected (Zhou, W. *et al.* 2011; Yan, H. *et al.* 2018; Peker, E. 2021).

These indicators are classified such as urban form layout: (1) average building storey at the point of measurement; (2) building facade material; (3) street width (m); (4) nearest green area type (park, recreation area, residence garden, refuge, traffic island, cemetery, garden of mosques, garden of schools etc.); (5) direct wind exposure (used with 1 and 0 to indicate direct exposure to prevailing sea wind [west and north-west in İzmir]); (6) average building storey within 500 m radius; (7) amount of green space within 500 m radius; (8) building typology (attached, detached, block, twin-attached); (9) street morphology within 500 m (grid, organic, radial); (10) street paving material (stone paving, asphalt); (11) average number of street lanes (width) within 500 m radius (average lane information is used to represent vehicle traffic volume), as seen in descriptive statistics in *Table 1* (Sakar, B. and Çalışkan, O. 2019; Martilli, A. *et al.* 2020; Gonzalez-Trevizo, M.E. *et al.* 2021; Marando, F. *et al.* 2022; Karimi, A. *et al.* 2023).

*Table 1. Descriptive statistics**

Indicator	Mean	Standard deviation
temperature	30.350	1.7237
build_storey	8.22	7.866
facade_material	1.09	0.289
street_width	12.563	5.9436
type_greenspace	Residence garden, 3000 m^2	1.597
directwind	50% direct sea breeze exposure	0.502
ave_build_storey_around	5.94	2.351
ave_greenspace_around	10.3532 ha	13.30750
type_building_morphology	detached	0.730
street_morphology	grid iron	0.664
street_material	asphalt	0.468
ave_streeline_around	2.94	0.998

*N = 88.

Findings and results

In the study, outdoor temperature is recorded at highly urbanized zones as LCZ 2 and LCZ 3. In the city centre, the outdoor temperature of 88 locations is recorded, and the built environment indicators in 11 different sub-categories are collected, and descriptive statistics are seen in *Table 1*. According to the data of 88 locations, the most common green typology is semi-public green areas of residential units, the average building storey is 8, the average street width is 12.56 m, the most common building typology is detached housing, and the most common street morphology is a grid-iron layout. Besides, the average height-to-width (H/W) ratio (mass to street) is measured at 2.12, which may cause huge solar radiation exposure (especially in east-west orientation).

In the regression model *(Table 2)*, the correlation coefficient R and the coefficient of determination R^2 are measured. The R-value of 0.726 indicates that the model is highly correlated. The R^2 value shows that 52.8 percent of the temperature value can be explained in light of the collected data, and an R-squared between 0.50 to 0.99 is acceptable in social science research, especially when most of the explanatory variables are statistically significant (Ozili, P.K. 2022). In the ANOVA table, we see that the regression model predicts the dependent variable significantly well with a reliable (sig.) coefficient of 0.000. The F value is 7.715; a value greater than 1.000 indicates that the efficiency of the model is within acceptable ranges *(Table 3)*.

According to the regression analysis, the statistically significant variables that have a positive relation with outdoor temperature are *street width, type of nearest (closer than 500 m) green space, direct wind (sea breeze) exposure, street material, and average number of street lanes within 500 m radius (Table 4)*. Considering the Beta constant value, it is seen that *direct sea breeze (west and north-west) exposure, the number of street lanes (representing traffic volume), and street pavement material* are the most positive effective indicators of the outdoor temperature in İzmir city. Notably, it is observed that the urban areas without direct sea breeze and closer to the asphalt streets with 3 additional traffic lanes *(city highway in İzmir)* have the highest diurnal outdoor temperature, and they are in LCZ 3. Since they are in LCZ 3, with limited green space and the highest building density, they may have the highest potential to intensify urban heat island effects during night-time.

As mentioned above, important indicators are determined as 'direct exposure to wind *(sea breeze)*', 'the number of street lanes'

Table 2. Model summary

Model	R	R square	Adjusted R square	Standard error of the estimate
1	0.726[a]	0.528	0.459	1.2676

[a]Predictors: (Constant), ave_streeline_around, street_material, ave_greenspace_around, build_storey, ave_build_storey_around, type_greenspace, directwind, street_width, type_building_morphology, facade_material, street_morphology

Table 3. ANOVA[a] table

Model 1	Sum of squares	df	Mean square	F	Sig.
Regression	136.376	11	12.398	7.715	0.000[b]
Residual	122.124	76	1.607	–	–
Total	*258.500*	*87*	–	–	–

[a]Dependent variable: temperature. [b]Predictors: (Constant), ave_streeline_around, street_material, ave_greenspace_around, build_storey, ave_build_storey_around, type_greenspace, directwind, street_width, type_building_morphology, facade_material, street_morphology.

Table 4. Coefficients[a] table

Model 1	Unstandardized coefficients Beta	Standard error	Standardized coefficients Beta	t	Sig.	95% confidence interval for Beta	
						Lower bound	Upper bound
(Constant)	25.268	1.464	–	17.257	0.000	22.352	28.184
build_storey	-0.009	0.026	-0,039	-0.324	0.747	-0.061	0.044
façade_material	0.633	0.688	0.106	0.921	0.360	-0.736	2.002
street_width	0.084	0.028	0.291	3.004	0.004	0.028	0.140
type_greenspace*	-0.242	0.099	-0.224	-2.432	0.017	-0.440	-0.044
Directwind (sea breeze)**	-1.303	0.326	-0.379	-3.997	0.000	-1.952	-0.653
ave_build_storey_around	-0.058	0.067	-0.080	-0.866	0.389	-0.193	0.076
ave_greenspace_within 500 m radius, ha	0.024	0.016	0.182	1.485	0.142	-0.008	0.055
type_building_morphology	0.101	0.242	0.043	0.419	0.676	-0.380	0.583
street_morphology	0.329	0.311	0.127	1.059	0.293	-0.290	0.948
street_material***	1.780	0.352	0.484	5.057	0.000	1.079	2.481
ave_street_lane within 500 m radius	0.755	0.183	0.437	4.113	0.000	0.389	1.120

[a]Dependent variable: temperature. *Ordinal data as: 8 = Fair green area, 435,589 m^2; 7 = Recreation area, 15,584 m^2; 6 = Cemetery, 9730 m^2; 5 = Park, 6748 m^2; 4 = Residence garden, 3100 m^2; 3 = School garden, 2785 m^2; 2 = Mosque garden, 1300 m^2; 1 = Refuge, 900 m^2. **Ordinal data as: 1 = Direct sea breeze from west and northwest; 0 = No direct sea breeze. *** Nominal data as: 1 = Asphalt; 2 = Cobble-stone paving.

representing the traffic volume, and 'street pavement material'. When the sea breeze exposure (prevailing wind direction is west and northwest) increases by one unit, the temperature decreases by 1303 units in the İzmir case. Afterwards, a one-unit increase in the street lane roughly increases the temperature by 0.755 units in the İzmir case. It is claimed that a height-to-width (H/W) ratio lower than 1.00 and strong air flow through urban canyons (sky view factor > 2.0) have a cooling effect on ambient outdoor temperature. In the study area, the H/W ratio is calculated at 2.12, and the common street layout is grid-iron, which causes a low sky view factor and high solar radiation exposure of urban canyons (streets), especially in east-to-west orientation in İzmir.

It is seen that wind exposure, street pavement material, and the number of street lanes are much more effective on urban outdoor air temperature than green spaces in İzmir. These indicators are more strongly correlated with lower temperatures rather than green space size in İzmir city. Moreover, there is no significant change in outdoor air temperature by the rise of green space size up to 50 hectares at most and an average of 10 hectares *(it is recorded 10.35 hectares in average and standard deviation is 13.30 at 88 different locations)* in LCZ 2 and LCZ 3 of İzmir city. The largest total amount of green space is recorded as 50 hectares, and it is rarely seen in LCZ 2 and LCZ 3, and the smallest total green space was measured at 0.98 hectares. There are various types of green spaces, such as parks with tree canopy, refuges, gardens of residential units, cemeteries, gardens of mosques, school gardens, and recreation areas in İzmir. The findings indicate that the average size of green space up to 10 hectares has no relation with the cooling effect on outdoor temperature in İzmir city.

Relying on the results of regression analysis with temperature records, the main related indicators with higher outdoor temperature are detected as traffic volume (*the arterial roads bigger than two-lane streets*) and the high levels of solar radiation exposure of urban canyons (*asphalt streets along the east-west direction).* It is assessed that it is important to lower solar radiation by narrower urban canyons (streets) in the east-west direction and designing elongated streets along the north-south axis instead of a grid iron layout. Moreover, direct exposure to sea breezes is one of the main sources of the cooling effect on higher outdoor temperatures across the study area.

Conclusions

In the era of climate change, urban areas are facing great challenges stemming from climate change-related hazards, high density, and rising population. The urban areas host huge populations and have varied economic facilities, social groups, and ecological systems. To manage climate change effects in urban areas, it is important to comprehend the mechanisms that exacerbate its impacts on socio-ecological and socio-economic systems. One of the major challenges that urban areas face is extreme heat and UHIs. The UHIs' impacts cause atmospheric and environmental problems, uncomfortable thermal conditions, individual health problems, and rising energy demand.

It is vital to discover the features of urban built environments that may cause UHIs configuration and decrease thermal comfort. This study uses LCZs mapping to discover 'highly urbanized' areas with limited green space and water bodies, and further performs a multivariate regression analysis to understand the relationship between urban typo-morphology and outdoor air temperature by taking advantage of site recordings in İzmir city. The main argument of this study is that urban morphology and typology must be in focus to design appropriate UHI mitigation strategies in cities. LCZs mapping helps to reveal distinct urban areas susceptible to urban heat island formation, and the regression model helps to discover prominent indicators that significantly contribute to elevated outdoor air temperature.

Within the scope of this study, it is found that urban typo-morphological and atmospheric features have a substantial impact in outdoor temperature. The direct sea breeze exposure is highly associated with higher temperatures rather than green space in İzmir. Moreover, the traffic volume based on street width is highly associated with higher temperatures. Due to the lower wind exposure and high traffic volume, highly urbanized zones (LCZ 2 and LCZ 3) have higher outdoor temperatures relatively. It is also assessed that it is important to lower solar radiation by narrower urban canyons (streets) in an east-west direction and increasing linear streets along the north-south direction. Besides, there is no significant relationship between daytime outdoor temperature and green space size, for a noticeable decrease in temperature, the average size of the green spaces must be increased within the context of İzmir city.

In conclusion, the findings show that direct wind (sea breeze in İzmir) exposure is much more associated with lower temperatures than small parks and green areas. Besides, relatively wider streets with solar radiation exposure and higher traffic volume are much more associated with higher outdoor temperature in İzmir. The study's scope is constrained by the complexity and heterogeneity of urban environments. The heat records of the sites and the number of sites (88 in this study) should be increased to reduce potential bias. Moreover, the results of the study are highly associated with the climatic conditions of İzmir, and there is a need for comparative studies of cities with different climatic conditions to draw broader generalizations. For further studies, the cooling performances of each indicator and each mitigation strategy should be compared by context-specific simulations. For convenient UHI mitigation and thermal comfort, rising capacity, a proper ventilation design, adequately sized vegetation and cool materials in urban canyons (streets) should be systematically integrated into urban design and planning decisions.

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The risk of urban floods caused by precipitation on the example of Bydgoszcz, Poland

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Abstract

The article concerns the flood risk assessment in Bydgoszcz in April–October 2010–2022. The distribution of daily precipitation sums for two meteorological stations in Bydgoszcz was analysed. The study confirmed that the risk of extreme precipitation is greatest in the summer months (May–August). It was found that some of the intense rainfall that might cause short-term flooding of urban areas was often local and caused by storm phenomena. Analysis of flood-related interventions by the State Fire Service in Bydgoszcz showed that 2022 had the highest number of incidents (117). The analysis of precipitation and State Fire Service interventions showed a small degree of dependence between the two, both at the city-wide scale and for individual city districts. The spatial distribution of these interventions allowed the Bydgoszcz city districts most exposed to the effects of pluvial flooding to be identified. The work showed the complexity of the issue of urban flood risk, of monitoring such phenomena at the city and district scales, and of countering the effects of such phenomena.

Keywords: flooding, extreme precipitation, intervention, State Fire Service, Bydgoszcz, Poland

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Introduction

Climate change refers to long-term changes in temperatures and weather patterns. Over the past decade, the world has warmed by 0.25 °C, following a roughly linear trend since the 1970s (Robinson, A. *et al.* 2021). In addition, there are increasing trends in extreme precipitation (Asadieh, B. and Krakauer, N.Y. 2015). In addition to the global scale, the climate is warming at all other spatial scales, although there are extreme fluctuations in the long-term trend of increasing temperatures. Also at regional and local scales, warming does not have a uniform rate (Kundzewicz, Z.W. 2011; Kocsis, T. *et al.* 2024). The occurring and projected climate changes and the resulting changes in recorded precipitation in Central Europe manifest themselves not so much in changes in mean annual precipitation totals, but in an unfavourable prolongation of drought periods and the occurrence of less frequent but more intense precipitation (Mikołajewski, K. *et al.* 2025).

Analysis of extreme precipitation in Poland showed that daily maximum precipitation in the summer half-year increased for many stations, and that increases in the summer half-year were more numerous than in the winter half-year (Pińskwar, I. *et al.* 2019). A study by Pińskwar, I. (2022) showed that between 1989 and 2018, total precipitation above the

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95th percentile decreased, but above the 99th percentile increased. In addition, increases in more extreme precipitation, i.e. in the 99th percentile more than in the 95th percentile, were shown with increasing global warming. The analysis of trends and frequency of extreme daily precipitation in Poland from 1951 to 2020 showed a significant positive trend for daily precipitation above 30 mm, 50 mm and 70 mm in September, and for daily precipitation above 100 mm in May. Spatially, the frequency of extreme precipitation in individual regions of Poland showed significant variations (Kalbarczyk, R. and Kalbarczyk, E. 2024).

Climate change is a serious threat and affects society in many ways, particularly in urban areas. The great sensitivity of cities and urbanised areas to climate change results primarily from the particular functional and spatial structural characteristics of such areas, i.e. their density of buildings and large populations (Short, J.R. and Farmer, A. 2021). These features make climatic phenomena a serious threat to city residents and their health (Kumar, S.V. and Singh, G.S.) and the urban fabric. Extreme weather events such as floods, droughts, heavy precipitation and heatwaves disrupt physical, social and institutional systems (Cho, S.Y. and Chang, H.J. 2017; Graczyk, D. *et al.* 2019; Kron, W. *et al.* 2019; Choryński, A. *et al.* 2022; Pińskwar, I. *et al*. 2023). Climate-change-related flooding is expected to increase in the future, thereby increasing existing flood risks (IPCC, 2014; Alfieri, L. *et al.* 2015; Tabari, H. 2020).

In addition to fluvial floods and storm surges, surface water flooding (also known as "pluvial flooding"), which is typically triggered by heavy rainfall, is expected to increase in urban areas (Falconer, R.H. *et al.* 2009; Huang, Y. *et al.* 2020). This is due to changing rainfall patterns, the expansion of urban areas and concomitant increase in area of sealed surfaces, and ageing and increasingly inefficient drainage infrastructure (Webber, J.L. *et al.* 2018; Guo, K. *et al.* 2021; Ajjur, S.B. and Al-Ghamdi, S.G. 2022). Research shows that the magnitude of urban floods increases non-linearly with increasing rainfall intensity. The maximum area of flooding also increases accordingly and is much more sensitive to flooding even in the case of milder rainfall (Sun, X. *et al.* 2021). The increasing frequency of urban floods is not caused solely by climate change, although their role is very significant. It is the effect of sealing the runoff surface accompanying urban changes in cities (Skougaard Kaspersen, P. *et al*. 2017). In cities, impermeable surfaces such as buildings, hardened concrete and asphalt surfaces dominate, which have a limited ability to absorb rainwater. As a result, the increase in impermeable surfaces increases the speed and volume of drained water. Halecki, W. and Młynski, D. (2025) found that in many European cities, the increase in impermeable surfaces often comes at the expense of a decrease in green and blue areas. The share of green areas within individual cities varies in terms of nature and function. The densely built-up cities of Central Europe contrast with the higher percentage of urban green areas in the Scandinavian countries (Halecki, W. and Młynski, D. 2025). There are clear indications that this trend will continue in the future, which will increase the risk of local floods. Europe's total share of sealed areas has increased by more than 6 percent since 2000. In addition, the urban population is expected to grow, which already accounts for three-quarters of the population living in EU countries (EEA, 2023).

Damage caused by weather phenomena has increased dramatically in recent decades. This damage means that such phenomena place an increasing burden on national economies and insurance companies, as do the rising costs of preventive measures (Kron, W. *et al.* 2019). In 2001–2019 alone, losses due to extreme phenomena in Poland amounted to EUR ~25 billion (Siwiec, E. 2022). This total included only direct losses, omitting indirect losses such as disruption costs to business operations and lost sales markets. Extreme weather and climate events caused economic losses to assets estimated at EUR 738 billion between 1980 and 2023 in the European Union, with over EUR 162 billion (22%) between 2021 and 2023 (EEA, 2023).

An essential part of the policy for countering the effects of extreme weather phenomena, especially in large urban agglomerations, is the targeted and centralised activity of public administration bodies involved in crisis management. In Poland, crisis management operates based on the 26 April, 2007 Act on crisis management (Act, 2007). This Act specifies the authorities responsible for crisis management and their tasks and principles of operation, and it regulates the principles for financing such tasks.

In Bydgoszcz, as in all major cities in Poland, the Bydgoszcz Crisis Management Centre (BCMC) has been operating since 2008 and is responsible for coordinating the activities of individual rescue units. The centre's main tasks involve collecting all information regarding the current and expected situation in the city and surrounding area, warning the population of threats, and coordinating all the activities of rescue and firefighting units of the State Fire Service (SFS), police and municipal guards. Based on annual reports on interventions by individual services provided by the centre, the number of interventions related to crisis management amounted to an average of 16.1 percent of all events recorded by BCMC officers in the city of Bydgoszcz and wider Bydgoszcz poviat in 2013–2022 (Raport, 2023). This number increased systematically, especially in the years 2013–2019. Therefore, analyses were carried out on the basis of the areas, most at risk to these phenomena in the city of Bydgoszcz, as well as areas not at risk.

The main aim of the work is to assess the risk of flooding of urban infrastructure and flood threats based on long-term precipitation data. Another goal is to examine the relationships between the occurrence of these events and interventions by the State Fire Service, at both city-wide scale and for individual districts. Of the many tasks performed by the State Fire Service, the article focuses only on interventions related to flooding.

Methods and data

Study area

The study focuses on the city of Bydgoszcz, which is the largest city in the Kuyavian-Pomeranian Voivodeship. The area of the city is 176 km^2. In terms of number of inhabitants, Bydgoszcz ranks 9th in Poland. At the end of 2022, there were 330,038 inhabitants, and the population density in the city was 875 people/km^2 (Statistics Poland, 2022). The city's administrative area is elongate; the western part stretches along the Bydgoszcz Canal and the centre and east extend along the Brda river to its confluence with the Vistula river, which is also the city's eastern border. The city extends 22 km from east to west and 10 km from north to south. The city's topography follows the patterns of classic flat-bottomed river valleys *(Figure 1).* The elevation of the terrain increases with the distance from the city's central districts, located on the banks of the Brda and Vistula. The lowest point in the city is on the banks of the Vistula at 28 m a.s.l. The highest point in the city is the summit of Góra Mielęcińska, 107 m above sea level, located a short distance to the east of the IHAR meteorological station ITP. Relative heights in Bydgoszcz increase towards the east, where they reach a maximum of 68 m in Fordon in the Vistula valley and 40 m in the Łęgnowo district.

In land use, forests (44.4%) and built-up (40.1%) occupy the largest area. Other land uses such croplands, herbaceous vegetation, herbaceous wetland, and waterbodies account for 15.5 percent of the city's area *(Figure 2).*

The climate of Bydgoszcz is usually conditioned by westerly polar maritime air masses that cause frequent weather changes in the area. Periods of more stable weather are provided by continental air masses and, less frequently, by Arctic air.

Total annual precipitation in Bydgoszcz is among the lowest in Poland (Grzywna, A. *et al.* 2020). In the World Meteorological Organization-recognised reference year 1991–2020, the mean annual precipitation

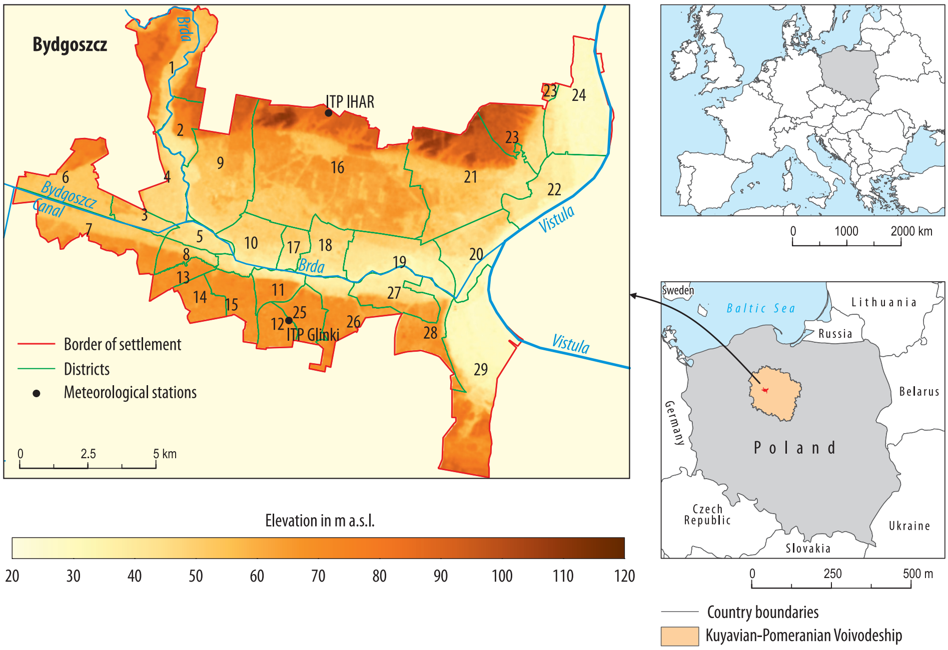

Fig. 1. Geographical position of the research area inside of Kuyavian-Pomeranian Voivodeship. Districts: 1 = Smukała-Opławiec-Janowo; 2 = Piaski; 3 = Flisy; 4 = Czyżkówko; 5 = Okole; 6 = Osowa Góra; 7 = Miedzyn-Prądy; 8 = Wilczak-Jary; 9 = Jachcice; 10 = Bocianowo-Śródmieście-Stare Miasto; 11 = Wzgórze Wolności; 12 = Glinki-Rupienica; 13 = Błonie; 14 = Górzyskowo; 15 = Szwederowo; 16 = Leśne; 17 = Bielawy; 18 = Bartodzieje; 19 = Bydgoszcz Wschód-Siernieczek; 20 = Brdyujście; 21 = Nowy Fordon; 22 = Stary Fordon; 23 = Tatrzańskie; 24 = Tereny Nadwiślańskie; 25 = Wyżyny; 26 = Kapuściska; 27 = Zimne Wody-Czersko Polskie; 28 = Łęgnowo; 29 = Łęgnowo Wieś. *Source*: Authors' own compilation.

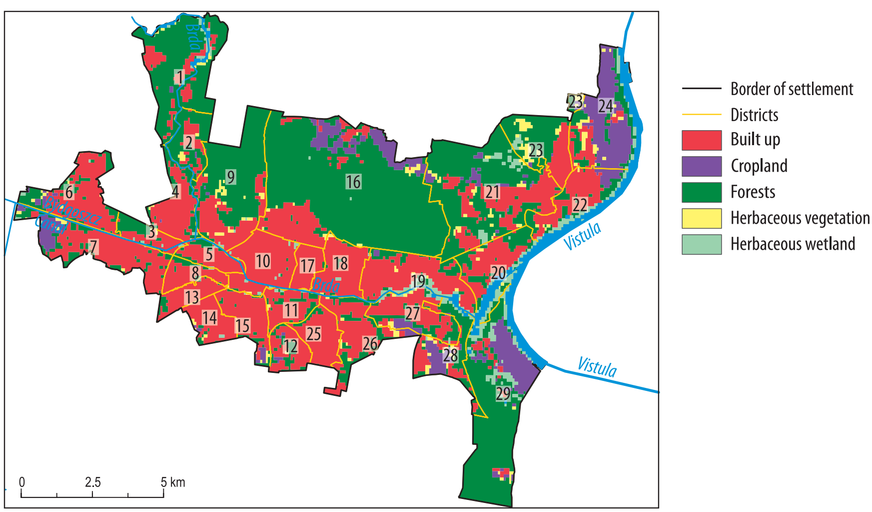

Fig. 2. Land use of the research area. District names 1–29: see *Figure 1*. *Source*: Authors' own compilation.

was 524 mm and varied from 666 mm (2010) to 377 mm (1991, 2003).

During the spring and summer months (April–October), the average seasonal precipitation was 353 mm for the period 1991–2020 analysed, with a high variability of precipitation: from 189 mm (1992) to 555 mm (2017). Precipitation during the April–October season accounted for 67 percent of annual rainfall. July was the wettest month, with an average rainfall of 81 mm, and April was the driest, with 27 mm. No significant decreasing or increasing trends were observed in the course of this precipitation, although periodic fluctuations were found, which is also confirmed by observations carried out at other measuring stations in Poland (Kubiak-Wójcicka, K. 2020; Ziernicka-Wojtaszek, A. and Kopcińska, J. 2020).

Bydgoszcz's average annual air temperature in the studied multi-year period was 9.4 °C. The warmest year (2019) was 10.7 °C, the coolest (1996) was 7.3 °C. The average annual amplitude was 4.4 °C. The pattern of air temperature by month is typical of Central Europe. Winters are colder and summers are warmer. The coldest months are January (-0.2 °C) and February (0.1 °C), and the warmest months are July (19.8 °C) and August (19.3 °C). The temperature distribution between 1991 and 2020 shows a clear upward trend. Climate warming was observed not only in the Kujawy region (Kubiak-Wójcicka, K. *et al.* 2021, 2024), but also in other regions of Poland (Marosz, M. *et al.* 2023) in different time periods.

The course of mean annual air temperature and annual precipitation totals in Bydgoszcz in the 1991–2020 period is presented in *Figure 3.*

Data and research methods

In order to characterise the meteorological conditions in the area under analysis, annual sums of precipitation and mean annual air temperature for the multiannual period 1991–2020 were used, which is a broader reference to the meteorological conditions prevailing in Bydgoszcz. On the basis of the average monthly and annual precipitation

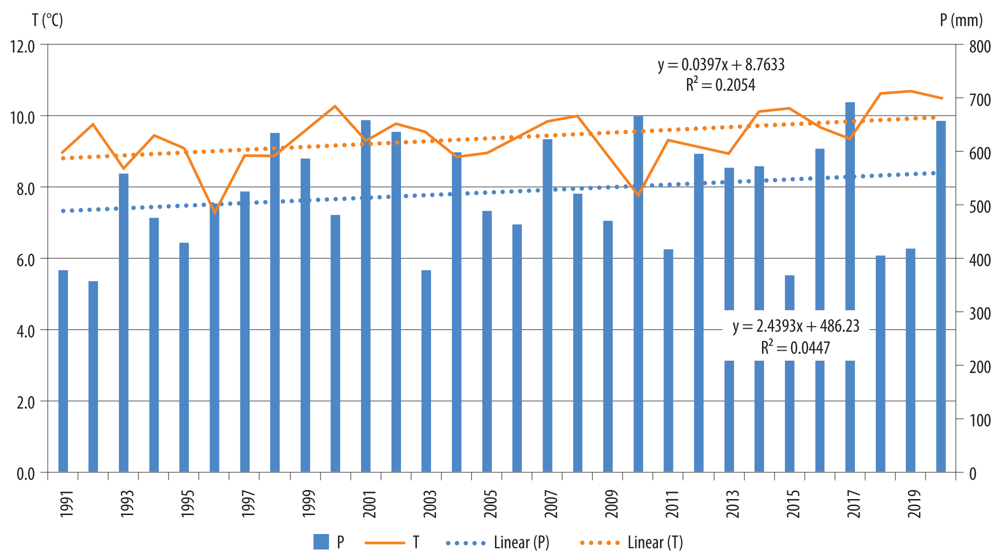

Fig. 3. Mean annual air temperature (T) and annual precipitation (P) totals at the station in Bydgoszcz in the years 1991–2020. *Source*: Authors' own research based on data from ITP-PIB.

and air temperature, trends of changes in the analysed multi-year period were calculated. Precipitation data from measurements performed by two automatic meteorological stations of the Institute of Environmental and Life Sciences – National Research Institute (ITP-PIB) were used for detailed analyses. The first (ITP Glinki) is located in the Glinki estate in the south of Bydgoszcz. This is a built-up district of the city lying at approximately 80 m a.s.l. The second station (ITP IHAR) is located on the premises of The Plant Breeding and Acclimatisation Institute – National Research Institute in the north of the city in an area adjacent to the Forest Park of Culture and Recreation (Poland's largest city park, at 800 ha). The distance between the two weather stations is approximately 8 km.

The data from both stations comprises daily rainfall totals for the years 2010–2022, measured in the period April–October. It is in these months that the highest rainfall sums are observed in Bydgoszcz at various time scales. In order to describe the rainfall distribution at individual locations in more detail, days were distinguished that met criteria for daily rainfall total thresholds of 10 mm, 20 mm, 30 mm, 40 mm, and 50 mm and more. This made the study sensitive to differences resulting from the uneven spatial distribution of rainfall and thus to the causes of local flooding. The next step was to indicate dates and periods in the rainfall calendar that repeatedly exhibit increased rainfall potentially conducive to flooding. Information on the rainfall situation in Bydgoszcz will be supplemented with information on the most important causes of synoptic situations that favour heavy rainfall.

In situations where there is a risk of flooding, the activities of the State Fire Service, which protects or eliminates the effects of both phenomena, are important. Similar to the preparation of rainfall data, the detailed analysis of interventions was limited to a common observation period, which covers the months of April to October in 2010–2022. These data were obtained from the Municipal Headquarters of the State Fire Service in Bydgoszcz and contain information on the date and time, address of, and reason for each intervention. The data were grouped and presented spatially, according to the city's division into districts.

Results and discussion

Precipitation from 2010 to 2022

During the multi-year period 2010–2022 study, annual precipitation totals showed a decreasing trend, which was related to the prevalence of annual precipitation totals below the multi-year averages. Precipitation totals for the April–October season 2010–2022 accounted for between 58.0 percent (2010) and 80.3 percent (2017) of annual precipitation. On average, total precipitation in the April to October season accounted for 67.1 percent of total annual precipitation over the 2010–2022 period, comparable to the 1991–2020 period. The research showed that the average total seasonal rainfall (April–October) at the two stations in 2010–2022 was 355.9 mm (ITP Glinki) and 311.2 mm (ITP IHAR). The wettest month in the studied period was July at the ITP Glinki station (75.7 mm), and at the ITP IHAR station, it was 57.8 mm *(Figure 4).* The highest precipitation totals at the ITP Glinki station were recorded in June 2020 (180.8 mm) and in July 2017 (125.8 mm). At the ITP IHAR station, the highest precipitation totals were recorded in June 2011 (149.5 mm) and October 2017 (120.3 mm). This difference probably results from the uneven distribution of rainfall from storm activity, which is particularly noticeable in these months. There were also some very dry months in the rainfall distribution. In April 2020, only 0.7 mm of precipitation fell at the ITP Glinki station, and in October 2014 – 1.6 mm. Slightly higher precipitation was found at the ITP IHAR station, where 1.1 mm was recorded in April 2019 and 2020 and 3.0 mm was recorded in October 2010.

The difference in the values of the average monthly precipitation totals at the two stations during the season (April–October) from 2010 to 2022 was characterised by high variability. In most months (58.2%), the difference

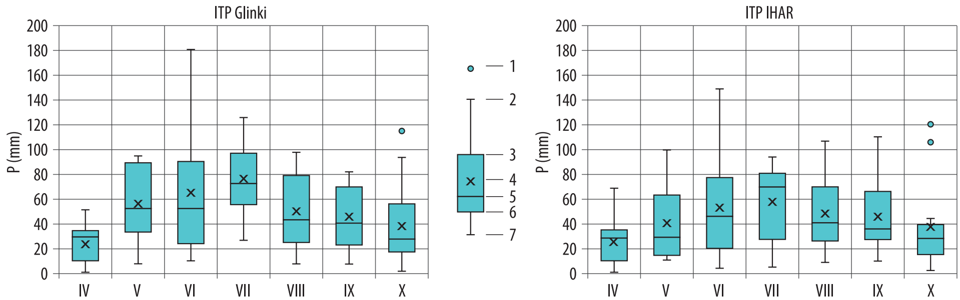

Fig. 4. Distribution of monthly rainfall totals at the ITP Glinki (left) and ITP IHAR (right) meteorological stations in April–October, 2010–2022. 1 = outlier points; 2 = maximum; 3 = 75 percentile; 4 = mean; 5 = median; 6 = 25 percentile; 7 = minimum. *Source*: Authors' own research based on data from the Institute of Environmental and Life Sciences – National Research Institute.

between the mean monthly precipitation at the two stations was less than 10 mm. The largest difference between monthly precipitation totals at the two stations was recorded in July 2016 (106.8 mm), in June 2020 (93.3 mm) and in May 2019 (75.9 mm). Only in 4 months (April 2010, and April, June and October 2022) was the rainfall total at both stations equal.

The correlation coefficient of the precipitation totals in the individual months remained at r = 0.76 throughout the entire multi-year study period. In the particular months, the interrelationships varied. In those months when precipitation totals were similar, the correlation coefficient ranged from r = 0.74 in June to r = 0.96 in April, while in months extremely differentiated in terms of precipitation, these relations were weaker. Such weak relationships were found in July (r = 0.40) and May (0.66). Thus, not in all months could the precipitation data from any one measuring station be representative of the entire city area.

Daily precipitation for the April–October season

Analysis of daily precipitation totals at both stations showed that the number of days with precipitation decreased with increasing precipitation totals. At the ITP Glinki station, the number of days with precipitation meeting the condition (P ≥ 10 mm) accounted for 10 percent of all days with precipitation in the studied multi-year period, and the number of days with P < 10 mm accounted for 90 percent, with no daily precipitation sum exceeding 50 mm recorded *(Table 1)*.

At the ITP IHAR station, such days with P > 10 mm precipitation were even less, i.e. 8 percent *(Table 2)*. Despite the small share of days with precipitation above 10 mm, the total daily precipitation amounted to as much as 49 percent of the total precipitation at the ITP Glinki station, and 42 percent at the ITP-IHAR station in the analysed multi-year period. This indicates a significant share of extreme precipitation (above 10 mm). At the same time, it should be noted that there was no precipitation > 50 mm at the ITP Glinki station and only one case of daily precipitation above 50 mm was recorded at the ITP IHAR station (9 June 2011 – 75.5 mm). Considering the sums of extreme precipitation recorded in individual ranges, the largest shares of the number of days and the total sum of precipitation were recorded in the 10–20 mm and 20–30 mm precipitation ranges.

In the distribution of average daily rainfall during the months of April to October, several frequently recurring days and periods of increased rainfall can be distinguished, which can cause localised flooding. The wettest days between 2010 and 2022 were 25 June (average daily rainfall of 6.6 mm) and 13 July (5.3 mm).

Table 1. Number of days (n) with precipitation (P) and sum of precipitation (∑) at ITP Glinki station meeting precipitation criteria in 2010–2022

P/year		P<10	10<P<20	20<P<30	30<P<40	40<P<50	P>50	∑P
2010	n	86	7	2	0	1	0	–
	∑	194.2	99.2	51.4	0	41.2	0	386.0
2011	n	78	5	1	1	0	0	–
	∑	190	57.2	25.2	36.4	0	0	308.8
2012	n	95	9	0	2	0	0	–
	∑	207.2	131.8	0	66.4	0	0	405.4
2013	n	73	8	2	1	0	0	–
	∑	153.9	112.6	52.6	34.2	0	0	353.3
2014	n	78	2	3	1	0	0	–
	∑	193,5	31.0	74.6	31.8	0	0	330.9
2015	n	80	5	0	0	0	0	–
	∑	148.2	65.2	0	0	0	0	213.4
2016	n	86	8	2	1	1	0	–
	∑	206.7	113.5	40.7	38.9	41.4	0	441.2
2017	n	97	10	6	2	0	0	–
	∑	203.8	141.8	138.4	71.2	0	0	555.2
2018	n	59	6	2	0	0	0	–
	∑	123.5	82.7	43.1	0	0	0	249.3
2019	n	77	4	1	0	0	0	–
	∑	166.0	63.6	21.4	0	0	0	251.0
2020	n	82	8	7	2	0	0	–
	∑	184.0	116.3	160.8	65.6	0	0	526.7
2021	n	86	4	1	1	0	0	–
	∑	180.4	60.9	23.1	35.2	0	0	299.6
2022	n	83	6	1	0	0	0	–
	∑	198.8	84.5	23	0	0	0	306.3
2010–2022	∑n	*1060*	*82*	*28*	*11*	*2*	*0*	–
	∑P	*2350.2*	*1160.3*	*654.3*	*379.7*	*82.6*	*0*	*4627.1*
	%	*51*	*25*	*14*	*8*	*2*	*0*	*100*

Source: Authors' own research.

In addition, rainfall between 4 mm and 5 mm was observed on several days. Such days included 1, 17 and 23 July and 17 June and 31 August.

Several wet and recurrent periods were found in the rainfall distribution, when the cumulative rainfall in some years exceeded even 50 mm. Such dates may include: 11–16.05 (52.9 mm); 5–12.06 (59.6 mm); 1–7.07 (61.8 mm) and 26–31.08 (57.1 mm). The maximum accumulation of precipitation of 85.9 mm was found on 11–17.07. Based on our own research and observations by other authors, the period 6.07–19.07 shows the highest storm activity combined with intense precipitation.

A review of synoptic situations favourable for the occurrence of high-intensity precipitation in the Bydgoszcz area allowed us to separate the most frequently recurring synoptic situations:

a) An area of low pressure over Bydgoszcz and the Kujawy region. This situation usually causes long-term, low- and medium-intensity rainfall lasting up to several tens of hours,

b) Rapid movement of atmospheric fronts and changes in air-mass types. Usually, hot

Table 2. Number of days (n) with precipitation (P) and sum of precipitation (∑) at ITP IHAR station meeting precipitation criteria in 2010–2022

P/year		P<10	10<P<20	20<P<30	30<P<40	40<P<50	P>50	∑P
2010	n	92	5	4	1	0	0	–
	∑	192.6	65.4	90.6	36.4	0	0	385.0
2011	n	66	9	0	0	0	1	–
	∑	174.2	126.7	0	0	0	75.1	376.4
2012	n	92	5	1	0	0	0	–
	∑	258.8	63.3	28.7	0	0	0	350.8
2013	n	81	9	0	2	0	0	–
	∑	176.8	123.7	0	70.6	0	0	371.1
2014	n	78	6	1	0	0	0	–
	∑	216.6	72.6	21.4	0	0	0	310.6
2015	n	70	1	0	0	0	0	–
	∑	123.7	11.6	0	0	0	0	135.3
2016	n	83	5	1	0	0	0	–
	∑	177.8	69.8	20.4	0	0	0	268.0
2017	n	97	9	4	3	0	0	–
	∑	258.3	137.5	90.7	104.9	0	0	591.4
2018	n	64	3	1	0	0	0	–
	∑	120.3	48.9	23.3	0	0	0	192.5
2019	n	63	1	0	0	0	0	–
	∑	110.2	10.1	0	0	0	0	120.3
2020	n	91	6	2	2	0	0	–
	∑	177.7	81.4	47.6	64.4	0	0	371.1
2021	n	92	4	1	0	0	0	–
	∑	159.6	49.1	28.3	0	0	0	237.0
2022	n	84	4	1	0	1	0	–
	∑	211.6	57.0	21.5	0	46.6	0	336.7
2010–2022	∑n	*1053*	*67*	*16*	*8*	*1*	*1*	*–*
	∑P	*2358.2*	*917.1*	*372.5*	*276.3*	*46.6*	*75.1*	*4045.8*
	%	*58.3*	*22.7*	*9.2*	*6.8*	*1.2*	*1.9*	*100.0*

Source: Authors' own research.

and dry continental air masses are displaced by cooler and humid polar–marine air. Thunderstorms occurring on atmospheric fronts are generally short-lived and accompanied by intense local rainfall,

c) Slow movement of a wavy cold front. This process leads to the formation of mesoscale low-pressure centres along a front line, where different air masses mix, which favours heavy rainfall.

d) Precipitation caused by storms within an air mass. These usually appear locally, during periods of high air temperature. Their formation is influenced by various factors, the most important of which are related to topography and land-cover type, as well as local temperature distribution.

In many cases, local storms and rainfalls occurred in the city. One such situation was observed on 19 July, 2015, when a storm front was moving over the city. Then, 19.2 mm fell at the ITP Glinki station, while no rainfall was recorded at the ITP IHAR station. Similarly, on 14–15 July, 2016, local storms caused 41.4 mm and 14.5 mm of rainfall at the ITP Glinki station, while, in the same period, only 0.2 mm of rain was recorded at the ITP IHAR station on the first day and none the next. A similar situation occurred on August 16, 2022, when a storm with heavy rainfall occurred in the west of the city. No precipitation was recorded at the ITP Glinki station on that day, while there was 4.2 mm at the ITP IHAR station. It is worth noting that these sums of precipitation were not record-breaking, but the effects of the downpours were determined by the short duration and high intensity of the rainfall. In addition, at that time, the air temperature remained high, above 30 ºC.

State Fire Service interventions

Based on the data on interventions by the State Fire Service (SFS), pumping water from flooded streets and apartments, such activities increased throughout the years 2010–2022. The greatest annual number of such interventions was recorded in 2022 (117) and 2014 (74), while the lowest was in 2013 (3) *(Figure 5, a).*

The monthly distribution was dominated by interventions in July (227 in total), which accounts for 42 percent of all interventions in 2010–2022. There were far fewer in August (153) and June (132) *(Figure 5, b).* On average, 42 interventions were made per season (April–October), of which 18 in July and 12 in August.

Most interventions were recorded in city districts in the west of the city, where topography is a factor that increases the risk of flooding. There are significant slopes here (the valley edge), which favour the rapid flow of water and its accumulation in the lower parts. These districts are Osowa Góra (141 interventions) and Miedzyń-Prądy (50), where houses predominate. A significant risk of flooding (112 interventions) was also found in the densely populated city centre in the Bocianowo-Śródmieście-Stare Miasto district. High-density buildings, little ability for water to percolate into the soil, and storm water systems that are not always cleared were all factors contributing to flooding.

Another area with an increased number of interventions is the housing estates located in the southern part of the city, in the Kapuściska

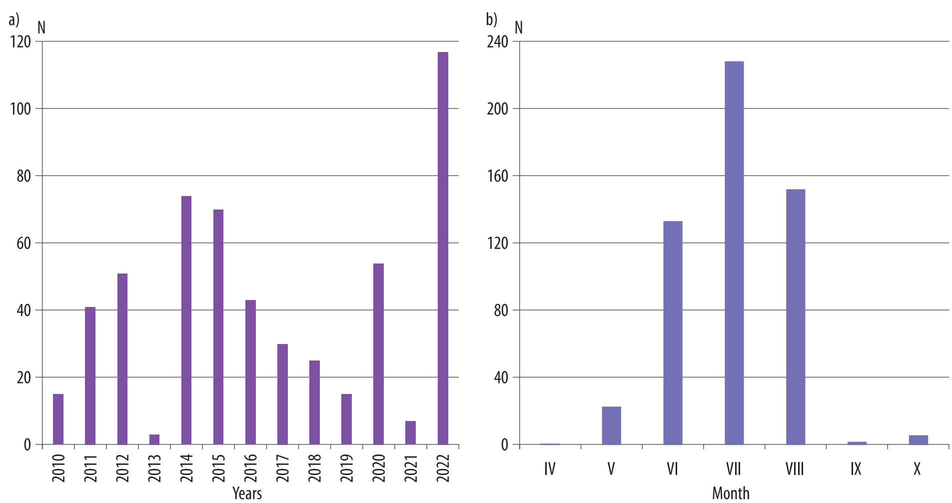

Fig. 5. Number of State Fire Service interventions (N) in Bydgoszcz to pump water from flooded streets and apartments in the years 2010–2022. a = in the multiannual period; b = in individual months of the season (April–October). *Source*: Authors' own study based on SFS data.

and Wyżyny districts. Here, the State Fire Service intervened 42 times. There are also areas in Bydgoszcz where interventions by the State Fire Service (SFS) were absent or very occasional. Such districts include Zimne Wody-Czersko Polskie, Łęgnowo and Łęgnowo-Wieś, which are characterised by low-density development and a large amount of biologically active areas *(Figure 6)*.

The year 2022 deserves special attention for having the highest annual number of interventions (117) *(Figure 7)*. In August, during the wet period of 14–21 August, the State Fire Service intervened 105 times as a result of local rainfall. According to rainfall data from 14 August, a daily total of 5.9 mm of rainfall was recorded at the ITP Glinki station and 6.8 mm at the ITP IHAR station, whereas no rainfall was recorded on the remaining days. However, on 16 August, 2022, in the Osowa Góra and Miedzyń-Prądy districts in the west of Bydgoszcz, the State Fire Service intervened due to flooding 37 and 13 times, respectively. Unfortunately, there is no rainfall measurement point in the areas of these settlements, so only based on the number and locations of State Fire Service interventions can it be concluded that rainfall was intense and local.

The second highest number of interventions was in 2014 (a total of 74 interventions), of which interventions in July (55) and August (18) predominated *(Figure 8)*. Interventions in July were related to rainfall that occurred at the beginning and end of the month. On 6–8 July, rainfall of 1.4 mm, 26.4 mm and 6.4 mm was recorded at the ITP station. Glinki. As a result of this rainfall, as many as 46 interventions were recorded over the 3 days, which mainly took place in the central part of Bydgoszcz. Most interventions on these days were recorded in the Bielawy and Bocianowo districts. At the ITP IHAR station, precipitation was considerably lower at 8.5 mm, 11.5 mm and 5.4 mm. On 30 July 2014, a total of 9 interventions were recorded in the western part of Bydgoszcz (Okole and Osowa Góra districts). No intense rainfall was recorded at either station on this day. Further interventions (18 in

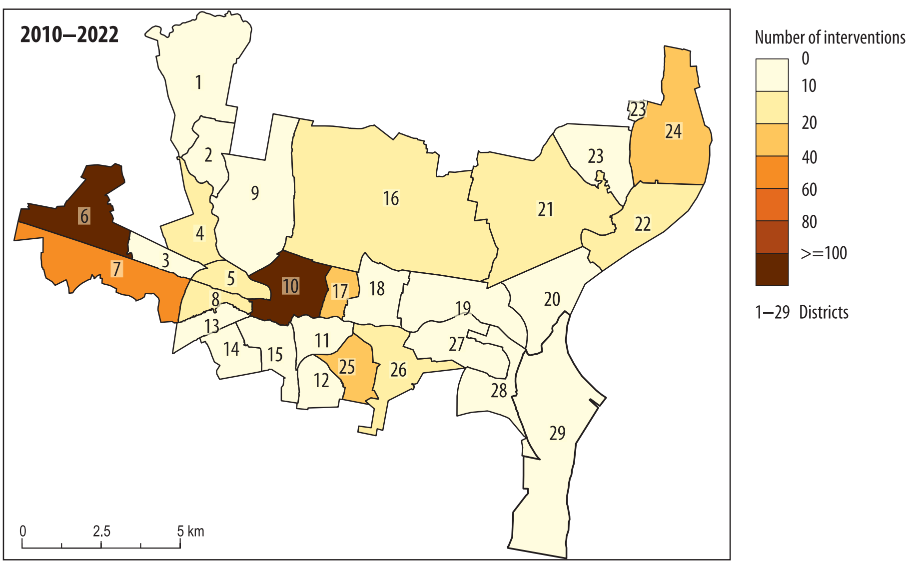

Fig. 6. Number of interventions by the State Fire Service between 2010 and 2022. District names 1–29: see *Figure 1*. *Source*: Authors' own compilation.

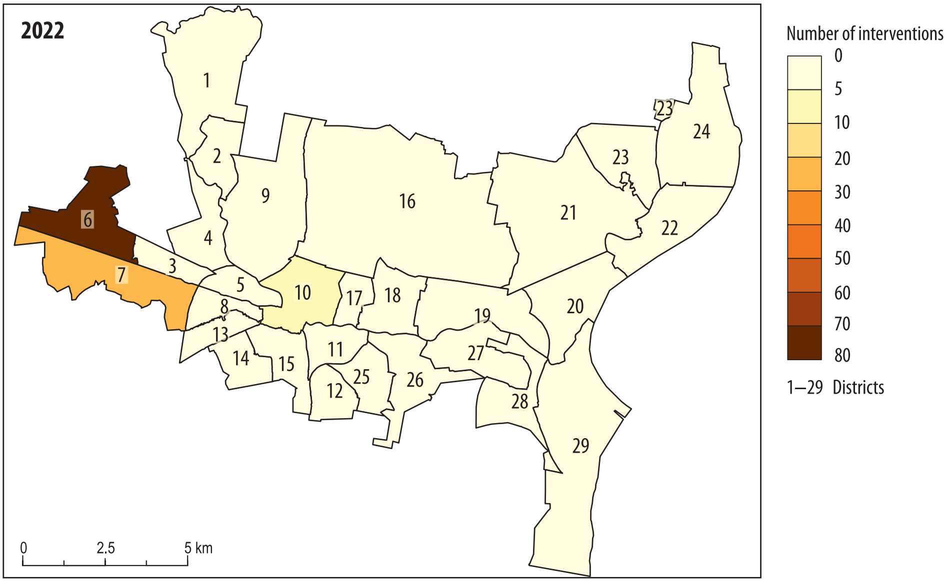

Fig. 7. Number of interventions by the State Fire Service in 2022. District names 1–29: see *Figure 1*.
Source: Authors' own compilation.

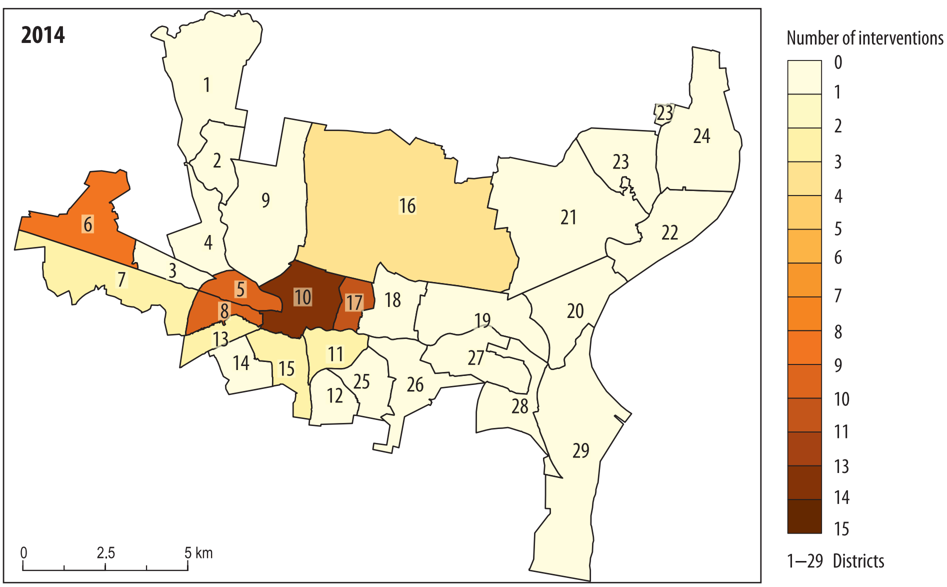

Fig. 8. Number of interventions by the State Fire Service in 2014. District names 1–29: see *Figure 1*.
Source: Authors' own compilation.

total in August) took place at the beginning of August 2014 and were the result of heavy rainfall recorded on 5 August (31.8 mm) at the ITP Glinki station, while 8.6 mm of rainfall was recorded at the ITP IHAR station on that day.

The study showed that only on some dates could the recorded precipitation totals be correlated with fire brigade interventions. Most often, interventions occurred as a result of several days of rainfall accumulation, less often as a result of a single high-intensity rainfall event. Such incidents occurred most often during the typical summer months, from June to August. The calendar of rainfall and fire brigade interventions for each month distinguishes several such dates: 7–9, 17–20 and 25–30 in June, 1–3, 6–8, 11–13, 15–19 and 28–29 in July, and 5–7, 14–16, 20–21 and 27–28 in August.

As an example, in the period 7–9.06.2011, as a result of accumulated rainfall (ITP Glinki – 59.6 mm, ITP IHAR – 98.8 mm), flooding occurred in Bydgoszcz and the state fire brigade had to intervene 36 times. However, the highest number of interventions (64) was recorded on 19.07.2015, which were caused by heavy rainfall (ITP Glinki – 19.2 mm, ITP IHAR – 0.0 mm). In the history of fire brigade operations, there were also interventions when no or little rainfall was recorded. Such a situation occurred on 16.08.2022 in the Osowa Góra district, where as many as 52 interventions were made. On that day, no rainfall was recorded at the ITP Glinki station, and at the ITP IHAR station, the rainfall total was 0.2 mm, as well as no rainfall was recorded on the previous day, i.e. 18 August. A similar situation occurred on 20 and 21 August 2022, when 31 and 18 interventions were recorded, respectively, with 0.2 mm and 3.2 mm rainfall. Unfortunately, the lack of a measuring point in this district did not allow to determine the intensity of the local rainfall.

Discussion

Research by Pradhan, P. *et al.* (2022) has shown that in Europe over the last seven decades (1950–2019), climate extremes are becoming more frequent, co-occurring and persistent. Increases in frequency and precipitation totals have been a characteristic feature of extreme precipitation changes. Seasonal changes in the spatial patterns of extreme precipitation trends may have resulted from seasonal changes in the prominence of precipitation drivers (Łupikasza, E.B. 2017). Due to the stronger fluctuations of extreme precipitation in summer, which are often associated with free convection, the anthropogenic signal is masked by internal variability (Tabari, H. *et al.* 2020). Averaged over Europe, anthropogenic influences contributed to larger increases in extreme precipitation anomalies (99.5% percentile) in all seasons of the year (Tabari, H. *et al.* 2020).

The results of rainfall monitoring in the years 2010–2022 at both measuring stations confirmed that the highest monthly rainfall in Bydgoszcz occurs in the summer months (April–October), and especially in June, July and August. This phenomenon has been observed by other authors in Central Poland (Kubiak-Wójcicka, K. 2020). In the analysed long-term rainfall distribution, it was found that rainfall was frequently concentrated in brief periods of time, leading on the one hand to an increased risk of flooding and, on the other, to periods with little or no rainfall being extended and, consequently, to the occurrence of various types of droughts (Bąk, B. and Łabędzki, L. 2013; Kuśmierek-Tomaszewska, R. and Żarski, J. 2021).

Based on the rainfall calendar in the studied multiannual period 2010–2022, several frequently recurring days and periods of increased rainfall were found. In at least some of them, rainfall caused local flooding. 6–19 July was considered the wettest period, with intense rainfall. Usually, frontal storms appeared during this period, preceded by a period of high temperature.

Local rainfall played an important role in the rainfall distribution in Bydgoszcz. This is evidenced by, among others, the areas where State Fire Service interventions were most common, which were remote from the stations recording rainfall. In some situations, flooding was limited to only a few streets and residential blocks while little to no rainfall was recorded at either station. Despite the distance of only 8 kilometres between the stations, the measured daily rainfall sums differed, which also translated into differences in rainfall sums at the monthly or seasonal (April–October) scales.

Precipitation from storms has a significant share in rainfall, especially the heaviest rainfalls. Research by Łaszyca, E. (2018) showed that, in Bydgoszcz in the years 1971–2010, most storm days occurred in July and June, and fewer in August and May. The number of storm days in the Bydgoszcz region shows an increasing trend (0.82 days per year), as shown by Sulik, S. and Kejna, M. (2022), who associate this fact with an increase in air temperature of 0.04 °C per year in the months from April to September. Piasecki, K. and Żmudzka, E. (2022) note that, if in highly urbanised areas the temperature distribution gives rise to strongly differentiated heat islands and at the same time the pressure distribution is not uniform, conditions for the formation of local storm activity arise. In such situations, local downpours occur, which can cause significant damage in relatively small areas.

The number of State Fire Service interventions to pump water from flooded streets and apartments was characterised by high temporal and spatial variability. The city's topography includes areas sensitive to pluvial flooding (e.g., districts in the west and centre of the city), areas at greater risk of fluvial flooding (areas in the immediate vicinity of the Vistula and Brda Rivers), and small, sparsely inhabited districts at practically no risk of pluvial or fluvial flooding.

The authors are aware that conducting rainfall monitoring at only two measurement points in such a large city as Bydgoszcz (176 km^2) turned out to be insufficient. For comparison, Maier, R. *et al.* (2020), who analysed the spatial variability of rainfall in the city of Graz (Austria), had at their disposal rainfall data from 22 rain gauges distributed over an area of 125 km^2. These studies confirmed that low- and medium-intensity rainfall shows good correlation among stations, while the relationships for larger rainfall sums are much weaker.

The lack of more rainfall measurement points in Bydgoszcz and the local nature of rainfall meant that it was impossible to demonstrate direct relationships between the recorded rainfall and the number of SFS interventions. According to Kaszewski, B.M. and Flis, E. (2014), a characteristic feature of extreme events is their small number, which means that the standard statistical methods used are unusable or do not give satisfactory results, and too low a density of meteorological stations also means that not all such events are recorded. Moreover, as Pińskwar, I. (2022) points out, data regarding SFS data may be subject to errors, as not every pluvial or fluvial flood is reported. Moreover, some interventions may also be due to the poor or improper functioning of technical infrastructure. This means that the assessment of flood risk in urbanised areas should be considered from a multi-aspect perspective (Kubal, C. *et al.* 2009). Taking into account the location of places frequently flooded due to rainfall, a detailed analysis of rainwater runoff in housing estates susceptible to flooding is recommended. One of the options for preventing flooding is to limit the total area of impervious surfaces and to propose concepts for water management in the form of green and blue infrastructure solutions. In this case, local adaptation to cope with future urban floods becomes important. A study by Zhou, Q. *et al.* (2018) in China showed that the volume of urban floods increases non-linearly with changes in rainfall intensity. A comparison of reduced flood volumes in mitigation and local adaptation scenarios (through drainage improvements) suggests that local adaptation is more effective than mitigation in reducing future flood volumes.

The vulnerability of urban areas to climate change and the need to strengthen their resilience to climate phenomena have been recognized in EU policies and continue to be an essential objective of the EU strategy on adaptation to climate change. The framework for a standard policy of EU Member States is set out in the document 'Adapting to climate change: Towards a European framework for action' (CEC, 2009). Based on these guidelines, each

EU Member State prepared its climate change adaptation strategy, first covering cities with more than 100,000 inhabitants, and then cities with smaller populations.

Cities across Europe have very diverse contexts, capacities and experiences and are at very different stages of readiness for adaptation, but all are taking some form of action (EEA, 2024). A comprehensive review of pluvial flood policies and strategies in urban areas across the European continent is provided by Prokić, M. *et al.* (2019). Perera, A.C.S. *et al.* (2024) reviewed 12 urban blue-green policies, tracking their evolution and comparing five common categories in European cities such as Berlin, Helsinki, London, Malmö and Southampton. The results indicate that most policies focus on increasing urban vegetation cover. Despite existing adaptation strategies, the issue of their implementation in individual regions is at different stages of advancement. A city's vulnerability to climate change's effects may vary within its administrative borders. Therefore, the first step should be to conduct a vulnerability analysis of the city, which will identify areas sensitive to extreme hydrometeorological phenomena.

Different methods exist to identify sensitive areas within the city in the literature. Various criteria are used to assess and area's vulnerability to the threat of pluvial floods, such as land use and cover, terrain height, terrain slope, and existing technical infrastructure. Research by Radu, C. *et al.* (2021) in one of the oldest districts of Bucharest in terms of development showed that the streets in the southeastern and north-western parts of the district are most vulnerable to flooding, which requires modernization of the sewage system. Similar research was conducted by Kamenská, M. and Smatanová, K. (2022) for selected Slovak cities, i.e. Hlohovec, Kežmarok, Košice-Západ, and Prešov. In these cases, the factors increasing the risk of flooding are: historically formed dense development of city centres, lack of vegetation and trees, extensive parking lots with impermeable surfaces and insufficient capacity of sewage networks. In turn, research conducted by Ullah, I. *et al.* (2023) in the historical city of Győr in Hungary allowed to determine the level of the city's resistance to floods using the integration of the physical typology of settlements with ecological factors in the study area. The research resulted in flood hazard maps.

Adaptation measures were also taken in Bydgoszcz. The Bydgoszcz City Adaptation Plan to Climate Change by 2030 (2021) took into account the main threats and four sectors most sensitive to climate change: public health, transport, water management and areas of high-intensity residential development. To increase the city's resistance to the occurrence of extreme phenomena, adaptation measures were planned, which included the development of blue-green infrastructure, modernization of the storm water drainage system, and introduction of systems for informing residents about threats. One of the effects of the implementation of the Adaptation Plan is the completed first stage of the project "Bydgoszcz green and blue. Retention and management of rainwater or meltwater" implemented by the Municipal Water and Sewage Company (MWiK) for 2025. The tasks consist of managing excessive amounts of rainwater by building retention reservoirs, developing small retention facilities and using rainwater for the needs of, among others, watering urban greenery. The implementation of the planned activities began in 2021. The assessment of the effectiveness of the planned and implemented adaptation activities to climate change in Bydgoszcz should be postponed until the completion of the construction of retention reservoirs, which is planned for 2027. Initial experiences indicate that the planned activities are bringing the expected effects.

Conclusions

The analysis performed in this study showed that:

- In this precipitation category, most days were recorded with daily precipitation in the range of 10–20 mm and 20–30 mm.
- Despite the small share of days with precipitation above 10 mm, the total daily pre-

cipitation constituted as much as 49 percent of the total precipitation at the ITP Glinki station and 42 percent at the ITP IHAR station in the analysed multi-year period. This indicates a significant share of extreme precipitation (above 10 mm). At the same time, it should be noted that there was only one case of daily precipitation above 50 mm at the ITP IHAR station and no such precipitation at the ITP Glinki station.

– The highest number of events related to flooding and waterlogging in Bydgoszcz took place in 2022 (117 fire brigade interventions) and in 2014 (74 interventions), while the lowest number was in 2013 (3 interventions).
– The monthly distribution was dominated by interventions in July (a total of 227), which accounted for 42 percent of all interventions in the period 2010–2022. There were significantly fewer in August (153) and June (132).
– The analysis of the distribution of daily precipitation and interventions by the State Fire Service showed three possible interrelationships:

1) Fire brigade interventions occurred as a result of several days' accumulation of precipitation;

2) Flooding causing fire brigade interventions was caused by incidental, extreme precipitation, while such precipitation was not always recorded simultaneously at both measuring stations;

3) Fire brigade interventions were not related to the recorded precipitation because it was absent or small.

The precipitation was of local character and appeared most often in the districts of Bydgoszcz, which were more distant from the measurement points. In such cases, the number of interventions was not only the result of extreme precipitation, but was also conditioned by local factors.

Areas most at risk of flooding were housing estates in the west and centre of Bydgoszcz. These are areas with unfavourable topographical conditions (steep slopes) and high proportions of sealed surfaces. Increasing biologically active areas that will delay surface runoff through appropriate land development using green and blue infrastructure is recommended.

In order to improve the monitoring of flood threats in Bydgoszcz, it is recommended to create an integrated network of rainfall measurement points in the city, especially in those areas where the largest number of fire brigade interventions are observed.

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Analysis of spatial dependencies and spatial effects in the relationship between economic growth and unemployment in Europe

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Abstract

The study presents an analysis of the relationship between unemployment and economic growth in European countries. The significant influence of the labour market situation on the economic condition of states is well-known. The analysis in this research was conducted using data from 43 selected European countries from 2006 to 2019. To evaluate the relationship between economic growth and the unemployment rate, enriched with spatial dependencies, spatial models for pooled time series and cross-sectional data (TSCS) were estimated. The neighbourhood was quantified using three types of connection matrices: (1) based on the common border criterion, (2) based on the maximum distance criterion, and (3) based on the similarity in economic situations. Matrices (1) and (2) relate to the geographical neighbourhood, while matrix (3) defines the economic neighbourhood based on the values of the consumption expenditures per capita. The choice of these types of matrices was associated with the migration process (geographical neighbourhood) and the imitation effect of labour market strategies (economic neighbourhood) mentioned above. Based on the estimation and verification results of the Spatial Durbin Models (SDM), the spatial spillover effects were evaluated. Cumulative spatial effects allowed us to determine countries with the greatest influence on others and countries that are following the leading ones.

Keywords: economic growth, economic neighbourhood, Spatial Durbin Model, short-term spatial effects, unemployment

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Introduction

Unemployment and insufficient economic growth are among the most important economic problems for every country nowadays. Policymakers and society concurrently monitor both processes as the primary indicators of economic development. Increasing the number of unemployed people concerns both developing and developed economies. However, unemployment in developing countries is primarily the result of capital inadequacy. In turn, technological progress is the reason for the decrease in the number of employed people in developed states (Soylu, Ö.B. *et al.* 2018). Another difference between unemployment in developed and developing countries is that the former experience extended periods of rapid economic growth. In contrast, the poorer ones either have never experienced significant growth or have had periods of economic growth and decline that occurred alternately (Madito, O. and Khumalo, J. 2014).

In theoretical and empirical macroeconomic research, the linkage between economic growth and the unemployment rate is widely studied. This relationship is one of the most important in economics. It is widely accepted that a higher growth rate of the Gross

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Domestic Product (GDP) of an economy causes a decrease in the unemployment rate. The negative short-run dependence between these processes was named Okun's law, which was formulated by Arthur Melvin Okun (Okun, A.M. 1962). Consequently, Okun pointed out that labour market modifications are the results of changes in economic development. The dependent variable in the most common direct regression of Okun's law is the difference between the actual unemployment rate (marked u_{it}) and the natural unemployment rate (or the equilibrium rate of unemployment – marked as u_{it}*). This process is dependent on the difference between actual (y_{it}) and potential or equilibrium output (y_{it}*). The regression parameter between these two processes is marked as β. Index *i* refers to the region (or another territorial unit), while index *t* indicates time. Moreover, β is an Okun's coefficient (ultimately with a negative sign). This method of considering Okun's relationship is called the Trial Gaps. Previous studies show that Okun's law is stable in many countries (Ball, L. *et al.* 2017). Instability in the relationship between states is visible in terms of the economic slowdown, resulting, i.e. from the financial crisis (Cazes, S. *et al.* 2011).

Apart from the Trial Gaps method, there are two alternative methods to estimate Okun's coefficient: (i) the First Differences method, and (ii) the Fitted Trend and Elasticity method (Barreto, H. and Howland, F. 1993). In the First Differences method, the form of the model is similar to that in the Trial Gaps method. However, the natural unemployment rate and potential output are replaced by the time lags of the actual unemployment rate (u_{it-1}) and actual output (y_{it-1}), respectively. As a result, the first differences of the unemployment rate and Gross Domestic Product are the dependent and independent variables, respectively. In turn, in the Fitted Trend and Elasticity method, the relationship between the natural logarithms of the unemployment rate (dependent variable) and GDP (independent variable) is considered. Moreover, the model is complemented by the deterministic time trend.

Based on the shown relationship, it is possible to answer what level of GDP should be expected under the economic conditions during the sample period if a certain level of unemployment is given. However, the reversed dependence has to be considered (Barreto, H. and Howland, F. 1993). The inverse relationship in the literature is also called Okun's law. The second approach is closer to economic growth theory, where the labour force is one of the factors that influence the production level. In this research, the economic growth changes as a result of changes in unemployment are speculated.

In general, Okun's law has been formulated for closed economies and refers to regional analyses. Nevertheless, nowadays, when we are dealing with the free movement of the labour force and capital, the law mentioned above can also be used in analyses across countries. As concluded by Palombi, S. *et al.* (2015) "(…) the reliability of Okun's coefficients is not only of paramount importance for macroeconomic policy, but also for the regional distribution of unemployment rates in an open spatial system". Hence, we are able to recognize that the set of territorial units which are open economies creates an open spatial system. In this case, the spatial dependencies between countries in the study of the relationship between unemployment rates and economic growth are also significant. Formánek, T. and Hušek, R. (2016) pointed out that the spatial connections shown during the analysis of the link between labour market conditions and economic growth can also be interpreted as the influence of real, practically unobservable, and difficult-to-quantify spatial effects. Among these effects, they mention cross-border work commuting preferences, accounting for administrative employment barriers between countries, language differences, and aerial distances vs. topology. The importance of including the spatial connections in the analysis of the topic mentioned above across countries can be explained with the *push-pull* concept of territorial mobility as well (Lee, E.S. 1966). Based on this idea, every country has characteristics that are conducive to taking up employment (for example, higher earnings, higher levels of work culture) as well as determinants that are unfavourable. Hence, labour force migration causes modifications in the national labour market, and at the same time, in the labour market abroad, as well as in the output of other states. Moreover, when the labour force of a country increases (for example, in times of positive economic changes), there can be a problem with providing jobs for all, and as a result, people decide to look for jobs abroad (Maza, A. 2022). Based on all these determinants, the spatial aspect in the analysis of the relationship between unemployment and economic growth is desirable. This paper provides information about the spatial spillovers determined across countries, which constitutes the novelty and research gap.

In this study, the relationship between the unemployment rate and economic growth in 43 selected European economies between 2006 and 2019 is considered. The aim of the research is to designate the consequences for countries' economic growth caused by the modifications in the labour market through changes in the unemployment rate, determining spatial spillover effects. Cumulative spatial effects allowed us to identify countries with the greatest influence on others and countries that are following the leading ones. This analysis allows us to formulate some recommendations for governments in order to use the cooperation between neighbouring countries to improve their own labour market conditions and, as a result, the economic development. Almost all studies analysing economic growth and unemployment in Europe deal with the European Union members only. In this research, it was important to include countries located in Eastern Europe (considered relatively less developed than the EU members) as well. This allows for a wider analysis of the subject of Okun's relationship in Europe. In turn, the period from 2006 to 2019 is the longest available period with complete data for the chosen countries.

In the formation of the crucial economic indicators, such as economic growth and unemployment, long-term tendencies containing the crisis periods are important. In the chosen period, the financial crisis from 2008 and economic slowdown from 2012 are included. Given that countries, especially neighbouring ones, cooperate nowadays, the spatial, and spatio-temporal dependencies in the presented investigation are included. This allows for evaluating the impact of specific changes in a given region on the economic situation in others. Therefore, the spatio-temporal Durbin Model is estimated, based on which the spatial spillovers are determined. The hypotheses of this study are as follows: (1) changes in the labour market in given country have a significant impact on the output of the other, (2) changes in the labour market conditions in more developed countries have a stronger influence on the economic growth in others than in poorer ones, (3) the economic similarity of territorial units is more important than their geographical proximity in the formation of the relationship between economic growth and unemployment.

Review of the scientific literature

In the literature, the relationship between the unemployment rate and economic growth is widely speculated. Almost all researchers consider this dependence based on Okun's law. In previous studies, it is tough to find analyses using Okun's law in the Fitted Trend and Elasticity approach.

The first type of study conducted on the relationship between these processes contains analyses for a single country based on time series. Valadkhani, A. and Smyth, R. (2015) considered this relationship for the US in the period of 1948–2015 using quarterly data. They estimated models for the Trial Gaps method of Okun's law, determining potential output and the natural rate using the Hodrick-Prescott filter (Hodrick, R.J. and Prescott, E.C. 1997). Binet, M.E. and

Facchini, F. (2013) speculated models in the Trial Gap version for French regions in the years 1990–2008. They concluded about regional heterogeneity based on Okun's coefficient estimation. In turn, Li, C.S. and Liu, Z.J. (2012) used a Vector Error Correction Model (VECM) and Granger causality test to investigate the long-term and short-term dependencies between unemployment and economic growth in China from 1978 to 2010, among others. The Granger causality approach is a very popular tool in the analyses concerning these processes. For example, Louail, B. and Riache, S. (2019) used this method to speculate about unemployment and economic growth in Saudi Arabia in the period 1991–2017. In turn, Alhdiy, F.M. with co-authors pointed out that changes in unemployment caused changes in the GDP per capita for Egypt in the years 2006–2013 (quarterly data used) (Alhdiy, F.M. *et al.* 2015). Besides, Sadiku, M. with co-authors, studied causality using the Granger approach between these processes in North Macedonia (Sadiku, M. *et al.* 2015). The case of the verification of Okun's law for Nigeria, South Africa, and the USA was of interest to Onakoya, A.B. and Seyingbo, A.V. (2020). Based on the First Difference approach, they concluded that for Nigeria, the law formulated by Arthur Okun is not applicable. Moreover, this major macroeconomic relationship was verified for developing countries like Jordan (Al-Habees, M.A. and Rumman, M.A. 2012), Albania (Nikolli, E. 2014), and South Africa (Madito, O. and Khumalo, J. 2014; Makaringe, S.C. and Khobai, H. 2018).

All authors cited so far have not considered the spatial dependence between territorial units, which is a crucial issue in terms of international cooperation. Villaverde, J. and Maza, A. (2016) used the spatial panel approach to examine Okun's law for Spanish regions from 2000 to 2014. They employed various types of connection matrices, primarily distance matrices, citing Tobler's First Law of Geography (Tobler, W.R. 1970). Based on the Spatial Durbin Model, Villaverde, J. and Maza, A. (2016) quantified the direct and indirect effects of output growth. Montero Kuscevic, C.M. (2014) also quantified spatial spillovers in the relationship between output and unemployment rate at the metropolitan statistical area level (MSA) in the United States. Pereira, R.M. (2014) focused on the same statistical area to estimate regional spillovers, with a particular emphasis on the asymmetry in Okun's law. Additionally, Oberst, C. and Oelgemöller, J. (2013), as well as Salvati, L. (2015), highlighted the spatial dependencies and regional effects in the relationship between unemployment and output growth. The first study examined the mentioned dependence for German regions, while the second study used data from Italian provinces. Basistha, A. and Kuscevic, C.M.M. (2017), Palombi, S. *et al.* (2017), Elhorst, J.P. and Emili, S. (2022), and Jankiewicz, M. (2023) emphasized the important role of spatial connections in analyzing the relationship and also quantified spatial spillovers based on estimated models of Okun's relationship. Nevertheless, they determined only cumulative direct and indirect spatial effects additionally at the regional level. This analysis shows the strength of the spatial spillovers for individual territorial units at the country level. Detailing the spatial spillover effects and the transfer of the analysis to the macroeconomic scale are the novelties introduced in this study. Okoro-Ugochukwu, N.A. and Adenomon, M.O. (2021) conducted their research on the relationship between unemployment and economic growth in Nigerian regions, also utilizing a spatial approach. In turn, Xu, B. *et al.* (2021) introduced spatial dependence in the analysis of the relationship between entrepreneurship and regional economic growth across China provinces from 2010 to 2016. In their research, they used Mixed Geographically Weighted Panel Regression with Spatial Autoregression (MGWPR-SAR). In all cited works, the spatial dependence in the analysis of Okun's relationship turned out to be statistically significant. This study employs different types of spatial connection matrices, which can provide further insights into the verification of Okun's law. Two matrices are based on geographical proximity: the first uses the common border criterion, while the second is built based on the maximum distance criterion (two countries are neighbours when the distance between them does not exceed 1000 kilometres). The geographical proximity is the most often considered in spatial analyses. This is related to the First Law of Geography formulated by Tobler, W.R. (1970). The third proximity matrix is based on economic similarity using the consumption expenditures per capita values. The premise for using this type of neighbourhood matrix is the significant role pointed out in the literature of consumption in the formation of economic growth and unemployment. Consumption is considered the main factor driving the economy. Moreover, the increase in consumption expenditures leads to a reduction in the unemployment rate. This is the very first time the proximity matrix based on the consumption expenditures level is employed in research based on Okun's law, which constitutes the next added value in the scientific literature.

Research methodology

The first part of the investigation deals with the analysis of a spatio-temporal structure of economic growth and unemployment to detect long-term tendencies in their formation. Initially, the spatio-temporal trend, which is responsible for the non-stationarity in the average, is analysed. The general form of the spatio-temporal trend model is characterized as follows:

$$Z(s_i, t) = \sum_{k=0}^{p} \sum_{m=0}^{p} \sum_{l=0}^{p} \theta_{kml} x_i^k \, y_i^m t^l + \varepsilon_{i,t}, \quad (1)$$

where Z denotes a considered process, $s_i = [x_i, y_i]$ is a vector of spatial units coordinates ($i = 1,2,\ldots, N$ denotes the number of territorial unity), $k + m + l \leq p$, and t indicates time.

Next, the spatial autocorrelation as the second component of the spatial structure, characterizing dependencies between neighbouring units, is tested. The Moran's I statistic verifying the presence of global spatial autocorrelation is described with the following formula (Moran, P.A.P. 1948; Schabenberger, O. and Gotway, C.A. 2005):

$$I = \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \cdot \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\,[y_i - \bar{y}][y_j - \bar{y}]}{\frac{1}{n}\sum_{i=1}^{n}[y_i - \bar{y}]^2} = \frac{n}{S_0} \cdot \frac{z^T W z}{z^T z} \quad (2)$$

where y_i indicates the observation of the process in the i^{th} region, $\bar{y}$ denotes the average value of the process, and W is the spatial connections matrix between units. In this study, three types of spatial connections matrix are concerned. The first of them is the most used in spatial analyses a neighbourhood matrix based on the common border criterion (marked with $W1$). The other two matrices are created using the maximum distance criterion, one of which concerns a geographic distance (signed as $W2$), but the next is built based on the economic distance (named as $W3$). According to the $W2$ matrix, two regions are neighbours when the distance between them does not exceed 1000 kilometers. In turn, the economic distance in the $W3$ matrix is calculated using the level of consumption expenditures per capita. The $W3$ matrix is constructed using the algorithm presented in the article conducted by Jankiewicz, M. and Szulc, E. (2021). To determine the economic spatial weights matrix, the Euclidean distance between pairs of countries is calculated (in case of only one variable, this is the Manhattan distance). Then, the borderline value of the distance between countries is fixed, and the values exceeding the borderline are replaced with zeros. Subsequently, the non-zero elements are transformed by inversion. Finally, the elements of the proximity matrix are row standardized to one.

In the next step of the study, for processes filtered out from the long-term tendencies, the spatio-temporal model of dependence is estimated. The general form of the model is as follows:

$$Y_{i,t} = \alpha + \beta_1 X_{1i,t} + \beta_2 X_{2i,t} + \varepsilon_{i,t}, \quad (3)$$

where $Y_{i,t}$ denotes the GDP per capita, whereas $X_{1i,t}$ and $X_{2i,t}$ are the unemployment rate and inflation, respectively, in i^{th} country in time t. In turn, α, β_1 and β_2 are the structural parameters of the model, and $\varepsilon_{i,t}$ indicates the spatio-temporal random component.

To confirm the need to include the spatial dependencies in the model (3), the Lagrange Multiplier tests (LM) in two versions – basic and robust – are used (Anselin, L. *et al.* 2004). Consequently, the spatio-temporal Durbin model is considered in the following form (Elhorst, J.P. 2011):

$$Y_{i,t} = \rho \sum_{i \neq j} w_{ij,t} Y_{j,t} + \alpha + \beta_1 X_{1i,t} + \beta_2 X_{2i,t} + \theta \sum_{i \neq j} w_{ij,t} X_{1j,t} + \varepsilon_{i,t}, \quad (4)$$

where $w_{ij,t}$ are elements of the block matrix of spatio-temporal connections which is expressed as (Szulc, E. and Jankiewicz, M. 2018):

$$W^* = [w_{ij,t}]_{NT \times NT} = \begin{bmatrix} W_1 & 0 & \cdots & 0 \\ 0 & W_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & W_T \end{bmatrix}, \quad (5)$$

wherein W_1, W_2,…,W_T are standard spatial connectivity matrices, such as in (2). These matrices are the same for all years in the case of $W1$ and $W2$. In turn, the economic distance matrix ($W3$) changes over time.

Based on the model (4), the so-called direct and indirect spatial effects can be quantified. To obtain the mentioned effects, the general form of the non-dynamic model, i.e., the model (6):

$$Y_t = \rho W Y_t + \alpha \iota_N + X_t \beta + W X_t \theta + \varepsilon_t, \quad (6)$$

should be transformed to its reduced form (Vega, S.H. and Elhorst, J.P. 2013):

$$Y_t = (I - \rho W)^{-1} \alpha \iota_N + (I - \rho W)^{-1} (X_t \beta + W X_t \theta) + (I - \rho W)^{-1} \varepsilon_t, \quad (7)$$

Excluding from the matrix X_t the vector corresponding to the variable X_k, i.e., X_{kt} the following form is obtained:

$$Y_t = (I - \rho W)^{-1} \alpha \iota_N + (I - \rho W)^{-1} (\dot{X}_t \beta + W \dot{X}_t \theta) + (I - \rho W)^{-1} (\beta_k I_N + \theta_k W) X_{kt} + (I - \rho W)^{-1} \varepsilon_t, \quad (8)$$

where $\dot{X}_t$ indicates the matrix from which the X_{kt} has been removed.

The matrix of partial derivatives of Y concerning the k^{th} explanatory variable of X in region 1 up to region N at a particular point in time, given as (9), designates the short-term effects.

$$\left[\frac{\partial Y}{\partial x_{1k}} \cdots \frac{\partial Y}{\partial x_{Nk}} \right] = (I - \rho W)^{-1} (\beta_k I_N + \theta_k W), \quad (9)$$

The diagonal elements of matrix (9) represents direct effects. In turn, the non-diagonal elements correspond to spillover effects. Direct effects define impacts of change in observation x_k for i^{th} spatial unit (marked with x_{ik}) on the values of the depending variable in the same region (y_i). With non-diagonal elements of effects matrices, two types of impacts (spatial spillovers) can be identified (LeSage, J. and Pace, R.K. 2009):

(1) *Average Impact to an Observation* – the average impact on individual observation y_i resulting from changing k^{th} explanatory variable by an amount across all observations (the average of the sum across the i^{th} row),

(2) *Average Impact from an Observation* – the average impact over all y_i from changing the k^{th} explanatory variable by an amount in the j^{th} observation (the average of the sum down the j^{th} column).

Data and empirical results

This study examines the relationship between economic development and unemployment in general. Economic growth is measured by Gross Domestic Product (GDP) per capita (variable Y). Unemployment is quantified as the percentage of unemployed individuals within the total labour force (variable X_1).

Based on the literature review, the analysis also includes the inflation rate (variable X_2) as an additional factor influencing the economic situation of each country. In particular, the study investigates the spatial, and spatio-temporal relations between the analysed processes. All data are obtained from the World Bank database (https://data.worldbank.org/indicator) and directly used. The following indicators were used: GDP per capita (current USD) – variable X_1, unemployment (% of total labour force) – variable , and inflation measured by the consumer price index (the annual percentage change in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals) – variable X_2. Data refer to the period of 2006–2019. All calculations and figures are performed using R software (version 4.1.1).

Table 1 presents the descriptive statistics of two crucial variables in this analysis – Gross Domestic Product (Y) and unemployment (X_1) over the period 2006–2019. It is worth noting that in the formation of both phenomena, the median value is lower than the mean value. In combination with the skewness coefficient values (1.3235 and 1.5696 for GDP and unemployment, respectively), we can note that the distributions of the considered variables are skewed right. This means that more than half of the observations have values lower than the mean. The volatility of the variables is similar and moderate. This is evidenced by the values of volatility index around 60 percent. Moreover, the kurtosis coefficient, with a value higher than two for both phenomena, indicates a too peaked distribution in comparison with the normal distribution. Additionally, in *Figure 1*, the scatterplot of the dependence between unemployment and economic growth for all countries in the whole research period (N = 602) is presented. The included regression line of negative slope allows us to pre-

Table 1. The descriptive statistics of variables used in the estimated models

Variable	Mean	Median	Minimum	Maximum
Y	34,263.0000	30,409.0000	7599.5000	114,890.0000
X_1	9.8093	7.6550	2.0100	36.0300
Variable	Standard deviation	Volatility index, %	Skewness	Kurtosis
Y	20,028.0000	58.46	1.3235	2.7865
X_1	6.2291	63.50	1.5696	2.2923

Source: Compiled by the author.

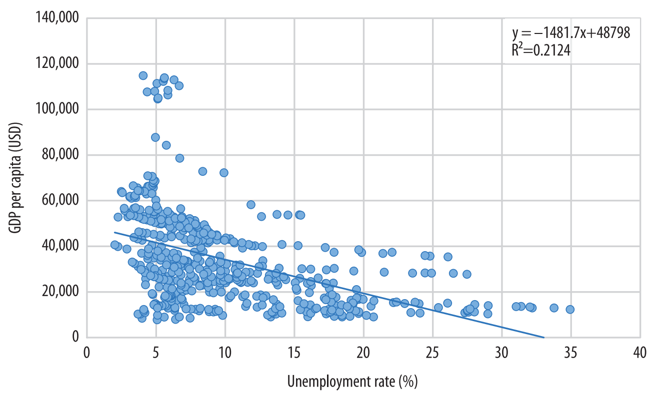

Fig. 1. The scatterplot of dependence between unemployment rate and economic growth in Europe in the period of 2006–2019 (N = 602). *Source:* Authors' own elaboration.

sume that in the considered area, higher values of unemployment are linked with lower economic growth.

In the first step of the research, the spatio-temporal trend models for GDP per capita and the unemployment rate were considered. The results of estimation and verification of the models mentioned above are presented in *Table 2*. The estimates of parameters θ_{100} and θ_{010} (negative and positive, respectively) show that in the examined period, the GDP per capita values have been increasing in the north-western direction. In turn, the average higher unemployment rate in the period was observed in South-eastern Europe. Moreover, the significant parameter θ_{001} for the GDP and also the p-values of the parameters θ_{001} and θ_{002} for the unemployment confirm the relevant changes of these processes over time.

For both models, residual spatial autocorrelation occurs in light of all defined spatial connection matrices. Nonetheless, the dependence between countries is stronger for the variable Y than X_1 for . Among the considered matrices, the highest value of Moran's I is obtained for geographical neighbours with a common border ($W1$), indicating the strongest reliance. But the strength of dependence between countries with similar values of consumption expenditures ($W3$) for GDP per capita does not differ significantly from that obtained for common border proximity. The geographical distance matrix shows the weakest connections between regions in terms of both GDP per capita and unemployment rate. On the other hand, the economic distance is not more significant for the unemployment rate than the physical distance.

Spatial dependence analysis began with the determination of its nature. For this purpose, a classical spatio-temporal model of the relationship between variables Y and X_1 was estimated and verified *(Table 3).* Additionally, the influence of inflation is considered (variable X_2). Estimates of significant parameters β_1 and β_2 indicate that increased unemployment and inflation rates harm economic growth. The negative sign of Okun's parameter (β_1) confirms the truth of the major macroeconomic relationship in European countries. Moreover, the significant Moran's statistics indicate the presence of spatial autocorrelation in the model residuals.

Table 4 shows the results of the estimation and verification of Spatial Durbin Models for the considered relationship. The sign of the estimate of parameter β_1 did not change compared to the OLS model (β_1 for OLS model is equal to -0.3852). Nevertheless, the strength of the dependence is less (the greatest difference is observed using the $W1$ matrix). Based on the significance of parameter p, it can be concluded that there is a similarity in GDP per capita between neighbouring countries. The most similar regions are those that have a common border, while the least similar are states with a similar level of consumption expenditures per capita. On the other hand, the statistical significance of parameter θ_1 indicates that changes in the labour market in neighbouring countries

Table 2. The results of spatio-temporal trend models estimation and verification

Parameter	Y			X_1		
	Estimate (p-value)			Estimate (p-value)		
θ_{000}	9.2835 (0.0000)			3.3423 (0.0000)		
θ_{100}	-0.0250 (0.0000)			0.0037 (0.0086)		
θ_{010}	0.0269 (0.0000)			-0.0325 (0.0000)		
θ_{001}	0.0162 (0.0001)			0.1302 (0.0000)		
θ_{002}	–			-0.0094 (0.0000)		
Moran test	$W1$	$W2$	$W3$	$W1$	$W2$	$W3$
I	0.3200	0.1821	0.3195	0.2283	0.0801	0.1119
p-value	0.0000	0.0000	0.0000	0.0000	0.0007	0.0002

Source: Compiled by the author.

Table 3. The results of the OLS Okun's relationship model estimation and verification

Parameter	Estimate	t-statistics	p-value
α	0.0632	3.7480	0.0002
β_1	-0.3852	-13.0850	0.0000
β_2	-0.0185	-6.6830	0.0000
Diagnostics			
R_2	0.2484		
Moran test	*W*1	*W*2	*W*3
	0.1801 (0.0000)	0.0795 (0.0007)	0.0881 (0.0023)
LM_{err}	33.8150 (0.0000)	10.6239 (0.0011)	7.6657 (0.0056)
LM_{lag}	68.0270 (0.0000)	24.9503 (0.0000)	43.0832 (0.0000)
RLM_{err}	21.2290 (0.0000)	9.7046 (0.0018)	77.4523 (0.0000)
RLM_{lag}	55.4420 (0.0000)	24.0311 (0.0000)	112.8698 (0.0000)

Source: Compiled by the author.

Table 4. The results of estimation and verification of the non-dynamic Spatial Durbin models

Parameter	Model		
	SDM *W*1	SDM *W*2	SDM *W*3
α	0.0430 (0.0049)	0.0654 (0.0001)	0.0568 (0.0003)
β_1	-0.2800 (0.0000)	-0.3514 (0.0000)	-0.3112 (0.0000)
θ_1	-0.1724 (0.0010)	-0.1383 (0.0381)	-0.4835 (0.0000)
β_2	-0.0148 (0.0000)	-0.0162 (0.0000)	-0.0148 (0.0000)
ρ	0.3854 (0.0000)	0.2224 (0.0005)	0.0818 (0.0541)
Diagnostics			
Moran test	0.0045 (0.4231)	0.0004 (0.4655)	-0.0387 (0.1215)
Log-lik	-162.8580	-194.6190	-160.4491
AIC	337.7200	401.2400	332.9000

Source: Compiled by the author.

(regardless of the used spatial connections matrix) significantly influence the output in a certain state. The impact has the same nature as changes in the unemployment rate in a certain country. In case of geographical proximity (matrices *W*1 and *W*2), it is the impact of weaker strength. In contrast, in the economic neighbourhood (matrix *W*3), the influence of labour market changes in other countries is stronger than changes within the given country. The statistical significance of parameters *p* (a close significance for *W*3 matrix) and θ_1 allows for quantifying short-term indirect spatial effects caused by shocks in the labour market conditions in European countries.

The desirable property of all models is the absence of spatial autocorrelation in residuals. Based on the Akaike criterion (AIC) and the logarithm of likelihood (Log-lik) values, the Spatial Durbin Model with the neighbourhood quantified using the *W*3 matrix is the best.

Figure 2 presents the spatial distributions of spatial spillovers obtained when considering a common border neighbourhood. The top map in *Figure 2* shows the distribution of average inflows via the unemployment rate in individual countries on the output growth in a given country. We can see that most of the Western and Northern European regions (Finland, Ireland, Norway, Sweden, United Kingdom) were among those that received transmission impulses from other regions with the lowest strength. It should be noted that these are countries characterized by relatively high economic growth. The countries most affected by all other countries through the transmission of labour market conditions included the Czech Republic, Estonia, Denmark, Hungary, Lithuania, Moldova, and Switzerland.

Map b) of *Figure 2* contains the distribution of the average impacts of a given country's unemployment rate on the economic growth in all other economies. It is worth noting that most of the countries least influenced by others were those that strongly affected other countries. Thus, changes in the unemployment rate in France, Germany, Serbia, Turkey, and Russia most strongly affect the output in other countries. On the other hand, countries such as the Czech Republic, Denmark, Estonia, Italy, Moldova, Portugal, Spain and Sweden gave the weakest transmission impulse to other countries.

In turn, *Figure 3* shows the distributions of indirect effects evaluated based on the geographical distance dependence between countries. As with *Figure 2*, the top map

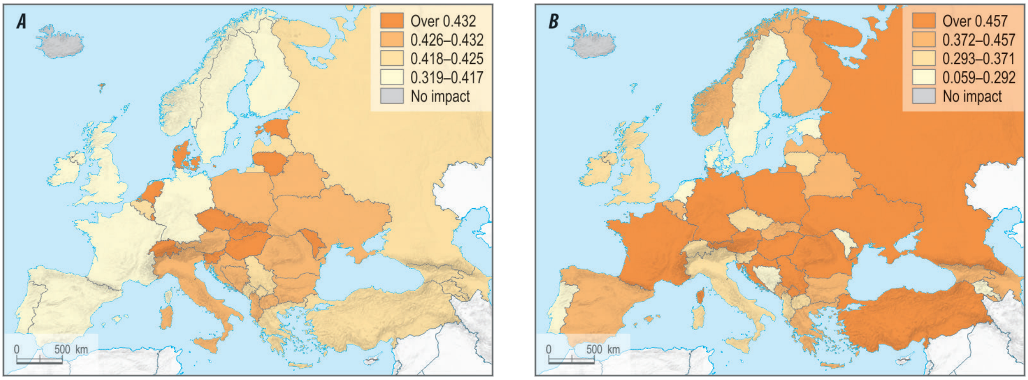

Fig. 2. The distribution of the average short-term impacts across Europe in the period of 2006–2019 of the spatially lagged unemployment rate on the output growth in individual economies *(A)*, and a change of the unemployment rate in a particular economy on the economic growth in all other economies *(B)*, based on the *W*1 matrix. *Source*: Authors' own elaboration.

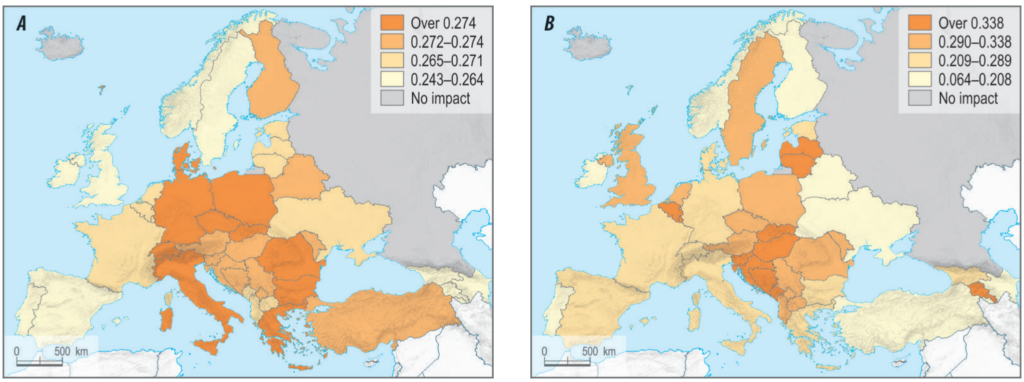

Fig. 3. For explanation see *Fig. 2*, but the values of *(A)* and *(B)* are based on the *W*2 matrix. *Source*: Authors' own elaboration.

contains average impacts to an observation, while the bottom map contains average impacts from an observation. Countries in Central Europe received the strongest transmission impulses from other countries. Moreover, Eastern and Northern European countries were highly sensitive to changes in the unemployment rate in other countries. Simultaneously, most of them had a poor effect on other economies. Among the selected countries, some showed weak strength in both spatial impacts, such as Ireland, Norway, and Spain. It is worth noting that most of the Central-Southern European countries (especially Western Balkans economies) were relatively most influenced by others. This group of regions also included Belgium, Latvia, and Lithuania.

Figure 4 presents the distributions of short-term indirect effects resulting from the economic distance between countries. We can see that, in general, countries in Eastern Europe received the highest strength transmission impulses from other countries, par-

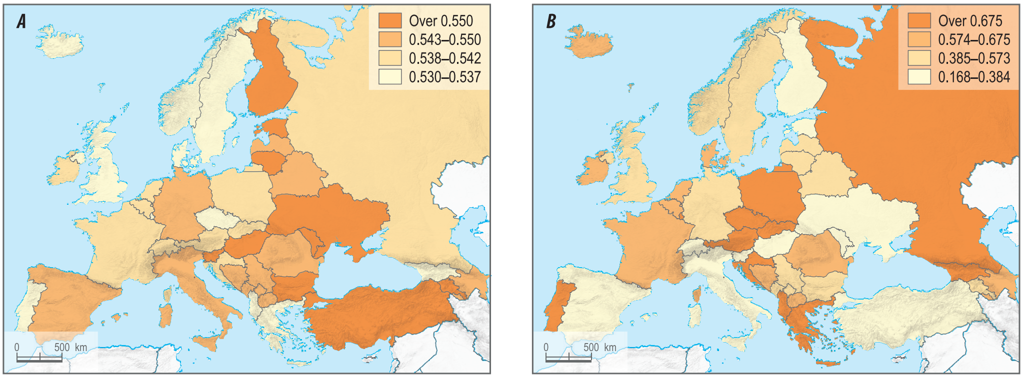

Fig. 4. For explanation see *Fig. 2*, but the values of *(A)* and *(B)* are based on the *W*3 matrix.
Source: Authors' own elaboration.

ticularly Belarus, Estonia, Latvia, Lithuania, Moldova and Ukraine. Changes in the unemployment rate in other economies had the most influence on output growth in several Southern European countries, including Croatia, Georgia Greece and Portugal. It is worth noting that the regions that were least influenced by others were the ones that most strongly affected other regions.

Conclusions

The relationship between the unemployment rate and economic growth, as one of the major relationships in economics, is widely considered in many studies. Almost all confirm the nature of this relationship, formulated by Arthur Okun, which points out that an increase in the unemployment rate causes a decrease in output growth. It is no different in this research that examines the case of European economies. Almost all cited studies concluded that the relationship between the unemployment rate and economic growth is negative. Some of them underlined the differences in the operation of Okun's law between emerging and developed economies. This is the clue for improving this research in the future by dividing the set of countries into two separate groups.

The analysis of spatial dependencies allows us to conclude the need to include interactions between neighbouring countries in Okun's relationship models. The use of several spatial connection matrices shows that the geographical neighbourhood (defined by a common border or distance between countries) was stronger than the economic neighbourhood adopted in this research (defined as similarity in the level of consumption expenditures). This means that, the third hypothesis of the research has not been confirmed. Therefore, there is a need to look for another economic similarity that may be more relevant in the relationship between the unemployment rate and economic growth than geographical proximity. This research shows that the geographical location is very important in the case of formation the economic phenomena. Undoubtedly, the geographical proximity is the source of the imitation effect, where economies follow their neighbours, primarily in terms of consumption, but not only. Most of the migrant workforce chooses the nearest countries as the goal of their migration. Additionally, the geographical neighbourhood allows economies to cooperate and establish unions more easily, what leads to their faster development. Which is why the geographical neighbourhood can be the driver for most of economic factors. Nevertheless, changes in economic growth and the unemployment rate in neighbouring regions significantly influence output growth in a certain country, regardless of the neighbourhood matrix adopted. This means that different factors are leading the labour force to take up jobs abroad. Some people prefer to be near their family home, while for others, higher earnings and much better working conditions drive migration much further. Undoubtedly, competition in the labour market and trust in the government of the host country are also factors that significantly influence the choice of workplace.

Quantified short-term spatial indirect effects show a difference in their distributions depending on the neighbourhood matrix used. Firstly, the knowledge spillover effect leads to a change in the country's labour market. Producers are able to rapidly transform their production systems by learning new technologies from manufacturers in other countries (particularly those similar in socio-economic conditions). As a result, economic growth accelerates, and short-term spatial effects become stronger. Moreover, the mobility of production factors strengthens the spatial spillovers in the short term as well, mainly labour force mobility. The worsening of the labour market in a given country often forces the population to migrate for work to other states. Comparing the spatial spillovers analysis with the studies conducted so far, this analysis confirms the significance of the spatial connections in the considered relationship, as concluded also by Palombi, S. *et al.* (2017), and Elhorst, J.P. and Emili, S. (2022). Based on the analysis presented in this paper, there is the opportunity to formulate some recommendations for policymakers. First of all, they should provide decent conditions of employment and reduce the negative modifications of the labour market conditions that have unfavourable consequences for output. So the *pull* factors have to be eliminated. Only then will the labour force not be transferred abroad. Moreover, policymakers should improve the effectiveness of economic policies and the overall condition of the economy, for example through the development of technologies and infrastructure in the labour market. All these decisions have relevant geographical consequences, particularly in the socio-economic dimension. The progressing modifications in the labour market and the economic structure can lead to changes in the age structure of the population and the structure of natural resource use. This study shows that the cooperation between the nearest economies significantly influences the economic situation. In the light of these results, policymakers should strive to the intensification of exchange of views and experiences with the governments of their neighbours. In order to slow down the outflow of human capital and, as a result, increase a potential of the national economy, policymakers should also support entities in case of the outplacement process.

Mostly in the short term, countries that received transmission impulses from other countries with the least (higher) strength were those more (less) affecting other countries. Moreover, the most highly developed countries in the short term were least sensitive to labour market shocks in the neighbouring states. Nevertheless, there is not an unambiguous division that points out that relatively highly developed countries have a greater influence on others than the poorer ones. Hence, the second hypothesis provided is not completely true.

In further research, it is worth conducting an analysis of the division into relatively poor and relatively rich economies. The division of countries considered in this study according to Human Development Index (HDI) level into developing and developed economies can provide significant conclusions about differences in the formation of economic growth resulting from changes in the labour market. Moreover, the research can be enriched with other types of spatial connection matrices. It is also interesting to compare the results obtained in this study with the analysis based on another method of estimation of Okun's relationship (Trial

Gap and First Differences methods). It is also worth studying the impact of the COVID-19 pandemic on Okun's relationship. There was a significant shock for the economies of the world, and relevant changes happened. For sure, in the studied relationship, structural change occurred. But the particular consequences of the COVID-19 pandemic can be an element of this study's improvement.

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SWOT analysis of ways to introduce innovations into agricultural production practices as a prerequisite for searching for promising areas in the field of agroforestry in the Russian Federation

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Abstract

This review aims to collect, analyse and systematize materials on ways to introduce innovations into agricultural production practices. Knowledge and understanding of the features of the mechanisms for introducing innovations allow us to evaluate agroforestry research in terms of its completeness. The basis of the research methodology is the methodological techniques of SWOT analysis. The result of the research is: the establishment of the main ways of introducing innovations into the practice of agricultural production; identifying the strengths and weaknesses inherent in these mechanisms; analysis of opportunities and threats associated with the implementation of innovations through these methods; assessment of the relationship between these tools. The main methods of promoting innovation in the field of agricultural production are: 1) the establishment of an advisory service, 2) the development and implementation of national and regional target programs, and 3) the creation and maintenance of an agroecological service. The identified ways of introducing innovation complement each other. Agroforestry research requires interdisciplinary research to integrate innovations in agroforestry development of territories into a broader agroecological context.

Keywords: method of introducing innovations, agricultural production, sustainable agricultural landscapes, advisory service, regional and national target programs, agroecological service, agroforestry

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Introduction

Agricultural production is the basis for ensuring food security of states (Zhuchenko, A.A. 2004; Dubinok, N.N. 2014; Ponisio, L.C. and Ehrlich, P.R. 2016; UNCTAD, 2017).

A threat to ensuring the production of agricultural products in the required volumes and required quality is negative environmental changes resulting from the irrational organization of the production process and climate change (Khitrov, N.B. *et al.* 2007; Challinor, A. *et al.* 2014; Lal, R. 2015; Kiss, M. 2019; Chaudhuri, S. *et al.* 2023). The most obvious of these changes in the natural environment is the loss of soil fertility (Oldeman, L.R. 1991; Pimentel, D. *et al.* 1993; Foley, J.A. *et al.* 2005; Imeson, A. 2012; Borrelli, P. *et al.* 2017; Cherlet, M. *et al.* 2018; Kertész, Á. and Křeček, J. 2019; Kulik, K.N. *et al.* 2023).

Agroforestry is one of the main types of reclamation. Due to the reclamation effect of woody plants, better conditions are created for the accumulation of humus and the supply of nutrients to plants (Abakumova, L.I. 2004, 2006; Barrios, E. *et al.* 2012; Kulik, K.N. and Pugacheva, A.M. 2016; Dollinger, J. and Jose, S. 2018; Marsden, C. *et al.* 2020; Ngaba, M.J.Y. *et al.* 2024). Important distinguishing features of this type of reclamation are the complex impact on land reclamation objects (Huang, W. *et al.* 1997; Kulik, K.N. *et al.* 2012;

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Trofimov, I.A. *et al.* 2014; Udawatta, R.P. 2017; Raj, A. *et al.* 2019; Melikhov, V.V. and Kulik, K.N. 2020; Voskoboynikova, I.V. and Ivonin, V.M. 2023). The properties of agroforestry, as a type of land reclamation, correspond to the trends in the development of agricultural production (Kosolapov, V.M. 2014; Vasilyeva, E.A. *et al.* 2014; Stavi, I. and Lal, R. 2015; Mansvelt, J.D. and Temirbekova, S.K. 2017; Trofimov, I.A. *et al.* 2018; USDA, 2019; Belokopytov, A.V. *et al.* 2022; Kesavan, A. *et al.* 2022). Agroforestry is a component of state policy in the field of ensuring the sustainability of agricultural landscapes (Rulev, A.S. and Koshelev, A.V. 2012; Buttoud, G. *et al.* 2013; Venna, R. and Burbi, S. 2023).

Many publications have been devoted to the current state of development of agroforestry work (Manaenkov, A.S. 1995, 1999, 2014, 2015; Nesvat, A.P. *et al.* 2011; Kulik, K.N. *et al.* 2012, 2015a,b, 2017, 2019, 2020; Kulik, K.N. 2014, 2015, 2018; Trofimov, I.A. *et al.* 2014; Kulik, K.N. and Pugacheva, A.M. 2016; Melikhov, V.V. and Kulik, K.N. 2018; Melikhov, V.V. and Kulik, K.N. 2020; Kulik, K.N. and Vlasenko, M.V. 2023). These works outline both the main achievements of agroforestry science and the difficulties of its development. The main modern problem, according to most authors, is the issue of a significant reduction in the area of existing protective forests. Many authors associate the reasons for this state of affairs with the transformation of the management system of the reclamation complex that occurred during the transition from a planned to a market economy (Strumilin, S.G. 1957; Baibakov, N.K. 1971; Nesvat, A.P. *et al.* 2011; Hruška, V. and Píša, J. 2019).

Diving into the problems of formulating future research allowed us to identify two important features of this process. The first feature is that identifying promising research areas is often associated with the perception of development trends at a general, conceptual level. Examples include such paradigms as adaptive landscape farming, nature-like technologies, zero land degradation, organic farming, smart villages, and others. The second feature is that an integral part of the process of searching for priority research areas is understanding the features of existing mechanisms for introducing innovations into agricultural practice. Methods or mechanisms for introducing innovations into practice are a kind of filter for differentiating theoretical concepts into viable and non-viable.

There are quite a lot of studies that reflect conceptual approaches to nature management. There are significantly fewer works devoted to generalizing existing mechanisms for implementing innovations in agricultural production practices. For this reason, the purpose of the study was to search for and generalize, using the SWOT analysis method, the properties of methods for implementing innovations in agricultural production practices. The objectives of the research included generalization of scientific works conducted in the Russian Federation and their comparison with world practices (European countries, the USA, China, India, Argentina, Brazil, and other countries). Expansion of the geographical coverage of sources involved in the analysis aims to increase the reliability of the identified generalizations.

Materials and methods

The object of research is published materials that describe specific ways to promote or introduce innovations into agricultural production practices. The achievement of the set goal was carried out in three stages.

The basis of the research methodology at the first stage is the methodological techniques used when handling scientific and technical information (Korkzhova, A.A. and Dera, V.G. 1985; Blumenau, D.I. 2002; Kushnarenko, N.N. and Udalova, V.K. 2006). The result of the research at the first stage of the ongoing research is the creation of a list of existing methods for introducing innovations into agricultural production.

The second stage of the research was a SWOT analysis of the identified mechanisms. SWOT analysis is a widely used method for assessing and structuring information. SWOT analysis is based on the assessment and comparison of four parameters: the strengths and weaknesses of the assessed object in comparison with analogous objects and an analysis of the opportunities and threats of the environment in which the assessed objects operate (Russel, J. 2019; Uchitel, Yu.G. 2019; Baghernejad, J. *et al.* 2023).

The third stage of the research is to compare the specific features of protective afforestation with the potential of the identified methods for promoting innovation in agricultural production. This comparison is aimed at identifying the preferred methods for promoting innovation in the field of agroforestry.

Results

The literature review is based on 168 sources. The distribution of publications by analysis topics is presented in *Table 1.*

The data in the table allow us to judge the diversity of the areas of scientific research covered by the review. A summary of literary sources made it possible to identify three ways of introducing innovations into the sphere of agricultural production:
– creation of a consulting service;
– implementation of federal or regional target projects;
– creation of a service for monitoring the agroecological condition.

Consulting service

A large number of scientific articles have been written about consulting services in the agro-industrial complex, the history of their development, goals, the tasks they solve, the mechanisms of their organization, legal support, sources of financing and personnel provision (Akkanina, N.V. 2004; Kireeva, O.V. 2004; Demishkevich, G.M. 2007; Datsyuk, P.V. 2008;

Table 1. Geography of publications

No.	Subject area of research	Geography of research (number of sources)	Total number of sources
1	Agroforestry	Russia (25); China, England, European Union, USA (2–2); France, India (1–1)	35
2	Sustainable development of agriculture and rational use of natural resources	Russia (9); European Union, USA (3–3); China, India (2–2);, Czech Republic, England, Germany, Hungary, Israel, Italy, Japan, South America [Argentina, Brazil], Spain, Ukraine (1–1)	29
3	Environmental degradation. Climate change. Environmental legislation	USA (4); Russia (3); European Union, Hungary, India (2–2); England (1)	14
4	Consulting service, experience in organization and analysis of functioning	European Union (13); Russia (11); Australia (2); England, Germany, India, Italy, Norway, South America [Argentina, Brazil], Ukraine, USA, Zimbabwe (1–1)	35
5	Targeted state programs in the field of nature management, experience of organization and analysis of functioning.	Russia (11); European Union (4); Africa, China, USA (3–3); Japan (2); India (1)	27
6	Agroecological service, experience of its organization and analysis of its functioning	USA (4); Russia (3); European Union (2)	9
7	Methods of handling scientific and technical information. SWOT analysis. Management. History and philosophy of science.	Russia (8); USA (5); European Union, Ukraine (2–2); India, Israel (1–1)	19
8	*Number of sources in all topics*		*168*

Source: Author's own research.

Law 2008; Farinyuk, Yu.T. and Glebova, A.G. 2011; Baumgart-Getz, A. *et al.* 2012; Belyakov, A.M. 2012; Samarkhanov, T.G. 2016; Paschen, J.A. *et al.* 2017; Ingram, J.A. and Mills, J. 2018; Nayanov, A.V. 2018; Apazhev, A. *et al*. 2019; Nettle, R. *et al.* 2021; Turner, J.A. *et al.* 2021; Ingram, J. *et al.* 2022; De Rosa, M. *et al.* 2023).

Advisory services are an important way of implementing public policy in the field of agricultural production (Birner, R. *et al.* 2009; EU Commission 2009; Badmakhalgaev, L.T. and Zverev, V.V. 2012; Curry, N.R. *et al.* 2012; Yunusova, P.S. 2014; Knierim, A. *et al.* 2017; Chaudhuri, S. *et al.* 2021; Ankita, P.V. and Chaudhuri, S. 2022; Kosova, A. 2022). By creating a "cultural environment", this tool ensures the multi-functionality of agriculture (Van Huylenbroeck, G. *et al.* 2007; Renting, H. *et al.* 2009).

"Strengths". Where the interests of the agricultural producer coincide with the interests of the state, this tool shows excellent results. An example is the introduction of drought-resistant and high-yielding varieties of grain crops.

The "weaknesses" of the advisory service include the advisory nature of its activities. Using this tool, it is difficult to implement innovations that do not bring quick profits (Chaudhuri, S. *et al.* 2023). An example is the creation of protective forest belts.

"Possibilities" of the consulting service. The range of work on agroforestry is extensive, including inventory of existing protective forest plantations, development of plans for their reconstruction, etc. To popularize a small business in the field of agroecological services, it is important to remember the capabilities of the consulting service (Manaenkov, A.S. 1999; Kulik, K.N. 2015; Kulik, K.N. *et al.* 2015a, 2023).

The "threats" of the extension service include the need to maintain impartiality to the results of scientific research. This instrument should be used with caution when introducing controversial innovations. Specialists from different extension services may have different views on the same problem, entering into conflict with each other (Faure, G. *et al*. 2012; Eastwood, K. *et al.* 2017; Compagnone, C. and Simon, B. 2018; Ingram, J. *et al.* 2022). An example is the "nautil" technology. Replacing the mechanical method of weed control with a chemical method is not supported by all scientists (Pittelkow, C.M. *et al.* 2015). In some countries, the use of glyphosate, one of the main available herbicides used in this technology, is banned at the state level (USDA, 2019; Law 2021).

An important feature of innovations promoted through this mechanism are short cycles between implementation and the result obtained. This factor is explained by the structure of financing consulting services, which is organized on a "fee for service" basis. Knowledge becomes a commodity that can be bought and sold (Foti, R. *et al.* 2007; Labarthe, P. and Laurent, C. 2013; Prager, K. *et al.* 2016). Commercialization of this service leads to duplication and fragmentation of knowledge, the emergence of problems with the dissemination of scientific knowledge (Klerkx, L. and Proctor, A. 2013; Klerkx, L. 2020; Ingram, J. *et al.* 2022).

Overcoming negative aspects in the functioning of consulting services is associated with strengthening the role of the public sector as a coordinating entity, developing uniform methods that experts are guided by, standardizing the training of consultants and their certification (Klerkx, L. *et al.* 2017; Ingram, J.A. and Mills, J. 2018; Ingram, J. *et al.* 2022).

Federal or regional target programs

The program-target approach to the introduction of innovations into agricultural production practice is discussed in a number of scientific papers (Law 1995; Ando, M.A. 2020; Bondarenko, L. 2020; Pryazhnikova, O.N. 2020; Xue, E. *et al*. 2021; Davydenko, N. 2022; Voroshilov, N.V. *et al.* 2022).

The program-target approach is based on a government contract. This approach is also called the "public goods at public expense" approach (Law 1995; Bondarenko, L. 2020; Voroshilov, N.V. *et al.* 2022; Venna, R. and Burbi, S. 2023).

The history of the development of agroforestry reclamation work is a clear confirmation of the use of the program-targeted approach (Kulik, K.N. 2014; Manaenkov, A.S. 2014; Kulik K.N. *et al.* 2015a,b, 2019).

One of the most striking examples of a previously existing target program is the so-called "Stalin's plan for the transformation of nature" (Kulik, K.N. 2014). This target program was developed by scientists from the USSR Academy of Sciences. The system of measures was aimed at combating drought, preventing the development of erosion processes, and preventing the occurrence of dust storms in the southern regions of the USSR. Over the 5 years of implementing this plan, more than 2.3 million hectares of forest were created, an ecological framework of forest belts was created on agricultural fields, the slopes of gullies and ravines, the banks of reservoirs were planted with trees and shrubs, over 13,000 ponds and reservoirs were created. The implemented measures led to an increase in grain yields by 25–30 percent, vegetables by 50–75 percent, and grasses by 100–200 percent (compared to the yield in unprotected fields). To date, in the territory of the former USSR states, this plan has no analogues either in terms of the complexity of measures or their scale (Kashtanov, A.N. *et al.* 2001). Modern examples can be national and regional projects (Website a [The Future of Russia, National projects], Website b [Regional Target Program], Website c [Long-term Regional Target Program]).

It is important to note numerous striking examples of the implementation of agroforestry reclamation work from world practice. Thus, targeted state programs for the development of agroforestry exist in the USA (Garrett, H.E.G. and Buck, L. 1997; McClure, B.K. 1998). These strategies were intensively developed under President Franklin Roosevelt, after the phenomenon of "dust storms" (Website d [Storms on U.S.]). Similar targets exist in Europe (Zanchi, G. *et al.* 2007; Rigueiro-Rodríguez, A. *et al.* 2009; Smith, J. 2010a,b), in Japan (Fujita, K. and Shaw, R. 2010; Matsushita, K. 2015), in India (Basu, J.P. 2014), in China (Carle, J. and Ma, Q. 2005; Liu, B. *et al.* 2009; Website e [UN]), in African countries (Goffner, D. *et al.* 2019; Ksenofontova, N.A. and Grishina, N.V. 2019; Website a [FAO]) and other countries.

"Strengths" of the program-target approach. The given examples of previously completed work confirm the broad possibilities of this method in solving complex and large-scale problems in the field of nature management.

The following features can be attributed to the "weaknesses" of the program-targeted approach to the implementation of innovations:

- High cost. The implementation of large-scale plans in the field of agroecology is not always possible (Dubinok, N.N. 2014).
- The program-targeted approach is based on the formulation of clear, measurable goals. This tool does not fit well into complex formulations and multifaceted concepts, such as: changing the nature of nature management, achieving sustainable nature management, overcoming irrational, unsystematic use of pastures. Achieving target measurable indicators, expressed in units of planted trees or hectares of developed territory, does not always imply correction of the processes that led to the emergence of an environmental problem. As a result, situations may arise when the fight is waged not against the cause, but against the effect. An example is a publication dedicated to the thirtieth anniversary of the "master plan to combat desertification of black lands and pastures of Kizlyar" (Kulik, K.N. *et al.* 2018). It highlights a chain of events: the emergence of an environmental problem, a surge in public interest, the development and implementation of land reclamation measures, and overcoming the consequences of the environmental problem. This sequence tends to repeat itself; it is a closed cycle (Kulik K.N. 2014; Kulik, K.N. *et al.* 2023).
- Perhaps the main drawback of the program-target approach is the fact that this method allows for the accumulation of environmental problems that are obvious

within the framework of individual nature management. The fight against negative phenomena begins only when the problems acquire a certain scale. In many ways, this state of affairs is a consequence of the peculiarities of the innovation mechanism under consideration. This method of implementation does not cover the local level of management decision-making – the level of an individual agricultural enterprise.

"Possibilities" of the program-targeted approach. With regard to agroforestry reclamation works, the program-targeted method of introducing innovations is the only and non-alternative way to solve a number of issues, such as the problem of afforestation of sandy arenas (Manaenkov, A.S. 1999), creation of protective forest plantations along river banks (Kulik, K.N. *et al.* 2017).

The "threats" of the program-targeted approach include the potential overestimation of the capabilities of this method. A worldview based on the belief that any environmental problem can be solved incorrectly. There are many examples in human history when anthropogenic destruction of the habitat led to the disappearance of civilizations (Diamond, J. 2016).

Agroecological service

Establishment of a specialized service responsible for monitoring the agroecological state of lands, development and implementation of melioration solutions aimed at increasing soil fertility. There is no experience of introducing innovations into agricultural production practices through this tool in Russia and a number of countries. However, in global practice there are striking examples of successful promotion of innovations in the field of soil protection (Bennett, H.H. 1955; Armand, D.L. 1983; Pavlovsky, E.S. 1992; Krasnova, I.O. 1997; Broslavsky, L.I. 2010; Kulik, K.N. *et al.* 2015a,b).

The Natural Resources Conservation Service in the United States is a large government agency with approximately 12,000 employees. This service has different names. The Soil Conservation Service originally grew out of the Soil Erosion Control Service, which was founded in 1933. In 1994, the Soil Conservation Service (SCS) was renamed the Natural Resources Conservation Service (NRCS – see Website f). The official website of the American Natural Resources Conservation Service has been extended by the biography of Hugh Hammond Bennett (see Website g). In the text of this article we will use the name 'agroecological service'.

The main function of the agroecological service is to ensure the achievement of the goal of reproduction of renewable natural resources (primarily soil fertility resources) by involving and stimulating specific agricultural producers in environmental protection activities. With the participation of specialists from this service, monitoring of the state of agricultural landscapes is carried out. The result of generalization of the monitoring data is an assessment of the agroecological state of vast territories and identification of agricultural enterprises within the boundaries of which the agro-landscapes are characterized by the maximum manifestation of degradation processes. Based on the assessment of the agroecological state of the lands, melioration measures are developed. The introduction of these measures into practice is stimulated by tax and credit policies. The system of response measures is diverse. In the event of organizing the fight against the catastrophic development of degradation processes, decisions can potentially be made related to the deprivation of property rights or the right to extend the lease of land to owners who do not comply with the instructions of the agroecological service.

This service has a hierarchical structure – there is a head organization at the federal level and a network of regional branches. The service has the appropriate material and technical support. The material embodiment of the agroecological service (staff, buildings, office equipment, etc.) is only the final stage of its creation. For the successful functioning of such an organization, it is necessary to first create a number of key elements in the areas of legislation, the organization of the provision of services for scientific support for the functioning of sustainable agro-landscapes and the judicial system (Lebedeva, A.N. and Lavrik, O.L. 1993; Bogolyubov, S.A. 2015; Ivanov, A.L. *et al.* 2022).

Improving the legislative framework is one of the prerequisites for ensuring the possibility of the emergence and functioning of the agroecological service. An example of a problem subject to legislative regulation is the issue of the need for legislative consolidation of the responsibility of the user of natural resources for the agroecological state of lands. The responsibility of the agricultural producer for the agroecological state of lands is manifested in his obligation to monitor the agroecological state of lands owned or leased, and the burden of implementing melioration measures aimed at preventing the development of degradation processes.

Many issues that are important to resolve when creating an agroecological monitoring service can be resolved by private licensed enterprises. Such issues include inventory of protective forest plantations, assessment of the state of small hydrological structures, etc. It is important to have modern methodological recommendations that allow standardization of typical work. When organizing the functioning of enterprises providing environmental services, it will be useful to take into account the experience of forming the cadastral engineer service (Law 2007, 2015, 2016).

Judicial system. It is necessary to have courts specializing in resolving disputes between participants in relations in the agroecological sphere (Lebedeva, A.N. and Lavrik, O.L. 1993; Bogolyubov, S.A. 2015).

Let us move on to the SWOT analysis of the agroecological service as a way of introducing innovations in the sphere of agricultural production.

The "strong point" of creating a specialized service for monitoring the agroecological state is the ability to organize the fight against degradation processes at the level of an individual agricultural enterprise. Organization of planning and implementation of melioration solutions through the agroecological service can change the nature of nature management in the agricultural sector. It can allow a transition from a scheme for combating consequences to a sequence based on the use of forecasting capabilities and the adoption of preventive measures to prevent the occurrence of degradation processes and phenomena.

The "weaknesses" of a specialized service for monitoring the agroecological state include the absence of such a service in a number of countries. To create it, it is necessary to overcome the disunity of various institutions and departments responsible for the implementation of state policy in the field of nature management.

An important circumstance in overcoming the problems of creating an agroecological service is taking into account the trends in the development of science associated with the digitalization of sectors of the national economy (Larichev, O.I. and Petrovsky, A.B. 1987; Saraev, A.D. and Shcherbina, O.A. 2006; Mayer-Schoenberger, W. and Cukier, K. 2014; Rosa Pires da, A. *et al*. 2014; Prause, G. and Boevsky, I. 2015; Vaishar, A. and Šťastná, M. 2019; Zhang, X. and Zhang, Z. 2020; Chaudhuri, S. *et al.* 2021; Szalai, Á. *et al*. 2021).

The "opportunities" of agroecological services lie in the unification of various spheres (scientific research, legislative activity, production activity and the activity of public administration bodies) within a single integrated cycle or a single production chain (Drucker, P.F. 2008; Adizes, I. 2014; Henry, N. 2014; Kulik, K.N. *et al.* 2023) of the process of creating sustainable agroforestry landscapes. As an example of a problem where it is important to build such relationships, we can consider the current "ownerless" legal status of previously created protective forest plantations. The situation may change. If an agricultural producer carries out its activities in such a way that the result is the development of degradation processes, then the agroecological service must issue it an order on the need to carry out reclamation work, and also set a deadline for this work. Based on the monitoring results, the agroecological service must assess the adequacy of the reclamation measures carried out. The consequence of such an organization of the process will be the interest of agricultural producers in owning melioration structures and managing their condition in the most economical and effective way.

"Threats". Agricultural enterprises are aimed at making a profit. Agroecological service is based on the possibilities of using the state function to ensure compliance with laws. It is extremely important to maintain a balance between the environmental imperative and the economic basis of an agricultural enterprise. It is possible that situations will arise when compliance with all environmental requirements will be able to cause bankruptcy of an agricultural producer.

Discussion

The conclusions made in different countries about the properties of the tools for implementing innovations in agricultural production practice are similar. This fact allows us to assume that the main features of the tools for implementing innovations are largely determined by their internal structure or are "inherent to them from birth" and are less related to geography. Socioeconomic factors are certainly important, but they determine the nuances and features of the functioning of advisory services in individual countries, but not their main features.

Table 2 provides a summary of the SWOT analysis of methods for introducing innovations into agricultural production practices.

The analysis of the table allows us to formulate the statement that there is no single correct and appropriate way to promote innovations in agricultural production practice. Each method has its advantages and disadvantages. The methods considered are not antagonistic, but, on the contrary, complement each other. Successful implementation of innovations can only be achieved by using the entire palette of tools. In this regard, it should be noted that in many countries, including Russia, there is no such tool as an agroecological service. Its creation carries great potential for the implementation of innovations, including for agroforestry.

SWOT analysis of methods for introducing innovations into agricultural production practice allows us to feel the trends in the development of the agricultural production management system as a whole. When searching for prospects for the development of agroforestry measures, it is important to take into account the trends in the development of the "supersystem".

Agroforestry is the implementation of a set of melioration measures carried out to improve the properties of lands, including the reproduction of soil fertility, by using the useful functions of agroforestry plantations (Law 2023). Conceptually, the role and place of agroforestry is reflected in the scheme of complex melioration of agricultural lands presented in *Figure 1.*

The "strengths" of agroforestry are related to the duration of the reclamation effect. The service life of protective forest plantations under favourable conditions can reach tens, and in some cases, hundreds of years (Rulev, A.S. and Pugacheva, A.M. 2019). The "weaknesses" of agroforestry are related to the fact that the effect of agroforestry measures begins to appear only 7–10 years after planting trees (Kulik, K.N. *et al.* 2015a,b). The "strengths" and "weaknesses" of agroforestry are opposites that are due to one circumstance - the use of woody plants as an ameliorative agent.

The categories "Threats" and "Opportunities" are also dialectically related, they are determined by the need for scientific support of agroforestry works. Knowledge and understanding of the features of the landscape and environmental conditions of the territories – the properties of the soil cover, underlying rocks, geomorphological features of the relief, features of water and wind regimes – is a key condition for the effectiveness of agroforestry measures

Table 2. Summary table of SWOT characteristics of ways to introduce innovations into agricultural production practices

Method name	Advantages	Flaws	Possibilities	Threats
Consulting service	A good result in resolving those issues when the interests of the manufacturer coincide with the interests of the state, when the result is visible in the short term.	The proposals of the consulting service are not necessarily of a recommendatory nature.	A good tool for promoting new services and products on the market that have the potential to generate profit.	You need to be careful when promoting goods and services that cause discussions and disputes.
Software-targeted approach	There are numerous examples of successful solutions to complex, large-scale, long-term problems in the field of environmental management.	The mechanism is capital-intensive, the country's budget does not always have enough funds to finance long-term reclamation activities. The mechanism allows for the accumulation of environmental damage at the local level.	This mechanism has no alternative in a number of cases. Examples are the creation of protective forest plantings in sandy areas and along river banks.	A dangerous worldview is one based on the belief that any environmental problem can be solved. The history of the development of a number of civilizations testifies to the opposite.
Agroecological service	Organization of the fight against degradation at the agricultural enterprise level. Prevention the destruction of agricultural landscape elements is cheaper than restoring them.	There is currently no such service in a number of countries.	Possibility of uniting business, science, legislative and regulatory activities of government bodies within a single production chain aimed at creating sustainable and safe production of agricultural products.	A double-edged tool. The need to maintain a balance between economic development and respect for the environmental imperative.

Source: Author's own research.

(Petrov, N.G. 1996; Rulev, A.S. 2007, 2015; Sukhorukikh, Yu.I. *et al.* 2015). Technologies for designing, assessing forest growing conditions, preparing soil for planting tree species, maintaining forest belts, solving problems of creating a forest seed base, variety testing and zoning of tree species and other issues (Kulik, K.N. *et al.* 2015b, 2017, 2019) can be implemented in practice only by creating a supporting infrastructure. In one case, the need for scientific support is a "problem" – the reduction in the area of protective forest plantations in the context of the transition from a planned to a market economy. In another case, it is an "opportunity". Agroforestry specialists are potentially able to solve most of the problems associated with the functioning of the agroecological service. This statement is a further development of the thesis on the perception of protective forest plantations as an "organizing principle for the use of agricultural lands" (Kulik, K.N. *et al.* 2017, 95).

The idea that a turning point in the development of agroforestry is taking place is suggested by the broader context of perception of the problem of finding promising research directions. Thus, a historical analysis of the development of sciences in general (Kovalchuk, M.V. 2012) allows us to identify periods when the subject of research is frag-

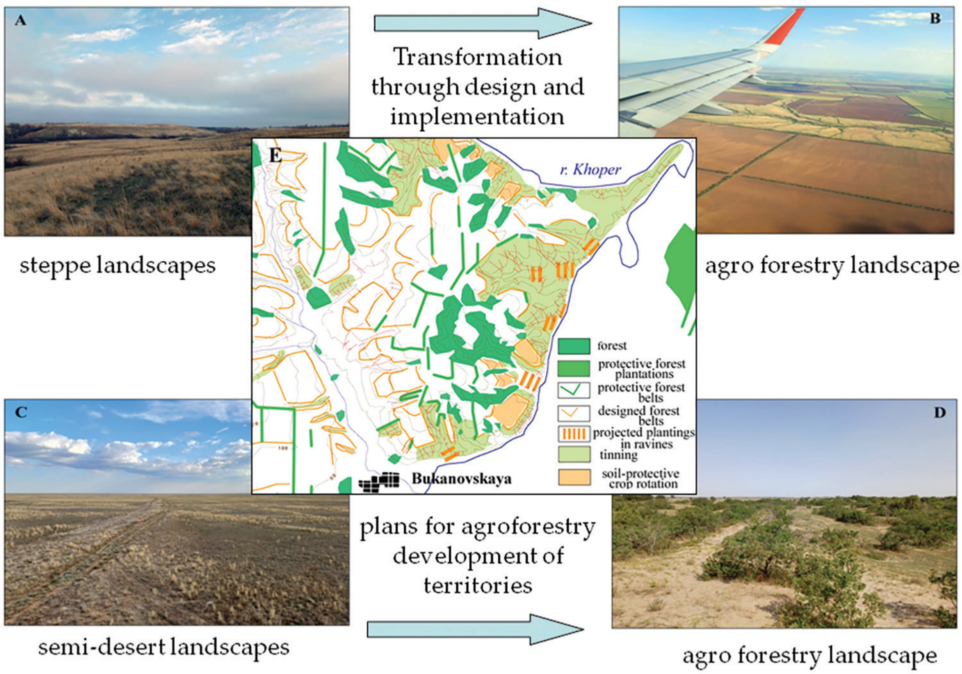

Fig. 1. Conceptual diagram of complex reclamation of agricultural land (by Tubalov, A.A. 2007). A = Steppe vegetation area, Gorodishchensky district, Volgograd region, Russia; B = Fragment of the implemented system of forest belts in the steppe zone, Ilovlinsky district, Volgograd region, Russia; C = Semi-desert vegetation area, Chernozemelsky district, Kalmykia Republic, Russia; D = Protective pasture afforestation in semi-desert, Nogai district, Dagestan Republic, Russia; E = Fragment of the agroforestry improvement plan, Kumylzhensky district, Volgograd region, Russia. *Source*: Authors' own research and processing.

mented and increasingly specialized branches of knowledge are formed, and periods when a common subject of research serves as the basis for unifying highly specialized branches of knowledge.

Repeating the same meanings, but in other words, can be found in works devoted to the generalization of patterns of system development (Altshuller, G.S. 2020). As an example, we can consider the rule of system development: growth of the system occurs to a certain limit, beyond which the system is included in the super system as one of its components, while the development of the system slows down sharply or stops, giving way to development at the level of the super system.

Events that occur in the future will either refute or confirm the conclusions made. The changes that are currently taking place inspire optimism. In Russia (based on the All-Russian Research Institute of Agroforestry), the Federal Scientific Centre for Agroecology of the Russian Academy of Sciences was created. The Soil Conservation Service in the United States was renamed the Natural Resources Conservation Service. The source and reason for these changes are related to the increasingly broad perception of the mission of these organizations.

Conclusions

The conducted research allowed to identify three ways of introducing innovations into agricultural production practice. These are methods such as: creation of consulting services; implementation of national and regional projects in the field of ecology; creation of a state agroecological service. SWOT analysis of these methods allowed to identify their strengths and weaknesses, opportunities and threats.

A promising direction of agroforestry research in the Russian Federation is the path associated with ensuring the creation and functioning of an agroecological service. This conclusion is associated with the specifics of agroforestry and the need to ensure the integrity of the application of existing methods for the introduction of innovations in agriculture.

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Health inequalities in Slovakia assessed by the Health Index: Unveiling regional disparities and their impact on the population

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Abstract

Health inequalities represent a significant social problem not only in the world but also in Slovakia. They are conditioned by several factors such as socio-economic status, geographic location, age, ethnicity and access to health care. Inequalities in the general health status of districts can be assessed using selected determinants. A composite indicator (Health Index) was used to quantitatively assess health inequalities in the districts. This Health Index consists of 8 assessment domains and 50 indicators at the district level (LAU1) in the Slovak Republic. We evaluated the data using the multi-criteria decision-making method (WSA method). The findings suggest that when districts are assigned different weights, changes occur in the health index values. Identifying problem regions is therefore very important. The health situation in Slovakia is not uniform and the results of the research showed differences between the West and the East. The districts located in the southern part of Slovakia, which achieved the lowest values of the index, can be included among the areas at risk in the context of the Health Index assessment. In order to mitigate them, it is necessary to improve access to health care, invest in prevention and improve the economic conditions of the population. It is also essential to propose possible solutions. These include improving access to preventive care and health education. The next step is reforms in the health system. These aim to reduce inequalities and improve public health.

Keywords: health inequalities, Health Index, WSA method, districts, Slovakia

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Introduction

According to the World Health Organization (2018), health inequalities refer to differences in health status as well as the distribution of health resources among different population groups. These disparities result from social factors, which may include, for example, access to education, educational attainment, employment status, income level, and gender or ethnicity. As defined by Global Health Europe (2009), the terms '*inequity*' and '*inequality*' are '*inequity and inequality*': these terms are sometimes confused but are not interchangeable. '*Inequity*' refers to avoidable inequities resulting from poor governance, corruption or cultural exclusion, while '*inequality*' simply refers to the unequal distribution of health or health resources due to genetic or other factors or lack of resources. '*Inequity*' is often measured in terms of the inequality of health or resources, which is appropriate where one might reasonably expect equality. For example, there is no reason for differences in access to health resources between men and women within a country other than cultural prejudice and or a failure of governance, basic health services should be available to all citizens within a community according to need.

In line with Arcaya, M.C. *et al.* (2015), we can refer to health inequalities as regular

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disparities that have an impact on the social and economic costs not only of the individual but also of society. Any measurable aspect of health that differs between individuals or between socially relevant groups can be termed health inequality. This is an unfair disparity, since in an ideal world everyone should have an equal opportunity to reach their full health potential. At the same time, no one should be disadvantaged in achieving it if the disadvantage can be avoided (Hübelová, D. *et al.* 2021a). Health inequalities are systematic differences in health between groups of people based on their social status. However, not every difference in the health status of a population automatically implies inequality – it becomes inequality when it is associated with characteristics that make it inequitable. Societies with significant health inequalities that affect broad segments of the population tend to face wide health inequalities. Conversely, if health inequalities affect only a small group (for example, benefit recipients, ethnic minorities or migrants), overall inequalities within the population may be relatively small, even if contrasts between these groups are stark (McCartney, G. *et al.* 2013). Schoon, P.M. and Krumwiede, K. (2022) point out that health inequalities that could be prevented by appropriate measures are the result of broader social inequalities. Given inequalities are shaped from birth and are significantly influenced by socio-economic factors throughout the life course. The conditions in which people are born, grow up, live, work and age are fundamental to their health. The realities of life are largely determined by the way in which finance, power and resources are distributed at national and local levels. At the same time, health inequalities are caused by government policies affecting the quantity, quality and distribution of determinants (Chiavarini, M. *et al.* 2014).

One of the key aspects of tracking health inequalities is the geographical space in which the disparities are analysed. Jutz, R. (2020) focuses in his paper on the comparison of health inequalities between post-communist countries of Eastern Europe and Western European countries. The study points out that the communist regime laid the foundations for different levels of health inequalities, especially in terms of education, in Eastern and Western Europe. Past research has shown that health inequalities within countries are closely related to welfare state systems. The structure and institutions of social security not only shape the daily lives of the population, but also have a major impact on socio-economic health inequalities. Factors such as access to health care, education levels, employment and living conditions are directly influenced by welfare state policies, which can either mitigate or exacerbate disparities. Chelak, K. and Chakole, S (2023) stress the importance of reducing health inequalities, with the key to addressing this being the elimination of the unequal distribution of power, finance and resources. The authors also highlight the importance of everyday living conditions, which can be influenced through the social determinants of health, as their impact on health status is considerable.

Eliminating health inequalities requires appropriate decisions from the economic and social policy environment, which influence a wide range of factors – employment, education, socio-economic status, social support networks, health policy and access to health care. Targeted interventions in these areas can make a significant contribution to improving community health and enhancing equity in health care. A wealth of research confirms that avoidable systematic health inequalities are present not only between societies, but also within them, and at all hierarchical levels. This is amply documented in the literature on the subject. As examples, some of the works of (Graham, H. 2004; Ottersen, O.P. *et al.* 2014; Cabrera-Barona, P. *et al.* 2015; Agenor, M. 2020).

Theoretical aspects

Population health is closely related to the socio-economic organisation of society, which forms the basis for effective policies to improve it. While it is important to ensure quality and efficient health services, health goes beyond health care. Government and private sector policies at all levels significantly influence the health status of the population. Health policy decisions should be based on the best available evidence, as should policies on the social determinants of health. A wide range of factors are addressed, such as the impact of early life, social gradients, job insecurity, psychosocial environment, transport, social support, food policy, poverty, social exclusion, ethnic inequalities, housing. These factors shape health inequalities and understanding them is key to developing effective strategies to mitigate them (Marmot, M. and Wilkinson, R. 2005). According to Marmot, M. (2010), a combination of poor social conditions, bad government policies and inequitable distribution of wealth in society causes health disparities among people. Social and economic disparities are an inseparable reality in every country. However, these differences should not cause disease, misery, poverty and suffering to the extent that we are seeing today. It is unjust, however, not uncontrollable. And that is the essence of health inequalities.

Public health research and action is built on a shared understanding of 'health' and the related concept of 'health inequalities'. The literature has discussed differences in how these concepts are understood and defined and how this translates into measurement, analysis and interpretation. The assumptions, emphasis and values underlying the use of different approaches are less often explicit (Krieger, N. 2011). Weinstein, J.N. *et al.* (2017) concur with the definition of health inequalities as they, like others, consider them as systematic differences that certain population groups must overcome to achieve optimal health. This leads to inequitable and avoidable disparities in health outcomes. In their publication, they explain the interconnectedness between health inequalities, structural inequalities and social determinants of health. The authors state that the social, environmental, economic and cultural determinants of health create the conditions in which structural inequalities produce health inequalities. Thus, the point is that structural inequalities, which represent a variety of personal, interpersonal, institutional, and systemic drivers. For example, racism, gender discrimination, class, adaptive capacity, etc., which are important for the equitable distribution of health opportunities and outcomes.

Like other authors, Adler, N. *et al.* (2007) confirm that the relationship between health and socio-economic resources is complex because they influence each other. The imaginary rung (the level of our socio-economic status) we are on affects our health, and our health in turn affects our ability to reach higher levels. Regarding perceptions of health inequalities in the United States, Dickman, S.L. *et al.* (2017) explain that the deepening of economic inequality in the US is accompanied by widening health disparities. They also argue that a health care system that could reduce health disparities often instead exacerbates them. Among the key findings, the authors note that the gap in life expectancy is widening among populations with different incomes, which in practice means that the wealthiest residents of the United States are living 10 to 15 years longer (10.1 years for women, 14.6 years for men) than the poorest population.

The World Health Organization talks about the fact that not only poverty itself causes health inequalities, but in fact the social meaning of disadvantage plays a role if you are poor, unemployed, socially excluded or otherwise stigmatized (Scholz, N. 2020). According to Docteur, E. and Berenson, R.A. (2014) a report by the European Commission identifies five broad challenges that need to be addressed in order to minimise health inequalities within the member states of the European Union. These challenges are (improving the evidence base to assist policy making, addressing the social determinants of health, ensuring universal access to health care, promoting and educating for healthy lifestyles, strengthening health governance).

In their study, Mackenbach, J.P. *et al.* (2018) analyse trends in health inequalities in 27 European countries. They explain that inequalities in mortality and morbidity are a highly persistent phenomenon among socio-economic groups. This is despite the fact that they have been the focus of public health policy in many countries. They analysed health trends by education in European countries, paying particular attention to the possibility of breaking trends that may have been affected by the 2008 financial crisis. Their research found that in Western Europe, inequalities in mortality have decreased due to a decline in overall mortality, both among lower- and higher-educated populations. Most Western European countries have been experiencing such a decline in mortality for several decades, influenced by steadily improving living standards, advances in prevention, particularly through changes in health-seeking behaviour, and health care. Advances in prevention have also resulted in a more rapid decline in mortality from smoking-related diseases and coronary heart disease. On the other hand, the high number of healthy life years in Malta can be attributed to factors such as high life expectancy, a well-functioning health care system, a reduction in premature deaths (especially from cardiovascular disease and cancer), but also to ongoing efforts to address public health challenges and an improving health system (Azzopardi-Muscat, N. *et al*. 2017). Health disparities across Europe between social groups have also been documented in another study by Salmi, L.-R. *et al.* (2017). The summary and results of the Addressing Inequalities in Regions (AIR) project, which identified illustrative interventions and policies developed in European regions aimed at reducing inequalities at the primary health care level.

As with poverty measures, health inequalities can be assessed in absolute or relative terms. This may be important when there are secular trends in the average health of the population (e.g., a downward trend in the average may increase relative inequalities even if absolute disparities remain stable). Consequently, methods for determining health inequalities vary depending on which inequality is of most interest. Health inequalities persist over time and have been found in most countries where they have been studied (McCartney, G. *et al.* 2019). According to Hübelová, D. *et al.* (2023), several classifications of the determinants of health inequalities and their impact on population health are known. As an example, we refer to the Conceptual Framework for Action on Social Determinants of Health (Solar, O. and Irwin, A. 2010). The impact of different factors on population health has been identified as follows: genetic basis accounts for 10–15 percent, health and health care accounts for 10–15 percent, environment accounts for 20 percent and lifestyle factors account for 50 percent (Marmot, M. and Wilkinson, R. 2005). In addition, the County Health Ranking Model (UW Population Health Institute, 2020) uses the following proportions: health and health care contribute 20 percent, environment contributes 10 percent, social and economic factors contribute 40 percent, and lifestyle factors contribute 30 percent. According to the EURO-HEALTHY project, the Population Health Index (PHI) is developed for EU countries at NUTS2 level (the regional level unit for the application of regional policies) and for 10 selected metropolitan areas (EURO-HEALTHY Consortium 2017). The results show that systematic spatial inequalities persist in Europe at NUTS2 level. In a spatial context, a study conducted in France (Fayet, Y. *et al.* 2020) is a geographic classification of health studies (GeoClasH). It is inspiring and stimulating due to its focus on the municipal scale when considering variables from the physical environment, social characteristics of the population and spatial accessibility to health care.

According to Pearson-Stuttard, J. and Davies, S.C. (2025), the recommendation for the CHI (Composite Health Index) was based on two themes: health as a basic economic asset and persistent health inequalities, particularly in terms of healthy life expectancy. Both themes have become more pressing since the COVID-19 pandemic, as economic inactivity and health inequalities have worsened. All data used in the Health Index come from publicly available sources, usually the Office for National Statistics (ONS) or other government departments. The purpose of the ONS Health Index is to measure the state of health within communities and provide detailed information using 56 indicators in three domains: healthy places (the wider determinants of health), healthy lives (health-related behaviours) and healthy people (health outcomes). The ONS Health Index revealed substantial differences in health status over time and geography. Although the national score improved from 2020 to 2021, it remained lower than before the pandemic. Health inequalities between communities have also deepened. Objective identification and monitoring of health inequalities is essential at two levels: (National Academies of Sciences…, 2016) to improve the average quality of health of the population and to reduce inequalities in achieving good health themselves. Creating a quality and sustainable environment and an adequate level of economic and social development simultaneously promotes good health and social justice (Costa, C. *et al.* 2019).

Data and method

To assess health inequalities in Slovakia, we used a composite indicator – the Health Index. The Health Index includes 47 health determinants and indicators. One of the key aspects in selecting the indicators was the availability of data in public databases over time and at the required geographic level (79 districts of the Slovak Republic). Another crucial aspect was determining the scope of available indicators (health determinants, health status, health care, etc. (Braveman, P. 1998). The overall Health Index is composed of eight areas (1. Economic conditions and social protection, 2. Education, 3. Demographic indicators, 4. Environmental conditions, 5. Individual living conditions, 6. Road safety and crime, 7. Health and social care resources, and 8. Health status). It highlights spatial differentiation in health inequalities based on a complex set of relevant determinants and health indicators. Through this index, we can track spatial differentiation using 47 indicators, expressed as a single value – the Health Index. The list of indicators is documented in *Table 1*.

The data were obtained from publicly available databases, including the Statistical Office of the Slovak Republic, the National Health Information Centre, the Ministry of Labour, Social Affairs and Family of the Slovak Republic, the Ministry of the Interior of the Slovak Republic, the Slovak National Emission Information System, and the 2021 Population and Housing Census. The data cover the years 2021 and 2022. The Health Index is a mathematical combination of variables reflecting several selected indicators (Nardo, M. *et al.* 2005). The method used to calculate the Health Index was a multi-criteria variance evaluation method, specifically the Weighted Sum Approach (WSA). The WSA method is based on the principle of maximizing utility. It also assumes linearity and maximization of all partial utility functions, which are obtained by normalizing the original input data. The higher the value of the Health Index, the more favourable the situation in the region. The calculations were performed using MS Excel, Microsoft Corporation, Redmond, DC, USA. We approached the Health Index values for individual districts in Slovakia in two ways. In the first case, each of the eight areas had equal importance with a weight of 1 (WSA method without weights). In the second case, each of the eight areas had a specific weight (WSA method with weights). The weights of the areas were adopted according to the methodology by (Hübelová, D. *et al.* 2021b). Their methodology explains how to create and determine the significance of each area, which was based on an interdisciplinary expert assessment using the Delphi method.

A total of ten independent experts from various scientific fields (sociology, demog-

Table 1. Description of the research group area 1–8

Area	Theme	Description
1. Economic condition	Employment rate	*Unemployed persons (total)*: number of available jobseekers aged 15–64 compared to persons of the same age, %
		Unemployed persons (men): number of available jobseekers aged 15–64 compared to persons of the same age, %
		Unemployed persons (women): number of available jobseekers aged 15–64 compared to persons of the same age, %
		Jobseekers aged 50–64: number of jobseekers aged 50–64 compared to persons of the same age, %
		Jobseekers aged 15–24: number of jobseekers aged 15–24 compared to persons of the same age, %
		Jobseekers with an unemployment duration of 12 months or more: number of jobseekers with an unemployment duration of 12 months or more compared to the total number of jobseekers, %
		Jobseekers with basic education: number of jobseekers with basic education compared to the total number of jobseekers, %
		Jobseekers with secondary vocational education without completing a leaving exam (incl. apprentices): number of jobseekers with secondary vocational education without completing a leaving exam (incl. apprentices compared to the total number of jobseekers, %
2. Education	Educational structure	*Population with basic and incomplete education*: share of persons with basic and incomplete education aged 15 and over in relation to persons of the same age, %
		Population with university education: share of persons with university education aged 15 and over in relation to persons of the same age, %
3. Demographic situation	Migration	*Foreigners by the most frequent citizenships*: sum of the number of most frequent citizenships of foreigners in relation to the whole population, %
	Aging	*Age index*: number of persons aged 65 and over compared to the number of persons aged 0–14, %
	Urbanization	*Level of urbanization*: share of population living in cities, %
	Ethnic structure	*Roma population*: share of population with Roma nationality, %
4. Environmental conditions	Air quality	*Annual average concentration of suspended particular matter PM2,5;* in μg/m^3
		Annual average concentration of suspended particular matter PM10; in μg/m^3
		Annual average concentration of benzol[a]pyrene; in ng/m^3
		Annual average NO2 concentration; in μg/m^3
		Annual average benzene concentration; in μg/m^3
5. Individual living conditions	Living conditions	*Average living space per person*; m^2
		Heating method: share of dwellings heated by electricity or gas to dwellings heated by solid fuels; coefficient
	Technical infra-structure	*Share of municipalities in the district with connection to the sewerage system terminated by a WWTP*; %
6. Road safety and crime	Traffic accidents	*Total traffic accidents*: total number of traffic accidents in relation to the total population; per 1000 inhabitants
		Total traffic accidents under the influence of alcohol: number of traffic accidents under the influence of alcohol relative to the total population; per 1000 inhabitants
		Deaths due to road accidents: number of deaths due to road accidents relative to the number of inhabitants; per 100,000 inhabitants
	Crime	*Deaths due to assault (attack)*: number of deaths due to assault (attack) relative to number of inhabitants; per 100,000 inhabitants
		Registered offenses: number of registered offenses in relation to the total population; per 1000 inhabitants

Table 1. Continued

Area	Theme	Description
7. Sources of health and social care	Health care capacities	*Physicians in healthcare facilities*: number of physicians relative to the total population; per 1000 inhabitants
		Hospital beds: number of hospital beds in relation to the total population; per 1000 inhabitants REGIONS (identical value of the region level assigned to the districts of the respective region)
	Social care capacities	*Place in social service facilities*: number of places in social services facilities relative to the total population; per 1000 inhabitants REGIONS (identical value of the region level assigned to the districts of the respective region)
8. Health status	Life expectancy and mortality structure	*Life expectancy at birth (men)*; year
		Life expectancy at birth (women); year
		Total mortality: total number of deaths relative to the total population; per 100,000 inhabitants
		Male mortality: number of male deaths relative to total male number; per 100,000 inhabitants
		Infant mortality: number of deaths within 1 year relative to total number of live births; per 1000 live births
		Neonatal mortality: number of deaths within 28 days of birth versus number of live births, per 1000 live births
		Deaths from infectious and parasitic disease: number of deaths from infectious and parasitic disease relative to the total population; per 100,000 inhabitants
		Deaths from circulatory system diseases: number of deaths from circulatory system diseases relative to the total population; per 100,000 inhabitants
		Deaths from respiratory diseases: number of deaths from respiratory diseases relative to the total population; per 100,000 inhabitants
		Deaths from malignant neoplasms: number of deaths from malignant neoplasms relative to the total population; per 100,000 inhabitants
		Deaths from gastrointestinal diseases: number of deaths from gastrointestinal diseases relative to the total population; per 100,000 inhabitants
		Deaths from other causes: number of deaths from other causes relative to the total population; per 100,000 inhabitants
		Intentional self-harm (men): number of men who died as a result of self-harm relative to the total number of men; per 100,000 inhabitants
		Intentional self-harm (women): number of women who died as a result of self-harm relative to the total number of women; per 100,000 inhabitants
		Death due to liver disease: number of deaths from liver disease (alcoholic, toxic, cirrhosis, chronic and other inflammations and diseases) relative to the total population; per 100,000 inhabitants
		Death due to smoking tobacco: number of deaths due to smoking tobacco (malignant neoplasm of larynx, trachea, bronchi and lungs) relative to the total population; per 100,000 inhabitants
		Diabetes mellitus deaths: number of deaths due to diabetes mellitus relative to the total population; per 100,000 inhabitants

Source: Authors' own research and processing.

raphy, environmental science, medicine and public health, law) and experts from practice (health policy, public health support, preventive medicine) related to population health anonymously assigned a weight (significance) to each area *(Table 2).* The areas were always evaluated as a whole, meaning the weight of individual areas was not influenced by the number of included indicators. The weights of the areas were determined through a questionnaire, and the experts' opinions were refined through a three-round evaluation (Han, H. *et al.* 2012). The Health Index in the Slovak population and its spatial differentiation will be evaluated in the light of the theoretical background and the appropriately chosen methodological approach.

The data used in this study relate to 47 indicators, divided into 8 different areas. Each of the examined areas contains between 2 and 17 indicators *(Table 3).*

Methodologically, we divided the creation of the study into three phases. In the first phase, we obtained the assessment of districts for each area separately (with equal weights for indicators within the areas) using the WSA method. In the second phase, the same method was applied to evaluate all eight areas together (first with equal weights for all eight areas, and then with different weights assigned by a group of experts). The overall result of our evaluation was the creation of the Health Index for individual districts in Slovakia. In the third phase, we graphically represented the Health Index values on a map of Slovakia, dividing them into clusters and identifying spatial disparities. For the evaluation, we used the Weighted Sum Approach (WSA), a method based on maximizing utility. This method is one of the most frequently used in this field. It is based on constructing a linear utility function on a scale from 0 to 1. The worst variant for a given indicator will have a utility of zero, while the best variant will have a utility of one. Other variants will have a utility between these two extreme values (Kampf, R. 2002).

According to Friebelová, J. and Klicnarová, J. (2007), the ideal variant H with evaluation (h_1, h_2, ..., h_n) and the baseline variant D with evaluation (d_1, d_2, …, d_n) must first be determined. The utility of the ideal variant is 1, and the baseline variant is 0. The resulting utilities for specific variants range between these values. Furthermore, a standardized matrix R is created, whose elements are obtained using the formula:

$$r_{ij} = \frac{y_{ij} - d_j}{h_j - d_j} \qquad (1)$$

where r_{ij} represents the standardized value of the i-th variant and the j-th indicator.

For each variant, the overall utility of the i-th variant, $u(y_i)$, is calculated as a weighted sum of partial utilities and their corresponding weights, where v_j is the weight of the j-th indicator:

$$u(y_i) = \sum_{j=1}^{k} v_j \cdot r_{ij} \qquad (2)$$

Table 2. Areas assessed in the Health Index and their associated weightings

No	Area	Weight
1	Economic conditions and social protection	0.19
2	Education	0.18
3	Demographic indicators	0.08
4	Environmental conditions	0.14
5	Individual living conditions	0.09
6	Road safety and crime	0.04
7	Health and social care resources	0.10
8	Health status	0.20

Source: Authors' own research and processing.

Table 3. Basic description of compared areas

No	Area	Number of criteria
1	Economic conditions and social protection	8
2	Education	2
3	Demographic indicators	4
4	Environmental conditions	5
5	Individual living conditions	3
6	Road safety and crime	5
7	Health and social care resources	3
8	Health status	1

Source: Authors' own research and processing.

In accordance with ALINEZHAD, A. and KHALILI, J. (2019), each indicator f_j (denoted as A_j^+) represents the highest value of the indicator, $A_j^+ = \max y_{ij}$, and A_j^- represent the lowest value of the indicator, $A_j^- = \min y_{ij}$. Based on the data y_{ij}, for each alternative (in our case, district) a_i and each indicator f_j, we calculate the standardized value r_{ij}:

$$r_{ij} = \frac{y_{ij} - A_j^-}{A_j^+ - A_j^-} \quad \text{(formula A1)}$$

$$r_{ij} = \frac{A_j^+ - y_{ij}}{A_j^+ - A_j^-} \quad \text{(formula A2)}$$

The final ranking is based on utility – the higher the value, the better it is:

$$u(a_i) = \sum_{j=1}^{k} v_j \cdot r_{ij}, \forall\, i = 1, ..., p. \quad (3)$$

Results

In this section, we will describe the steps we followed in calculating the utility in our study. As an example, we will use the Area 2 (Education), which consists of two indicators (criteria): 2_1 Population with basic education (%) and 2_2 Population with higher education (%). The evaluation using WSA starts with the data matrix Y *(Table 4)*, where the lowest (minimum) and highest (maximum) values are found. The use of formula A2 applies to the first criterion, which we want to minimize, and the use of formula A1 applies to the second criterion, which we want to maximize. Next, the matrix is standardized according to the formula r_{ij}. For example, for the district Bratislava I, the standardized value for the indicator 2_1 is calculated as (40.23–2.82) / 37.41 = 1.000. The best district has a value of 1 (in the case of indicators 2_1 and 2_2, this is the district Bratislava I, as shown in *Table 5*). Next, an equal weight (in this case, ½) is assigned to each indicator, and a weighted matrix is calculated (see *Table 5*). Finally, the overall utility for each district is computed as the sum of the values in the row of *Table 5 (Table 6)*. This result from the first phase is used as input for the second phase, where the same steps are carried out for the eight areas (treated as indicators). Subsequently, we are able to determine the Health Index value for each district of Slovakia.

The Health Index will be spatially analysed at the level of districts of Slovakia. The spatial breakdown of Slovakia is shown in *Figure 1*.

One important step was to identify the key determinants and indicators of health positions that underlie health inequalities. We

Table 4. Data for Area 2, selected districts – Education

Data (Y matrix)			
No.	District	Crit. 2_a	Crit. 2_b
1	Bratislava I	2.82	55.41
2	Bratislava II	7.80	30.78
3	Bratislava III	5.92	35.96
4	Bratislava IV	5.83	37.52
5	Bratislava V	7.13	31.43
…	…	15.78	16.73
50	Lučenec	19.65	10.81
51	Poltár	26.52	7.07
…	…	17.19	11.88
78	Spišská Nová Ves	16.08	11.16
79	Trebišov	18.19	9.02
–	Crit. type	min	max
–	minimum A_j-	2.82	5.90
–	maximum A_j+	40.23	55.41
–	max-min	37.41	49.51
–	crit. weights v_j	0.50	0.50

Source: Authors' own research and processing.

Table 5. Normalized matrix for Area 2 – selected districts

Normalized matrix R (r_{ij} values)			
No.	District	Crit. 2_a	Crit. 2_b
1	Bratislava I	1.0000	1.0000
2	Bratislava II	0.8670	0.5025
3	Bratislava III	0.9172	0.6072
4	Bratislava IV	0.8848	0.6386
5	Bratislava V	0.88.48	0.5158
…	…	…	…
50	Lučenec	0.5502	0.0992
51	Poltár	0.3665	0.0237
…	…	…	…
78	Spišská Nová Ves	0.6457	0.1064
79	Trebišov	0.5891	0.0631

Source: Authors' own research and processing.

Table 6. *Results of WSA for Area 2 (weighted matrix and utility of selected districts)*

Weighted matrix				
No.	District	Crit. 2_a	Crit. 2_b	Utility $u(a_i)$
1	Bratislava I	0.5000	0.5000	1.0000
2	Bratislava II	0.4335	0.2513	0.6848
3	Bratislava III	0.4586	0.3036	0.7622
4	Bratislava IV	0.4424	0.2579	0.7791
5	Bratislava V	0.3399	0.0780	0.4178
…	…	…	…	…
50	Lučenec	0.2581	0.0137	0.3028
51	Poltár	0.2800	0.0316	0.3116
…	…	…	…	…
78	Spišská Nová Ves	0.2247	0.0172	0.2419
79	Trebišov	0.2179	0.0063	0.2243

Source: Authors' own research and processing.

analysed the districts that we deliberately selected based on the highest and lowest health attainment values calculated by the WSA method *(Table 7).* We used a decomposition of the Health Index into domains to identify key determinants and indicators (outcomes) of community health that reflect positive and negative inequalities *(Table 8)*. A more detailed analysis of the results was carried out for the districts, which were assigned different weights. Within the domains, we specified sub-indicators. Decomposing first, we present a comparison of the results of all domains by districts with a high value of the Health Index WSA calculated with weights (districts – Bratislava I, Bratislava IV, Senec, Bratislava V, Košice I).

The main contributors to the positive results for these districts include Area 2 (education; weight 0.18) and Area 8 (health; weight 0.20). In Area 2, education is characterised by an above average proportion of people with a university degree and a low proportion of people with incomplete or primary education. In Area 8, health conditions are associated with above-average life expectancy and below-average overall standardized mortality, as well as below-average mortality by underlying causes of death, including deaths caused by tobacco smoking and diabetes mellitus. In Senec district, the results are also favourable in Domain 3 (demographic conditions; weight 0.08) and Domain 8 (health status; weight 0.8).

In Domain 1, the districts of Bratislava I, Bratislava IV and Bratislava V scored particularly favourably on the economic conditions and social protection index *(Figure 2).* These

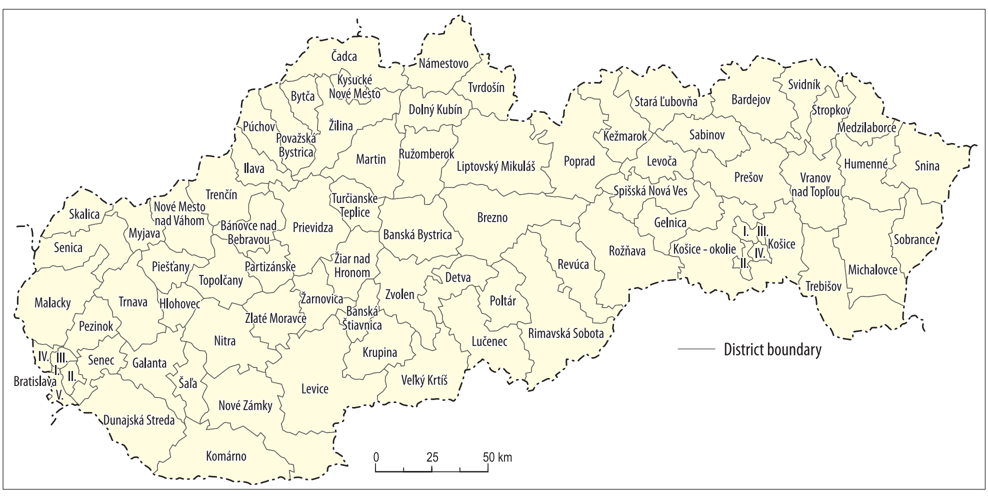

Fig. 1. Regional division of Slovakia. *Source:* Authors' own processing.

Table 7. *WSA (Weight 1) and WSA (different weightings)*

No.	WSA (Weight 1)		WSA (different weightings)	
	District	Health Index	District	Health Index
1	Senec	0.71	Bratislava I	0.82
2	Bratislava I	0.70	Bratislava IV	0.74
3	Bratislava V	0.68	Senec	0.73
4	Košice I	0.67	Bratislava V.	0.73
5	Košice IV	0.67	Košice I	0.72
75	Trebišov	0.41	Trebišov	0.38
76	Sobrance	0.40	Medzilaborce	0.37
77	Rožňava	0.38	Rožňava	0.35
78	Rimavská Sobota	0.35	Rimavská Sobota	0.31
79	Revúca	0.32	Revúca	0.30

Source: Authors' own research and processing.

districts benefited from the dynamic economic environment of the capital city, which is characterised by a high concentration of investment, a well-developed business sector and a wide range of employment opportunities. The average unemployment rate in these districts was significantly lower than the national average, reflecting the stable economic base and high level of employment. In the capital Bratislava and in the Košice I district, we observe unfavourable results in area 3, which includes demographic indicators (with a weight of 0.08). This negative trend is due to the current demographic situation, characterised by declining birth rates, an ageing population and an increasing dependency index, which points to a growing proportion of economically inactive residents. On the contrary, Senec district maintains a favourable position in this area. This development is mainly the result of above-average birth rates and high immigration rates. The inflow of new inhabitants is closely linked to the strong suburbanisation process that has been observed in the region for a long time. Senec benefits from its proximity to Bratislava, while the attractiveness of the district is enhanced by the availability of housing, quality infrastructure and favourable conditions for family life.

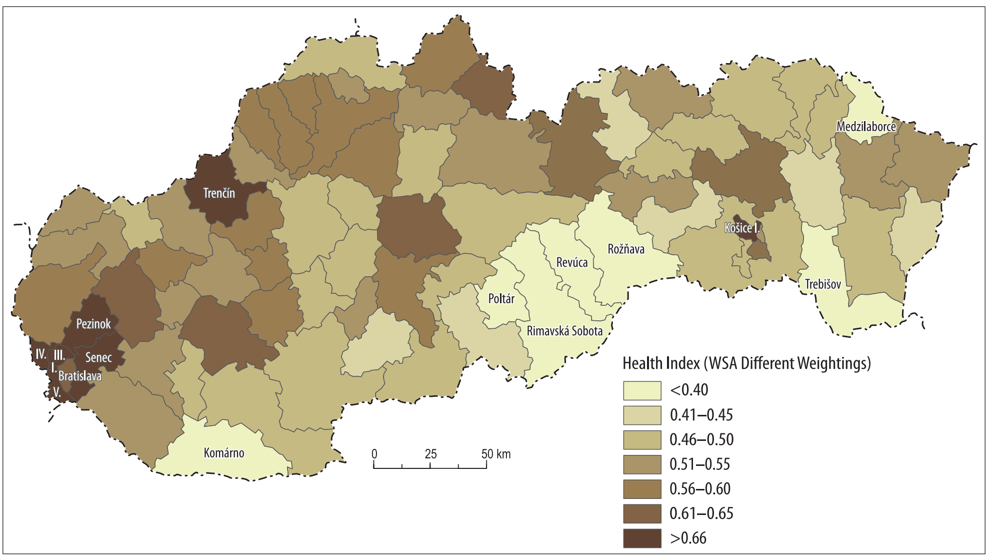

Fig. 2. Spatial differentiation based on the calculation of the Health Index values using equal for the different areas – WSA method (2021–2022). The higher Health Index values are indicated by the darker colours of the districts. *Source:* Authors' own research and processing.

Table 8. Basic description of compared areas by Health Index WSA Different Weightings

WSA (Different Weightings) Determinants of Health																		Health Indicators
	Area 1				Area 2		Area 3		Area 4		Area 5		Area 6		Area 7		Area 8	
District	Health Index		Economic conditions and social protection		Education		Demographic indicators		Environmental conditions		Individual living conditions		Road safety and crime		Health and social care resources		Health status	
	Rank	Index value	Rank	Index value	Rank	Index value	Rank	Index value	Rank	Index value	Rank	Index value	Rank	Index value	Rank	Index value	Rank	Index value
Bratislava I	1	0.822	1	0.941	1	0.954	54	0.491	39	0.989	3	0.781	79	0.461	3	0.445	4	0.784
Bratislava IV	2	0.741	5	0.911	2	0.779	77	0.324	48	0.981	7	0.569	23	0.831	73	0.153	2	0.838
Senec	3	0.736	9	0.896	14	0.482	1	0.948	11	0.996	24	0.410	16	0.860	79	0.073	1	0.874
Bratislava V	4	0.735	2	0.927	4	0.703	75	0.381	23	0.993	1	0.895	40	0.781	48	0.256	8	0.737
Košice I	5	0.725	24	0.804	5	0.688	76	0.347	8	0.997	4	0.646	68	0.629	1	0.723	13	0.708
Poltár	73	0.399	66	0.424	76	0.195	16	0.594	18	0.995	72	0.166	3	0.944	68	0.191	67	0.514
Komárno	74	0.383	45	0.687	75	0.221	58	0.479	62	0.963	74	0.152	11	0.902	58	0.218	78	0.362
Trebišov	75	0.380	72	0.354	40	0.326	34	0.537	29	0.992	75	0.137	37	0.783	41	0.262	73	0.472
Medzilaborce	76	0.370	73	0.330	53	0.286	73	0.428	12	0.996	59	0.244	36	0.787	2	0.583	79	0.349
Rožňava	77	0.351	76	0.277	37	0.342	38	0.526	37	0.989	68	0.210	60	0.684	15	0.326	77	0.413
Rimavská Sobota	78	0.306	79	0.178	62	0.263	51	0.494	43	0.985	77	0.118	47	0.742	36	0.271	71	0.492
Revúca	79	0.302	78	0.086	59	0.276	59	0.478	51	0.977	71	0.174	73	0.587	54	0.232	74	0.463

Source: Authors' own research and processing.

The Bratislava I district shows unfavourable results in area 6, which includes road safety and crime index. This negative trend is primarily influenced by an above-average number of traffic accidents, which are a consequence of high traffic intensity and heavy traffic in the city centre. At the same time, there is an increase in the number of registered crimes, with property crime, pickpocketing and vandalism being among the most common, which are typical of busy urban areas.

Domain which focuses on individual living conditions (with a weight of 0.09), shows a similar regional distribution as the other socio-economic indicators. The districts of Slovakia's two largest cities, Bratislava I and Košice I, continue to maintain the best scores. Their favourable position is the result of a higher standard of living, the availability of quality housing, good civic amenities and a wide range of services in health care, education and culture. However, despite these positives, certain challenges remain in these areas, such as the high cost of housing, differences in income levels of residents. On the other hand, in Domain 7, which includes health and social care resources (with a weight of 0.10), Bratislava IV and Bratislava V districts perform less favourably compared to other Bratislava districts. The main reason for their weaker position is the low bed capacity of hospitals, which is insufficient to cover the needs of the growing population in these areas.

Area 4, which focuses on ecological conditions (with a weight of 0.14), shows rather unfavourable results for this group of districts, mainly due to above-average air pollution levels. This negative trend is due to high urbanisation rates, dense traffic, industrial activity and increased emissions, which affect air quality and the overall environment (scorecard).

The same methods of decomposing and comparing the results of individual areas were also applied to the districts with low Health Index scores, which include Revúca, Rimavská Sobota, Rožňava, Medzilaborce and Trebišov. The analysis was again conducted using the WSA method with assigned weights, which allowed for a more accurate assessment of the factors influencing the health status of the population in these regions. This group of districts is associated with unfavourable results of the Health Index assessment. The most pronounced negative impacts are seen in Domain 1 (economic conditions and social protection; weight 0.19), Domain 8 (health; weight 0.20) and Domain 2 (education; weight 0.18). These districts are among the weakest economically in the country, characterised by high unemployment rates and low average wages, which limit the living conditions of their inhabitants. The low level of education is also a significant problem, with a high proportion of residents having only primary education. This trend is largely influenced by the socio-economic situation, as well as by the higher representation of the Roma national minority. The health situation in these regions is also unfavourable, with above-average mortality rates and some causes of death, such as diseases of the circulatory system. This situation is exacerbated by the lack of access to healthcare, the limited number of doctors and healthcare facilities, and the low level of preventive care.

Other domains, namely Domain 3 (demographic indicators; weight 0.08), Domain 4 (environmental conditions), Domain 6 (road safety and crime index) and Domain 7 (health and social care resources), could not be clearly assessed in the interpretation of the results for the identified group of districts with the lowest Health Index values. For example, in Domain 3 (demographic indicators), the index is characterised by a wide range of values, with some districts, such as Trebišov and Rožňava, achieving higher values due to a younger or average age structure of the population. On the contrary, the Medzilaborce district shows a low value of the demographic index, which is due to an above-average age index and a significant migration loss, as the younger population often leaves for better economic opportunities in other regions or abroad. These differences suggest that demographic factors have a different impact on the overall Health Index in different districts (see *Figure 2*).

The WSA assessment method with equal weights spatially identifies the districts of Slovakia that achieved the highest Health Index values, which include Bratislava I, Bratislava IV, Bratislava V, Senec, and Košice I. In contrast, the districts located in the southern part of Slovakia – Rožňava, Revúca, and Rimavská Sobota – showed the lowest Health Index values Higher Health Index values are indicated by darker shading, reflecting a more favourable situation. Regions with a high Health Index are characterized by positive regional differences, such as a high proportion of university graduates, positive net migration, and low unemployment rates. Conversely, regions with a low Health Index display negative regional disparities, including high unemployment, a low share of university-educated residents, negative net migration, and high infant mortality. These regions also report the presence of socially excluded communities with an ethnic minority (Roma) and a higher proportion of residents with a lower socio-economic status.

A very similar situation is also manifested in area 4 (environmental conditions; weight 0.14), where, however, the districts of Revúca and Medzilaborce show significantly different values. While Revúca scores above average on the pollution index, Medzilaborce, on the other hand, shows favourable environmental conditions. In the case of Revúca, the unfavourable environmental quality is mainly influenced by industrial activity, the historical burden of metallurgy and mining, as well as the high production of emissions from local industrial enterprises. On the contrary, the favourable situation in Medzilaborce is the result of several factors such as the low level of industrial activity, lower population density and extensive forest cover in the vicinity, which contribute to better air quality.

The results in Domain 5 (individual living conditions; weight 0.09) show a similar trend, with a low index of living conditions in these districts, which is mainly the result of several factors. One of the main reasons for this is the low proportion of households heating their homes with electricity or gas, leading to a greater reliance on solid fuels such as wood or coal.

In Domain 7 (health and social care; weight 0.10) we observe a favourable situation in Medzilaborce district, where the index values benefit significantly from the good availability of social services. This positive development is mainly due to the relatively high number of places in social service facilities available to the population, which improves the quality of life of the elderly and vulnerable groups. These factors, together with the relatively low population density and less pressure on local health and social institutions, allow for more efficient and individualised care. In Slovakia, the Health Index shows regional variations, with an east-west gradient. Although the lowest values of the Health Index were recorded mainly in the districts of southern Slovakia, the spatial pattern of the east-west gradient remains an important geographical phenomenon.

The WSA assessment method with equal weights, spatially identifies the districts of Slovakia that achieved the best Health Index values, which included the districts of Senec, Bratislava I, Bratislava V, Bratislava V, and Košice I. In the southern part of Slovakia there are districts Revúca, Rimavská Sobota, and Rožňava, where we recorded the lowest values of the Health Index (*Figure 3*).

Discussion

According to Rosenkötter, N. *et al.* (2015), health inequalities have not been a major policy priority in the context of the development of a sustainable health information infrastructure in Europe. However, a significant shift has been taking place in recent years. The debate on the importance of health information infrastructure and the steps to further develop it has intensified considerably. This development is probably related to the increasing demands for health information, which serves as a basis for the formulation of country-specific recommendations. Monitoring WHO and European Union policy is therefore crucial, as both institutions place emphasis on the development of quality information. Experts involved in health data monitoring and reporting in Europe stress the need for a sustainable health information infrastructure and an appropriate legal framework. This phenomenon requires systematic monitoring and analysis, especially in terms of morbidity and health inequalities.

For this reason, it is also important to examine health inequalities at the regional level, which allows for a more precise identification of spatial disparities and their causes. In this paper, the territorial level of districts of Slovakia (LAU1) was therefore deliberately chosen. The spatial differentiation of health status and its determinants at this level provides a more detailed view compared to the national or regional NUTS2 level. Such analyses are not only crucial from the perspective of international statistics and projects, but play an important part in effective measures to reduce inequalities.

A variety of methods have been used to assess health inequalities, including the development of indices (composite indicators) at international and national level, as reported by Freitas, A. *et al.* (2018), Fernandez-Crehuet, J.M. (2019), and Pearson-Stuttard, J. *et al.* (2019). One of the significant factors was the presence of COVID-19. The pandemic further deepened existing health inequalities, highlighting disparities in access to healthcare and overall population health (Bambra, C. *et al.* 2020; Kerschbaumer, L. *et al.* 2024). In Slovakia, the topic of health inequalities comes to the fore only sporadi-

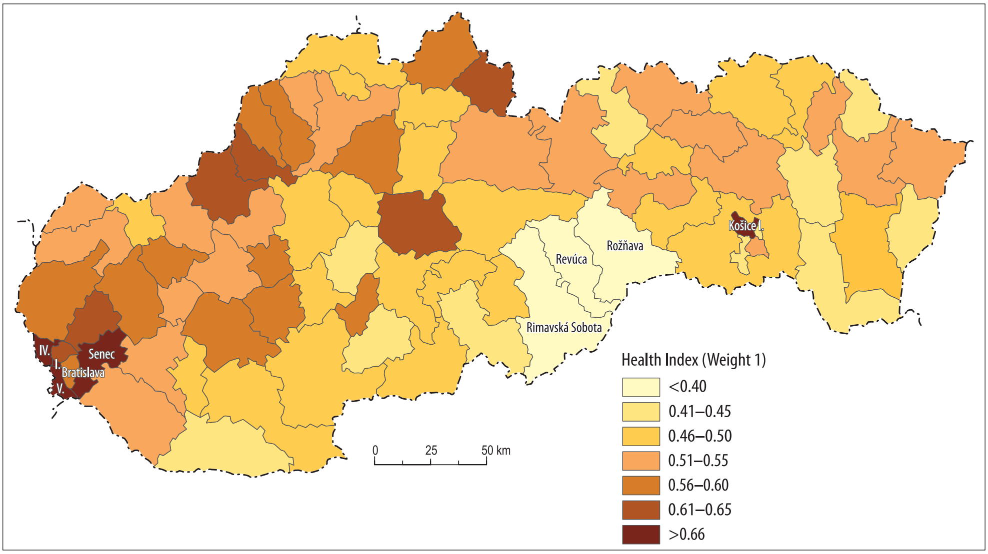

Fig. 3. Spatial differentiation based on the calculation of the Health Index values using different weightings – WSA method (2021–2022). The higher Health Index values are indicated by the darker colours of the district. *Source:* Authors' own research and processing.

cally and mostly remains in the background of expert analyses and statistical surveys. Most discussions on the health situation in the country focus on selected indicators such as life expectancy, incidence of civilisation diseases or access to health care.

What is missing, however, is a broader societal discussion that highlights how health inequalities are linked to socio-economic factors, education, employment or living environment. While statistics and analytical outputs provide valuable information, they often do not reveal the complex causes and consequences of health inequalities. For example, health disparities between different regions of Slovakia are not only reflected in figures on hospital admissions or mortality rates, but are deeply rooted in the availability of quality housing, healthy lifestyles and healthcare infrastructure. However, these links are only minimally discussed publicly (Sopóci, J. and Hrabovská, A. 2015).

A systematic comparison of the findings of research on various aspects of health inequalities carried out in Western and Central European countries has made it possible to confirm these conclusions and to identify some basic trends in this area. For example, research findings in post-socialist countries have also confirmed the existence of a significant relationship between socio-economic status and health. The increasing economic and social differentiation in post-socialist countries has been accompanied by growing health inequalities between different social classes. These states also have higher levels of health inequalities than Western European states (Džambazovič, R. and Gerbery, D. 2014). Meanwhile, the changes undergone by the Central and Eastern European states have had the most negative consequences regarding health inequalities on populations with lower socio-economic status. In the Slovak Republic, for example, Roma in particular have been affected (Ginter, E. *et al.* 2001; Rosicova, K. *et al.* 2011).

In the context of the selected Health Index indicators, a considerable number of expert studies and papers have been produced in Slovakia. Regarding the mortality indicator, this issue has been addressed, for example, by Mészáros, J. (2008), and Šprocha, B. *et al.* (2015). From the demographic point of view, health inequalities have been analysed by Káčerová, M. *et al.* (2014), while the environmental aspect has been elaborated in detail in Rapant, S. *et al.* (2010, 2013). A comprehensive analysis of the health status of the population in Slovakia was provided by Vilinová, K. (2012). Together, these studies offer a comprehensive view of the factors influencing the health situation in the country. Sopóci, J. *et al.* (2015) argue that in the long and short term we observe deepening socio-economic disparities between regions and their position within the Slovak Republic is changing based on their economic and social development. The most significant consequence of this development is the concentration of social and economic problems in certain regions. The most developed region in Slovakia is the Bratislava Region, but even this region is not a homogeneous territorial unit. Here, too, there is a visible differentiation between Bratislava and other districts of the Bratislava Region. It cannot be denied that within the Slovak Republic, the Bratislava Region has a specific position in terms of material and socio-economic conditions, demographic characteristics and also in terms of health care.

The Slovak Republic, as one of the V4 countries, is very often characterised and compared with countries in this area in terms of aspects of health inequalities. Poland, for example, has recently stepped up health promotion in an effort to increase healthy life expectancy and reduce health inequalities. As in other countries, Poland has a high prevalence of health problems determined primarily by lifestyle-related factors. Karasiewicz, M. *et al.* (2021) in their study point to the need to intensify health promotion in rural, remote and disadvantaged populations. From their findings, they model the conclusion that despite the efforts of policy makers, there is still a high risk of unmet health needs in deprived areas. According to Sowa-Kofka, A. (2018), the health care system in Poland faces various challenges in ensuring equal access to services. The level of public spending on healthcare is one of the lowest in the European Union. Insufficient funding affects the quality of health services offered, increasing waiting times, resulting in an increase in inequalities. Rój, J. and Jankowiak, M. (2021) report that based on the distribution of socio-economic determinants of health, they identified inequalities among geographically defined populations. They show that in Poland, due to their geographic location, the population does not have the same opportunity to reach their full health potential. The results of their research confirmed that voivodeships are considerably heterogeneous in terms of the distribution of socio-economic determinants of health. Kobza, J. and Geremek, M. (2015) report that the reduction in mortality from cardiovascular diseases, as well as changes in diet quality or the impact of economic conditions on health outcomes, also played a significant role in the longer survival years in the health of the Polish population.

According to Hübelová, D. *et al.* (2023), spatial health inequalities persist in the Czech Republic, influenced by economic, social, demographic and environmental factors, as well as local access to health care. This is despite the fact that the Czech Republic is a relatively demographically, socially, economically and ethnically homogeneous country with a low proportion of socially excluded individuals or those living below the poverty line. However, regional or micro-regional health inequalities have persisted for a long time. The study shows that both the inner and outer peripheries exhibit poor health outcomes, challenging the assumption that urban areas are better off. The causes of inequalities in the rural periphery stem primarily from demographic and institutional factors and an inadequate labour market. As far as reducing the intensity of health inequalities in the Czech Republic is concerned, the study shows that the success rate is not great. It cites a combination of poverty and other vulnerability indicators such as age (children, elderly), disability or minority origin as a cause that exacerbates these inequalities.

Hübelová, D. *et al*. (2021c) point to a very favourable situation in the Czech districts of Prague-East and Prague-West, thanks in particular to a high proportion of university graduates, low unemployment, low ageing index, low infant mortality, low abortion rate as well as affordable housing subsidies. It can be stated that such a favourable situation of the districts in question is due to the immediate proximity of the district of Prague – capital city. On the contrary, the unfavourable situation in the districts of Chomutov, Teplice and Most (all districts belong to the Ústí nad Labem Region located in the north-west of the Czech Republic), compared to the districts of Prague-West and Prague-East, is characterised by differences such as high housing subsidies, high unemployment rate, low proportion of university graduates, negative migration balance or high infant mortality and abortion rates. On the basis of such results, it was possible to specify regional disparities in demographic and socio-economic indicators that cause health inequalities, either negatively or positively.

As far as the Czech health system is concerned, the Ministry of Health plays both a regulatory and a strategic role. Both the Czech Republic and Slovakia have a public health insurance system that is largely regulated by the government. Health insurance is compulsory and access to healthcare is practically universal. Vrabcová, J. *et al.* (2017) argue that factors influencing years of healthy life in the Czech Republic include improvements in living conditions, public health interventions and advances in medical care. These improvements have contributed to an increase in the number of healthy life years, which is an important indicator of potential demand for both health and long-term care services, especially for the elderly.

Uzzoli, A. *et al.* (2020) explain that the general health status of the Hungarian population is worse than justified by the level of economic development. The deterioration in health status that had been ongoing since the mid-1960s turned into an epidemiological crisis in the early 1990s and affected the entire adult population. Since the second half of the 1990s, Hungary has faced significant improvements in many health outcomes, but the country still lags behind many more developed countries. Most of the main health indicators are worse than the OECD average, indicating that Hungary belongs to the middle tier of countries in the world in terms of the overall health of its population.

The poorer health outcomes are related to significant regional disparities in the country. Relatively, the greatest spatial inequalities are observed especially between the western and eastern parts of Hungary. The disparity between the west and the east of Hungary is also confirmed by the geographical distribution of health services, where we can observe significant differences, especially in specialised care. The disparity in public funding of outpatient capacity means that waiting times for diagnosis are prolonged, as doctors can only examine a certain number of patients for a selected paid time. In practice, this means that residents who have sufficient finances often use private services to reduce waiting times for examinations or to ensure access to better quality services (Albert, F. 2018).

Overall inequality can also be seen in life expectancy in Hungary, especially between the highest and lowest income groups. The latter could be reduced by as much as half, by reducing avoidable causes of death to the levels seen in Hungary's wealthiest settlements. The evidence on the role of avoidable deaths suggests that there is considerable scope for policy makers to increase the life expectancy of individuals in poorer areas as well as to reduce existing inequalities. Specifically, these include incentives to improve diets and reduce smoking, reduce solid fuel heating to improve air quality, provide better access to health care, and help poorer people receive standard health check-ups (Bíró, A. *et al.* 2021).

Conclusions

According to Hübelová, D. *et al.* (2021a) since 2009, the European Union has made reducing health inequalities a priority among its activities, with the support of the Commission's Communication Solidarity in Health in the form of the Communication 'Reducing Health Inequalities in the European Union'. Our analysis provides new information in several ways. In one place, we provide a comprehensive assessment of population health indicators using combined data from different databases. We work with data at a detailed spatial (district) resolution, allowing targeted action to reduce health inequalities at the local level. This assessment approach has not yet been applied in Slovakia. It is important to continue research on this issue. Research could focus on the districts that perform worst in terms of the Health Index and on possible explanatory factors at the individual level.

Using the weighted sum method, we have obtained aggregate Health Index values. We approached this index in two ways. In the first case, each of the given eight domains had equal importance with a weight of 1 (WSA method without weights). In the second case, each of the eight domains had a specific weight (WSA method with weights). On the basis of calculations, graphical and cartographic processing, we found that in both cases the districts with higher, more favourable values of the Health Index are mainly located in the western part of Slovakia (Bratislava I, Bratislava IV and Senec). On the contrary, districts with lower, more unfavourable values are mostly located located in the southern and eastern part of the country (Revúca, Rimavská Sobota, Rožňava).

The Health Index is a comprehensive indicator that reflects the health status of a population based on a number of factors. In Slovakia, the index varies according to geographical location, with a strong east-west gradient. Western Slovakia, especially the Bratislava and Trnava regions, is characterised by a better health status of the population. Eastern Slovakia, especially the Prešov and Košice regions, joined by the Banská Bystrica Region, shows worse results. The differences between these regions are conditioned by several factors. Western Slovakia has better access to healthcare, which means a higher concentration of hospitals, specialised medical facilities and doctors. The economic situation in these regions is more favourable, which allows for a higher standard of living, better nutrition, healthier lifestyles and a better level of prevention. In addition, there is a higher level of education, which contributes to a better awareness of healthy lifestyles and disease prevention.

In contrast, eastern and southern Slovakia face a number of challenges that negatively affect the health status of the population. The availability of healthcare is worse in these regions, with fewer hospitals and specialised doctors. Lower economic levels, higher unemployment rates and lower average incomes make access to healthcare more difficult and affect lifestyles. In addition to these factors, migration also plays an important role. Young and educated people often leave eastern and southern Slovakia for the west in search of better conditions, thus, deepening regional disparities. Infrastructure is also an important aspect, affecting access to healthcare and overall living standards in individual regions.

The health situation in Slovakia is not uniform and the differences between the regions are marked. In order to mitigate them, it is necessary to improve access to healthcare in the regions of eastern and southern Slovakia, invest in prevention and increase economic opportunities for the population. Closing these gaps is key to improving the overall health status of Slovaks and improving the quality of life across the country. The COVID-19 pandemic has exposed and exacerbated existing health inequalities and socio-economic conditions in Slovakia as well. Although the virus affected all segments of society, its impact was not evenly distributed. Vulnerable groups such as the elderly, economically weaker families, marginalised communities and the disabled were the most affected. The pandemic has also exposed problems in the Slovak health sector, such as undersized hospitals, shortages of medical staff and ineffective health care management. Measures such as lockdowns and restrictions on healthcare for other diseases have caused the deterioration of the health status of many patients.

It is important to note that local governments have an important role to play in promoting health and addressing health inequalities. Municipalities, cities and counties have competence in a number of areas related to the determinants of health (e.g., housing, social care, environment, spatial planning, etc.). Through their decisions, they can largely influence the factors that affect the health of the population. One of the key roles of local governments is to be able to bring together a wide range of actors at the local level to create the conditions for interdisciplinary cooperation that would lead to the development and later implementation of policies, programmes and activities to promote health. Within Slovakia, the Government of the Slovak Republic has approved the National Health Promotion Programme for 2021–2030. At this level, there are projects such as Healthy Communities, whose main activity is the implementation of community health promotion. Having access to a wide range of data and information on key health indicators is essential for successful interventions to tackle health inequalities. This is where our paper could find its future application, as it contains a wealth of data and information that could be implemented in the design of programmes or activities to promote health in the districts of Slovakia.

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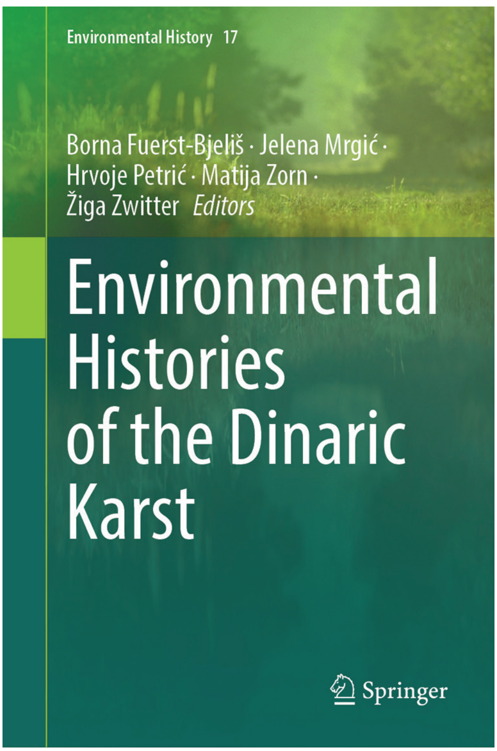
BOOK REVIEW SECTION

Fuerst-Bjeliš, B., Mrgić, J., Petrić, H., Zorn, M. and Zwitter, Ž. (eds.): Environmental Histories of the Dinaric Karst. Cham, Springer, 2024. 466 p.

The volume *Environmental Histories of the Dinaric Karst* offers a comprehensive exploration of the interplay between human societies and the karst environments of the Dinaric region. Karst terrains – characterized by soluble rocks, subterranean drainage, and a scarcity of surface water – form ecologically complex landscapes. The dynamic interplay of natural constraint and human adaptation render them particularly illuminating for environmental historical inquiry. Bringing together scholars from geography, history, archaeology, and environmental sciences, this volume presents a rich and multifaceted analysis of landscape transformation, water management, forestry, and climate variation in one of Europe's most distinctive natural regions. The editors, including established scholars from research institutions in Belgrade, Ljubljana, and Zagreb, contribute to a growing discourse that transcends traditional disciplinary boundaries, reinforcing the importance of an integrated approach to environmental history. In doing so, they align with the renowned American historian John Robert McNeill, quoting him, somewhat extensively, at the beginning of the introduction and both at the start and end of the conclusion. Moreover, the volume places the environmental history of the region within a broader European and global context, demonstrating its relevance to contemporary debates on sustainability, climate change, and resource management. This synthesis of perspectives and methodologies makes the book a valuable contribution to karst studies, environmental history, and the socio-economical historiography of Southeast Europe.



The volume is divided into four interrelated thematic sections: *Cultural Landscape, Woodland and Forests, Water and Climate,* and *Environmental Degradation*. Sixteen chapters, authored by thirty-one researchers from seven European countries, cover a vast temporal spectrum, from prehistoric human-environment interactions to contemporary ecological challenges. Within each thematic section, the chapters are arranged chronologically, providing a coherent narrative. The rich illustrations – photographs, maps, diagrams, and tables – further deepen the reader's understanding and engagement with the material. The introduction by the editors sets the stage by contextualizing the Dinaric Karst as both an ecological and cultural macro-region. Here, the authors outline what they call the "intellectual history" of karst studies, highlighting the Carniolan naturalist Johann Weichard von Valvasor (1641–1693) for his early observations of karst features and the Serbian geoscientist Jovan Cvijić (1865–1927), whose PhD thesis *Das Karstphänomen* (The Karst Phenomenon, 1893), supervised at the University of Vienna, laid the foundation for karst geomorphology. Over the following decades, the toponym "Karst," originally used to describe a cavernous limestone plateau east of Trieste, came to represent a universal model for understanding dissolutional features in soluble rocks.[1]

[1] On the internationalization of the term "karst" and its historical context, see, among others, Gauchon, C. (1999), Trudgill, S.T. (2008), Ford, D. (2015), Milanović Pešić, A. *et al.* (2019), Knez, M. *et al.* (2020), and Mattes, J. (2025).

In Part I (*Cultural Landscape*), Maja Andrič and Dirk Nikolaus Karger reconstruct the Holocene vegetation history of the region, using paleo-environmental data to illustrate the shifts in land use over millennia and tracing key transitions such as the domestication of plants and the establishment of agricultural practices. Similarly, Tjaša Tolar, Philip Mason, and Bine Kramberger explore archaeological evidence for prehistoric to medieval woodland management, emphasizing the role of early societies in shaping the region's forests through controlled burning, clearing, and selective tree harvesting. Dimitrij Mlekuž Vrhovnik and Tomaž Fabec provide a diachronic assessment of landscape formation from prehistoric to early modern times, demonstrating the extent to which human intervention has transformed karst terrain. They document how settlements, agricultural expansion, and infrastructural development reshaped the natural environment, influencing both its physical form and ecological balance. Extending this narrative, Ivan Tekić *et al.* look at modern landscape changes and fire risks in the Croatian Dinaric Karst, combining historical insights with projections for the future. Finally, Ante Blaće *et al.* examine land use and land cover changes on Croatian islands since the early 20th century, evaluating how shifts in human activity have affected the environment and outlining broader patterns of transformation across the region.

Part II (*Woodlands and Forests*) shifts the focus to the historical management of forest resources, with papers examining the impact of deforestation and afforestation practices. Filip Pavelić, Hrvoje Petrić and Mislav Radošević study attempts to regulate forest resources in the Croatian military frontier in the 18th and 19th centuries. They provide a detailed account of how forest management strategies were implemented to sustain local economies, prevent land degradation, and secure military supply chains while navigating the challenges of imperial and local governance. Meta Remec's case study discusses the environmental impact of afforestation with non-native Austrian pine (*Pinus nigra*) in south-western Carniola and Slovenia since the 1850s, highlighting the ecological consequences of introducing non-native tree species and the long-term effects on soil composition, local flora and biodiversity. In another insightful contribution, Ivan Laković and Jelena Lazarević explore the relationship between traditional forest management and transhumance practices in Montenegro. By analysing how these pastoral practices interacted with the landscape, the authors show how the seasonal movement of livestock across the mountains influenced both the forests and the social structures of rural communities.

Part III (*Water and Climate*) examines the hydrological and meteorological variations that have shaped the environmental history of the Dinaric Karst. Andrej Studen offers a micro-historical account of water scarcity and food crises in the 19th-century settlement of Senožeče (Senosetsch, Senosècchia), exploring how changes in water availability affected agricultural practices and the daily lives of local inhabitants. Aneja Rože Kravanja's chapter shifts the focus to the development of water infrastructure in the Karst Plateau between Ljubljana and Trieste during Habsburg rule. She examines how human interventions, such as the construction of wells and canals, interacted with the region's natural water cycles, revealing the complexities of managing water resources in a karst landscape. This human-nature dynamic is further explored by Mauro Hrvatin and Matija Zorn, who provide a data-driven assessment of climate trends and flood hazards in Slovenia's Dinaric Karst. Their study demonstrates how the region's hydrology is particularly vulnerable to climate change, illustrating the increasing frequency and intensity of extreme weather events.

Part IV (*Environmental Degradation*) focuses on examining the ecological consequences of human activity. Martin Meiske analyses the early 20th-century wood-impregnation industry in Bosnia and Herzegovina, revealing the significant environmental damage caused by industrial processes designed to preserve wood. His work highlights the often-overlooked environmental costs of industrialisation in the region, showing how these activities damaged forests and the wider landscape. Building on this theme, Daniela Ribeiro and Matej Simčić investigate human disturbances in the Bela Krajina landscape, in particular the impacts of deforestation, agricultural intensification and infrastructure expansion. Their study examines the long-term environmental consequences of these activities, which have left deep marks on local ecosystems. Klemen Kocjančić further investigates the exploitation of the Dinaric Karst during the Second World War, focusing on the Third Reich's military and "scientific" use of the region's natural resources. His work reveals the destructive impact of wartime activities on both the natural environment and the communities living in the area.

A comprehensive conclusion, penned by the editors, summarises the main findings of the volume and highlights their wider implications. It stresses the need for further research in environmental history, particularly its role in shaping conservation policies and sustainable land management practices in the region. Crucially, the editors advocate for an interdisciplinary perspective that merges historical insights with modern strategies to tackle contemporary environmental challenges and safeguard ecosystems affected by human activity.

One of the major strengths of the volume is its multifaceted methodology, which combines historical narrative with scientific analysis. Particularly laudable is the collaboration of researchers from different post-Yugoslav countries who have come together for this transnational project. By incorporating approaches from palynology, geomorphology, archival research and ethnographic studies, among others, the book underlines the importance of integrating different perspectives in environmental history. The geographical breadth and chronological depth of the contributions further enhance the relevance of the volume, providing insights that extend beyond the Dinaric Karst region. Against this backdrop, the absence of geological perspectives is astonishing. Since the nineteenth century, geologists (and speleologists) have played a crucial role in advancing the understanding of the Dinaric Karst and its environments, both above and below ground. However, differing research agendas and fieldwork methodologies have led to increasingly distinct disciplinary cultures. In particular, the consolidation of physical geography as an academic field around the 1890s initiated a process of boundary work that served to differentiate it from geology, despite their shared empirical interests and spatial focus. These dynamics have resulted in the formation of separate "thought collectives" (Fleck, L. 1935) – epistemic communities shaped by shared cognitive styles and conceptual frameworks – which continue to influence disciplinary alignments and exclusions to this day.

While the book excels in presenting empirical data and case studies, a more explicit theoretical engagement with global environmental history frameworks would have been beneficial. The editors refer to key figures in the field, such as the aforementioned John R. McNeill and the Austrian historian Verena Winiwarter, but a more systematic and direct discussion of conceptual approaches – such as socio-ecological resilience or landscape memory – could have strengthened the book's overarching arguments. A closer look at the individual contributions also reveals some imbalances. While the (natural) scientific analyses are generally robust and well-supported, some historical interpretations seem somewhat less well-founded and, at time, may appear overly generalized. An example is the statement in the introduction that "modern science was born in Europe" (p. 6) in the seventeenth century – a claim that raises questions about what exactly is meant by "modern", especially given that the term "science" itself only emerged around the 1800s. Equally problematic is the assertion that Valvasor was "the first true speleologist" (p. 6) when both the term and this field of research did not develop until some 200 years later. Another problem arises in the discussion of Jovan Cvijić's impact on karst geomorphology (pp. 8–10), where the wider political dimensions of his work are largely overlooked – particularly in relation to his role in framing the Dinaric Karst as a geographical feature uniting regions of the later Kingdom of Serbs, Croats and Slovenes (1918).

One of the refreshing contributions comes from Martin Meiske, who offers valuable insights into an understudied area of environmental history in Bosnia and Herzegovina. His investigation of a Viennese impregnation company founded by the German entrepreneur Guido Rütgers (1832–1892) sheds light on the region's industrial history. While Meiske carefully explores the complexities of Austria-Hungary's "quasi-colonial rule" in Bosnia – a much-debated topic in Habsburg historical scholarship – his contribution leaves open the question of how private and public stakeholders, as well as the profit expectations of all involved parties, ultimately interacted. This is particularly evident in the editors' generalised assertion, mentioned in the introduction, that "Austria-Hungary paid little or no attention to the local population and the environment" (p. 18). Such a sweeping statement is difficult to sustain and raises further questions: Who exactly is meant here – policymakers, officials in Vienna, Budapest and Sarajevo, scientists, (foreign) entrepreneurs, or all of them together?

Finally, I would like to suggest three additional dimensions that could further enhance the understanding of the environmental history of the Dinaric Karst:[2]

1. *Political aspects:* The historical development of karst studies was closely linked to nationalist and imperial interests. Karst landscapes became important in shaping colonial claims and national identities in the Balkans. Cvijić's work, for instance, was instrumental in advancing both Serbian and Pan-Slavic aspirations, while also contributing significantly to the rise of scientific nationalism. It could be interesting to explore how environmental knowledge of the Dinaric Karst and its multi-lingual populations was used in state-building, its role in international scientific exchange, and its impact on socio-political tensions within and beyond Austria-Hungary, Serbia, and later Yugoslavia.
2. *Orientalism and the karst concept*: The history of karst research highlights the connection between European perceptions of the Balkans and the portrayal of karst landscapes as "wild," "inhospitable," or "wastelands." Early scientific descriptions frequently echoed Orientalist tropes, presenting the region as both a geological rarity and a cultural periphery. A deeper exploration of how these narratives shaped research methodologies, conservation policies, and scientific discourse offers valuable insights into the intersection of cultural perceptions and environmental studies.
3. *The rise of ecological thinking in the Dinaric Karst:* Ecological awareness of karst environments began to take shape early on, notably through figures like Joseph Lorenz von Liburnau (1825–1911), whose work played a pivotal role in shaping conservation and land management strategies. Lorenz von Liburnau's studies on deforestation, hydrology,

[2] While some of these aspects were touched upon in my recent article (Mattes, J. 2025), they merit further and more in-depth analysis.

and the interdependence of physical conditions and animal life, initiated in the 1860s during his time as a teacher in Rijeka and later as a senior ministry official in Vienna, were instrumental in framing karst landscapes as fragile ecosystems. Early ecological thinking also advocated for the "cultural elevation" of Slavic-inhabited areas and, thus, corresponded to Habsburg's colonial-expansionist ambitions in the Balkans.

Overall, *Environmental Histories of the Dinaric Karst* is a significant contribution to environmental history and karst studies. Its meticulous research, interdisciplinary approach, and regional focus make it a valuable resource for historians, geographers, ecologists, and policymakers interested in the long-term dynamics of human-environment interactions. Despite some limitations, the volume successfully advances the field of environmental history and offers a compelling model for future macro-regional studies.

Johannes Mattes[3]

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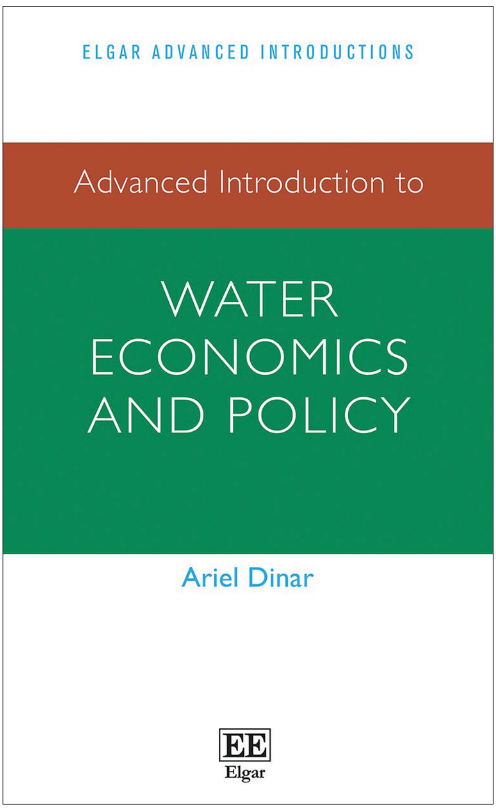
Dinar, A.: Advanced Introduction to Water Economics and Policy. Cheltenham–Northampton, Edward Elgar, 2022. 132 p.

Water economics and policy play a crucial role in managing water as a vital resource and addressing its allocation and sustainability. Water scarcity affects billions' lives worldwide, exacerbating competition among agricultural, industrial, and domestic users – even in countries which were considered rich in water for a long time but are increasingly suffering from declining water resources due to climate change, including regions like the Danube–Tisza Interfluve in Hungary. Hence, the efficient use of water is a critical task for contemporary societies. Efficient use, however, requires effective water economics involving proper pricing that reflects the real value of water and encourage conservation and efficient use, as subsidized water rates can lead to overconsumption, while consumption-based pricing and pricing reforms can reduce waste (Dinar, A. and Yaron, D. 1992). These questions are investigated in much detail in the current book, providing a comprehensive and authoritative overview of water economics and policy.



The author of the volume, Ariel Dinar, is a Fulbright Senior Specialist and a Distinguished Professor of Environmental Economics and Policy at the University of California, Riverside (UCR), and School of Public Policy. His book, published in 2022 with Edward Elgar, represents the many years of Dinar's practical and research experience in the field of water economics and management. While exploring water economics and policy, it covers topics like water scarcity, environmental flows, and ecosystem services. It includes examples from different countries (e.g., the United States, Australia, and South Africa) and analyzes the most significant water-using sectors. The volume provides an opportunity for the readers to understand water management from an economic perspective.

The volume contains 10 regular chapters, whereas Chapter 11 provides a summary of the entire book. The book refers to four case studies that exemplify innovative water management strategies and highlight successes, challenges, and lessons for global water governance. The results in the case studies justify the importance of institutional frameworks and governance, market-based allocation and trading, environmental considerations, stakeholder engagement and participation, and transboundary cooperation and agreements.

Dinar addresses the following research questions:

– *Water economic and policy fundamentals*: What are the fundamental principles of water economics? How are water markets and pricing mechanisms functioning? What are the key challenges in water supply and demand management?
– *Water allocation and markets*: How do water allocation mechanisms impact economic efficiency? What are the benefits and limitations of water markets and trading? How do water rights and institutions influence water allocation?
– *Water governance and institutions*: What are the key features of efficient water governance? How do institutions and policies impact water management outcomes? What role do stakeholder participation and engagement play in water governance?
– *International water policy and cooperation*: What are the principles of international water law and cooperation? How do transboundary water agreements impact water security? What are the challenges and opportunities in international water cooperation?

In Chapter 1, Dinar provides a solid foundation for the book, introducing essential concepts and the context of the book under review. The chapter dives deeper into water's economic value and highlights the complexities and nuances involved in evaluating water's value. Considering water, Dinar differentiates between three sorts of economic value. First, the *instrumental value of water*, which reflects water's utility in various economic activities such as agricultural production, industrial processes, energy generation, municipal and domestic use, etc. Second, he highlights the *intrinsic value of water*, referring to water's inherent worth and importance beyond its utility, economic, or functional value.

In this concept, Dinar acknowledges that water has value in and of itself, regardless of its use or benefits to humans. As he highlights, some aspects of the intrinsic value of water could include water's ecological importance, aesthetic appeal, and cultural and spiritual significance. I believe that recognizing the intrinsic value of water encourages a more holistic and sustainable approach to managing it and conserving it for future generations.

The book also recognizes the *existence value of water*, which directly represents the societal benefits of water such as aesthetic and scenic value, and water's value for biodiversity conservation and climate regulation. Dinar also makes a strong case with regard to the real-world application of valuing and preserving water, where he elucidates on cost-benefit analysis for water infrastructure projects.

In Chapter 2, two countries (Morocco and Israel) are employed as case studies to highlight high levels of water scarcity and abundance. According to Dinar, since 1962, Israel faced a reduction in its water availability from 330 to 90 m^3/capita per year, which is nearly 70 percent reduction. In the same period, Morocco faced a decline from 2200 to 850 m^3/capita per year, which is nearly 60 percent reduction. The significant reduction in water availability in both countries resulted from various factors such as rapid population growth, intensified agricultural water use (accounting for 88% of overall end-use), over-extraction and inefficient use (including outdated irrigation systems and the lack of water conservation measures), changing precipitation patterns and increased evaporation due to rising temperatures as the result of climate change. In Israel, this shift has resulted in significant economic costs and environmental impacts, including the discharge of concentrated brine into the ocean, which can harm marine life. The situation is not much different in Morocco as reduction has exacerbated water scarcity issues, particularly in rural areas, resulting in significant implications for agriculture, industry, and human consumption, leading to food insecurity and economic losses. Hence, the consequences of reduced water availability in both Morocco and Israel are far-reaching and interconnected, which highlights the need for sustainable water management practices, increased efficiency, and conservation measures to address this critical issue.

Dinar accentuates in Chapter 4 the importance of flexibility in water allocation and water storage solutions, and the importance of stakeholder engagement, a phenomenon that led to a major stride in the successful implementation of California's Water Market and Trading System. California has experienced many droughts over the years. This has led to the introduction of various policies related to water conservation, declaring conservation a way of life by the California State Legislature (Dinar, A. and Tsur, Y. 2021). Another classic measure is the Australia's Murray-Darling Basin Reform, which is an example of successful water governance through market-based mechanisms, environmental consideration, and collaborative management. These cases illustrate that effective collaboration and stakeholders' engagement are positive ways to ensure sustainable water governance system (Grafton, R.Q. *et al.* 2011).

Dinar makes it succinctly clear in Chapter 3 that water scarcity can be addressed through various strategies, such as economic incentives, pricing mechanisms, water markets and trading can improve allocation efficiency.

While water markets can promote efficient water use by allocating water to its most valuable uses (Bauer, C.J. 2004) and serving as a potential tool for managing water resources sustainably, strategic investment in water infrastructure is crucial for economic growth in general (Bosworth, B.P. *et al.* 2002). As Dinar highlights in Chapter 9, the impact of, and adaptation to, climate change in the wastewater sector (based on data from China) and the irrigated agricultural sector (according to data from the Júcar River Basin in Spain) are further critical topics, for both sectors are highly vulnerable to climate change and may face irreversible damages if water allocation, investment, and long-time planning are not properly coordinated and implemented.

The hydrological cycle is heavily impacted by climate change due to the fact that altered climatic conditions caused by the increase in atmospheric levels of CO_2 and other greenhouse gases affect the distribution of precipitation, which is the main cause of variability in the water balance both spatially and intertemporal. For instance, the frequency of low water levels is affected primarily by changes in the seasonal distribution of rainfall (Fecht, S. 2019).

In Chapter 5, the author stresses the coordinated relationship between the environment, water interactions, and management. According to Dinar, water serves as an important input to sustain healthy water-dependent ecosystems, which provide valuable services such as recreation. According to Watson, L. *et al.* (2020), the total value of global ecosystem service is estimated at 1.3 trillion international dollars in 2005 values.

In the same chapter, Dinar highlights the concept of environmental flows, which is the quantity and quality of water that is required to maintain the health and integrity of the ecosystems of a river or stream. These ecosystems encompass the natural flow regime, including the magnitude, frequency, duration, and timing of flows that sustain the aquatic environment and support the wide array of plant and animal species that depend on it (Brisbane Declaration 2007). The importance of environmental flows cannot be underestimated as they play complex roles such as maintaining aquatic habitats, regulating water quality, preventing erosion and sedimentation as well as preserving aesthetic, spiritual, and recreational values of water.

However, there are several threats to environmental flows such as water diversion and extraction, the construction and operation of dams, which alters the natural flow regime and disrupts sediment transport, and climate change, which affects the timing, magnitude, and frequency of flows. It is therefore imperative to advance strategies to mitigate these threats.

Chapter 6 takes the reader to economic and policy considerations in groundwater management. Due to the impact of climate change on the sustainability of groundwater storage, scientists have realized that groundwater level changes correspond to global climate variations (Gurdak, J.J. 2017; Russo, T.A. and Lall, U. 2017; Thomas, B.F. and Famiglients, J.S. 2019). Dinar argues that economic considerations become increasingly relevant as the good or resource becomes scarcer. In the case of water, scarcity is determined by the physical amount of water available for use, or by its distribution as affected by climate change, but also by its quality.

The direct and indirect negative effects associated with groundwater depletion and contamination on the environment and humans require regulatory interventions. Policy interventions such as caps on water extractions, taxes on energy used for pumping, and taxes on water extraction aim to regulate groundwater extraction and agricultural production above an aquifer. A remarkable example of intervention policies is the Sustainable Groundwater Management Act in California. Although groundwater in California has not been regulated formally by the state, many proactive measures have been adopted by the people, e.g., digging wells into their land and pumping as much water as they need, which have sustained the people during the long drought periods since 2010.

In Chapter 8, Dinar examines the various institutional frameworks and agreements that govern international water management, highlighting the challenges and opportunities that arise when multiple countries share a common water source. The focus of the chapter is on the economics and policy of international water management. Frameworks such as the Global Water Governance led to the establishment of the Global Water Partnership and the World Water Council, which have facilitated the promotion of global cooperation and knowledge-sharing in water management. Also, formal agreements between riparian states, such as the Treaty of the Nile (1929), and the Indus Waters Treaty (1960), provided a foundation for cooperation and management of transboundary water resources, helping to address conflicts and promote sustainable development. According to Dinar, uncoordinated national development policies (as different countries may have conflicting development goals, which poses a challenge to managing shared water resources), and differences in economic power and interests can also influence cooperation and conflict among riparian states. These complexities highlight the need for a multidisciplinary approach to managing shared water resources, one that takes into account the economic, political, and social factors at play.

Mechanisms for regulating water pollution (Chapter 7) belong to another group of significant policy mechanisms. Depending on the type of water pollution, the observation is that water pollution is increasing as industrial activities become more intensive (Pacific Institute, 2010). Yet, water pollution can also be the result of household-, agriculture-, and mining-related water use. While each type of pollution has its own unique characteristics and effects on human and ecosystem health, the principles related to their regulation could be quite similar, which regulating mechanisms need to be addressed adequately.

Dinar proposes groups of regulatory mechanisms that can be employed to deal with water pollution. These include (i) Tradeable Discharge Permits (TDP), i.e., an automatic cost-effective abatement mechanism providing strong incentives to polluters to innovate by making their abatement process more effective and efficient, and (ii) emission taxes, which require polluters to pay for their use and abuse of the environmental resources and services. The economic principle behind these mechanisms is that polluters are allowed to emit as much as they want, but they will be charged a fee per each unit of emission.

Based on my reading and subjective review and evaluation, *Advanced Introduction to Water Economics and Policy* offers a unique blend of theoretical foundations, practical applications, and cutting-edge research, making the book an essential resource for scholars, policymakers, and professionals in water economics and policy. Readers new to water economics and policy will find it informative, while experts will appreciate the updated statistics and framework. The volume, published in 2022, builds upon the foundations established in the edited volume by Dinar, A. and Schwabe, K. (2015) and provides an updated and comprehensive introduction to the topic. It includes significant additional chapters on climate change and water management, which cover the topic of the impact of climate change on water resources, water vulnerability, and risk assessment, as well as climate-resilient water infrastructures.

The book is an essential resource for scholars, policymakers, and professionals seeking to understand the complex interactions between water resources, economics, and policy. It offers a nuanced understanding of water economics and policy, emphasizing the complexities of managing this vital resource. Dinar's book offers some undisputable novelties that must be emphasized. Dinar was able to integrate economics, policy, hydrology, and social sciences to provide a comprehensive understanding of water management. He also takes a global perspective on water issues, paying attention to countries in both the Global North and Global South, by which he highlights remarkable regional differences and similarities.

Thanks to these merits of the volume, readers can draw many lessons from it in economic, policy, and environmental terms as well. The book also succeeds in accentuating that water economics and policy require interdisciplinary approaches, and efficient governance and institutions are critical for sustainable water management.

However, while the book touches on social and cultural factors, it primarily focuses on economic and policy aspects. Its focus on broader social and cultural aspects is limited. I have also observed some technical complexity as some sections require sound prior knowledge of economics and hydrology, which many potential readers trained in other water management-related disciplines may not possess. In addition to these, although Dinar highlights the effects of climate change on water resources and social welfare in Chapter 9.2, I believe this topic received marginal attention especially if we consider how climate change-induced environmental shifts have become profoundly global, thus, triggering significant social problems for billions of humans worldwide. Another limitation in my view is the limited attention Dinar pays to rural and indigenous communities. The unique water challenges such as water-borne diseases, health and climate change impacts, water scarcity and variability, etc., faced by these communities are rather overlooked, which hinders the proper representation of the actual problems these people are facing due to the lack of access to water, and goes against a fair integration of these people's experiences into the global academic discourse.

Nonetheless, the above limitations highlight new opportunities for future research that may refine and expand the academic and professional discourses of water economics and policy. In my view, it would be especially critical to (i) incorporate climate change impacts and resilience strategies into the analysis in more detail, (ii) explore non-economic values of water by paying more attention to cultural perspectives on water, (iii) meticulously investigate Global South contexts with special attention to challenges rural/indigenous communities are facing, (iv) integrate interdisciplinary insights from social sciences and ecology, and (v) evaluate the efficiency of policy and governance frameworks.

In conclusion, water economics and policy require a multifaceted approach, balancing economic, social, and environmental objectives. By adopting innovative solutions, effective governance, and cooperation, we can ensure sustainable water management for future generations. Therefore, I highly recommend this book to everyone, especially students, researchers, and scholars passionate about policies and governance systems in the water resource sector.

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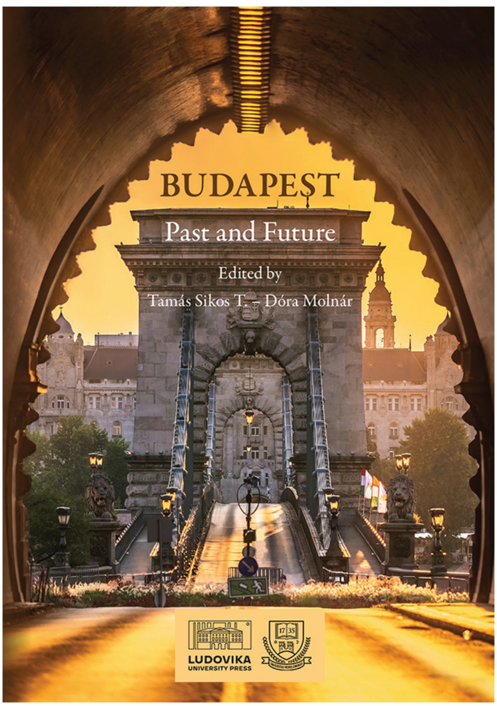
Sikos, T.T. and Molnár, D. (eds.): Budapest: Past and Future. Budapest, Ludovika University Press, 2025. 304 p.

Budapest, 150 years old, is not only the capital of Hungary, by far the country's most populous city, the most important regional centre of the Carpathian Basin, but also the country's dominant industrial, commercial, financial, and logistical centre. In this book, fifteen authors pay tribute to the "one and a half century old" metropolis by reviewing, analysing, and evaluating the long way the present-day city has travelled in "space and time" from the early Middle Ages to the present day.

Edited by Tamás Sikos T. and Dóra Molnár, the volume is structured in eleven thematic chapters and "walks around" the historical-geographical processes of today's capital city, from the natural endowments determining the development of settlements, through the analysis of the effects of infrastructure and networking, to the discussion of several important social and economic factors such as population, agglomeration, transport, trade, and tourism. It is particularly welcome that the authors have not overlooked the issues of prosperity, digitalisation, and creativity.

In the first chapter of the volume, the author (Pál Beluszky) deals with the history of the development



of the capital and its geographical causes from antiquity to the present day. In the first half of the chapter, the author discusses the natural geography of the 'urban genesis', the city's landscape, its place in international trade (flow of goods), and its role. The historical-geographical chapter, based on important sources of statistical data and richly illustrated with maps, visualises the spatial and temporal development of the capital city, together with its economic and social aspects. Of particular value is the fact that the author not only reviews the spatial and temporal dimensions of development in a descriptive manner, but also explains the socio-economic aspects of the development process. The chapter puts into context the milestones and turning points in the development of the international metropolis, the strategic role of the Danube and the importance of the closely related trade in cereals, but also its macro-regional determinants in a European context, from the great geographical discoveries to the impact of the industrial revolution. The human geography dimension of development is not overlooked by the author either: in addition to quantitative trends in population change, we can learn about the important milestones in Budapest's development as a financial and cultural centre, and the impact of the capital becoming a dominant macro-regional centre on the country as a whole and its network systems. The strength of the chapter is that it not only gives an insight into the history of Budapest, but also provides a thorough and easy-to-understand introduction to the general theory of urban development, and the spatial and temporal context of urban development, from micro-localisation issues (crossing the Danube), through the strengthening of the regional role (e.g. transport links, becoming a financial centre), to the macro-regional dimension (the city's place in Europe, in the European division of labour).

The second chapter of the work (László Jeney) deals with the macro-regional place and role of Budapest in the East-Central European context, in a Polish-Czech-Slovak-Hungarian comparison. For centuries, this region has been, on a historical scale, the territory of multi-ethnic empires without national sovereignty. The author of this chapter rightly takes this period as his starting point, outlining the medieval framework for the development of the cities of Buda and Pest in comparison with Prague, Warsaw, and Bratislava. He then goes on to present the framework of urbanisation and metropolitan development in three main periods. First, the independence movements of the 19th century, then the new framework of independent statehood, followed by socialist-style urbanisation, and finally the urbanising effects of the era of globalisation and European integration. The chapter not only discusses the comparison of large cities with each other, but also describes the specific processes of urban networking and the characteristics of urban hierarchies in each country, supported by statistical data. It is interesting to note how the four countries under study have very different characteristics in terms of urban structure, and to what historical reasons the monocentric urban development of Hungary and Budapest can be attributed. The author has made good use of the available space, capturing the key moments of metropolitan development in Central and Eastern Europe, but has not gone far enough in explaining the deeper context of metropolitan competition.

In the third chapter, the author (Dóra Molnár) reviews the development of the administrative system of the capital, discusses the administrative functioning of the period following the creation of a unified Budapest in 1873 (from the previously separate towns of Buda, Óbuda, and Pest), linking it to important historical milestones. The reader is given an insight into the administration of the unified city created in the second half of the 19th century, followed by the basic features of the district system in the post-World War I period, and then the main features of the 'Greater Budapest' concepts are presented: 23 municipalities are added to the 14 districts of the capital, thus, creating the capital as we know it today with 22 districts (23 from 1990, with Csepel becoming an independent district). The second half of the chapter deals with two topical and important issues. On the one hand, it briefly and clearly describes the specificities of the functioning of the administrative system after 2010 and the relationship between the metropolitan and district governments, and on the other hand, it deals with the relationship between the capital and the agglomeration. Three maps provide an overview of the different versions of the Greater Budapest concept, the changes in the capital and the agglomeration, its complexity and the relations between the municipal administrations of the agglomeration. The author gives a thorough presentation of the fragmented administrative system of the metropolis and its catchment area, points out the importance of suburbanisation processes, and highlights the concepts and models of administrative anomalies that have appeared so far. However, the author does not formulate her own proposals, it would have been worthwhile to outline several variants of solutions and international best-practices for a more efficient organisation of public administration in the metropolitan agglomeration.

The main finding of the chapter on the development of the housing market in the capital (Zoltán Kovács and Gáborné Székely) is that housing construction cycles were more in line with economic cycles than demographic processes, and the authors distinguished four characteristic cycles. In each period, the authors have focused on the typical developments, their financing (public, private, municipal), and their social implications. The focus is on housing problems in the pre-World War I period, the challenges posed by migration from annexed territories in the interwar period, the massive public investment and nationalisation of property development in the socialist period, and private development in the post-war period. The analysis of the 'current' situation of the housing stock is very thorough, with numerous map illustrations (year of construction, size, floor area). It is unfortunate that the authors analyse the city's housing structure based on 2011 statistics, which are now a decade and a half old. It would have been worthwhile to focus on the evolution of housing by comfort level, but it is welcome that the analysis of house prices is included in the chapter.

The volume devotes a separate, extensive chapter to the analysis of the health status of the metropolitan society and the functional characteristics of the health care system (Viktor Pál and Annamária Uzzoli). This endeavour is closely linked to the fact that the health situation of Hungarian society, especially in European comparison, can be considered as very poor. In the introduction to the chapter, the authors devote a special section to clarifying the conceptual framework of quality of life and to defining the objective and subjective elements of quality of life. The objective elements of quality of life are then examined: trends in mortality and morbidity rates, morbidity statistics, life expectancy at birth, etc. It is important to note that, in order to gain a better understanding of the data, the authors examine county-level or even national (district-level) statistics for a number of statistics, and assess the health statistics of the districts of Budapest. In relation to the subjective, personal experience of the health situation, data from the EHIS (European Health Interview Survey) are presented in a Hungarian, regional comparison. In the context of "current health issues", candidates will analyse the local impact of the COVID-19 pandemic in the capital and the territorial specificities of primary care, hospital care and private health care in Budapest. It is interesting to note that no close spatial relationship between vacant primary care practices and private care can be identified. The chapter provides a detailed picture of the health situation of the population in the capital, the structure of care, and current health system regulatory issues.

An earlier chapter dealt with the administrative framework of the capital and its agglomeration. The chapter on the agglomeration processes of Budapest clarifies the conceptual framework and the specific dimensions of agglomeration: demography, economy, networks, ecology, urban architecture and morphology. The authors (Zoltán Kovács and Zoltán Dövényi) trace the agglomeration processes of Budapest from the 19th century onwards, presenting the spatial traces of the agglomeration process in the municipalities surrounding the capital. The available data provide insights into demographic and economic trends, industrial investment, population growth trends, and the mobility of social groups in the capital, the suburbs and the outer agglomeration ring, as well as in other areas of the country. More emphasis is given to the period of agglomeration processes under state socialism and after the change of regime, and the available spatial data are more detailed and more disaggregated. Accordingly, a number of map visualisations help to understand the last thirty years of agglomeration processes, providing a spatial cross-section of population change, spatial patterns of commuting and housing market changes. A map showing the functional structure of the Budapest agglomeration illustrates the diverse structure of the capital's attractiveness, which the authors present and analyse in the context of international literature. It is regrettable that this chapter does not include data on spatial trends over the last decade and a half.

The next chapter presenting the transport network of the capital and its agglomeration is more concerned with the development directions and possibilities of the transport infrastructure than with its current state. In the chapter, the author (Tibor Tiner) points out the transport conflicts and their background in his own model, and builds on this to present the current transport situation in the capital, highlighting the most conflicting parts: individual vs. development of public transport, lack of transversal network connections, challenges of suburban public transport, cycling, P+R and B+R connections, ageing vehicle fleet, fragmented regulation, outdated sectoral approach to development, etc. Following a brief overview of the situation, the author discusses the short and longer term objectives, their feasibility and the benefits to be achieved. It presents strategic transport network developments that could greatly improve the organisation of increasingly intensive suburban traffic, the preference for public transport over passenger transport, the accessibility of major transport hubs, and faster and easier transport through inter-modality. The developments outlined by the author follow the most modern sustainability principles, pointing to the development of rail transport modes of (also) high priority in Budapest (tram network, development of rail access to Liszt Ferenc International Airport), the expansion of Danube bridges and crossing capacities (e.g. Galvani Bridge), the development of pedestrian and cycling transport, the development of intermodal nodes (e.g. Kelenföld), major rail developments to link the main stations (Southern Circular Railway, linking the Western and Southern Railway Stations with tunnels), and more intensive development of the agglomeration and the capital's rail network (development of the suburban railway [HÉV] and rail lines). As the time horizon for such developments is measured in decades rather than years, it is welcome that the author is more concerned with the future rather than the present, with the 'should be' rather than the 'is'.

The capital's retail sector has seen dynamic development over the past decades, especially after the change of regime, in parallel with the transition to a market economy. It is therefore not surprising that the author (Tamás Sikos T.) focuses on this period and analyses the retail structure of the capital and the immediate agglomeration together. One of the emblematic processes of the market economy transformation following the regime change was the transformation of the retail sector from a state-owned, supply-driven operation to a private, demand-driven one, which was accompanied by the emergence of new retail formats (shopping centres, hypermarkets) in the capital city, which significantly redrew the retail map of the capital and the whole country. The author presents and analyses the spatial elements of this process of change, showing not only the transformation and expansion of retailing zones in the capital (commercial zones), but also changes in shopping habits. The chapter examines not only the location and role of the transformation processes and new retail centres within the administrative boundaries of the capital, but also the expansion of retail functions (hypermarkets, shopping centres, outlet centres) in the agglomeration zone, with particular reference to the 'edge city' (Budaörs–Törökbálint). The author deals not only with the 'winners' but also with the 'losers' of the transformation process, pointing out the decline in the importance of the ring road (secondary zone) and the significant centre investments in both the capital and the agglomeration (GL Outlet, M1 outlet), which failed to succeed from a business point of view. It is important that the author also mentions the current issues of retail transformation, such as the rise of online sales and the Russian-Ukrainian war, but he does not give them much space, even though the impact of online retailing in particular on shopping habits and, thus, indirectly on the sustainability of store networks and large-scale facilities is of crucial importance.

An important "quality" issue in Budapest's urban development is which "good places", in addition to homes and workplaces, are also important determinants of quality of life. The authors (Mariann Fonyódi, Kornélia Kiss, and Gábor Michalkó) invite the reader on a historical walk and present the "good places" of three historical periods, outlining the socio-cultural context in which the given "good place" is given meaning, role, and significance. The first period is the period up to the end of World War II, an era still "without tourism", the "good places" being used and experienced by the locals, mainly the middle class and the upper social strata. The second period is the period of state socialism, in which the "good places" have changed due to increased mobility, domestic and international tourism and the emergence of a "socialist lifestyle". A characteristic feature of the period is that the 'good places' of the domestic population and foreign tourists are completely separated, they travel, consume, and experience recreation differently. The third period is the period up to the present day, the era of postmodernism, in which almost all forms of tourism are present: individual and group, slow and fast, eco-sustainable and over-tourism, luxury and mass, domestic and foreign, etc. New trends such as the impact of social media, new forms of accommodation (Airbnb and Booking.com), festival tourism (Sziget [or Island] Festival in Budapest), the impact of COVID-19 and war are also present, but mobility and the experience and communication of "good places" (Tripadvisor) are becoming part of everyday life.

The penultimate chapter of the volume (Dóra Szendi) discusses the "smart city" aspects of Budapest. The context of the chapter is quite different from the chapters discussed so far, as the capital is discussed in an international metropolitan comparison, mainly in comparison with other Central and Eastern European cities. The chapter first clarifies the conceptual approaches to the smart city and its development, and then presents the availability of smart city strategies in the metropolitan areas (Warsaw, Prague, Bratislava, Vienna, Budapest, Ljubljana). Afterwards, the main features of Budapest's smart city strategy are presented, and finally, the rest of the chapter evaluates the position of each of the Central and Eastern European capitals in the smart city rankings (IMD smart city index; IESE Cities in Motion Index). The chapter is a thorough exploratory and analytical work, but it does not focus much on the actual opportunities that Budapest has to further develop into a real smart city, or on the challenges that are important obstacles to this process.

The last chapter of the volume (Tamás Egedy) deals with the creative economy. It is welcome that the historical-geographical work, prepared for the 150th anniversary of the capital, also includes innovative topics such as the smart city or the analysis of the position of creative and knowledge-intensive industries. The chapter is divided into three main sections: the first section clarifies the concept and importance of the creative industries and the creative class, the second section provides a statistical analysis of the relative position of the capital (in the country), and the third section presents the main findings of an empirical study of the members of the creative class in the capital, including the current situation of the capital for creative workers and creative industries, and the future opportunities, threats and threats facing the capital. The author gives a good description of the dominant position of Budapest and the agglomeration in this sector and highlights the challenges that the whole creative industry is facing today.

All in all, the volume *Budapest: Past and Future* is a wide-ranging yet thorough work, written by many authors, primarily a historical-geographical work, which pays tribute to the 150th anniversary of the capital city of Budapest with scientific rigour but in a readable way.

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GUIDELINES FOR AUTHORS

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