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The diagnostic continua of the soils of Europe

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Abstract

Diagnostic horizons, properties and materials are commonly applied building units of national and international soil classification systems. The presence, depth or absence of diagnostic information supports the process of objective soil classification, such as the World Reference Base (WRB). While the diagnostic units and associated descriptive qualifiers convey information that reflect pedogenesis, they also indicate important, and often complex properties that are related to soil fertility and other soil functions. The spatial extent or the continuum of diagnostic information is often different from the spatial extent of the mapping units in general soil maps (mostly reflecting soil types). This paper presents the spatial distribution of selected diagnostic units and qualifiers for the European Union and describes their significance for key soil functions. The derivation of selected diagnostics was performed based on the information provided in the European Soil Database and by taking into consideration the definitions, rules and allocation procedure of soils to the appropriate Reference Soil Group (RSG) defined by the WRB key. The definition of the presence/absence of the diagnostic units were performed by extracting information related to the first level of the WRB classification and to the qualifiers provided by the ESDB on the Soil Taxonomic Units (STU) level. The areal percentage of the STUs (thus, the derived diagnostics) within Soil Mapping Units (SMUs) was calculated and was visualized on separate maps. The study demonstrated the importance of the spatial information that the diagnostic elements convey, especially related to soil functions.

Keywords: diagnostic units, World Reference Base, European Soil Database, soil functions

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Introduction

Sustainable land management is based on appropriate soil information (European Commission 2006, p. 231) and on the understanding of the functional capacity of different soils (Bouma, J. *et al.* 2012). The concept of soil functions builds on the soil-based ecosystems services (Haygarth, P.M. and Ritz, K. 2009; Bouma, J. *et al.* 2012). Schulte, R.P. *et al.* (2014) and van Leeuwen, J.P. *et al.* (2017) related five major soil functions to agricultural land use. These include (1) primary productivity, (2) water purification and regulation, (3) climate regulation and carbon sequestration, (4) soil biodiversity and habitat provisioning, and (5) recycling of nutrients. The assessment or estimation of the capacity of a soil to perform these functions depends on complex interaction of soil properties with environment (climate) and management.

In the World Reference Base (WRB) (FAO 1998; IUSS Working Group WRB 2006, 2015) diagnostic horizons, properties and materials are used to define the highest taxonomic level – the Reference Soil Group (RSG) – while qualifiers provide supplementary information and serve to further define the soil type. To be

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considered "diagnostic", these elements must reach a certain degree of expression, which is determined by appearance, measurability, importance, relevance and quantitative criteria. For example, a surface, organic matter rich horizon requires a minimum thickness (20 cm), a minimum level of base saturation (50%) and organic carbon content (0.6%), together with structure and colour criteria to be considered as a mollic horizon.

The diagnostic units and the qualifiers convey information by themselves on complex soil properties, that are the result of soil forming processes, which in turn are related to a range of functions, such as the capacity of a soil to cycle nutrients (Michéli, E. *et al.* 2019). Most soils, belonging to a particular soil type, carry properties that might be characteristic for different other soil types, and the principles and rules of the applied soil classification system support the decision on the eventual soil type (RSGs in the WRB) (Dobos, E. *et al.* 2019).

However, the spatial extent or the continua of the diagnostic units may be, and often is, different from the soil mapping units in general soil maps. Therefore, in studies where the functional capacities of soils are a consideration, it is important to define the spatial extent of the constituent diagnostic units. For example, several RSGs might have hydromorphic properties related to groundwater caused by excess water (gleyic properties), but not all of those soils are classified as Gleysols because of the principles, priorities and construction of the classification key. However, as gleyic properties influence several soil functions, it could be important to define their overall spatial extent in all soils which are affected by hydromorphic properties, regardless of the taxonomic class (soil type).

The most complete and uniform soil map and database for the European Union is the 1:1 Million Soil Geographical Database of Eurasia (EC ESBN 2004; Panagos, P. 2006), hosted by the European Soil Data Center (ESDAC) at the JRC (https://esdac.jrc.ec.europa.eu/). The database provides the percentage of the dominant and all associated soil types per map unit while the visualized units reflect only the dominant soil types (RSGs with one qualifier) of the soil mapping units. The objective of this paper was to derive the spatial extent (in area percentage of the map units and in area percentage of the territory of the EU) of selected diagnostic units which may influence the capacity of the five soil functions in conjunction with environment and management.

Materials

The European Soil Database (ESDB)

The derivation of the selected diagnostics was performed based on the Soil Geographical Database of Eurasia (SGDBE), which is a part of the European Soil Database (ESDB) v2.0 (EC ESBN 2004; Panagos, P. 2006), and covers the interest area of the study, the territory of the European Union and Switzerland. This product is the result of a collaborative project involving all European Union member states and neighbouring countries. The ESDB is a simplified representation of diversity and spatial variability of soil coverage. The database consists of Soil Typological Units (STU), which represent soil names and are described by attributes specifying the nature and properties of the soils. As the original geographical representation (1:1 Million scale) did not allow the spatial delineation of STUs, they were grouped into Soil Mapping Units (SMU) to form soil associations. The associations refer to areal percentage of STUs and represented by one or more polygons in the geometrical dataset. The visualized maps generally present the polygons of the SMUs by representing the dominant STU *(Figure 1).*

The digital database includes further analytical and environmental information for the semantic units. Each dominant STU is also supplemented with a representative soil profile with basic horizon data. The SGDBE consists of a geometrical and a semantic dataset linking attribute values to the polygons. Besides the wide range of attributes defined for the STUs,

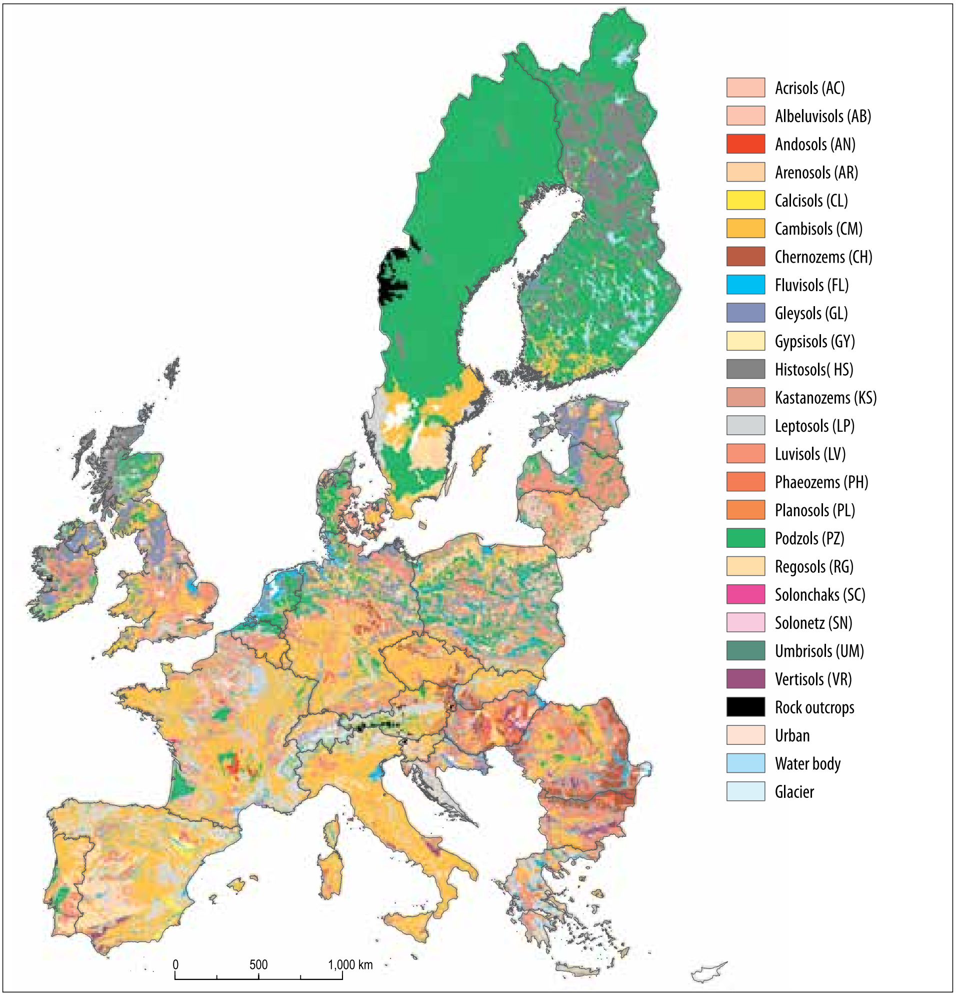


Fig. 1. The soils of the European Union. The distribution of the dominant Reference Soil Groups (WRB 1998) in the European Union and Switzerland according to the European Soil Database.

the database defines the WRB (1998) classification as well. The "WRB-FULL" attribute refers to the group code of the STU from the WRB. The attribute consists of the Soil reference group code (WRB-LEV1) and the first qualifier adjective code (WRB-ADJ1) of the STU.

Figure 1. shows the distribution of the major soil types for the European Union. The colours on the map refer to the RSG which is dominant in the particular SMU according to the ESDB.

The World Reference Base for Soil Resources

The World Reference Base for Soil Resources (WRB) is an international soil classification and correlation system endorsed by the International Union Soil Sciences (IUSS) (Deckers, J. *et al.* 2005). While most countries in the EU developed their own soil classification and mapping systems, the WRB enables the harmonization of soil databases and soil maps from different sources (Jones, A. *et al.* 2005). The 1st and 2nd editions of the WRB (FAO 1998; IUSS Working Group WRB 2006) served as a tool for the correlation of national soil classification units to the ESDB. The WRB consists of two categorical levels. The first level, the Reference Soil Groups (RSG) is defined by the classification key. The RSGs share an assemblage of defined diagnostic features and serve as reference for correlation of national classification units. The second level, the qualifiers, provides additional specific information. The diagnostic information of the RSGs and qualifiers were designed to provide practical considerations and expressions on ecological functions and management strategies. *Table 1.* summarizes the selected WRB units that were used in this study.

All diagnostic features are important for some aspects of soil functions. The selection was based on the expert judgement of the authors to select the ones that are mostly influencing agricultural land management. The information available at the time of the database construction was also considered and was often a limiting factor (eg., mollic horizon was not diagnostic for Umbrisols, or Stagnosols was not among the defined RSGs). Although the cambic horizon is the most common diagnostic horizon (with 26.14% area in the EU) it was not selected. The cambic horizon and the Cambisols are distinguished by moderate subsurface development without distinct features. For the Cambisols, the most informative indications are the associated qualifiers providing more specifics on function related properties, however, the structure of the database allowed only one qualifier.

The *spodic horizons* are also common, occupying 11.61 percent of the studied territory and carry important information on the soil forming environment. They generally develop in sandy material and represent subsurface accumulation of organic matter and iron oxides under leached, acidic conditions, determining limited choices of land use. Since the area percentage of the RSG Podzols for which the spodic horizon is diagnostic are identical no calculations were needed and *Figure 1.* provides the information on the spatial distribution.

The argic horizon is a clay enriched subsurface horizon with higher clay content than the overlying layer. The texture differentiation may be caused by illuvial accumulation of the clay, by destruction or selective erosion of the clay in the surface horizon, by biological activities or combination of causes. The argic horizon is diagnostic for the Acrisols, Albeluvisols, Alisols, Luvisols and Lixisols but may occur in several other RSGs.

The *calcic horizon* is an accumulation of secondary carbonates, mostly in the subsurface. In humid areas it is related to the leaching of the carbonates to deeper depth, while in dry areas the calcic horizon occurs closer to the surface and is often associated with carbonate rich parent material. The calcic horizon is diagnostic for the Calcisols, Chernozems and Kastanozems RSGs.

Gleyic properties are related to reducing conditions caused by saturation with groundwater at a shallow depth for long periods (FAO 2001a, b.) The gleyic properties are diagnostic for the Gleysols.

The *histic horizon* is related to the accumulation of organic material, consisting of partially decomposed plant biomass under wet conditions (Jobbágy, E.G. and Jackson, R.B. 2000; FAO 2001a, b). The slow decomposition is often associated with low temperature as well. The histic horizon is diagnostic for Histosols.

Table 1. Selected WRB units ("Diagnostics") and the RSGs (WRB-LEV1 and qualifiers (WRB-ADJ1) in the ESDB from which they were derived

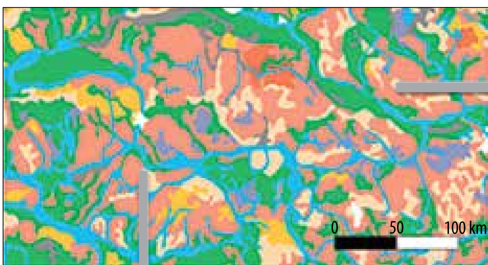
Diagnostics	WRB-LEV1 (RSG)	WRB-ADJ1 (Qualifier)
Argic horizon	Luvisols, Acrisols, Albeluvisols	Luvic (presence of argic horizon)
Calcic horizon	Calcisols, Kastenozems, Chernozems	Calcic (indicating calcic horizon)
Gleyic properties	Gleysols	Gleyic
Histic horizon	Histosols	Histic
Mollic horizon	Chernozems, Kastanozems, Phaeozems	Mollic

The *mollic horizon* is the result of the accumulation of well humified, stable organic carbon in the topsoil, mostly under ancient grassland vegetation (Lal, R. 2000). The mollic horizon is diagnostic for the Chernozems, Kastanozems and Phaeozems RSGs but occurs in other RSGs.

Methods

The derivation of the diagnostics and the qualifiers was performed by taking into consideration the definitions, rules and allocation procedure of soils to the appropriate RSG defined by the WRB key. By having a WRB RSG code (WRB-LVL1), and the first adjacent codes (WRB-ADJ1 (qualifier) for each STU in the ESDB, the definition of the diagnostic horizons, materials and properties is possible. While the areal percentage of the STUs within the SMUs is provided, the same attributes (in percent) were calculated for each of the diagnostics. An example of this approach is presented in *Figure 2*. In this example, SMU1 consist of three STUs. STU1 (Stagnic Luvisol) represents 50 percent, STU2 (Cutanic Luvisol) represents 30 percent and STU3 (Luvic Phaeozem) represents 20 percent of the SMUs' area (making a total of 100%).

Luvisols, by definition, have an argic horizon, while the Stagnic qualifier refers to the presence of Stagnic properties, hence STU1 has an argic horizon and stagnic properties. In STU2, the argic horizon is again present while the Cutanic qualifier indicates the presence of clay skins in the argic horizon (no additional information). Similarly, for STU3, Phaeozems by definition have a mollic horizon, while the Luvic qualifier indicates the presence of the argic horizon, hence STU3 has both mollic and argic horizons. On the visualized map, the entire SMU would be represented by the dominant Stagnic Luvisol STU. The database provides the information on the areal share of the Luvisols (80%) of the SMU. Based on the derived diagnostic information, the argic horizon occurs in the entire SMU and is combined with the mollic horizon in 20 percent of the SMU area and with Stagnic properties in 20 percent of the SMU area.



SMU1	Areal repres.	WRB name	Derived diagnostics
STU1	50%	Gleyic LUVISOL	Argic horizon Gleyic properties
STU2	30%	Cutanic LUVISOL	Argic horizon
STU3	20%	Luvic PHAEOZEM	Argic horizon Mollic horizon

Argic horizon	100%
Gleyic properties	50%
Mollic horizon	20%

SMU2	Areal repres.	WRB name	Derived diagnostics
STU1	50%	Luvic KASTANOZEM	Argic horizon Mollic horizon
STU2	30%	Arenic LUVISOL	Argic horizon
STU3	20%	Gleyic LUVISOL	Argic horizon Gleyic properties

Argic horizon	100%
Mollic horizon	50%
Gleyic properties	20%

Fig. 2. Exemplified derivation procedure of the selected diagnostics based on the Reference Soil Group and qualifier provided information in the ESDB.

Results and discussions

The map series of this study (*Figures 3* to *7*) provide (left) maps of the spatial distribution of the selected diagnostics together with the indication of their percentage area within the SMUs, and (right) the spatial distribution of the RSGs for which they are diagnostic, also with the indication of their percentage area within the SMUs. The areal percentages are given for the territory of the EU plus Switzerland.

The *argic horizon* occupies 17.81 percent of the examined territory *(Figure 3).* This is mostly affiliated to the Luvisols (14.74%), followed by the Acrisols (1.85%) and Albeluvisols (0.26%). The higher clay content in the subsoil influences infiltration and storage of water, nutrient movements and adsorption processes (Avery, B.W. 1983; Bockheim, J.G. and Hartemink, A.E. 2013). It should be emphasized that sampling of only the topsoil for nutrient management, monitoring or other purposes often misses this important information. The presence of a clay accumulation horizon also influences the depth distribution of the stable fraction of soil organic carbon (Torres-Sallan, G. *et al.* 2017), and so can be attributed to climate regulation. Only 0.96 percent of the argic horizons occur in other RGS (Chernozems, Phaeozems, Kastanozems, Planosols, Andosols and Anthrosols), therefore the maps in *Figure 3*, seem very similar. However, in the limited represented area the argic horizon has the same importance on the discussed processes.

The *calcic horizon* occupies 13.36 percent of the examined territory of Europe *(Figure 4)*, however, 11.16 percent of that does not occur in the RSGs for which the calcic horizon is diagnostic (Calcisols, Chernozems, Kastanozems) but in other RSGs (Gleysols, Luvisols, Gypsisols, Planosols, Solonchaks, Solonetz, Vertisols). The accumulated carbonates represent a significant, stable carbon reservoir that has implications on climate regulation (Monger, H.C. and Gallegos, R.A. 2000; Nordt, L.C. *et al.* 2000; Lal, R. 2004). At the same time, the presence of the calcic horizon, especially at shallow depth, is influencing (often limiting) the reaction of soil processes, the availability and cycling of nutrients and also biodiversity (Richter, A. *et al.* 2018).

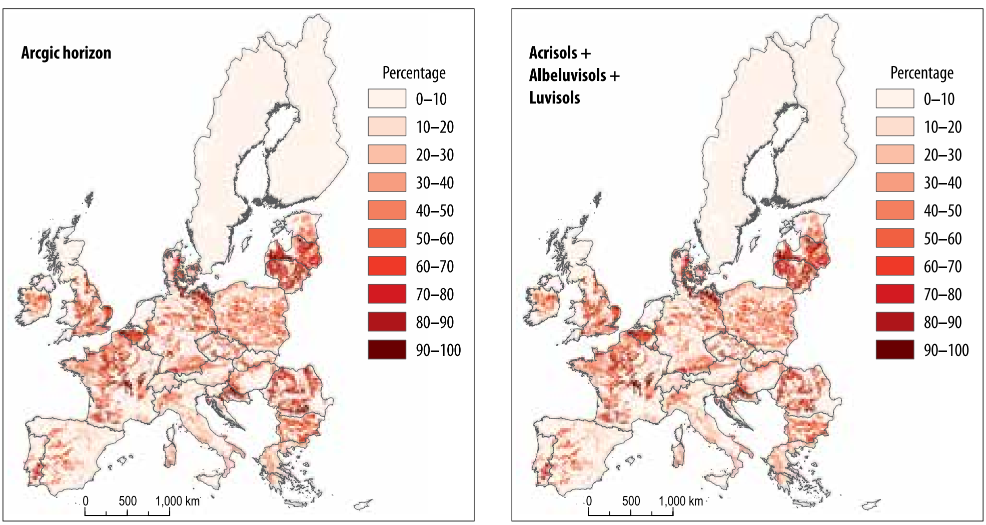
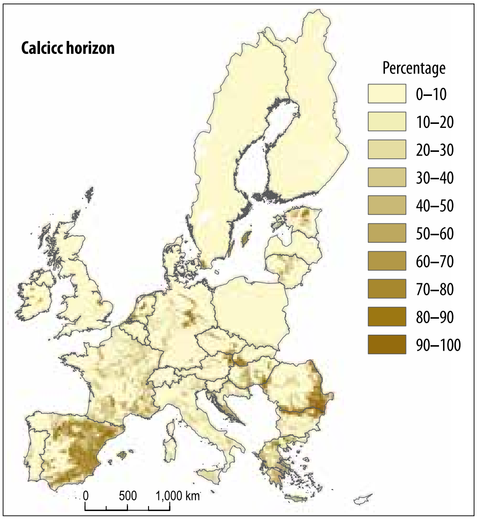


Fig. 3. The spatial distribution of the argic horizon with the indication of their area percentage within the SMUs (left), and the spatial distribution of the RSGs for which the argic horizon is diagnostic (AB, AC, LV), with the indication of their combined area percentage within the SMUs (right).



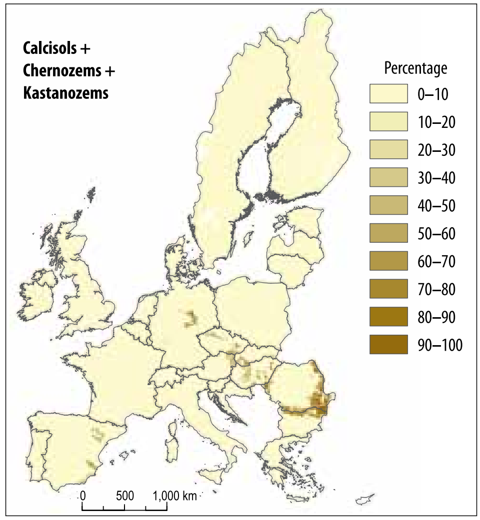


Fig. 4. The spatial distribution of the calcic horizons with the indication of their area percentage within the SMUs (left), and the spatial distribution of the RSGs for which calcic horizon is diagnostic (CL, CH, KS), with the indication of their combined area percentage within the SMUs (right).

Gleyic properties occur in 14.25 percent of the presented territory *(Figure 5)*, however, only 5.30 percent occur in the Gleysols for which the gleyic properties are diagnostic. The rest (8.95%) occur in many other RSGs (Acrisols, Albeluvisols, Cambisols, Chernozems, Fluvisols, Luvisols, Phaeozems, Planosols, Podzols, Regosols, Solonchaks and Umbrisols). Soils with Gleyic properties and the related reducing conditions, often suffer nutrient availability problems, which causes significant changes in soil biodiversity as well (Richter, A. *et al.* 2018). The presence of the gleyic properties may limit the rooting depth of several plants as well. While excess water has favourable influence on carbon sequestration and hence on part of the climate regulation function (Lal, R. 2004), we must also consider the other aspects of climate regulation, such as nitrous oxide and methane emissions which are strongly positively influenced by excess soil water for prolonged periods of time, as defined by the Gleyic properties (Anthony, T.L. and Silver, W.L. 2021).

Histic horizons occur in 6.66 percent of the territory of the EU and Switzerland *(Figure 6)*. Most of them (6.48%) occur in the Histosols, for which the histic horizon is diagnostic, while only 0.18 percent occur in other RSGs (Albeluvisols, Andosols, Fluviosls, Gleysols, Podzols, Planosols). The spatial distribution of Histosols well represents the distribution of the important diagnostic horizon. The histic horizon stores a significant portion of the organic matter of the world soils (Batjes, N.H. 1996; Lal, R. 2004; Jones, A. *et al.* 2005) and plays an important role in climate regulation. Their moisture and nutrient holding capacity are also important in the water and nutrient cycles. Therefore, management decisions should consider the preservation of histic horizons.

The *mollic horizon* occurs in 5.63 percent of the examined territory *(Figure 7)*, of which 3.62 percent occurs in the Chernozems, Kastanozems and Phaeozems, for which it is diagnostic according to the applied version of the WRB 1998. These soils are regarded as highly fertile soils, however, the mollic horizon serves the same important role in the many other RSGs (Andosols, Cambisols, Fluvisols, Gleysols, Leptosols, Planosols,

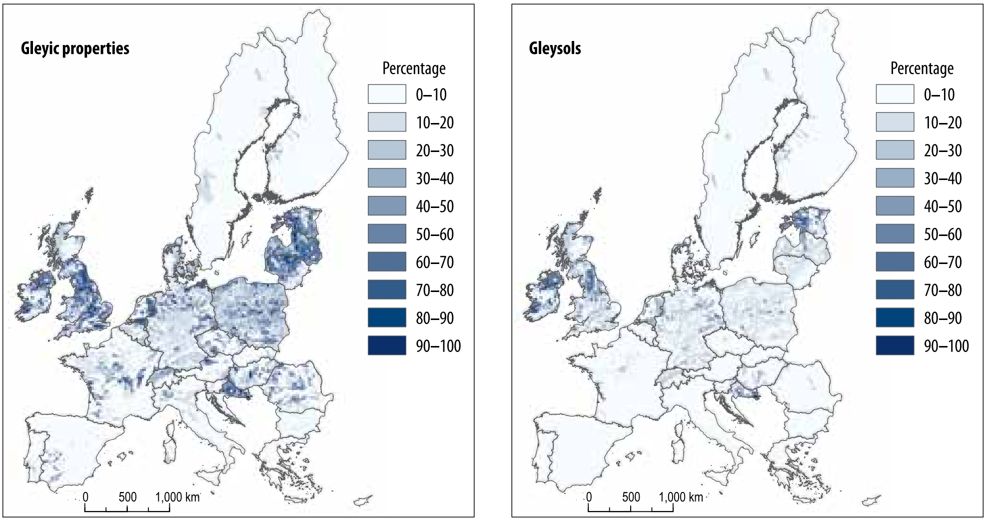


Fig. 5. The spatial distribution of the gleyic properties with the indication of their area percentage within the SMUs (left), and the spatial distribution of the RSG, the Gleysols for which is gleyic properties are diagnostic, with the indication of the area percentage within the SMUs (right).

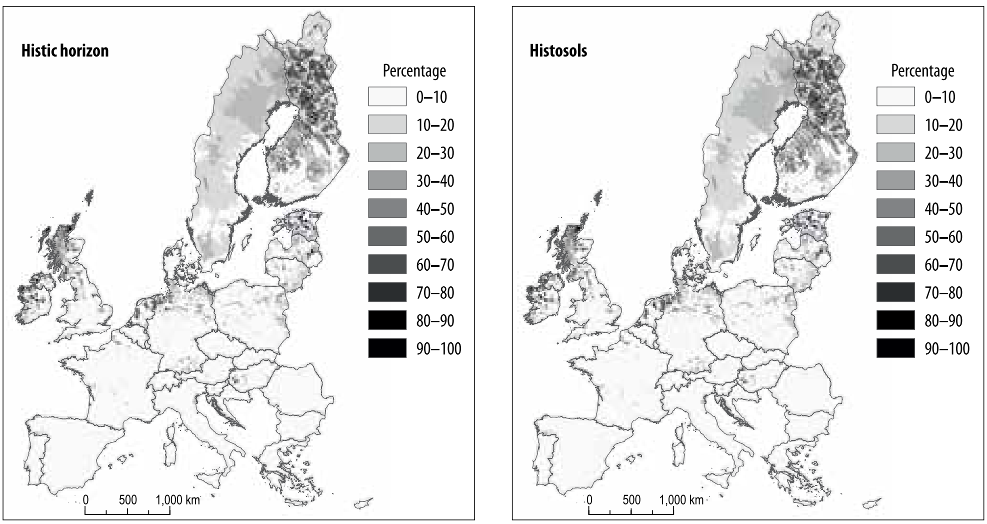


Fig. 6. The spatial distribution of the histic horizon with the indication of their area percentage within the SMUs (left), and the spatial distribution of the RSG, the Histosols for which the histic horizon is diagnostic, with the indication the area percentage within the SMUs (right).

Solonetz, Solonchaks) which occurs in 2.01 percent of the area. The mollic horizon has favourable physical and chemical properties. It is an important factor in relation to the water and nutrient holding capacity of soils (Sauerbeck, D.R. 2001) and is also a favourable habitat for biodiversity. The organic carbon that is stored and preserved in mollic horizons are important for climate regulation as the oxidation of the accumulated organic

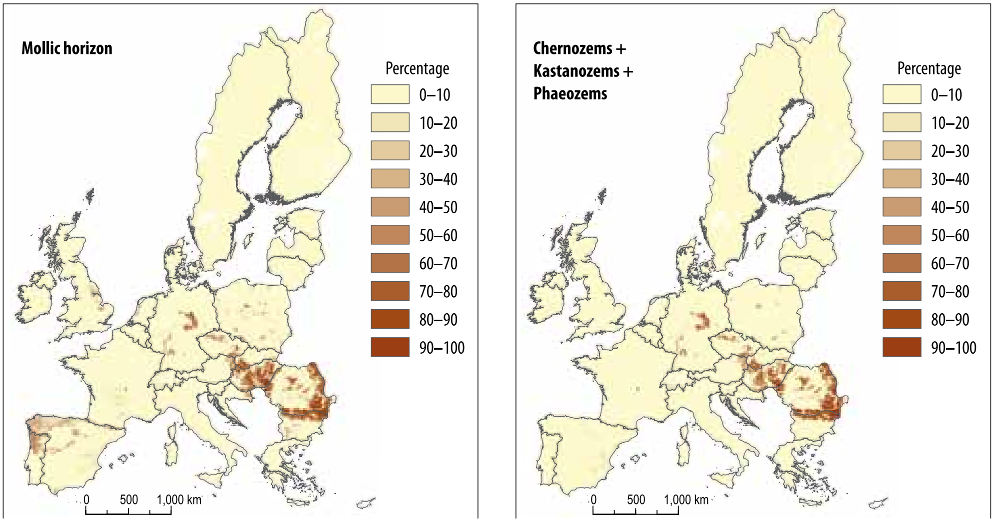


Fig. 7. The spatial distribution of the mollic horizon with the indication of their area percentage within the SMUs (left), and the spatial distribution of the RSGs (CH, KS, PH) for which the mollic horizon is diagnostic, with the indication the area percentage within the SMUs (right).

matter in cultivated soils may contribute to greenhouse gas emissions (Schlesinger, W.H. 2000; Lal, R. 2004).

Conclusions and limitations

In this paper we demonstrated the importance of the spatial definition of the diagnostic units and qualifiers, regardless of the RSGs, as they carry important information by themselves. With the described methodology, it was possible to extract all diagnostic information and define their areal percentage within the SMUs, thus, providing important information on the functional capacities of the areas covered. In addition to the units selected for this exercise, other diagnostic units and qualifiers could be presented. It must be stated that only one qualifier is provided to the RSGs in ESDB, while several more might be relevant to certain STUs, which might influence the percentage of the extent. The other limitation is that the exact spatial definition with the currently available map and database is not possible. Beside the identified presence of the diagnostics and qualifiers, their depth distribution is often an important issue. The ESDB was released in 2001 and updated in 2006, Since that time national databases and maps were improved or developed, while the 2nd and 3rd editions (2006, 2014) of the WRB were published.

However, the small scale of ESDB does not support field-scale management planning the result of this research can be the starting point to understand the diagnostic continuum of soils across Europe. Considering the importance of proper land use planning and the wealth of the European Union, it is suggested to encourage national soil data providers to make high spatial resolution soil data and associated semantic information more available. It is also important to emphasize that in upcoming surveys and data collection all the diagnostics should be established from observation and data and not be extracted from the classification.

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Projected values of thermal and precipitation climate indices for the broader Carpathian region based on EURO-CORDEX simulations

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Abstract

Since our climate is in a rapid changing phase, it is crucial to get information about the regional patterns of basic climatic parameters and indices. The EURO-CORDEX project provides high-quality regional climate model outputs, but these raw datasets are not convenient for the application in wider geoscience studies. According to the authors' knowledge, there is a lack of published spatial information about basic climate parameters and indices in Central Europe and especially in the broader Carpathian region therefore the basic aim of this study to fill this gap. The study presents the future trends in daily air temperature and precipitation and various climatic indices in the broader Carpathian Basin region during the 21st century. The indices are calculated using multi-model average temperature and precipitation data from EURO-CORDEX model simulations for the future time periods (2021–2050, 2071–2100) and emission scenarios (RCP4.5, RCP8.5). The indices present the future trends of the heat load, energy demand as well as extreme precipitation and drought characteristics. Based on the results the temperature increase is obvious and the heat load and energy demand quantifying indices follow the temperature trend. However, the trend is difficult to evaluate in the case of precipitation. The changes in the precipitation and the related indices can be considered small and appear within the regions. The future changes are the most considerable in the Carpathian Basin, but the entire examined region faces crucial changes in the following decades.

Keywords: climate change, 21st century, climate indices, Carpathian Basin, EURO-CORDEX model simulations

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Introduction

Climate change, a very important environmental phenomenon on earth, has become one of the most important issues facing humanity today. In the first two decades of the 21st century, global average temperatures were 1 °C higher than between 1850 and 1900, and this difference could be between 3.3 °C and 5.7 °C by the end of the century, according to the worst-case scenario (IPCC 2021). Rising temperatures have complex environmental effects on a global, regional and local scale. As part of this process, we may experience an increase in the frequency of extreme weather events (such as summer heat waves) in our daily lives (Meehl, G.A. and Tebaldi, C. 2004; Pongrácz, R. *et al.* 2013). This could have far-reaching implications for society's health status and mortality rates (Baccini, M. *et al.* 2008; Kovats, R.S. and Hajat, S. 2008; McGregor, G.R. *et al.* 2015; Bartholy, J. and Pongrácz, R. 2018).

The most recent climate projections are based on the Representative Concentration Pathways (van Vuuren, D.P. *et al.* 2011). The most commonly used of these are the less (RCP4.5) and the highly pessimistic (RCP8.5) scenarios (IPCC 2013). Under these scenarios, global temperature increases of 2 °C and 4 °C, respectively, are expected by the end of the century, compared to the period 1986–2005, but the change at the regional level may be very different from these values (IPCC 2013).

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To help assess future climate trends, in addition to the basic temperature and precipitation values, the use of so-called climate indices can further nuance and detail the picture of the change ahead. An example of such an index is when we count the days when the daily minimum temperature exceeds 20 °C (tropical night) in a given period. The number of these days shows well the annual duration of unfavourably warm weather conditions, as a high minimum temperature is also likely to mean a high daytime temperature (Pieczka, I. *et al.* 2018). There are several other similar indices, such as the number of summer days, hot days, heavy rainy days, and so on (see e.g., Dankers, R. and Hiederer, R. 2008; Sillmann, J. and Roecker, E. 2008). Analyses of the predicted values of these indices and their spatial patterns may be very useful for further detailed exploration of the characteristics of expected future climate change.

Going to a regional level, this paper deals with the region of the Carpathian Basin and its wider environment using climate projection outputs (related to the temperature and precipitation indicators) of the EURO-CORDEX regional models in case of RCP4.5 and RCP8.5 scenarios. Looking back on a few years, the earlier and similar modelling results based on the mentioned outputs to date, and at least in part related to the current study area, are as follows (grouped according to the extent to which their study areas differ from the domain of the present study):

– The study area covers a country, province or region (Štěpánek P. *et al.* 2016; Dalelane, C. *et al.* 2018; Pieczka, I. *et al.* 2018; Vuković, A. and Mandić, M.V. 2018; Kis, A. *et al.* 2020; Olefs, M. *et al.* 2021; Torma, C.Z. and Kis, A. 2022).

– The study area covers all or most of Europe (Jacob, D. *et al.* 2014; Kovats, R.S. *et al.* 2014; Rajczak, J. and Schär, C. 2017; Spinoni, J. *et al.* 2018; COACCH 2019; von Trentini, F. *et al.* 2019; Coppola, E. *et al.* 2021; Evin, G. *et al.* 2021; Badora, D. *et al.* 2022).

The importance of this topic is also highlighted by our previous studies: for many cities, we found a significant increase in the annual number of various thermal indices, so a strong warming trend is expected by the end of the century (Skarbit, N. and Gál, T. 2016; Bokwa, A. *et al.* 2019; Gál, T. *et al.* 2021). Information from regional climate projections on temperature- and precipitation-related climate indices is essential for the development and implementation of climate change mitigation and adaptation plans in this region.

According to our knowledge, published EURO-CORDEX model results are not available for the whole study area mentioned above, thus, information about the process of climate change based on this database is difficult to access for the broad scientific community. Therefore, the main aim of the study is to fill these gaps and contribute to obtain accurate spatial information about climate change. These results could also provide vital information for climate mitigation and adaptation plans, moreover it could serve as a starting point for other studies in smaller scale or in different disciplines.

The specific aims of the study are the following, (i) presenting the model averages of all available EURO-CORDEX outputs for basic climatic parameters (daily mean air temperature and daily precipitation), (ii) calculation of the most crucial climate indices in order to describe the different details of future climate, namely the heat load (warm and tropical nights, summer and hot days), energy demand (heating and cooling degree days) as well as extreme precipitation and drought characteristics (heavy and very heavy precipitation days and consecutive dry days).

Methods

Study area

This study would like to present the future conditions of the Carpathian Basin and surrounding areas of Central and Eastern Europe. The study area lies between longitudes 11° and 30°, and latitudes 43° and 51°.

This area covers southeast Germany, south Poland, Czech Republic, Slovakia, west Ukraine, almost the whole area of Austria, Hungary, Romania, Moldova, Slovenia, Croatia and the northern parts of Bosnia and Herzegovina and Serbia *(Figure 1).*

Applied model simulations

The study examines the future conditions through the average values of two periods: 2021–2050, and 2071–2100. For these periods the average of bias-corrected air temperature, daily

Fig. 1. Location in Europe marked by the red rectangle (a), and detailed map of the study area (b) with the mentioned regions in *Table 4. Source of the background map*: Elevation map of Europe (European Environment Agency – https://www.eea.europa.eu/data-and-maps/figures/elevation-map-of-europe).

maximum and minimum air temperature and precipitation data of different EURO-CORDEX model simulations with resolution 0.11° were used (Jacob, D. *et al*. 2014). All available model simulations that include these parameters for the study area, thus, the output of 13 simulations were applied for RCP4.5 and RCP8.5 scenarios (van Vuuren, D. P. *et al.* 2011) *(Table 1).*

Table 1. Details of the applied EURO-CORDEX model simulations

Nr	Institute	Global climate model	Regional climate model
1. 2. 3. 4.	CLMcom	CNRM-CM5 EC-EARTH HadGEM2 MPI-ESM-LR	CCLM4
5.	DMI	EC-EARTH	HIRHAM5
6. 7.	KNMI	EC-EARTH HadGEM2	RACMO22E
8.	MPI	MPI	REMO2009
9.	SMHI	CNRM-CM5	RCA4
10.		EC-EARTH	
11.		IPSL-CM5A-MR	
12.		HadGEM2	
13.		MPI-ESM-LR	

Applied indices

Besides the basic climatic parameters (temperature, precipitation), several climate indices were calculated to describe different aspects of the process of climate change *(Table 2).* Four indices were applied to examine the heat load change. The night heat load was analysed through the average number of warm and tropical nights, which indices are based on the daily minimum temperature. While the daytime heat load was determined with the change of the summer and hot days, using the daily maximum temperature.

In order to present the change of energy demand the heating degree days (*HDD*) and cooling degree days (*CDD*) were examined (see *Table 2*). Their calculation was based on Matzarakis, A. and Thomsen, F. (2009). The *HDD* and *CDD* give the heating and cooling energy demand of the buildings during the heating and cooling period, respectively. In case of the *HDD* the heating threshold of 15 °C was used. The index summons the difference of this value and the daily mean temperature when it does not reach this threshold. The *CDD* calculated in a similar way, in this case we applied the cooling threshold of 18 °C and the index summons the difference between the threshold and the daily mean temperature when it exceeds that. Selecting a suitable threshold for a larger area is inherently difficult because of the different regional climates, thus, studies for Europe or parts of Europe use several different thresholds (Cartalis, C. *et al*. 2001; Golombek, R. *et al*. 2012; Lindberg, F. *et al*. 2013; Moreci, E. *et al*. 2016; Chervenkov, H. *et al*. 2020). The focus of this analysis is mostly on the change in the

Table 2. The examined climate indices and their definition with the applied parameter

Nr.	Index	Definition	Applied parameter
1. 2.	Warm night (WN) Tropical night (TN)	$T_{min} \geq 17$ °C $T_{min} \geq 20$ °C	Daily minimum temperature (T_{min})
3. 4.	Summer day (SD) Hot day (HD)	$T_{max} \geq 25$ °C $T_{max} \geq 30$ °C	Daily maximum temperature (T_{max})
5. 6.	Heating degree day (HDD) Cooling degree day (CDD)	$\sum (15 - T_a)$ when $T_a < 15$ $\sum (T_a - 18)$ when $T_a > 18$	Daily mean temperature (T_a)
7.	Heavy precipitation day (HPD)	$R_d > 10$ mm	Daily precipitation sum (R_d)
8.	Very heavy precipitation day (VHPD)	$R_d > 20$ mm	
9.	Consecutive dry days (CD)	$R_d < 1$ mm (maximum number of consecutive days per time period)	

value of the indices, so the choice of thresholds was not considered relevant.

The extreme precipitation characteristics were investigated through two indices, the heavy and very heavy precipitation days when the daily precipitation sum exceeds 10 mm and 20 mm, respectively (see *Table 2*). While the change of drought circumstances was studied through consecutive dry days. In case of this index the maximum number of consecutive dry days per time period was determined, when the daily precipitation did not reach 1 mm. While the other applied indices are average values for the 30 periods, this index shows the maximum number for the whole periods.

Results

Basic climatic parameters

Temperature

In the period of 2021–2050, the daily average (T_a) temperature in the northern part of the study area is mostly between 8 °C and 10 °C (*Figure 2*, a and b). It is over 10 °C in the lower areas in Germany, Czech Republic and Poland, which covers a larger area in scenario RCP8.5 (see *Figure 2*, b). In the Carpathians the values are between 4 °C and 8 °C, lower values appear in the eastern part. Similar values appear in the Alps. In the Carpathian Basin, T_a is higher than 10 °C in almost the whole area. In the southern part, the temperature exceeds 12 °C. The greatest difference between the two scenarios occurs in this area. In case of scenario RCP8.5, the values over 12 °C appear over a larger area, especially in the southern and central part of Hungary and in the Little Hungarian Plain. In the Romanian Plain, the values are over 12 °C in most of the area. In the Dinaric Alps, T_a will be between 6 and 10 °C. On the coast of the Adriatic Sea T_a exceeds 14–16 °C.

In 2071–2100, under RCP4.5, values over 10 °C can be typical in the north areas of the study area (*Figure 2*, c). In the Carpathians and the Alps, T_a can be over 6 and 8 °C in more area, values under 4 °C almost disappear. In almost the whole Carpathian Basin and the Romanian Plain, T_a will be above 12 °C, and in Serbia in a small area over 14 °C. The values will exceed 10 °C in several areas of the Dinaric Alps, while on the coast of the Adriatic Sea there is not relevant change.

According to scenario RCP8.5 major changes will occur. Apart from the mountains and higher areas, T_a will be over 12 °C (*Figure 2*, d). T_a in the Carpathians and Alps will be above 8 °C. The typical values in the Carpathian Basin and the Romanian Plain will be over 14 °C, in the Dinaric Alps 16 °C. In the Mediterranean, the temperature will exceed 16 °C or even 18 °C in a large area.

Precipitation

In 2021–2050, the annual precipitation (P) will be between 600 mm and 800 mm in the most northern parts of the study area (*Figure 3*, a and b). In the Carpathians, Alps and Dinaric Alps the values are typically over 800 and 1,000 mm and in many areas exceed 2,000 mm. In the Carpathian Basin, P will be between 600 and 800 mm, but in the central and southern part it is lower than 600 mm. The pattern of P does not depend on the scenario in this period. Values close to 400 mm will appear in the southern and south-eastern parts of the study area.

In 2071–2100, there are no remarkable changes compared to the previous period under any of the scenarios (*Figure 3*, c and d). The only major change will appear in the area of the Carpathian Basin where P will be over 600 mm in a large area. This change is more pronounced in scenario RCP8.5 (see *Figure 3*, d).

Minimum temperature-based indices

Warm nights

The warm nights (*WN*) in 2021–2050 will be between 10 and 20 in the northern areas and under 10 in the higher areas (*Figure 4*, a and b). In the Carpathian Basin, *WN* are over 30 and exceed 40 in the central and southern

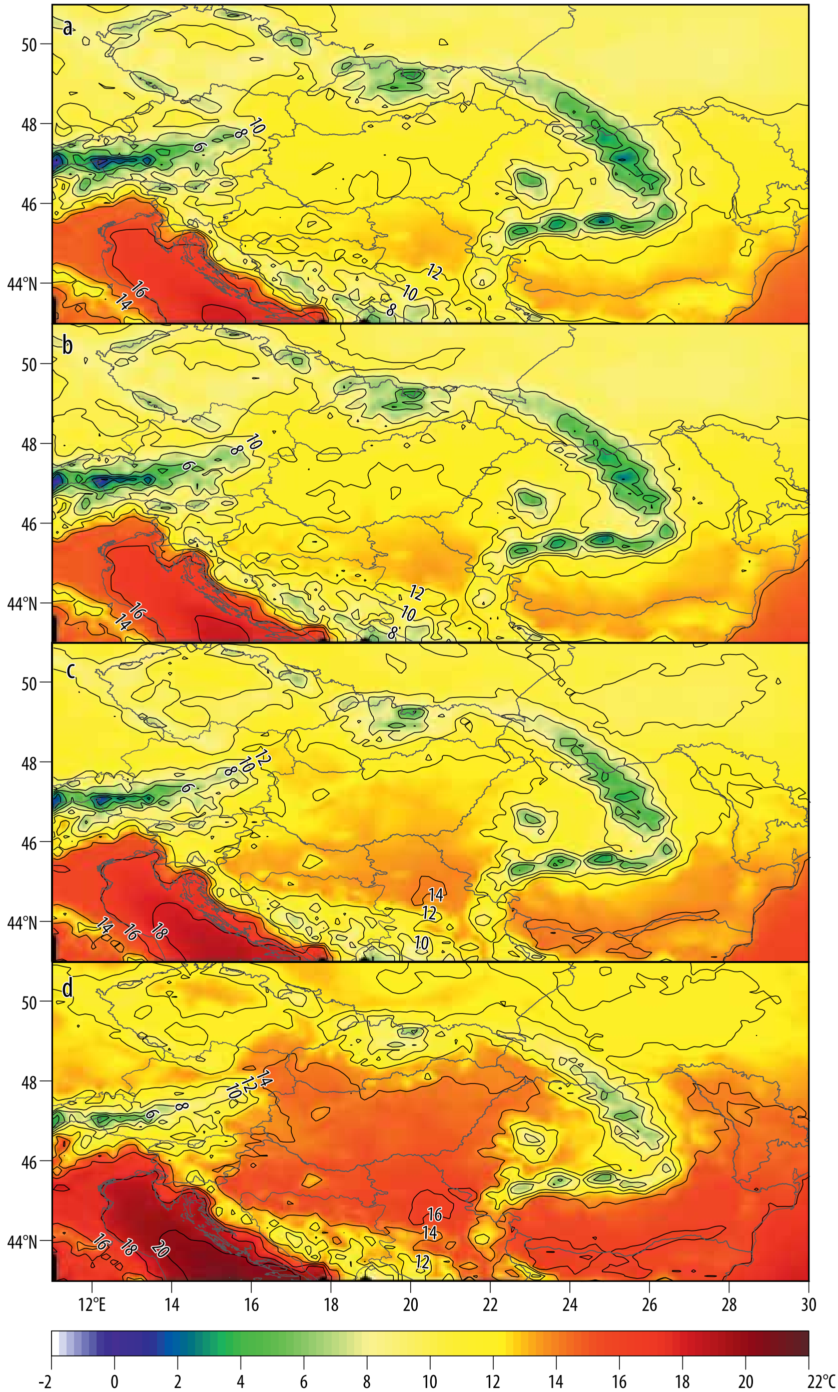

Fig. 2. Daily average mean temperature in 2021–2050 by RCP4.5 (a), in 2021–2050 by RCP8.5 (b), in 2071–2100 by RCP4.5 (c) and in 2071–2100 by RCP8.5 (d).

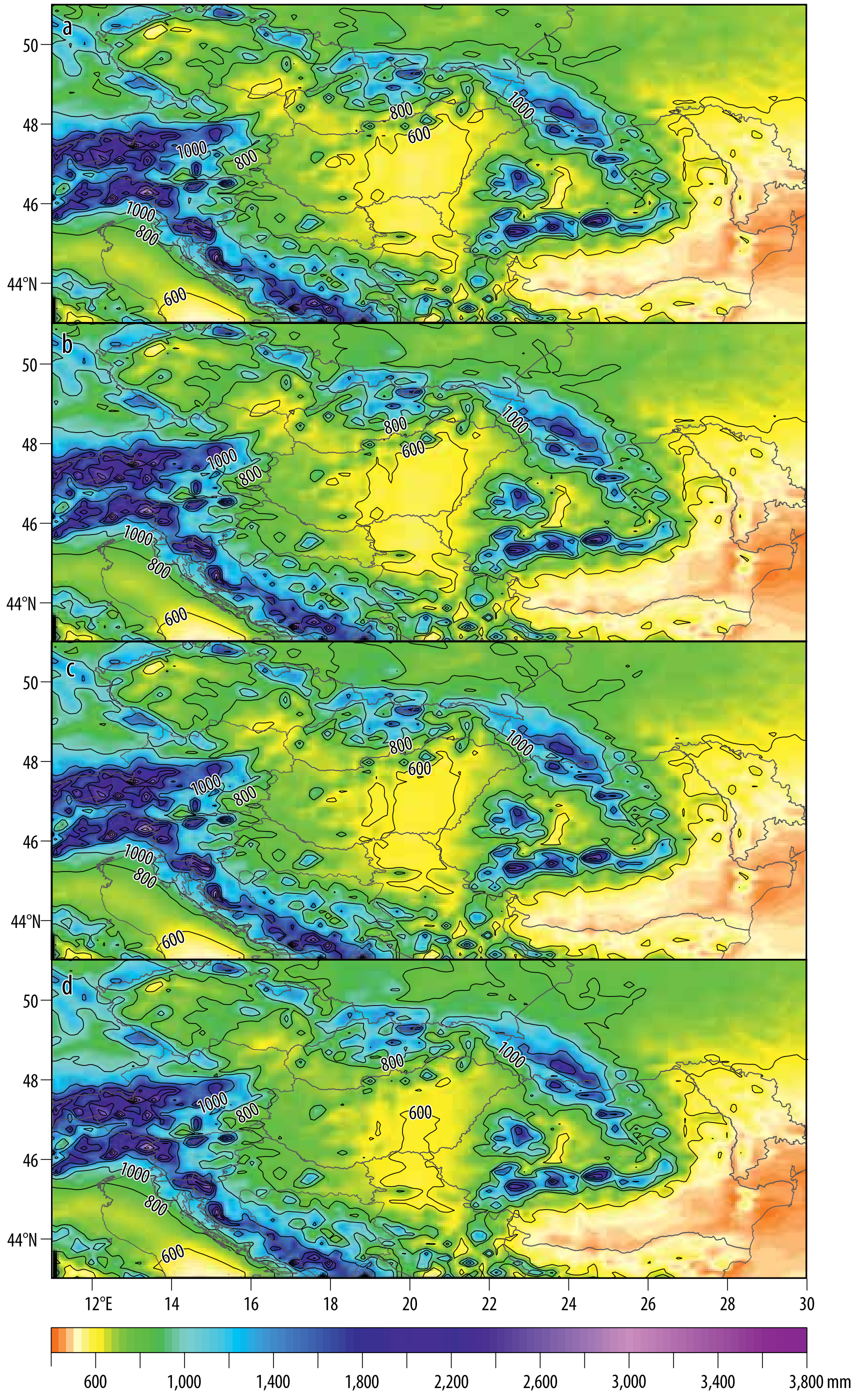

Fig. 3. Average annual precipitation in 2021–2050 by RCP4.5 (a), in 2021–2050 by RCP8.5 (b), in 2071–2100 by RCP4.5 (c) and in 2071–2100 by RCP8.5 (d).

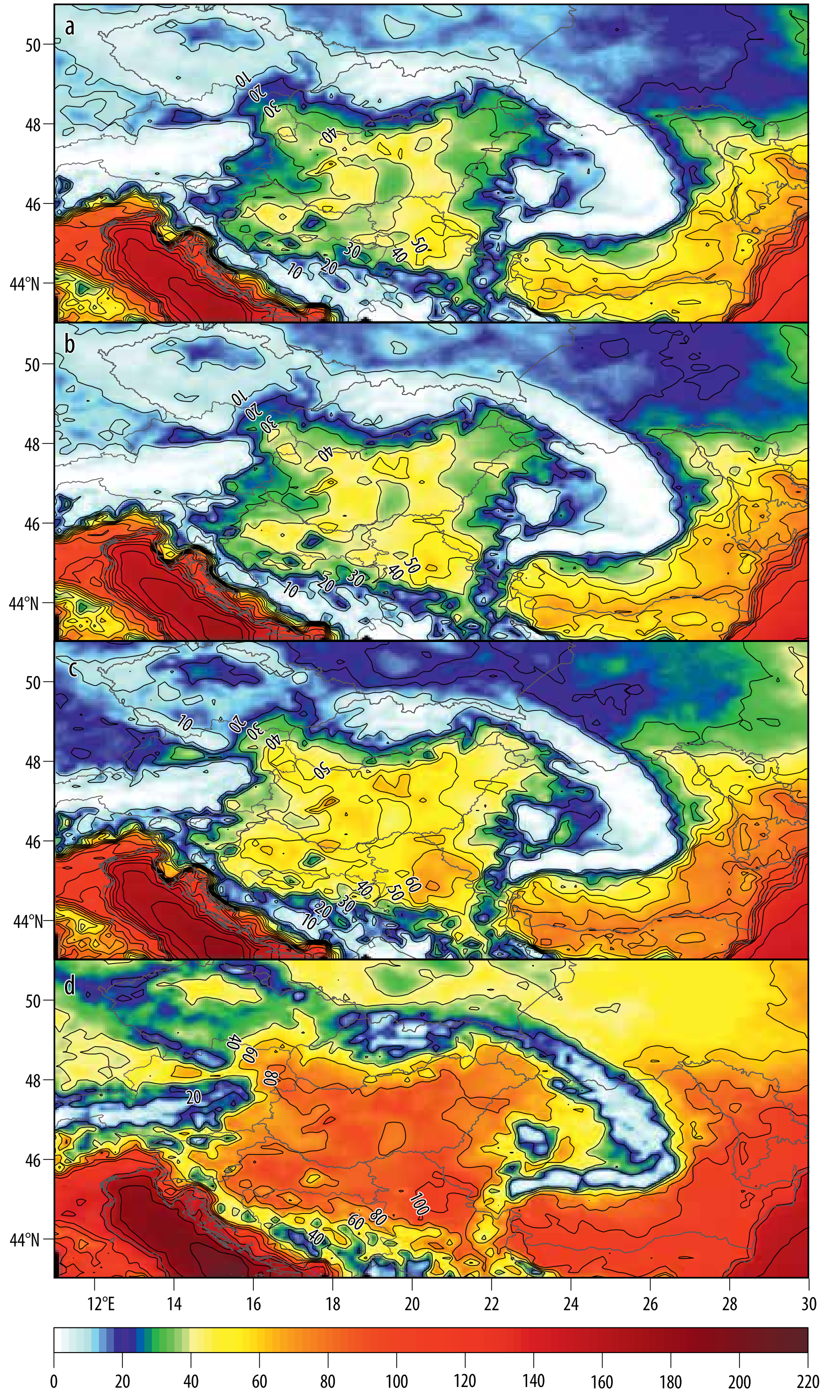

Fig. 4. Average number of warm nights in 2021–2050 by RCP4.5 (a), in 2021–2050 by RCP8.5 (b), in 2071–2100 by RCP4.5 (c) and in 2071–2100 by RCP8.5 (d).

parts. Higher values appear in the Romanian Plain where *WN* exceed 40 or even 60. There are higher (over 80) values on the Adriatic coast. There is minimal difference between the scenarios. The only spectacular difference appears in the Carpathian Basin, the Romanian Plain and on the seacoast.

In 2071–2100, under scenario RCP4.5, *WN* will exceed 20 in the northern and north-eastern parts of the study area *(Figure 4*, c*)*. Furthermore, fewer areas in the mountains have values below 10. The values are over 40 and 60 in almost every part of the Carpathian Basin and in the central and southern part and in the main part of the Romanian Plain, respectively. On the coast of the Adriatic Sea, *WN* will exceed 80 or even 100.

According to scenario RCP8.5, major changes will take place at the end of the century *(Figure 4*, d*)*. In the mountains *WN* will be below 20 in only a few areas and between 40 and 60 in the northern and north-eastern areas. In the Carpathian Basin they exceed 60, and in most of the areas 80 and in Serbia even 100. In case of the Romanian Plain, values over 80 and 100 will be typical. On the Adriatic coast *WN* will be over 120–140.

Tropical nights

In 2021–2050, the number of tropical nights (*TN*) is low, except the Carpathian Basin and Romanian Plain, it will not reach 5 *(Figure 5*, a and b*)*. It will exceed 10 in the central and southern part of the Carpathian Basin and 20 the eastern and southern parts of the Romanian Plain. On the coast of the Adriatic Sea, the values will be higher than 40 or even 60. There are hardly noticeable differences between the scenarios.

Under the RCP4.5 scenario, *TN* will be higher than 10 in the whole area of the Carpathian Basin and 20 in its central and southern parts *(Figure 5*, c*)*. In the Romanian Plain it exceeds 20 and 30 in its central and eastern parts. On the seashore, *TN* will reach 40 or even 60.

There will be a huge change for 2071–2100 according to scenario RCP8.5 *(Figure 5*, d*)*. Values below 10 will occur only in the mountains. The number of *TN* will be higher than 20 in the entire area of the Carpathian Basin and in most parts it can exceed 40 and in some southern parts 50. Higher values will be in the Romanian Plain where *TN* exceed 60 and in some eastern part 70. On the shores of the Adriatic Sea, the values can be over 80–100.

Maximum temperature-based indices

Summer days

In 2021–2050 the number of summer days (*SD*) is between 20 and 40 in the northern part of the study area *(Figure 6*, a and b*)*. In most parts of the mountains the values are under 20. In the Carpathian Basin *SD* are over 80 and 100 in its southern part. In almost the entire area of the Romanian Plain the values are over 80 and 100 in the inner parts. Similar values can appear on the Adriatic coast where the typical values are over 80 and 100. The difference between the scenarios is minimal.

For the period of 2071–2100, the *SD* is higher than 60 in the northern parts of the study area according to RCP4.5 *(Figure 6*, c*)*. Furthermore, more areas in the mountains can have *SD* over 40. In the Carpathian Basin, the number of *SD* is above 100 in a larger area and values over 120 can appear in the southern part. In the Romanian Plain *SD* is over 120 in almost the entire area. Values are also above 120 on the Adriatic coast where they can be over 140 too.

Under scenario RCP8.5, *SD* is above 80 and 40 in most parts of the north of the study and in the mountains, respectively *(Figure 6*, d*)*. In the entire Carpathian Basin, the values are over 100, but it can be 120 in most areas and 140 in the south. *SD* can exceed 140 in almost the whole Romanian Plain. On the Adriatic coast, *SD* above 140 are typical, but values above 160 also appear.

Hot days

The number of hot days (*HD*) in the period 2021–2050 is under 10 in the Alps, Carpathians

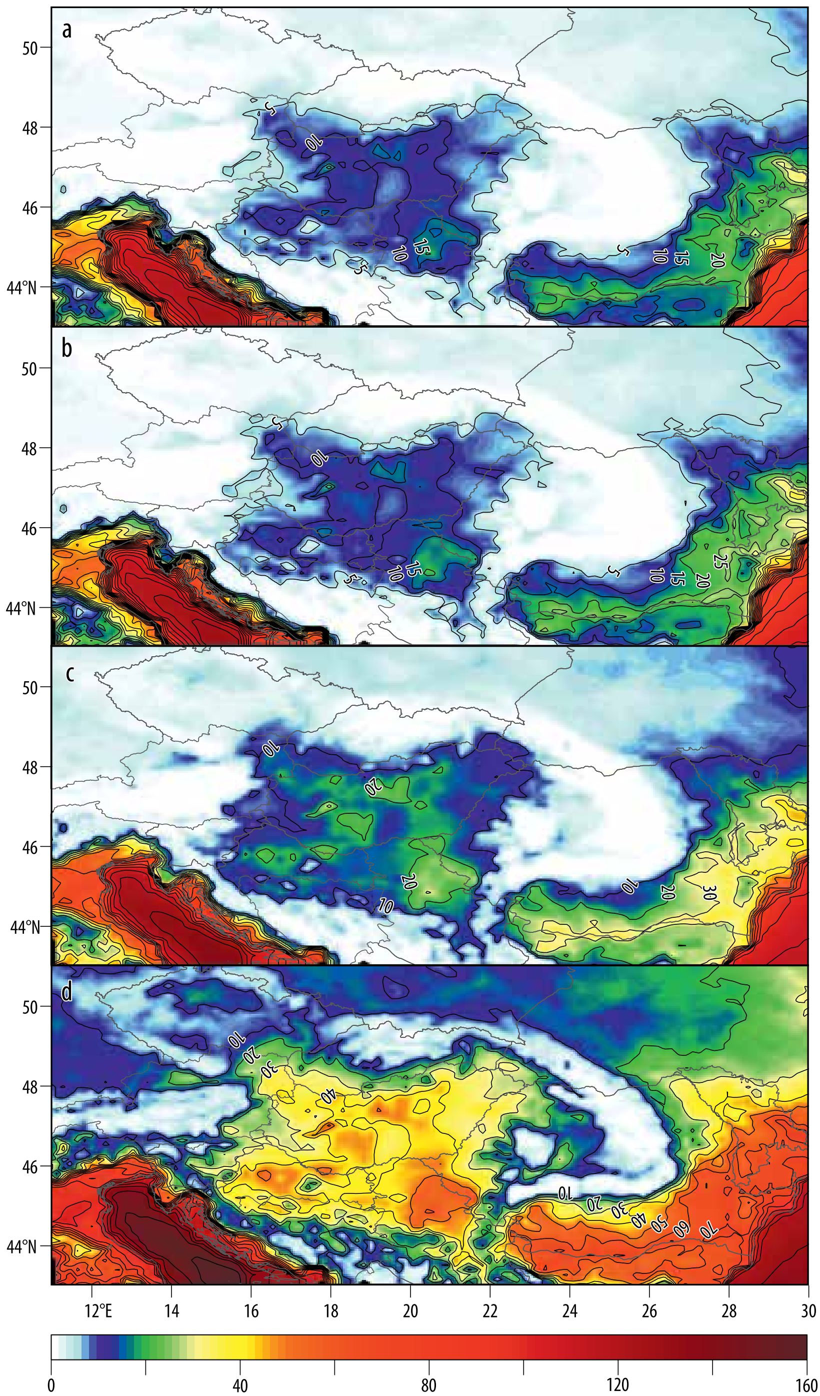

Fig. 5. Average number of tropical nights in 2021–2050 by RCP4.5 (a), in 2021–2050 by RCP8.5 (b), in 2071–2100 by RCP4.5 (c) and in 2071–2100 by RCP8.5 (d).

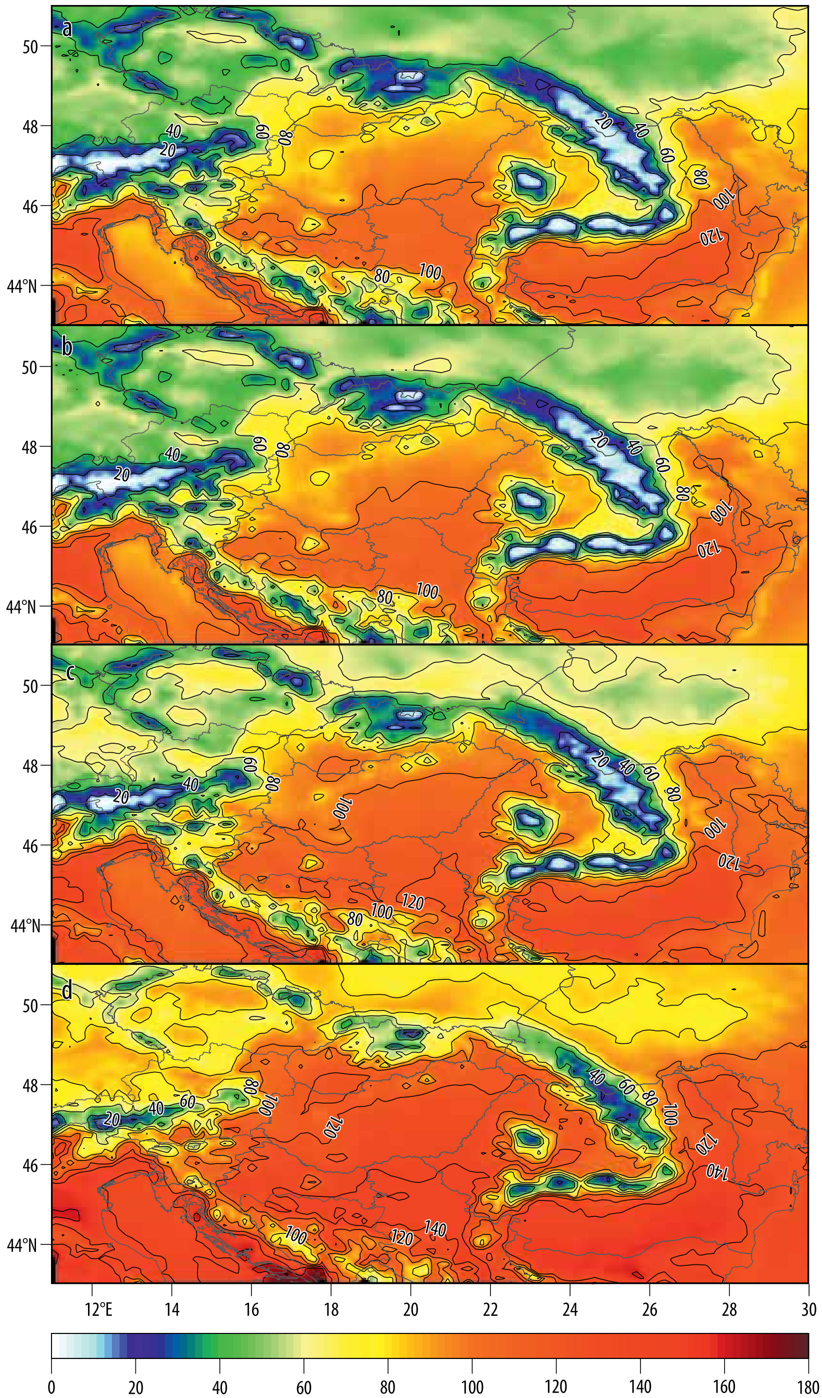

Fig. 6. Average number of summer days in 2021–2050 by RCP4.5 (a), in 2021–2050 by RCP8.5 (b), in 2071–2100 by RCP4.5 (c) and in 2071–2100 by RCP8.5 (d).

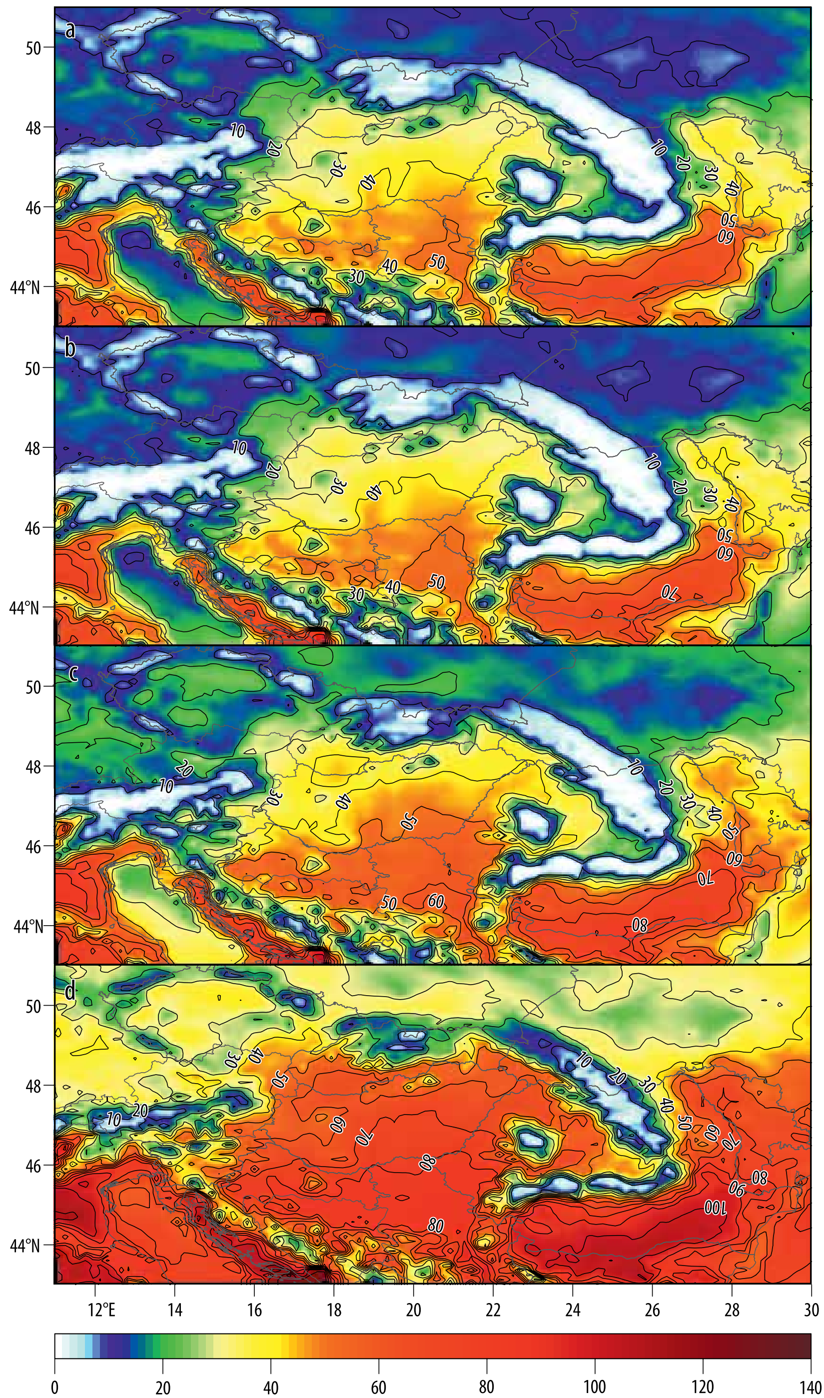

Fig. 7. Average number of hot days in 2021–2050 by RCP4.5 (a), in 2021–2050 by RCP8.5 (b), in 2071–2100 by RCP4.5 (c) and in 2071–2100 by RCP8.5 (d).

and higher altitudes in the north, however, it is between 10 and 20 in the lower parts of the northern areas *(Figure 7*, a and b*)*. In the largest area of the Carpathian Basin the *HD* is over 30 and in the southern part, 40 or even 50. In most of the Romanian Plain the values are over 60 and in a smaller area 70. On the shores of the Adriatic Sea *HD* is over 50–60. There are minimal differences between the scenarios; the values differ only in some smaller areas.

In the period 2071–2100, according to RCP4.5, the values exceed 20 in the northern part of the study area *(Figure 7*, c*)*. There can be fewer areas in the mountains where the values do not exceed 10. *HD* can be over 30 in the entire Carpathian Basin, 40 in most parts of it and 50–60 in the southern parts. In most parts of the Romanian Plain the values can exceed 70 and in a smaller area 80. On the Adriatic coast, *HD* can be 70–80.

Under scenario RCP8.5, the values can be over 30 in most parts of the northern areas and 10 or even 20 in the mountains in 2071–2100 *(Figure 7*, d*)*. *HD* can be over 50–60 in the entire Carpathian Basin, while 70–80 in the southern parts of it. Higher values can appear in the Romanian Plain and the Adriatic coast, since in these areas *HD* can exceed 90–100.

Measures of energy demand

Heating degree days

The heating degree days (*HDD*) in 2021–2050 will be between 2,000–3,000 in the northern parts of the study area *(Figure 8*, a and b*)*. In the mountains, the values will be higher than 3,000 and in most parts they exceed 4,000. In the northern Carpathian Basin *HDD* will be between 2,000 and 2,500 while in the southern parts under 2,000. In large parts of the Romanian Plain *HDD* will be between 1,500 and 2,000. The lowest values, under 1,500 *HDD*, will appear near to the Adriatic Sea. The differences between the scenarios are minimal.

In 2071–2100, according to RCP4.5, the *HDD* will not exceed 2,500 in the north, higher values will appear only in the mountains *(Figure 8*, c*)*. In some smaller northern areas, the *HDD* will not reach 2,000. While in the Carpathian Basin and the Romanian Plain the values will be between 1,500 and 2,000.

Under scenario RCP8.5, *HDD* will exceed 2,000 only in the mountains and in some higher areas in the Czech Republic and Ukraine *(Figure 8*, d*)*. In the Carpathian Basin and Romanian Plain the values will be between 1,000 and 1,500, as well as between 500 and 1,000 on the Adriatic coast.

Cooling degree days

The cooling degree days (*CDD*) in 2021–2050 will be under 100 in the mountains, and they exceed 100 in most and 200 in some minor northern areas *(Figure 9*, a and b*)*. In the Carpathian Basin *CDD* will be over 300 in north and 400–500 in the southern part. In almost the entire Romanian Plain the values will be over 500. The highest number of *CDD*, over 600–700 will appear on the coast of the Adriatic Sea. There are some minor differences between the scenarios, but they are not remarkable.

In 2071–2100, under scenario RCP4.5, the values will be higher than 200 in almost the entire northern part of the study area *(Figure 9*, c*)*. *CDD* will be under 100 only in the mountains. In almost the entire part of the Carpathian Basin *CDD* will be over 400–500 and 600–700 in the south. In the Romanian Plain, *CDD* will exceed 700–800 and 900–1,000 on the Adriatic coast.

According to scenario RCP8.5, *CDD* will be over 300–400 in 2071–2100 in the northern parts *(Figure 9*, d*)*. In the mountains, there are very few areas where the *CDD* will not reach 100. In almost the whole Carpathian Basin, *CDD* will exceed 700 and in the southern parts 800–1,000. In most parts of the Romanian Plain, the values will be over 1,000–1,200 and 1,400–1,600 on the coast of the Adriatic Sea.

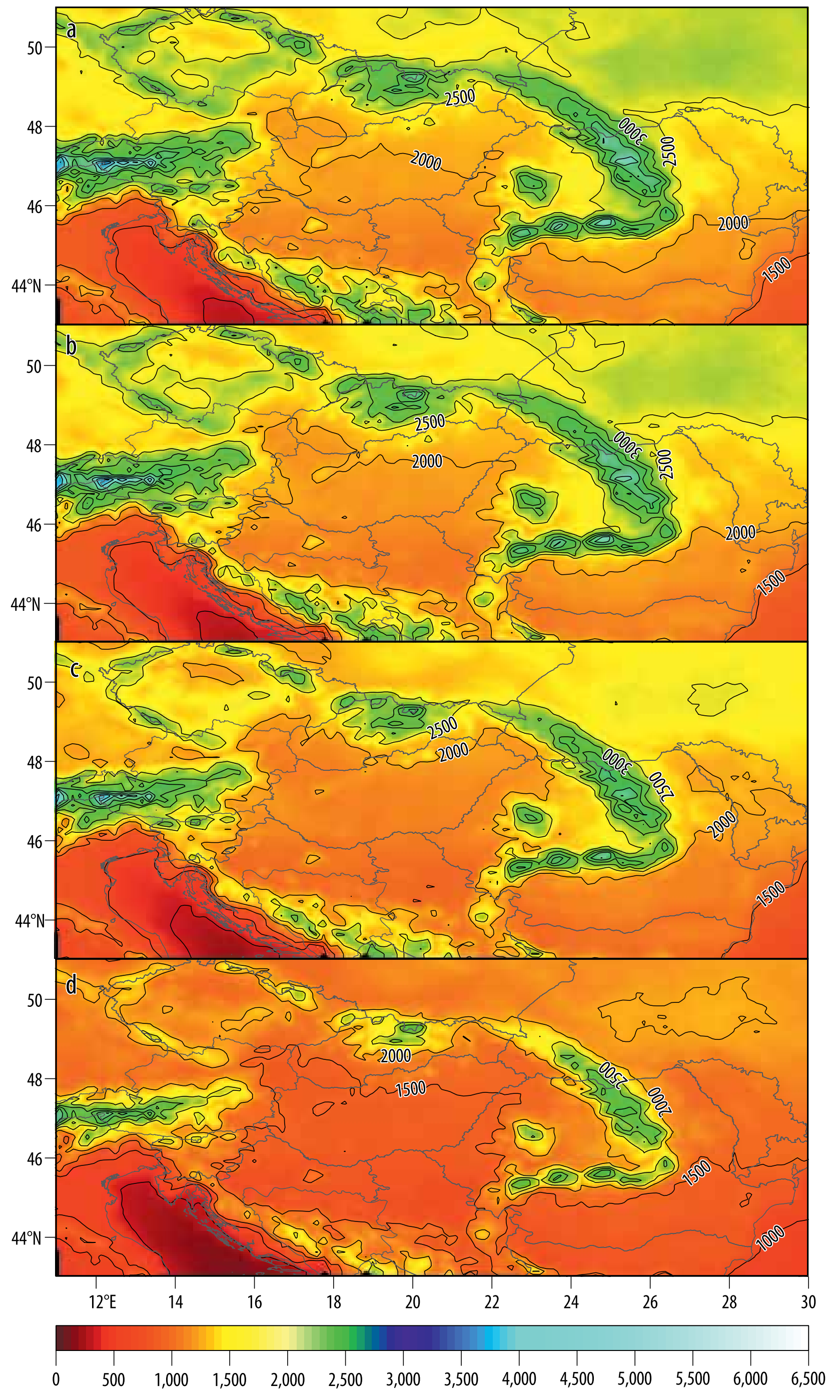

Fig. 8. Average heating degree days in 2021–2050 by RCP4.5 (a), in 2021–2050 by RCP8.5 (b), in 2071–2100 by RCP4.5 (c) and in 2071–2100 by RCP8.5 (d).

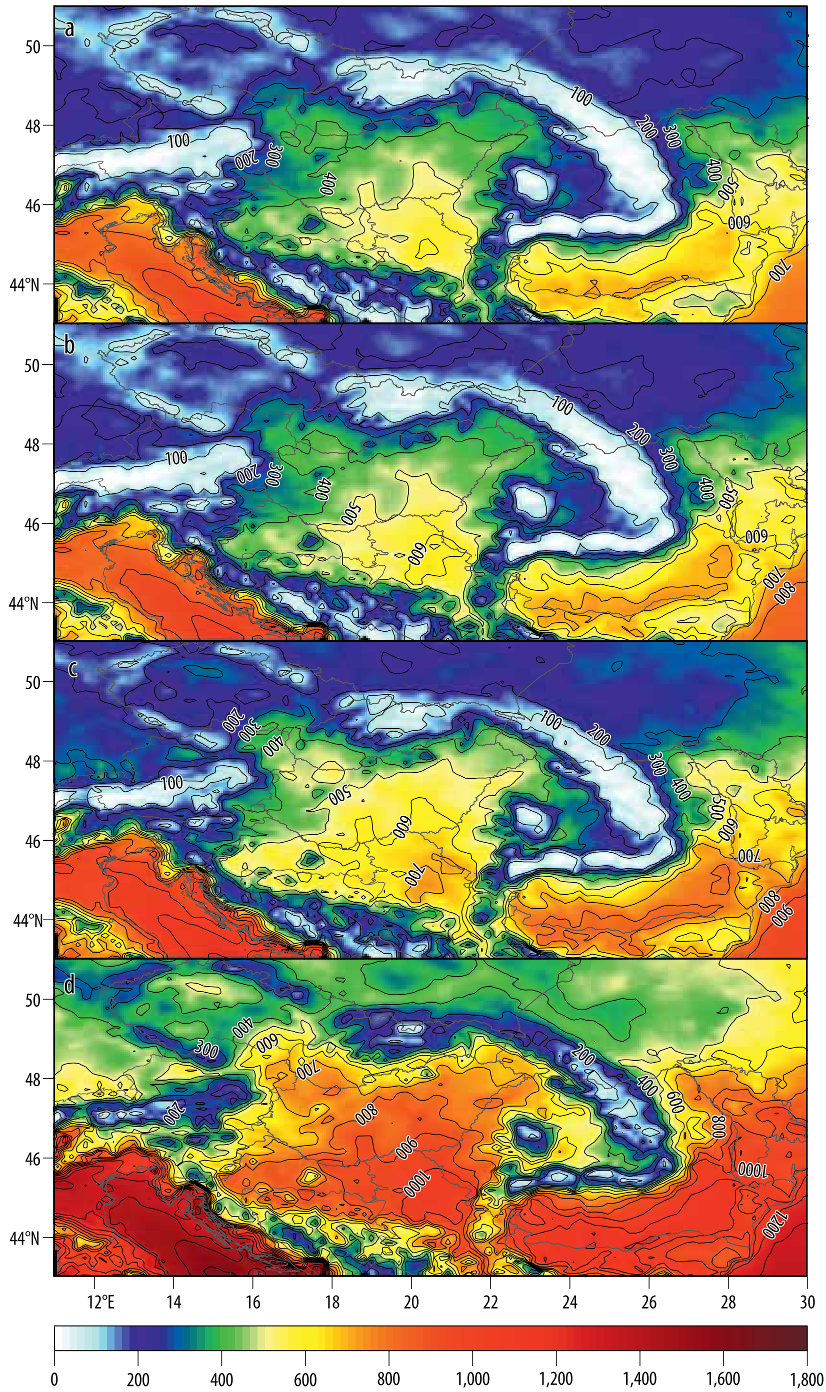

Fig. 9. Average cooling degree days in 2021–2050 by RCP4.5 (a), in 2021–2050 by RCP8.5 (b), in 2071–2100 by RCP4.5 (c) and in 2071–2100 by RCP8.5 (d).

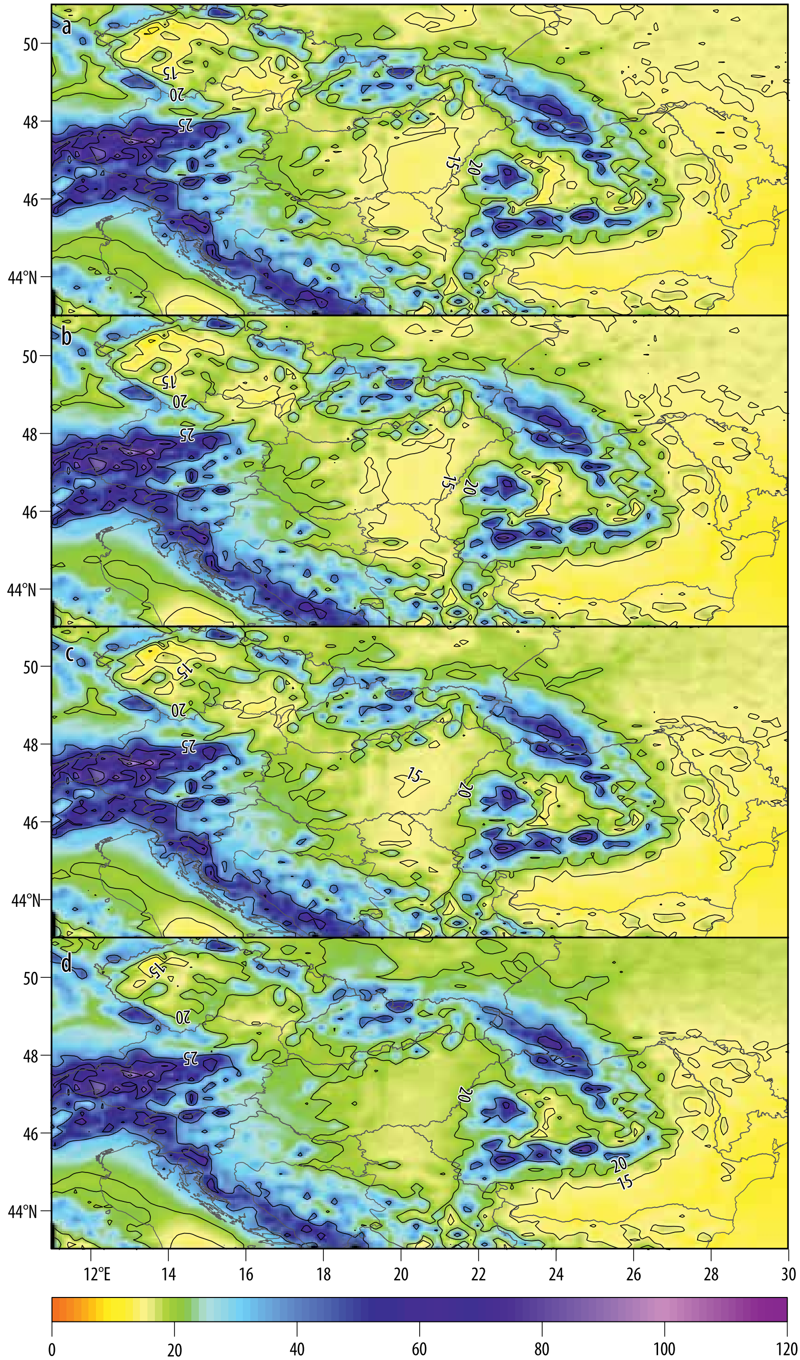

Fig. 10. Average number of heavy precipitation days in 2021–2050 by RCP4.5 (a), in 2021–2050 by RCP8.5 (b), in 2071–2100 by RCP4.5 (c) and in 2071–2100 by RCP8.5 (d). (The scale of the isolines is 5 and 20 under and above 20, respectively.)

Precipitation-based indices

Heavy precipitation days

The heavy precipitation days (*HPD*) in 2021–2050 will be under 20 in the Czech Republic, the northern and eastern part of the study area and in the Carpathian Basin *(Figure 10*, a and b*)*. In most of these areas, the values will be under 15, especially in the Carpathian Basin and Romanian Plain. Around the mountains, western and southern parts of the study area, *HPD* will be over 20–30. In the mountains, values are over 40 and in some smaller areas even 60–80. There is not relevant difference between the scenarios.

For the period of 2071–2100, *HPD* increase in especially lower lying regions. Under scenario RCP4.5, the size of the areas, where the value of *HPD* is under 15, decreases *(Figure 10*, c*)*. This process is the most remarkable in the Carpathian Basin, but it is also noticeable in the Czech Republic and in the northeast region. In these regions, *HPD* values above 20 will appear in some areas.

In case of scenario RCP8.5, the tendency is similar and larger changes will occur *(Figure 10*, d*)*. The affected areas are the same to the previous scenario. According to RCP8.5, *HPD* will be over 15 in the entire Carpathian Basin and 20 in its northern and western parts.

Very heavy precipitation days

In 2021–2050, the very heavy precipitation days (*VHPD*) will be under 5 in most parts of the study area, while values over five will appear around the mountains and south-eastern region *(Figure 11*, a and b*)*. In mountainous areas, the values will be above ten and in some parts, especially in the Alps, over 20–30. The difference between the scenarios are minimal.

For 2071–2100, the values increase and the number of *VHPD* exceed 5 in case of RCP4.5 in the west of the Carpathian Basin *(Figure 11*, c*)*. Under scenario RCP8.5, the change is more remarkable *(Figure 11*, d*)*. The affected areas are the northern and western parts of the Carpathian Basin, the areas north from the Carpathians and north-western part of the study area.

Consecutive dry days

The consecutive dry days (*CD*) in 2021–2050 will be under 40 in the north-western part of the study area and in the mountains *(Figure 12*, a and b*)*. In the Alps, *CD* will be under 30 in a larger area, while in most areas of the Carpathians and Dinaric Alps they will exceed 50. In almost the entire Carpathian Basin *CD* will be over 50 and 60 in some scattered areas, which are larger in the case of scenario RCP8.5 (see *Figure 12*, b). In the Romanian Plain, values will exceed 70 and in a smaller area 80, which are also larger under RCP8.5. On the Adriatic coast, the values will be over 50–60.

For 2071–2100, minor changes will occur compared to the previous period *(Figure 12*, c and d*)*. In the Carpathians, values higher than 40 and 50 will appear in several areas. In the Carpathian Basin, the *CD* will be over 60, especially in its eastern and southern parts. In the Romanian Plain, values over 80 will occur, particularly under scenario RCP8.5 (see *Figure 12*, d). In the case of this scenario, values over 60 will appear on the Adriatic coast.

Conclusions

In order to summarize our results, the range of the examined climatic parameters and indices are presented in the main regions of the study area *(Table 3)*. In the last part of the century the temperature increase is obvious, but the trend is difficult to evaluate in the case of precipitation. The heat load and energy demand quantifying indices follow the temperature trend. Examining the changes of precipitation and the related indices, the changes can be considered small, and these changes appear more within the regions. Noticeable changes will appear in the Carpathian Basin, where *P* will decrease, while *HPD*, *VHPD* and *CD* will increase.

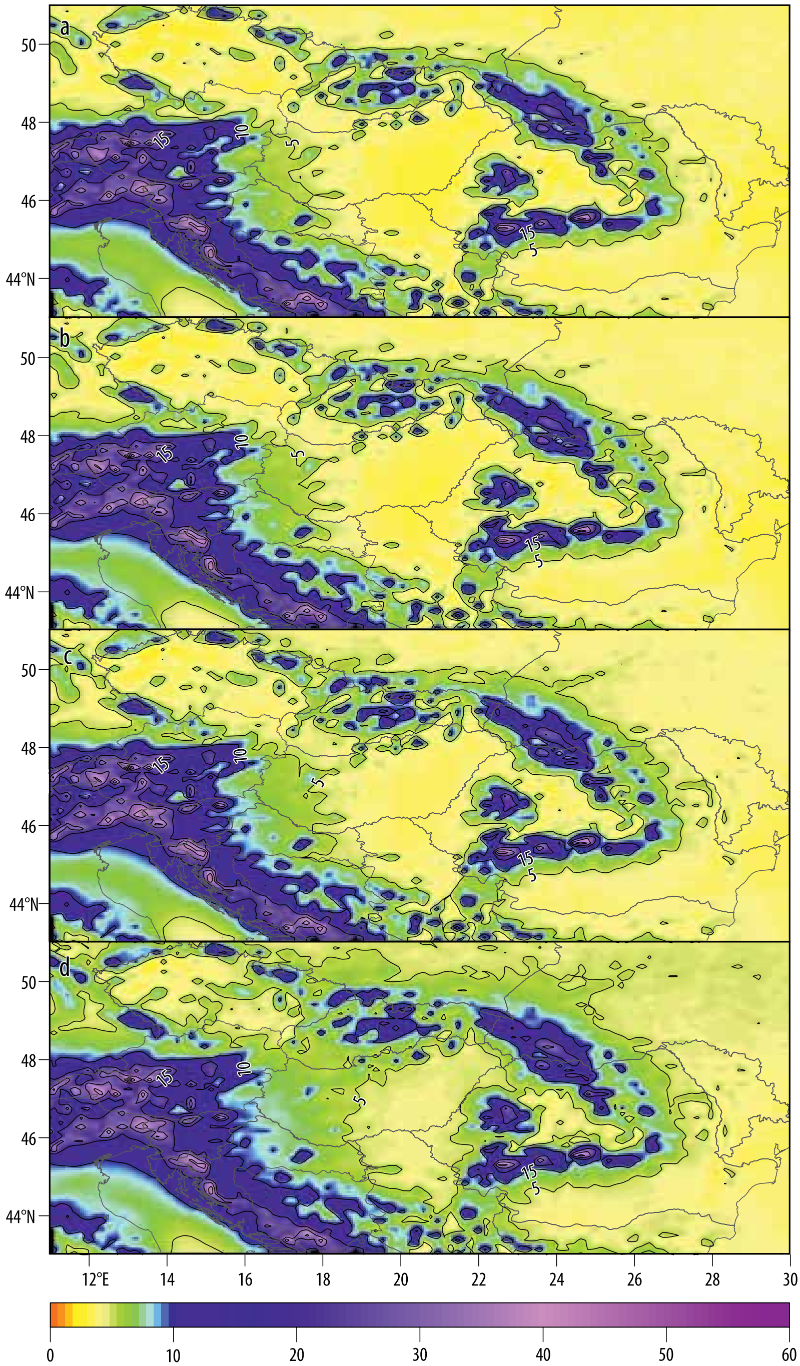

Fig. 11. Average number of very heavy precipitation days in 2021–2050 by RCP4.5 (a), in 2021–2050 by RCP8.5 (b), in 2071–2100 by RCP4.5 (c) and in 2071–2100 by RCP8.5 (d). (The scale of the isolines is 5 and 10 under and above 10, respectively.)

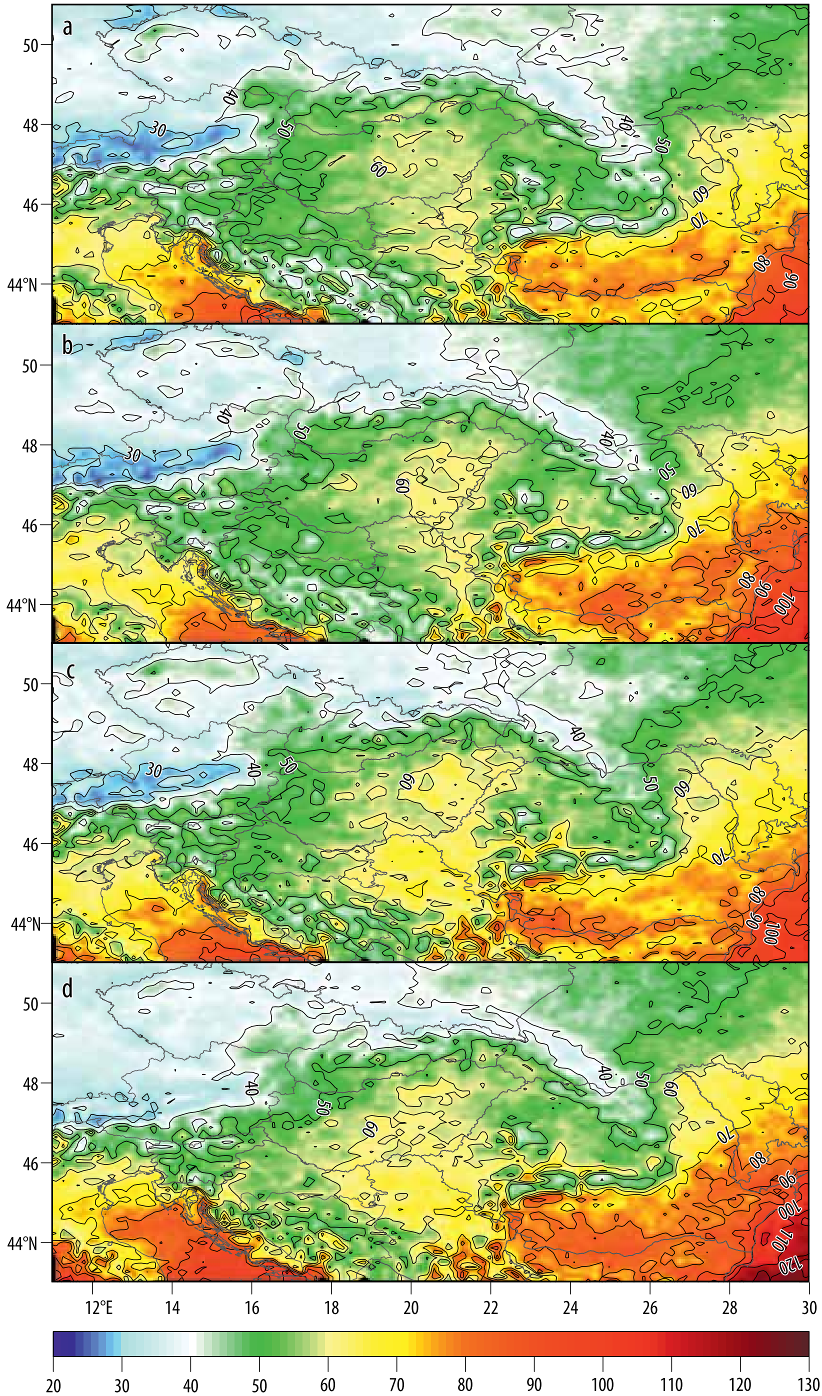

Fig. 12. Maximal number of consecutive dry days in 2021–2050 by RCP4.5 (a), in 2021–2050 by RCP8.5 (b), in 2071–2100 by RCP4.5 (c) and in 2071–2100 by RCP8.5 (d).

Table 3. The range of the basic climatic parameters and indices in the main regions of the study area

Index	Period, scenario	Region					
		Alps	Carpathians	Dinaric Alps	Carpathian Basin	Romanian Plain	Adriatic coast
T	21–50	2–8	4–10	6–10	10–14	10–14	12–18
	71–00, 4.5	0–10	6–10	8–12	12–16	12–16	16–20
	71–00, 8.5	4–12	6–12	8–14	14–18	14–18	18–22
P	21–50						
	71–00, 4.5	1,000–3,600	800–3,000	800–3,000	400–800	400–800	600–1,000
	71–00, 8.5						
WN	21–50	0–10	0–10	0–20	30–50	40–60	50–70
	71–00, 4.5	0–10	0–20	0–20	40–60	50–70	80–100
	71–00, 8.5	10–20	10–20	20–60	60–100	80–100	120–140
TN	21–50	0–5	0–5	0–5	5–15	10–20	30–40
	71–00, 4.5	0–5	0–5	0–5	10–25	15–30	40–60
	71–00, 8.5	0–10	0–10	10–20	30–50	30–60	80–100
SD	21–50	0–40	0–40	40–60	80–120	100–140	100–140
	71–00, 4.5	0–60	0–60	60–80	80–140	100–140	120–160
	71–00, 8.5	20–80	20–80	80–120	100–160	120–160	140–180
HD	21–50	0–10	0–10	0–20	20–60	40–80	40–90
	71–00, 4.5	0–20	0–20	0–30	30–70	60–90	60–90
	71–00, 8.5	0–30	0–30	30–50	50–90	80–110	80–120
HDD	21–50	3,500–6,500	3,000–5,000	2,500–4,000	2,000–2,500	2,000–2,500	1,000–2,000
	71–00, 4.5	3,000–5,500	2,500–4,500	2,000–3,000	1,500–2,000	1,500–2,000	1,000–1,500
	71–00, 8.5	2,000–4,000	2,000–3,500	1,500–2,500	1,000–1,500	1,000–1,500	500–1,000
CDD	21–50	0–100	0–100	0–300	300–700	400–800	700–1,000
	71–00, 4.5	0–200	0–200	100–300	400–800	600–900	800–1,100
	71–00, 8.5	100–400	100–400	200–500	600–1,000	900–1,200	1,000–1,300
HPD	21–50			40–80	0–20		
	71–00, 4.5	40–100	20–80	40–80	10–20	0–20	20–40
	71–00, 8.5			40–60	15–20		
VHPD	21–50		5–40	5–40			
	71–00, 4.5	10–60	5–50	5–50	0–10	0–10	5–20
	71–00, 8.5		5–50	5–50			
CD	21–50	20–40		30–50	50–70	70–90	50–70
	71–00, 4.5	20–40	30–60	40–50	50–80	70–90	50–70
	71–00, 8.5	30–40		60–60	50–80	70–100	60–80

It is important to mention that in case of precipitation there are no relevant changes in any region, however, based on the precipitation-related indices (*HPD*, *VHPD*, *CD*) the Dinaric Alps and the Carpathian Basin regions are facing considerable changes in the rest of the century (see *Table 3*). The highest temperature change occurs in the mountainous regions, especially in the Alps, however in case of temperature-related indices the spatial differences of the future change are more complex. In case of warm nights, tropical nights, summer days and hot days in the Carpathian Basin, Romanian Plain and Adriatic coast the changes are more severe. The trend in the heating degree days predict decreasing energy demand in all regions. In some areas in Carpathian Basin and Romanian Plain, as well as in almost the entire Adriatic coast, the energy demand for cooling will be more important than for heating.

Based on the results it is obvious that the entire region will face crucial changes in the following decades, therefore all the effort of climate mitigation and adaptation initiatives should be prioritized. These results may help to draw attention to these changes and hopefully it will help other climate change studies, climate strategies and climate adaptation plans.

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Predicting the future land-use change and evaluating the change in landscape pattern in Binh Duong province, Vietnam

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Abstract

The main purpose of this study is to simulate future land use up to 2030 and to evaluate the change in landscape pattern due to land-use change from 1995 to 2030 in Binh Duong province, Vietnam. Land-use maps generated from multi-temporal Landsat images from 1995 to 2020 and various physical and social driving variables were used as inputs. Markov chain and Decision Forest algorithm integrated in Land Change Modeler application of IDRISI software were used to predict quantity and location of future land-use allocation. Meanwhile, FRAGSTATS software was used to calculate landscape metrics at class and landscape levels. The simulation results showed that there will be 253.8 km^2 of agricultural land urbanized in the period from 2020 to 2030. The urban areas will gradually expand from the edge of the existing zones and fill the newly planned areas from South to North and Northeast of the province. The results also revealed that the studied landscape was decreasing in dominance and increasing diversity and heterogeneity at landscape level. The processes of dispersion and aggregation were taking place at the same time in the entire landscape and in the urban class. Meanwhile, the classes of agriculture, mining, and greenspace were increasingly dispersed, but the shape of patches was becoming more regular. The water class increased the dispersion and the irregularity of the patch shape. Finally, the landscape metrics of the unused land fluctuated over time.

Keywords: land-use prediction, landscape pattern, remote sensing, Land Change Modeler, FRAGSTATS, IDRISI

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Introduction

Socio-economic development can impact on land-use change process in many ways (Lambin, E.F. and Meyfroidt, P. 2010). In developing countries, the process of urbanization and the shift of socio-economic development policies, such as from agriculture-based to industry-oriented economy, lead to high land-use demand (Nourqolipour, R. *et al.* 2016). As a result, the land-use transition is intense. Much of the transition in this context has been from natural and semi-natural to artificial landscapes. In recent years, due to population growth and urbanization, land-use change has taken place strongly in the vicinity of existing urban areas and in the key economic development zones in Vietnam (Truong, N.C.Q. *et al.* 2018; Ha, T.V. *et al.* 2020; Nguyen, Q. and Kim, D.-C. 2020).

For example, in Binh Duong province, which is in the neighbourhood of the largest metropolis of Vietnam, and in the southern key economic zone, urbanization and industrialization have taken place very strongly in the last 25 years (Le, V.H. 2019; Le, V.N. *et al.* 2019). As a result, a large amount of agricultural land has been converted into industrial zones and urban areas. This type of conversion is still ongoing.

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Land-use change affects landscape patterns and, as a result, ecosystem functions (Lin, T. *et al.* 2013; Estoque, R.C. and Murayama, Y. 2016; Tolessa, T. *et al.* 2017; Kertész, Á. and Křeček, J. 2019; Tang, J. *et al.* 2020). Therefore, quantification of changes in landscape patterns, including shape, size, and spatial distribution, is essential, especially where land-use change is dramatic, such as in emerging urban areas. The quantification facilitates comparison and assessment of landscape change during past and future land-use change. At the same time, it can also partly reveal the impact trend of land-use changes on the structure and function of diverse types of landscapes and ecosystems. This information may be useful for decision-making and land-use planning toward efficient use of resources and sustainable development (Vaz, E. *et al.* 2014; Abdolalizadeh, Z. *et al.* 2019). The landscape pattern change is often assessed by landscape metrics at the three levels including patch, class, and landscape (Turner, M.G. and Gardner, R.H. 2015; Gergel, S.E. and Turner, M.G. 2017; Gudmann, A. *et al.* 2020).

To calculate landscape metrics, land-use maps are often used as input. The maps in the past can be generated by historical geodetic measurement and administrative land-change records over the years. Another fast and effective method that is widely applied is to interpret from remote sensing images (Rahman, M.T. 2016; Zhang, B. *et al.* 2017; Singh, S.K. *et al.* 2018). Although the use of remote sensing images to create land-use maps has some limitations such as resolution, classification algorithms, the ability to distinguish land use, etc., this is still a useful approach due to its promptness and proactivity. Meanwhile, future land-use maps can be collected from land-use planning maps or from simulation based on past variability trends and future demand in terms of quantity and spatio-temporal distribution (Zheng, H.W. *et al.* 2015; Saxena, A. and Jat, M.K. 2019; Yin, L. *et al.* 2021).

There are many models developed for land-change simulation, such as CLUE-S, CLUMondo, Land Change Modeler (LCM), LucSim, DinamicaEGO, SLEUTH, etc. Each model has its own pros and cons, and the choice of model to use depends on the goals and the available data of the study (Camacho Olmedo, M.T. *et al.* 2018). LCM is one of the popular applications used to assess and simulate land-use change. The advantage of this application is that it is simple to use, easy to set up input parameters, has clear instructions, and many simulation algorithms are integrated. Many studies have used this application for land-use change prediction for various purposes (Megahed, Y. *et al.* 2015; Nor, A.N.M. *et al.* 2017; Islam, K. *et al.* 2018; Mishra, V.N. *et al.* 2018).

With the mentioned issues in mind, this study was carried out for two main purposes including (1) Using LCM to simulate the future land use in Binh Duong province in 2025 and 2030, and (2) Quantification and evaluation of landscape change due to land-use change from 1995 to 2020 and forecast to 2030.

Materials and methods

Study area

This study was conducted in Binh Duong province which located in the southeast region of Vietnam *(Figure 1).* The land-use change in the province took place dramatically from 1997 when the province was re-established. Agricultural land and unused land were converted to other uses, most of which were devoted to expanding residential and industrial areas. These changes were mainly due to socio-economic factors including urbanization, industrialization, and structural changes in agricultural production, and related policies (Le, V.H. 2019; Le, V.N. *et al.* 2019; Bui, D.H. and Mucsi, L. 2022).

Data

This study used the land-use maps in 1995, 2001, 2005, 2010, 2015, and 2020 which were

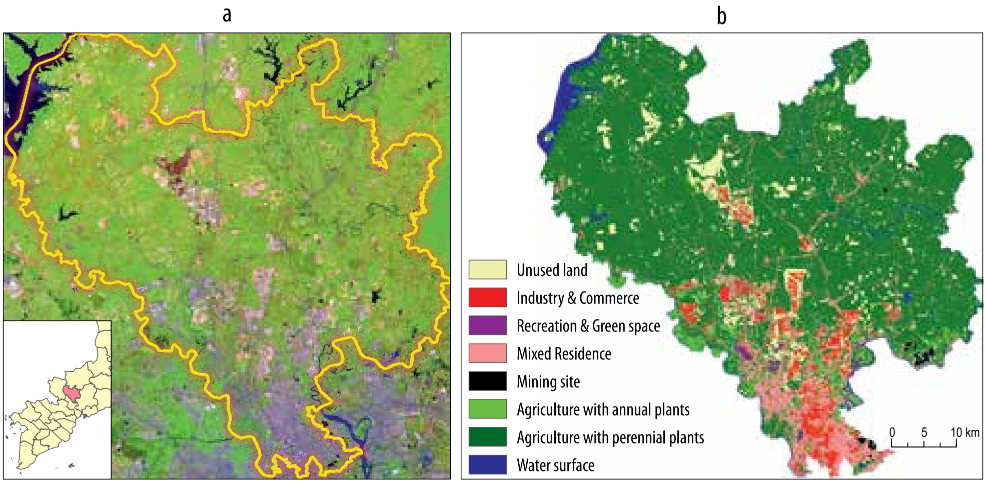

Fig. 1. Study area in two maps. a = Composite from Landsat-8 OLI image (RGB: 6-5-2) acquired on 06/01/2020 and downloaded from the USGS website (https://earthexplorer.usgs.gov/); b = Land-use map in 2020 derived from the study of Bui, D.H. and Mucsi, L. 2022.

generated from multi-temporal Landsat images from the study of Bui, D.H. and Mucsi, L. (2022). The map was in the WGS-84 UTM 48N projection and a spatial resolution of 30 m and consisted of 8 land-use types *(Table 1)*. The overall accuracy of these maps was reported to be 89.2, 88.9, 89.6, 90.8, 93.0, and 90.1 percent, respectively. The producer's accuracy ranged from 70.8 to 100 percent, while the user's accuracy ranged from 70.9 to 100 percent. Therefore, it is appropriate and dependable to use them for land-change prediction and landscape analysis.

To explore the drivers for the land-use change, which was a key step for the simulation model of land-use change, several kinds of data were collected and pre-processed. SRTM 1 Arc-Second 30m digital elevation model (DEM) was downloaded from the website https://earthexplorer.usgs.gov/. Slope and aspect were extracted from the DEM. Population density raster data were downloaded from the website https://www.worldpop.org/ with a spatial resolution of 100 m. A raster of the mean population density in the period of 2010–2020 was calculated and resampled to a 30-m spatial resolution using bilinear method. All these raster data were pre-projected to WGS-84 UTM 48N. In addition, open water surfaces were extracted from the Open Street Map project (https://www.openstreetmap.org/) and downloaded

Table 1. Land use categories

ID	Original land use class	New class for Land Change Modeler	New ID
1	Unused land	Agricultural land	1
2	Industry and commerce	Industry and commerce	2
3	Recreation and greenspace	Others	3
4	Mixed residence	Mixed residence	4
5	Mining site	Others	3
6	Agriculture with annual plants	Agricultural land	1
7	Agriculture with perennial plants	Agricultural land	1
8	Water surface	Others	3

from the website https://download.geofabrik.de/. Forest protection areas and planned industrial parks for 2020 and 2030 were extracted from the planning map of the provincial government. The 3-level main road network was extracted from the administrative map in 2014 and modified based on the Google satellite images.

The location points of the administrative and economic centre of the province and districts (hereinafter referred to as province centre and district centres, respectively), airport, train stations, and river ports were manually digitalized based on the Google satellite images. All these data were collected in vector format. Therefore, they were rasterized to a spatial resolution of 30 m and a projection of WGS-84 UTM 48N. After that, the maps of Euclidean distance to the open water surfaces, planned industrial parks, main roads, province centre, district centres, and transportation ports were extracted in turns. Furthermore, based on the land-use maps, the map of Euclidean distance to current residential and industrial areas in 2001 and 2020 was also produced, respectively.

Land-use change prediction

This study tended to simulate the land use of the study area in 2025 and 2030 based on the land-use maps of previous periods and land-use change drivers. We only focused on simulating the transition from agricultural land to urban land, which was the major transition taking place in recent years. The land-used maps were re-classed from eight to four categories as shown in *Table 1.* It should be noted that the two urban classes were not grouped together because their expansion was driven by varied factors. As a result, the transition from agricultural land to urban land would be included two submodels. One was the transition from agricultural land to industrial and commercial regions (agri_to_indus), and the another was the transition from agricultural land to mixed residential areas (agri_to_resid). Other conversion types were ignored.

The LCM application integrated in the Terrset IDRISI 2020 software was used. The simulation process consists of calibration, validation, and prediction. The overall process is illustrated in the *Figure 2.* The LCM includes six algorithm options for simulation, including Multi-layer Perceptron neural network, Decision Forest (DF), Logistic regression, Support Vector Machine, Weighted Normalized Likelihoods, and SimWeight. After some trials, the DF algorithm was chosen. The number of trees was set at 100, and the number of variables at split was the square root of a number of input variables.

At the calibration phase, the land-use maps of 2001 and 2010 were used as the earlier and later maps, respectively, combined with a set of variables to build the model. The purpose of these phases was to select appropriate variables as drivers for the land-use change transitions. The variable selection was based on the Out of bag (OOB) accuracy in the output report of the transition submodels. If the OOB accuracy when holding a given variable constant was greater than OOB accuracy with all variables, it means that the given variable might not be significant in the model (Eastman, J.R. 2020a), and it was excluded. At the validation phase, the predicted map in 2020 was simulated and compared with the reality map in 2020 to validate the model. The performance of the model was evaluated by the Kappa coefficients (Pontius, R.G. 2000; Hagen, A. 2002, 2003; Hagen-Zanker, A. *et al.* 2005), and Figure of merit (FoM) (Pontius, R.G. *et al.* 2008) for the hard-classification and the area under the curve (AUC) (Mas, J.F. 2018) for the soft-classification outputs.

After the performance of the model was confirmed and satisfied, the prediction phase was performed. In this phase, the land-use maps in 2015 and 2020 were used as input to predict the maps in 2025 and 2030 with the same set of drivers selected at the calibration and validation phases. The reason to use the maps 2015 and 2020 was that the urban area

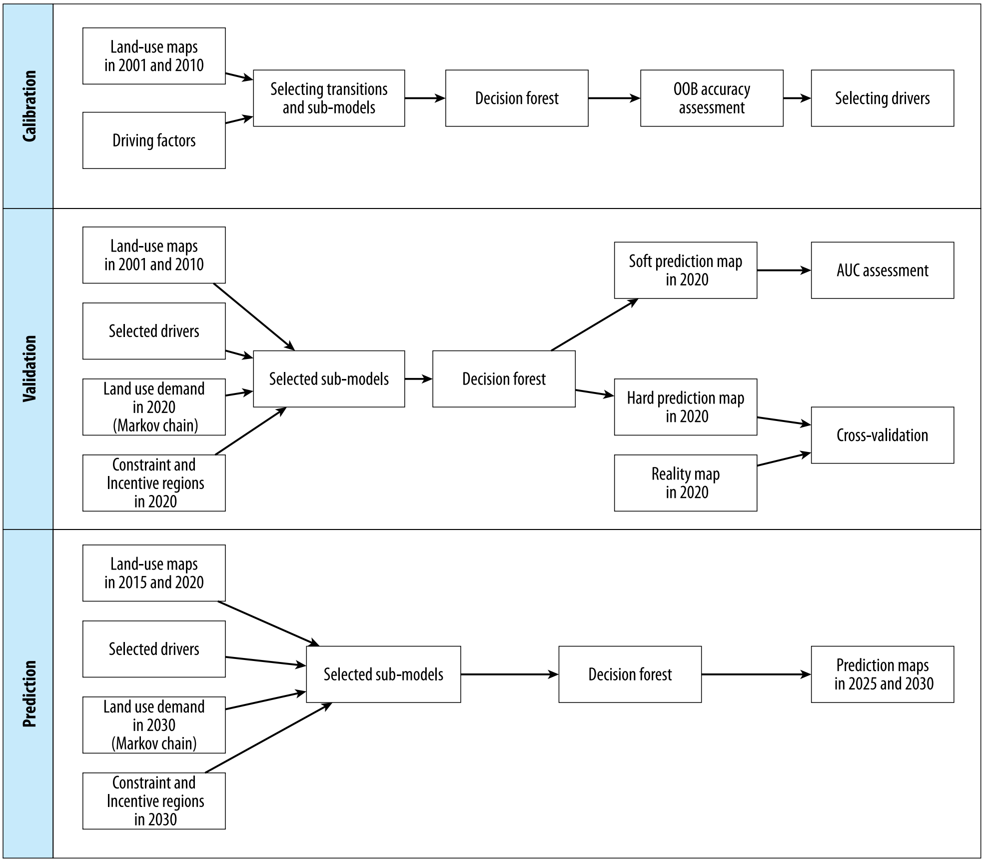

Fig. 2. Simulation process

in Binh Duong province has expanded at an increasing rate from 1995 to 2020 (Bui, D.H. and Mucsi, L. 2022), therefore, the two latest maps used may capture the most recent trend of urban expansion. This may more accurately reflect future land-use demand for the simulation. The land-use demand was calculated based on the Markov chain with the assumption that future conversion would be at a similar rate to the current period (Zheng, H.W. *et al.* 2015). This calculation was built-in into LCM. The LCM also allows setting constraints and incentives for a particular type of conversion. The weights for these regions can be set between in a range of 0 to 1, where 0 is strictly forbidden and 1 is strongly encouraged. In this study, the protection forest was considered the prohibited area for both types of urbanization (weight of 0). For the agri_to_indus sub-model, it was encouraged to develop inside the planned industrial parks with a weight of 1, and the rest was set to a weight of 0.1. For the agri_to_resid sub-model, the weights were set to 1 and 0 for areas outside and inside the planned industrial parks, respectively.

After the prediction phases, the 4-class predicted maps in 2025 and 2030 were overlaid with the land-use map in 2020 (8 classes) to generate the 8-class land-use maps in 2025 and 2030, which would be used for calculating landscape metrics.

Landscape metrics

To measure the change in landscape patterns over time, this study used landscape metrics (McGarigal, K. *et al.* 2012; Turner, M.G. and Gardner, R.H. 2015; Gergel, S.E. and Turner, M.G. 2017) at landscape and class levels. Because the mixed residential, industrial, and commercial areas formed the urban landscape, they were re-classed into a common class named urban. From the land-use maps, landscape metrics were calculated in FRAGSTATS 4.2 software based on the eight-cell neighbour rule (McGarigal, K. *et al.* 2012). The metrics were chosen so that they were representative of the features of the landscape, were not redundant, and have been widely and effectively used in previous studies (Su, S. *et al.* 2014; Dadashpoor, H. *et al.* 2019). The features measured included dominance, diversity, and fragmentation. The selected metrics is shown in *Table 2*, and a detailed definition and description of the metrics can be found in the FRAGSTATS Manual document (McGarigal, K. *et al.* 2012).

Results

Simulation of land-use change in future

Driving factors

Based on the results of the analysis of OBB accuracy in the DF outputs, the drivers included in the two sub-models are presented in *Table 3.* The drivers included in these sub-models are reasonable. A common point of both sub-models is that natural factors related to topography (DEM, slope, aspect) do not affect urbanization. Possibly because the terrain of the whole area is relatively flat, except for a few low-mountain areas within the protected area, the weighting of these factors is likely to be the same in most places. The impact of other drivers of each sub-model was explained in detail below.

For the agri_to_resid sub-model, the included drivers can be explained by the following reasons. First, the new settlements are often formed from the edge of existing neighbourhoods. Second, the more populous the places, the higher the demand for housing and utilities. Third, the choice of housing also depends on the accessibility to utility services, which are often concentrated in the central areas of the province and districts. Last, to access these facilities as well as workplaces, accessibility to the transportation network is clearly an influencing factor. Meanwhile, the excluded factors may be due to several reasons. According to the general development orientation of the province, residential areas are formed close to industrial zones, which make up industrial – urban – service complexes, thus, making the distance to the existing industrial park redundant. Except for Tan Son Nhat Airport, the rest of ports (train stations and river harbours) are cargo stations, not passenger stations, so it has no

Table 2. Landscape metrics used

Metric	Name	Level used	
		Landscape	Class
AREA_MN	Mean Patch Size	x	x
CONTAG	Contagion Index	x	–
IJI	Interspersion and Juxtaposition Index	x	x
LPI	Largest Patch Index	x	x
LSI	Landscape Shape Index	x	x
NP	Number of Patches	x	x
PD	Patch Density	–	x
PLAND	Percentage of Landscape	–	x
SHDI	Shannon's Diversity Index	x	–
SHEI	Shannon's Evenness Index	x	–

Table 3. Drivers for sub-models

No	Input drivers		Selected drivers by Decision Forest algorithm	
			Agri_to_resid	Agri_to_indus
1 2 3	DEM Slope Aspect		–	–
4	Distance to	water sources	–	x
5		province centre	x	–
6		district centres	x	x
7		existing residential areas	x	–
8		existing industrial areas	–	x
9		planned industrial zones	–	x
10		main road	x	–
11		ports	–	x
12	Mean population density in 2010–2020		x	–

impact. The distance to the water source is not included probably because residential areas mainly use water from boreholes or water supply systems, which are relatively well distributed in urban areas.

Similarly, for the sub-model of agri_to_indus, the impact of included drivers can be explained as follow. First, new factories tend to form near previously developed places where infrastructure already exists. Second, the selection of sites within or near planned industrial zones is also to take advantage of the planned infrastructure and preferential policies from the provincial government. Third, reducing the distance to district centres and ports can increase market access and reduces transportation costs. Last, the ability to access water is probably to serve the needs of exploiting water resources for production activities. Meanwhile, the excluded drivers can be explained by some reasons. Similar to the case of the agri_to_resid sub-model, the distance to the existing residential areas is redundant. Distance to the province centre is also redundant compared to the distance to district centres. Besides, population density does not affect industrial development, maybe because of convenient transportation, people can go to work farther, so it is not necessary to form factories near densely populated areas to utilize human resources. Interestingly, the distance travelled does not affect the model either. Maybe because the current transport system has developed relatively widely, and the planning of new industrial zones also leads to the expansion of the transport network to access these zones. Therefore, this variable has no effect.

The performance of selected models

Four different maps of the study area (reality map, hard prediction map, soft prediction map and cross-validation map in 2020) are illustrated in *Figure 3.*

For hard prediction, the Kappa coefficients and FoM were used to evaluate the accuracy of the predicted map in 2020 and thereby validate the performance of the selected model. The results showed that Kappa, Kappa location, and Kappa histogram coefficients reached 0.71, 0.72, and 0.99, respectively. The simulated map contained the percentages of hits, null successes, misses, and false alarms of 3.77, 87.75, 4.54, and 3.94 percent, respectively. As a result, the FoM achieved 30.77 percent, producer's accuracy achieved 41.71 percent, and user's accuracy achieved 48.88 percent.

It can be seen that these values were relatively low. An important source of error was that the hard classification result was only one outcome in many equally plausible scenarios (Eastman, J.R. 2020b). Therefore, it was difficult to predict exactly the location in terms of pixel-level where the change would take

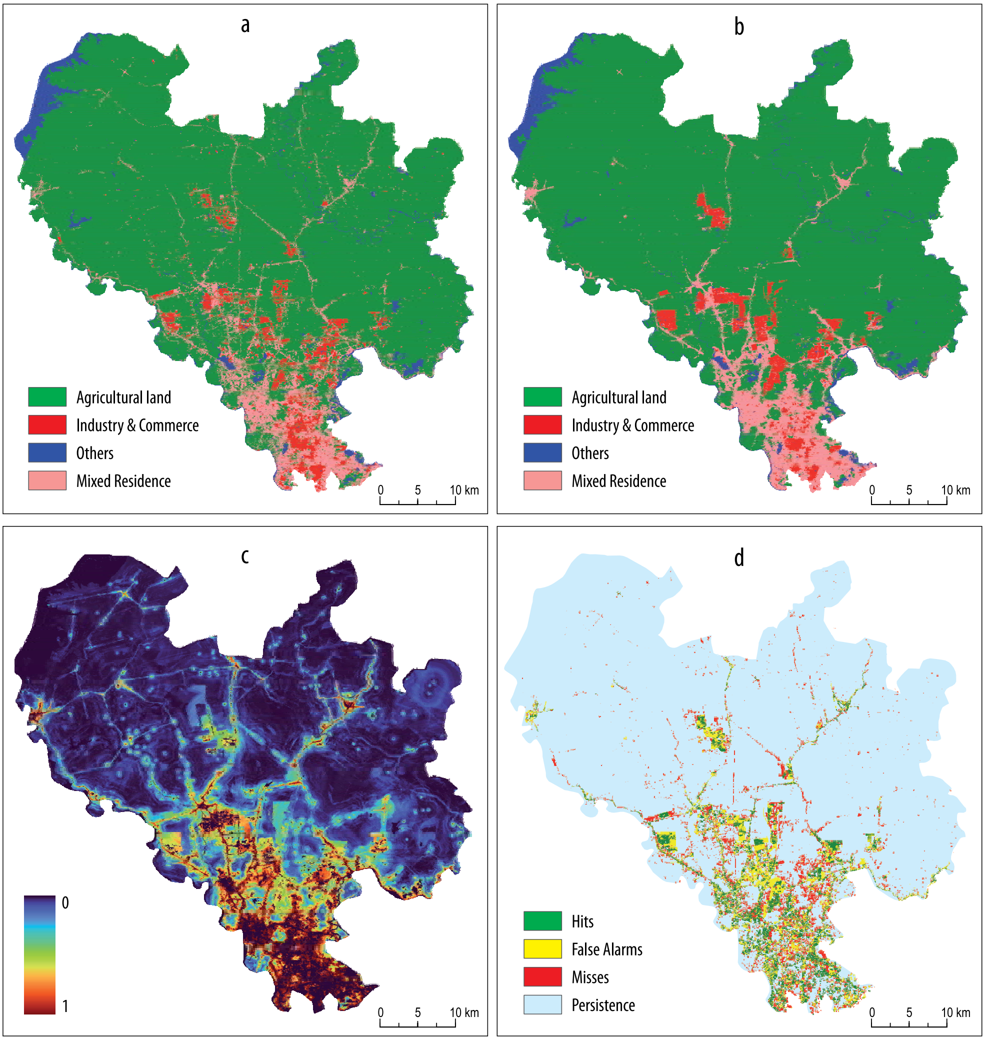

Fig. 3. Reality map (a), hard-prediction map (b), soft-prediction map (c), and cross-validation map (d) for the study area in 2020.

place. As can be seen visually, the hits, false alarms, and misses tended to occur in the same location in close proximity. This revealed that predicting the location of the change was relatively accurate. For 2-dimensional assessment, when validating by fuzzy Kappa using the exponential decay function (radius of neighbourhood = 4, halving distance = 2), the fuzzy Kappa value reached 0.77 and the average similarity achieved 0.94, which is much better than the traditional kappa coefficients. In addition, for 3-dimensional assessment, according to Pontius, R.G. *et al.* (2008), the FoM is proportional to net changes in the study area. In this study, the actual rate of change from agricultural land to urban in the period 2010–2020 accounted for 4.32 percent of the entire area and 8.52 percent of the total agricultural area in 2010. The calculated FoM value was relatively high compared to these rates.

Furthermore, Peng, K. *et al.* (2020) mentioned that "the spatial allocation algorithm cannot well simulate the isolated patches that newly emerged". Last but not least, the FoM value in this study was higher than that in other studies, where the FoM was less than 20 percent (Megahed, Y. *et al.* 2015; Peng, K. *et al.* 2020).

The soft prediction result was validated by the AUC. The AUC is an index used to evaluate "how well a continuous surface predicts the locations given the distribution of a Boolean variable" (Eastman, J.R. 2020b), and it was calculated from the receiver operator characteristic (ROC). The AUC value ranges from 0.5 (bad model) to 1 (perfect model) (Estoque, R.C. and Murayama, Y. 2016; Peng, K. *et al.* 2020). The AUC in our model reached 0.96, which validated that the model could simulate potential areas for urban expansion from agricultural land with high accuracy.

Predicted maps and land-use change in 2025 and 2030

The simulation results gave that a total of 126.9 km^2 and 253.8 km^2 of agricultural land are expected to urbanize by 2025 and 2030, respectively. Specifically, residential areas may expand to 309.3 km^2 in 2025 and 395.9 km^2 in 2030, corresponding to an increase of 86.5 km^2 (138.8%) and 173.1 km^2 (177.7%), respectively, compared to 2020. The residential development is still concentrated in the South of the province and around the centre of the districts, where the infrastructure for development is an advantage. Meanwhile, the area of industrial and commercial zones may reach 150.4 km^2 in 2025 and 190.8 km^2 in 2030, corresponding to an increase of 40.4 km^2 (136.7%) and 80.8 km^2 (173.4%), respectively, compared to 2020. The new factories are going to fill the existing industrial parks and expand to the new planned industrial zones in the North and Northeast.

Corresponding to this urban expansion, from 2020 to 2025, perennial cropland, unused land, and annual cropland may be decreased by 77.8 km^2, 40.7 km^2, and 8.4 km^2, corresponding to a decline of 4.0, 16.4, and 9.4 percent, respectively, compared to 2020. Meanwhile, by 2030, these land-use types may be decreased by a total of 168.8 km^2, 67 km^2, and 18 km^2, corresponding to a decline of 8.8, 27.0, and 20.3 percent, respectively, compared to 2020. The predicted land use in 2025 and 2030 are illustrated in *Figure 4.*

Landscape pattern change

Landscape level

The trends of the landscape indices at the landscape level are shown in *Figure 5.* Landscape change was analysed according to dominance, diversity, and fragmentation.

Dominance: The dominance in the studied landscape was revealed by the LPI and SHEI. LPI increased in the period 1995–2010, then decreased in the period 2010–2020. It was also predicted to continuously decrease sharply in the period 2020–2030. Meanwhile, the SHEI decreased during the period 1995–2001 but increased continuously from 2001 to 2020 and was expected to continue to increase until 2030. The overall trend for LPI was to decrease while SHEI was to increase over the entire study period. This showed that although there was still a high dominance of a class in the landscape (in this case, the woodland), the area proportion of the classes was tending towards a more uniform distribution. In other words, there is a trend of transitioning from a landscape with only one dominant land-use type to a mixed landscape with many different land uses (Weng, Y.C. 2007).

Diversity: Landscape diversity was reflected by the SHDI, which tended to increase over the study period. Of which, the SHDI decreased in the period 1995–2001, increased continuously in the period 2001–2020, and was forecasted to continue to increase until 2030. This indicated an increase in diversity, which also means heterogeneity, in the landscape.

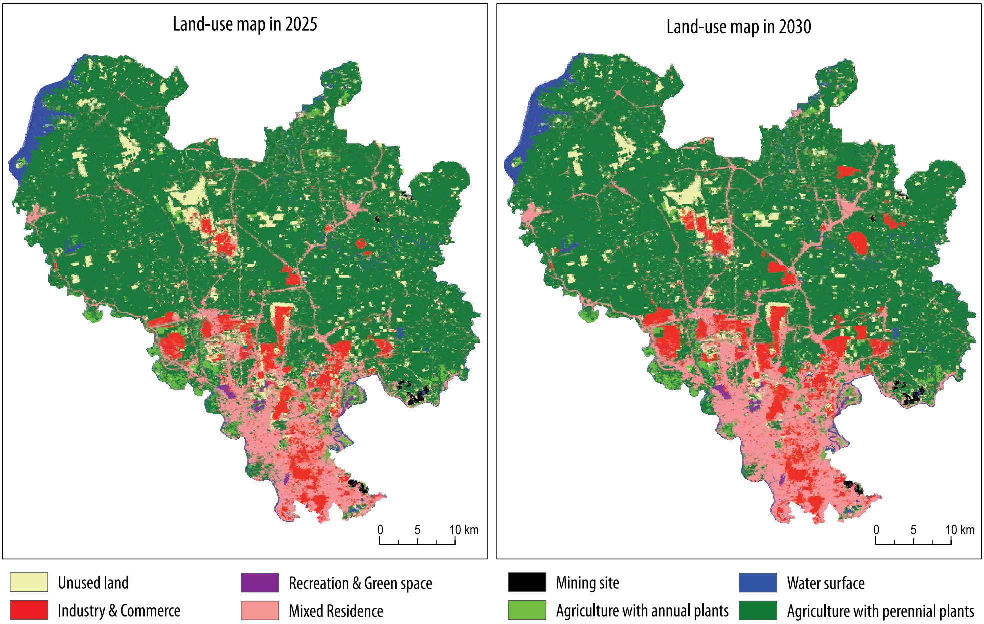

Fig. 4. Predicted land use in 2025 (left) and in 2030 (right)

Fragmentation: The results showed an increasing trend of AREA_MN and IJI and a decreasing trend of NP, CONTAG, and LSI. NP and AREA_MN were the two indices that had an opposing trend and represented the characteristics of the land-use transformation in the study area, which had both dispersion and aggregation processes. When the landscape was fragmented, new fragments were formed (NP increased), and the average area of fragments decreased (AREA_MN decreased). But as these individual patches were gradually expanded, and clumped together into a larger patch, NP would be decreased and AREA_MN would be increased. The increasing trend of AREA_MN and decreasing trend of NP in the whole study period revealed that the aggregation process may be probably stronger, especially from 2020 to 2030. An increase in the IJI indicated that the landscape was more dispersion. However, this trend only took place strongly in the period 2001–2015, which most influenced the overall trend, while in other periods the increase was insignificant. A decrease in the CONTAG indicated a slight decrease in the degree of aggregation and infectivity between regions of the same class, i.e., an increase in the degree of interlacing, while a decrease in LSI revealed that structure fragments become less irregular and less complex.

In general, the results showed that the indices have a fluctuation over time, and the fragmentation of the landscape still existed in parallel with the aggregation, but the aggregation was somewhat stronger. This can be largely attributed to the strong transition from crops to woody land from 1995 to 2005, and then urban expansion in later stages, when urban areas formed separately at first were gradually expanded and became more interconnected, forming more compact regions with more regular shapes. In addition, part of this may also be because the prediction was only interested in the transition from agricultural land to urban.

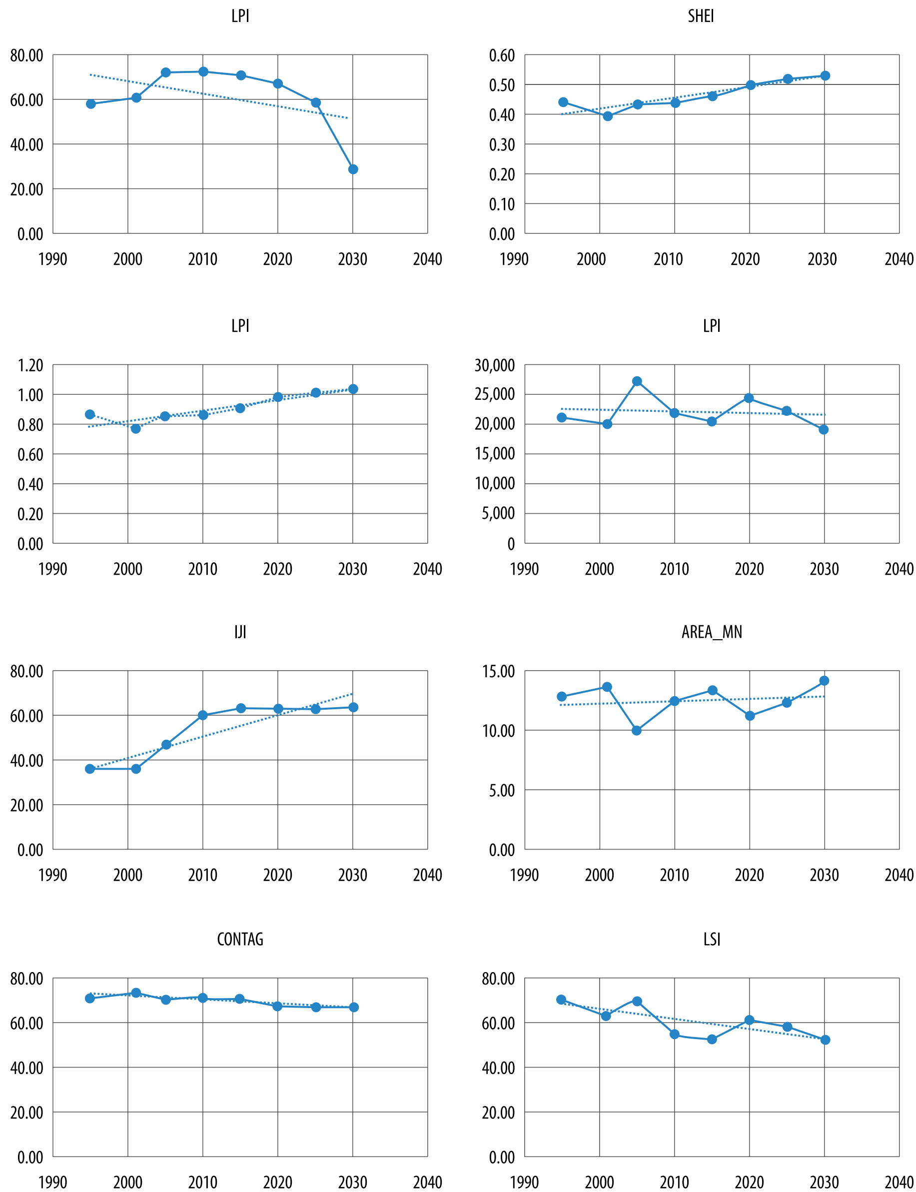

Fig. 5. Landscape metrics calculated at landscape level. LPI = Largest Patch Index; SHEI = Shannon's Evenness Index; SHDI = Shannon's Diversity Index; NP = Number of Patches; IJI = Interspersion and Juxtaposition Index; AREA_MN = Mean Patch Size; CONTAG = Contagion Index; LSI = Landscape Shape Index

Class level

The calculation results of the class-level metrics are presented in *Table 4*.

Agriculture with perennial plants (AP): The PLAND and LPI of AP increased between 1995 and 2010, decreased between 2010 and 2020, and were expected to continue to de-

Table 4. Landscape metrics calculated at class level

Land-use type	Year	PLAND	NP	PD	LPI	LSI	AREA_MN	IJI
Agriculture with perennial plants	1995	70.52	3,472	1.29	57.91	71.20	54.69	37.08
	2001	75.64	2,834	1.05	60.91	60.79	71.86	32.49
	2005	75.51	3,383	1.26	72.07	64.28	60.10	47.87
	2010	77.13	2,832	1.05	72.55	44.99	73.32	66.77
	2015	75.29	2,728	1.01	70.91	43.41	74.31	71.27
	2020	71.52	3,310	1.23	66.94	54.20	58.17	73.36
	2025	68.62	3,520	1.31	58.55	52.97	52.49	72.48
	2030	65.24	3,122	1.16	28.82	49.26	56.27	72.36
Agriculture with annual plants	1995	20.20	10,238	3.80	2.16	113.30	5.31	31.78
	2001	17.98	11,060	4.11	2.12	119.89	4.38	29.78
	2005	13.09	14,550	5.40	0.78	129.10	2.42	39.67
	2010	5.49	8,519	3.16	0.47	93.41	1.74	45.32
	2015	3.69	5,853	2.17	0.21	73.99	1.70	52.95
	2020	3.29	5,482	2.04	0.14	69.11	1.62	50.53
	2025	2.98	5,024	1.87	0.14	66.74	1.60	53.45
	2030	2.62	4,458	1.66	0.14	63.01	1.58	54.19
Urban	1995	0.19	381	0.14	0.03	21.54	1.34	63.72
	2001	0.95	787	0.29	0.14	33.34	3.27	63.33
	2005	2.50	1,128	0.42	1.90	38.66	5.97	66.03
	2010	4.77	2,633	0.98	2.84	55.96	4.88	58.14
	2015	7.39	2,949	1.10	4.63	56.56	6.75	63.28
	2020	12.36	4,514	1.68	8.24	70.90	7.37	58.48
	2025	17.07	3,779	1.40	12.34	62.17	12.16	59.66
	2030	21.79	2,874	1.07	17.22	49.90	20.41	61.28
Mining site	1995	0.04	28	0.01	0.01	7.74	4.17	51.16
	2001	0.05	39	0.01	0.01	8.55	3.63	63.53
	2005	0.11	17	0.01	0.06	6.83	17.87	74.70
	2010	0.16	34	0.01	0.04	7.07	12.51	79.77
	2015	0.22	26	0.01	0.10	7.12	22.73	83.54
	2020	0.25	27	0.01	0.09	8.21	25.16	86.22
	2025	0.25	27	0.01	0.09	8.21	25.16	86.36
	2030	0.25	27	0.01	0.09	8.21	25.16	86.10
Recreation and green space	1995	0.02	25	0.01	0.01	4.07	1.81	64.62
	2001	0.04	67	0.02	0.03	6.41	1.55	72.27
	2005	0.03	106	0.04	0.02	6.84	0.79	77.29
	2010	0.19	347	0.13	0.09	11.42	1.45	77.48
	2015	0.30	804	0.30	0.09	20.79	1.02	72.71
	2020	0.45	1,291	0.48	0.09	28.50	0.94	68.84
	2025	0.45	1,291	0.48	0.09	28.50	0.94	61.69
	2030	0.45	1,291	0.48	0.09	28.50	0.94	56.19
Water surface	1995	2.38	458	0.17	1.55	25.50	14.02	33.12
	2001	2.61	593	0.22	1.64	28.38	11.83	37.75
	2005	2.30	554	0.21	1.33	29.73	11.20	52.99
	2010	2.96	708	0.26	1.64	33.65	11.26	54.51
	2015	2.97	729	0.27	1.55	34.57	10.97	56.80
	2020	2.91	887	0.33	1.47	36.80	8.83	63.31
	2025	2.91	887	0.33	1.47	36.80	8.83	65.51
	2030	2.91	887	0.33	1.47	36.80	8.83	66.93
Unused land	1995	6.64	6,346	2.36	0.24	87.63	2.82	38.99
	2001	2.73	4,360	1.62	0.10	70.75	1.68	55.99
	2005	6.45	7,324	2.72	0.29	90.14	2.37	50.55
	2010	9.30	6,595	2.45	1.15	86.88	3.80	58.98
	2015	10.13	7,152	2.66	1.63	85.72	3.81	54.59
	2020	9.22	8,616	3.20	0.79	90.33	2.88	50.84
	2025	7.71	7,397	2.75	0.79	83.81	2.81	49.47
	2030	6.73	6,340	2.35	0.51	76.58	2.86	47.92

cline until 2030, while the NP and AREA_MN fluctuated. The PLAND always accounted for the largest proportion in the landscape (over 65%), and the LPI and AREA_MN were also much higher than the rest classes, while its NP is smaller than that of agriculture with annual plants (AA), and unused land (UL). It showed that AP was the dominant class in terms of the area and size of the patches. Since 2010, there has been a trend of gradually decreasing dominance and increasing dispersion (PLAND, LPI, and AREA_MN decreased, and NP and IJI increased), but the degree of dominance and aggregation was still high, and the shape of the patch was gradually less complex (LSI decreased).

Agriculture with annual plants: The PLAND of AA was steadily decreasing from about 20.0 percent in 1995 to 3.29 percent in 2020 and to 2.62 percent in 2030. Its LPI, AREA_MN, and NP showed a strong downward trend. The NP was reduced but still higher than the rest classes except for the UL. Meanwhile, the IJI increased, and LSI decreased. This showed that AA was increasingly decreasing in area, and at the same time, the degree of fragmentation was high. The shape of patches of AA was the most irregular compared to other classes, but it tended to become more regular over time.

Urban: The PLAND of urban grew rapidly from 0.19 percent in 1995 to 12.36 percent in 2020 and is forecasted to be 21.79 percent in 2030. The LPI, NP, and AREA_MN increased. This revealed two parallel processes in this class including (1) A gradual expansion from the edge of existing cities and interconnection between urban regions, which increased clumping and aggregation (LPI and AREA_MN increased and IJI decreased) and (2) The formation of new discrete urban areas (NP increased). Thus, the dispersion here was due to the second process, not division from existing urban patches. In addition, these two processes also caused the shape of patches to fluctuate (LSI fluctuated).

Mining site (MS) and Recreation and Green space (RG): These were two rare classes in the landscape accounting for a small proportion (< 0.5%). However, they also showed an increasing trend over the years in terms of PLAND and LPI. For the RG class, NP increased, AREA_MN decreased, IJI changed slightly, and LSI increased. They revealed that RG areas were formed more, and they were more discrete and less connected. Furthermore, the shape of its patches more complicated. Similar to the urban class, the fragmentation here was mainly due to new formations, not division from existing patches. Meanwhile, for the MS class, NP fluctuated, AREA_MN increased, IJI increased, and LSI decreases slightly. This showed that the area of quarries was gradually expanding and was more dispersed with a more regular shape.

Water surface: The PLAND slightly increased, NP increased, AREA_MN decreased, IJI increased, LSI increased, and LPI was relatively stable over the years. This revealed that the new water surface areas were formed separately and more irregularly.

Unused land: This class had special characteristics. It was an intermediary for conversion between other classes, so the indices of this class often fluctuated strongly over the years.

In general, from 1995 to 2020, the study area experienced an intense change in the direction of increasing the fragmentation and dispersion of natural and semi-natural landscapes. These changes might be largely influenced by two parallel processes of urban landscape including aggregation and dispersion. These changing trends are forecast to continue. Clearly, changes in land use, and consequent changes in landscape pattern, are often aimed at serving the needs of socio-economic development. However, the fragmentation and dispersion of natural and semi-natural landscapes can have negative impacts on the ecological environment, ecosystem services, and benefits humans derive from them (Estoque, R.C. and Murayama, Y. 2016; Tolessa, T. *et al.* 2017), and, thus, may influence the sustainable development goals. Some of the major environmental conflicts that will arise in the next decade in the study area may include (1) a decline in provisioning services (food, raw material) due to the decline in agricultural land, (2) a decline of the regulating services (climate, water/

water flow, erosion and fertility, purification and detoxification of water, air, and soil) due to an increase in impervious surfaces, and (3) a decline in supporting services (ecosystem process maintenance) due to fragmentation of natural and semi-natural habitats. Due to the limitation of the objective of this study, we did not quantify these aspects. For a more definitive assessment, further studies are needed

Conclusions

Based on land-use maps of previous periods, this study used the LCM application of IDRISI software to forecast land use in Binh Duong province, Vietnam to 2030, mainly the transition from agricultural-land types to urban-land types. The Markov chain and the Decision Forest algorithm were used to predict future land-use allocation in terms of quantity and location, respectively. Various drivers were assessed. The research results revealed that the drivers of distances to province centre, district centres, existing residential areas, and main road and mean population density had an impact on the conversion from agricultural land to residential land, while the transition from agricultural land to industrial and commercial areas was driven by the factors of distances to water sources, district centers, existing industrial areas, planned industrial zones, and transportation ports. The selected model has been validated with the accuracy of the hard prediction being Kappa = 0.71, Kappa location = 0.72, Kappa histogram = 0.99, fuzzy Kappa = 0.77, and FoM = 30.77 percent and the accuracy of the soft prediction being AUC = 0.96. This result indicated that the model was suitable to predict the future land use in the study area. The simulation results showed that, in the period from 2020 to 2030, there will be 253.8 km^2 of agricultural land urbanized. The residential areas and the industrial-commercial zones are expected to expand to 395.9 km^2 and 190.8 km^2, respectively. These areas will expand in the direction of gradually expanding from the edge of the existing zones and filling the newly planned areas from south to north and northeast.

This study also measured landscape pattern change caused by land-use change using landscape metrics calculated on FRAGSTATS software. At the landscape level, the results revealed that the studied landscape was increasingly decreasing in dominance and increasing diversity and heterogeneity. In addition, the processes of dispersion and aggregation are taking place at the same time. At the class level, the classes of agriculture, mining, and greenspace were increasingly dispersed, but the shape of patches was becoming more regular. Meanwhile, the urban class had similar characteristics to the entire landscape in terms of two parallel processes including dispersion and aggregation. The water class increased the dispersion and the irregularity of the patch shape. Finally, the landscape metrics of the unused land fluctuated over time.

This study provides insight into the causes and consequences of land-use change, especially in emerging urban areas in developing countries where sustainable development often has to trade-off with economic development goals. Changes in land use and landscape can affect the ecological environment, ecosystem services, and the benefits humans derive from them. Further studies on these issues are needed.

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Palmer-type soil modelling for evapotranspiration in different climatic regions of Kenya

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Abstract

Reference evapotranspiration (ET_0) and real evapotranspiration (ET) are vital components in hydrological processes and climate-related studies. Understanding their variability in estimation is equally crucial for micrometeorology and agricultural planning processes. The primary goal of this study was to analyze and compare estimates of (ET_0) and (ET) from two different climatic regions of Kenya using long-term quality controlled synoptic station datasets from 2000 to 2009 with 3-hour time resolution. One weather station (Voi, 63793) was sought from lowlands with an elevation of 579 m and characterized by tropical savannah climate while the other (Kitale, 63661) was sought from Kenya highlands with humid conditions and elevation of 1850 m above sea level. Reference evapotranspiration was calculated based on the FAO 56 standard methodology of a daily basis. One dimension Palmer-type soil model was used for estimating of real evapotranspiration using the wilting point, field capacity, and soil saturation point for each station at 1 m deep soil layer. The ratio of real and reference evapotranspiration dependent on the soil moisture stress linearly. Calculations of estimated evapotranspiration were made on daily and monthly basis. Applications of the site-specific crop coefficients (K_C) were also used. The result indicated that the differences among daily and monthly scale calculations of evapotranspiration (ET) were small without and with an application of crop coefficients (ET_{Kc}). This was due to high temperatures, global radiation, and also high soil moisture stress due to inadequate precipitation experienced in the tropics where Kenya lies. Results from Voi showed that mean monthly ET_0 ranged from 148.3±11.6 mm in November to 175.3±10.8 mm in March while ET was from 8.0±4.5 mm in September to 105.8±50.3 mm in January. From Kitale, ET_0 ranged from 121.5±8.5 mm/month in June to 157.1±8.5 mm/month in March while ET ranged from 41.7±32.6 mm/month in March to 126.6±12.2 mm/month in September. This was due to variability in temperature and precipitation between the two climatic regions. The study concludes that ET_0 and calculated evapotranspiration variability among the years on a monthly scale is slightly higher in arid and semi-arid climate regions than in humid regions. The study is important in strategizing viable means to enhance optimal crop water use and reduce ET losses estimates for optimal agricultural yields and production maximization in Kenya.

Keywords: crop coefficient, climatic regions, Kenya, reference evapotranspiration, real evapotranspiration, soil model

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Introduction

Kenya's mainstay of the economy is predominantly rainfed agriculture. Droughts of various severities, frequencies, timings, duration, intensity, and spatial extent vary from one climatic region to another and threaten food security in the country (Huho, J.M. and Mugalavai, M.E. 2010; Bowell, A. *et al.* 2021; Kipkemboi, K.B. *et al.* 2021). Therefore, a better understanding of hydrological processes and the distribution of water balance com-

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ponents is important (Okello, C. *et al.* 2020; Ferina, J. *et al.* 2021) to cushion inhabitants against extreme meteorological events. The components which include reference evapotranspiration (ET_0) and real evapotranspiration without and with an application of the crop coefficient (ET and ET_{Kc}), precipitation (P), soil moisture content (θ), soil recharge, soil surface runoff (R), and soil moisture loss coupled with other soil parameters should be given an in-depth insight to aid in operationalizing water management decisions.

Hydrological processes are crucial in plant developmental stages in times of water excess and/or stress. This is because crops have different rates of transpiration at different stages compounded by other factors such as environment and management practices (Zotarelli, L. *et al.* 2010; Ngetich, K.F. *et al.* 2012; Djaman, K. *et al.* 2017; Macharia, J.M. *et al.* 2021). For instance, during early crop developmental stages that is stages between vegetative emergence (VE) and vegetative tasseling (VT) (Ransom, J. *et al.* 2014) evaporation becomes the major process in water loss. For a fully grown crop, at reproductive stages (silking to physiological maturity) transpiration plays a major role and water stress causes more harm at the initial seedling stage and continued damage as crops near tasseling (Allen, R.G. *et at.* 1998). Soil water deficiency caused by unpredictable precipitation is an impediment to high yields in agriculturally potential areas. This prompts timely planting to ensure optimum utilization of available soil water during the rainy season (Ferina, J. *et al.* 2021). Since ET_0 and evapotranspiration are key determinants, long term modeling studies in Kenya and Africa are vital because of variations in water demand and soil characterization (Omondi, J.O. *et al.* 2017). A wide range of scientific methods have been used to estimate ET_0 (Penman, H.L. 1948) from different climatic components. This study used the FAO 56 standard methodology to estimate ET_0 on daily basis and one dimension Palmer-type soil model (Palmer, W.C. 1965; Ferina, J. *et al.* 2021) was used to estimate real evapotranspiration. The main aim of the study was to model ET_0, ET and ET_{Kc} in different climatic regions of Kenya. This was geared towards comparing changes in their estimates since they are influenced by climatic parameters and soil parameters which differ seasonally and from one climate region to another.

Recent studies (Hao, X. *et al.* 2018; McColl, K.A 2020) identified incorrectness of vital limiting cases and surface energy imbalances. This is due to the heterogeneity of regional characteristics in the Penman-Monteith evapotranspiration method. They provided a counter equation to correct the errors. McColl, K.A. (2020) suggests that it is more accurate in real-world conditions and it is not bound to additional assumptions, empiricism, or computational cost. This implies the complexity of the estimation of evapotranspiration since it relies on the heterogeneity nature of land surface features. As a key component of the hydrological cycle and its critical role in various sectors such as water resource management and agriculture (McColl, K.A. and Rigden, A.J. 2020), its study in various climate regions in Kenya which vary spatially resource-wise, is also very important in the current regime of climate change and variability. However, in our study, we relied on the standard and traditional Penman-Monteith method, because of its accuracy and ease of application to compute potential evapotranspiration.

The goal of this study is to evaluate estimates of reference (ET_0), and real evapotranspiration from two climatic regions of Kenya for proper planning and management of water resources using the traditional methodology (Zotarelli, L. *et al.* 2010; Ferina, J. *et al.* 2021) for present and future agricultural processes across water and agricultural sectors in daily and monthly time scale.

Geography and climate of Kenya

Kenya is geographically located at a longitude 34° E – 42° E, and latitude 5° S – 5° N. It has rich, diverse, and complex geomorphological features which are key modifiers of the climate system. The highest point is Mount Kenya (5,199 m) above sea level, while ranges, arid and semi-arid plains, and plateaus dominate the majority of the land. To the south, it is the Indian Ocean that regulates coastal climate (Ayugi, B. *et al.* 2020). In the western part of the country lies a complex rift valley lakes system. The climate varies from the modified tropical climate of the Kenya highlands to the desert climate of Central Northern Kenya (Obiero, J. and Onyando, J. 2013).

Study area and data sources

Different climatic regions of selected counties

The study was carried out in the different climatic regions of Kenya and from two counties *(Figure 1, Table 1)*. One, Trans-Nzoia County, is mountainous and climatically characterized by humid conditions, and the other, Taita-Taveta County, is lowland comprising of Taita, Mwambirwa and Sagalla hills with an altitude of 2,208 m a.s.l., and characterized by arid and semi-arid to tropical savannah climate. Trans-Nzoia County is humid, highland equatorial, mild, and generally warm and temperate. The Köppen-Geiger climate classification is Cfb (Peel, M.C. *et al.* 2007; Beck, H. *et al.* 2018). The annual average temperature is approximately 16 °C around Mount Elgon, and 28 °C in the lower areas. The diversity of agroecological factors coupled with agro-climatic zones has influenced spatial variation in the rainfed agriculturally productive region (Mbaisi, C.N. *et al.* 2016). Annual rainfall amount ranges between 1,267 mm to 1,808 mm while its elevation is between 1,800–2,000 m a.s.l. (Nyberg, J.M. *et al.* 2020).

Taita-Taveta is 89 percent arid and semi-arid. It is characterized by a tropical savannah climate (Aw). Mean monthly temperature is approximately 23 °C while the maximum and minimum are approximately 18 °C and 25 °C (Ogallo, L.A. *et al.* 2019). Its climate is influenced by south-easterly winds. On average, the county highlands receive 265 mm of precipitation, while the lowlands receive 157 mm during long rains between March, April, and May (MAM) while during short rains between October, November, and December (OND), rainfall amounts range from 341 mm in lowlands to 1,200 mm in highlands. Annual average precipitation amounts to 650 mm. The county is divided into three major topographical zones namely upper zone, comprising of Taita, Mwambirwa, and Sagalla hills region

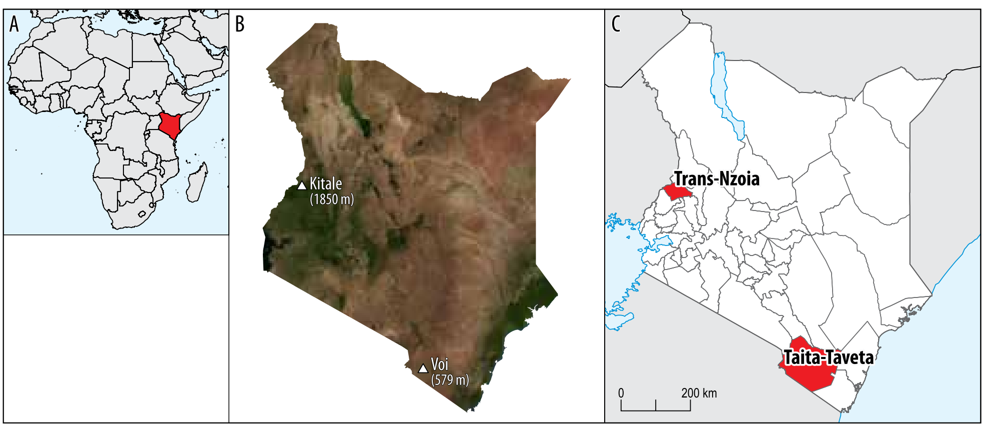

Fig. 1. Sketch map of Africa (a); Weather stations and their elevations (b); The two Kenyan counties under study: Trans-Nzoia, and Taita-Taveta in a sketch map of Kenya (c)

Table 1. Synoptic stations of counties under study, their geographical locations and duration of data set

County	Weather station	WMO-ID	Latitude	Longitude	Altitude, m	Duration of data set
Highland						
Trans-Nzoia	Kitale	63661	0.9733°N	34.9588°E	1,850	2000–2009
Lowland						
Taita-Taveta	Voi	63793	–3.3981°S	38.5581°E	579	2000–2009

with altitudes ranging between 304 and 2,208 m a.s.l., the lower zone consists of plains and the zone of national parks and mining areas (Government of Kenya, 2013; Mwakesi, I. *et al.* 2020). It is dominated agriculturally by maize, beans, and peas. Maize crop is the staple food from both counties as well as the whole of Kenya.

Dataset and quality control

Data with 3-hour time resolution was downloaded from Voi and Kitale synoptic weather stations and arranged into datasets from 2000–2009 (Meteomanz.com). Methodology of linear interpolation was used to check if the missing measurement periods were smaller than 12 hours. Mean daily course of the meteorological elements combined with the measured variables before and after the data gap was used for longer missing periods. If the lack of data was between half a day and 5 days, then the missing period was replaced with the average daily course from the data of the days (1 or 2 depending on the length of the data gap) before and after the missing period. If the data gap was even longer then we replaced the averages of 9 years for the given measuring period (8 measuring period each day). The measured and gap-filled time periods have been aligned during the initial and final 12 hours of the data-deficient period (5–5 data points) with a linear or exponential approximation.

Errors in the SYNOP messages (for instance bad digits) were also filtered in the temperature, relative humidity, pressure, wind speed, direction, and time series from the Meteomanz database based on a Visual Basic macro. 2.6 and 4.5 percent accounted for the missing data from Kitale and Voi SYNOP station daily data. The quality-assured database was arranged in Excel tables. After the data set was cleaned, step by step analysis of ET_0 (FAO 56 methodology, Zotarelli, L. *et al.* 2010; Lakatos, M. *et al.* 2020), calculated evapotranspiration using soil parameters ET and extended with maize coefficient, ET_{Kc} was undertaken using own Visual Basic Macro programmes developed in MS Excel.

Methodology

Due to complexity of the climate parameters required, FAO 56 standard methodology (Equation 1) of the daily base was used to estimate reference evapotranspiration, ET_0 (Allen, R.G. *et al.* 1998). There are also many methods for the estimation of potential evapotranspiration (E_{pot}), for instance, temperature as well as both temperature and terrestrial radiation-based methods (McMahon, T.A. *et al.* 2013; Lang, D. *et al.* 2017; Musyimi, P.K. *et al.* 2021). The definition of potential evapotranspiration is that from a surface of unlimited water but in this definition of potential evapotranspiration, the evapotranspiration rate does not relate to a specific crop while for the definition of reference evapotranspiration is that from a well-watered grass surface (Irmak, S. and Haman, D.Z. 2003).

Penman-Monteith reference evapotranspiration method is accepted as accurate, adopted, and recommended worldwide as a standardized method for ET_0 estimation across various climatic characterization for instance in Muranga County of Kenya (Shilenje, Z.W. *et al.* 2015). One dimension Palmer-type soil model (Equations 2–7) was used for estimating evapotranspiration using site-specific soil parameters *(Table 2)* which included wilting point, field capacity, and soil saturation point for each station at 1 m deep soil layer (Ács, F. and Breuer, H. 2006; Ács, F. *et al.* 2007; Dy, C.Y. and Fung, J.C.-H. 2016; Ferina, J. *et al.* 2021). This is obviously a rough approach since this study did not take into account the areal variability of the depth of the root zone. Therefore, the most commonly used 1 m depth value was applied.

The Palmer-type evapotranspiration model has also been applied in Kenya in previous studies to compute climate-based indices and evaluate meteorological and agricultural droughts (Marshall, M.T. *et al.* 2012). The soil types with the parameters were obtained from a soil map of Kenya with a 5 km space resolution which was taken using the Weather Research and Forecasting (WRF) model due to the scarcity of soil data parameters (Dy, C.Y. and Fung, J.C.-H. 2016) (see *Table 2*). The integration of the two models in the methodology was applied because the use of evapotranspiration-driven models in agricultural studies is still in its initial stages due to data scarcity in sub-Saharan Africa (Marshall, M.T. *et al.* 2012). Ratio of real and reference evapotranspiration dependent on the region-specific soil moisture stress. Application of the site-specific crop coefficients (K_C) were also applied in the model (Equation 3). This study used the maize coefficient as specified by FAO (Allen, R.G. *et al.* 1998; Tyagi, N.K. *et al.* 2003), because it is the staple food of Kenya and widely grown in the counties under study (Luciani, R. *et al.* 2019). The parameters used in Equation (1) are for daily time step by step in which analysis of each station climate data was done using Visual Basic Macro programmes developed in MS Excel.

Considering the i^{th} day of the year. The reference evapotranspiration for the i^{th} day of the year is [mm day^{-1}]:

$$ET_{0i} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}, \quad (1)$$

Meteorological variables for the given day of the year (without the notation *i*) are: R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}], G = soil heat flux density [MJ m^{-2} day^{-1}], T = mean daily air temperature at 2 m height [°C], u_2 = wind speed at 2 m height [m s^{-1}], calculated from the reference wind measurement in 10 m height (Zotarelli, L. *et al.* 2010; Lakatos, M. *et al.* 2020), e_s = saturation water vapour pressure [kPa], e_a = actual water vapour pressure [kPa], $e_s - e_a$ = saturation water vapour pressure deficit [kPa], Δ = slope of the water vapour pressure curve [kPa °C^{-1}], γ = psychrometric constant [kPa °C^{-1}].

The daily evapotranspiration without (*LE*) and with the crop coefficients (LE_{Kc}) calculated by the 1D Palmer model for the i^{th} day of the year is determined by the soil type (see *Table 2*), the plant constant (Kc_i) and the parameterization of β_{i-1} function respectively. The latter is considered a simple linear function of the available soil moisture ($\theta_{i-1} - WLT$) (see Equation 4). There are other approaches as an exponential form of parametrization of function (Mintz, Y. and Walker, G.K. 1993). During the test calculations, no significant differences were observed among the different methodologies, so we kept the linear approximation. The initial soil moisture [in mm] in the upper 1 m deep soil layer is the previous daily ($i - 1$) value, θ_{i-1}

$$ET_i = \beta_{i-1} \cdot ET_{0i}, \quad (2)$$

$$(ET_{Kc})_i = Kc_i \cdot ET_i, \quad (3)$$

$$\beta_{i-1} = \begin{cases} 1 & if \ FC \leq \theta_{i-1} \\ \left(\frac{\theta_{i-1} - WLT}{FC - WLT}\right) & if \ WLT \leq \theta_{i-1} \leq FC, \\ 0 & if \ \theta_{i-1} \leq WLT \end{cases} \quad (4)$$

where ET_i = real evapotranspiration, β_{i-1} = soil moisture availability parameter in a one-meter-deep layer of soil, WLT = wilting point, FC = field capacity, and Kc_i = specific crop coefficient for a given day. Parameterization knowing the amount of daily precipitation (P_i), of Runoff (R_i) provide the base on the daily water balance equation. (Units are mm in our cases.)

Table 2. Soil characteristics of synoptic stations in regions under investigation*

Stations	Soil type for WRF model	Saturation point (SAT), % v/v	Field capacity (FC), % v/v	Wilting point (WLT), % v/v
Lowland				
Voi	Sandy clay loam (7)	40.4	31.5	6.9
Highland				
Kitale	Loam (6)	43.9	32.9	6.6

*According to Dy, C.Y. and Fung, J.C.-H. 2016.

A simple 1D bucket model was applied. If, at the end of the day, the estimated soil moisture value exceeds the saturation point ($\theta_i > FC$), then the remainder is considered as a runoff (R_i). The model does not take into account the terrain conditions nor the depth of groundwater and the surface water movement:

$$R_i = \begin{cases} 0 & if\ (\theta_{i-1} - ET_i + P_i) \leq SAT \\ (\theta_{i-1} - ET_i + P_i) - SAT & if\ (\theta_{i-1} - ET_i + P_i) > SAT \end{cases}, \quad (5)$$

The value of soil moisture, θ_i and corrected evaporation ET_i (practically near zero) can also be easily calculated at the end of the i^{th} day, when the soil moisture is near wilting point, as we know that: $WLT \leq \theta_{i-1} \leq SAT$:

$$\theta_i = \begin{cases} WLT & if & (\theta_{i-1} - ET_i + P_i) \leq WLT \\ (\theta_{i-1} + ET_i + P_i) & if & WLT > (\theta_{i-1} - ET_i + P_i) \leq SAT \\ SAT & if & (\theta_{i-1} - ET_i + P_i) > SAT \end{cases}, \quad (6)$$

$$ET_i = \begin{cases} ET_i & if\ (\theta_{i-1} - ET_i + P_i) \geq WLT \\ (\theta_{i-1} + P_i - WLT) & if\ (\theta_{i-1} - ET_i + P_i) < WLT \end{cases}, \quad (7)$$

Although the Palmer-type soil model is globally and regionally used for its suitability in the analysis of hydrological processes, it has a limitation in that it does not consider the application and use of other soil properties such as textural variation among soils, physical and chemical composition of various soils which vary from one region to the other (Ferina, J. *et al.* 2021). This study also did not put into consideration such inputs due to a range of issues such as scarcity, uncertainty, and unavailability of the properties of soil data from Kenya. However, the model is useful as it forms a basis for future studies of other soil properties as well as provides room for its improvement.

A normality and hypothesis test

The methods to analyze the normality of the time series used in the study are Kolmogorov-Smirnov (K-S) test, and Shapiro-Wilk test (Ghasemi, A. and Zahediasl, S. 2012). The importance of the normality test was to help decide the statistical significance test for mean and standard deviation from the two counties. This study relied on the Shapiro-Wilk test as it is recommended for small samples. The distribution of 10-year rainfall data portrayed a normal distribution while monthly precipitation between the two counties showed variation in normality among the months regardless of the season. A simple F-test was used to compare the standard deviation of annual precipitation, ET, ET_0, ET_{Kc}, from the two counties while the T-test (was used when the distribution between the months was normal) and Mann-Whitney U-test (was used when the distribution between months was skewed) were used to compare the monthly mean of precipitation. This was due to its applicability in determining the stability of time series data, its ease, and simplicity of use (Lim, G.-K. *et al.* 2020). The following four hypotheses were tested based on the normality of the data:

– H_0: There is no statistical significant difference of annual precipitation, ET, ET_0, ET_{Kc}, between the two climatic regions of the two counties.
– H_1: There is statistical significant difference of annual precipitation, ET, ET_0, ET_{Kc}, between the two climatic regions of the two counties.
– H_0: There is no statistically significant difference between the two climatic regions of

the two counties based on mean monthly precipitation data.

– H_1: There is statistically significant difference between the two climatic regions of the two counties based on mean monthly precipitation data.

Results and discussion

This section describes the pattern of temperature and precipitation and compares spatial variation of the mean monthly ET_0 and estimates ET without crop coefficient ($Kc_i \equiv 1$) and evapotranspiration with crop (maize) coefficient, ET_{Kc} from arid and semi-arid Taita-Taveta and humid Trans-Nzoia counties of Kenya. It also examines decadal and annual means (x) and standard deviations (σ_X) of precipitation (P), reference and estimated real evapotranspiration (ET_0, ET, ET_{Kc}), ET/ET_0 and ET_{Kc}/ET_0 ratios. The importance of analyzing ratios of the regions under study was to determine evaporative stress indices which are also synonymous with drought index, a reflection of temperature properties on the surface. Evaporative stress indices have been previously used to examine droughts of various durations more so short-term, crop growth and irrigation demands as well as water stress (Yao, A.Y.M. 1974; Choi, M. *et al.* 2013; Anderson, M.C. *et al.* 2016; Liu, Y. *et al.* 2019). It was also important to compare the evaporative index using ET with and without the application of the maize coefficient.

Temperature and rainfall pattern of the counties under study

Results indicated that the mean monthly temperature ranged from 22.7 to 28.4 °C in Taita-Taveta County while in Trans-Nzoia County the range was between 17.8 to 21.9 °C. (There are tropical regions.) Mean annual precipitation in Taita-Taveta was 574.2±205.8 mm while absolute minimum and maximum were 212.3 mm in the year 2003, and 801.4 mm in the year 2004 respectively. The rainfall amount of 212.3 mm was too low compared to the mean of 574.2 mm, indicating drought. Similar droughts were experienced across Kenya in the 2000s. Arid and semi-arid regions which cover 80 percent of land mass were highly affected (Nyaoro, D. *et al.* 2016; Venton, C.C. 2018).

In Trans-Nzoia County, the mean annual precipitation was 1,200±174 mm while maximum and minimum absolute values were 1,014.2 mm in the year 2000 and 1,460.3 mm in the year 2001 respectively. There was a noticeable variation in precipitation in the two regions under study *(Figure 2)*. This conforms to the results of Huho,

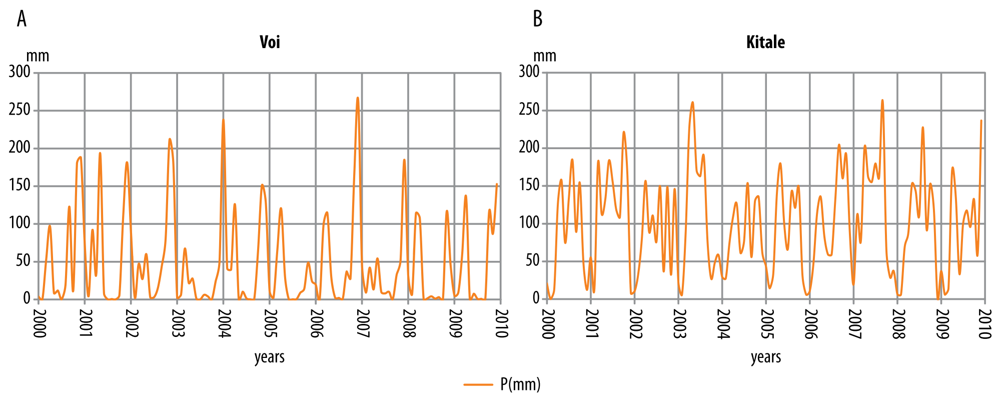

Fig. 2. Monthly precipitation variation (2000–2009) in Voi synoptic station, Taita-Taveta County (a), and in Kitale synoptic station, Trans-Nzoia County (b)

Table 3. Decadal mean monthly ET_0 in Lowland, Voi station, Taita-Taveta County (Aw)

Year/Month	1	2	3	4	5	6	7	8	9	10	11	12	Mean ($\bar{x}$)	SDev. (σ_X)
2000	162.9	176.1	166.4	158.2	147.3	135.7	143.6	155.9	157.8	178.1	144.2	150.5	*156.4*	*13.0*
2001	146.3	158.6	180.2	154.2	162.8	143.8	149.0	170.4	178.1	191.0	153.1	139.6	*160.6*	*16.2*
2002	144.4	159.8	165.3	157.3	169.9	177.7	177.3	157.7	156.4	164.8	157.7	151.0	*161.6*	*10.0*
2003	170.1	164.6	198.3	177.4	164.7	167.3	182.2	175.3	175.3	191.2	170.4	182.4	*176.6*	*10.5*
2004	152.7	149.6	183.0	160.6	188.2	160.2	177.1	172.9	179.2	167.6	151.6	147.4	*165.8*	*14.1*
2005	161.2	169.3	176.4	165.0	182.3	174.8	165.5	164.4	169.4	181.5	148.5	172.9	*169.3*	*9.4*
2006	182.3	173.4	169.4	153.6	165.8	166.8	167.6	174.9	162.2	156.4	133.1	137.3	*161.9*	*14.1*
2007	144.5	155.9	170.9	173.8	157.3	167.0	167.3	157.2	166.7	174.4	151.1	150.1	*161.4*	*10.1*
2008	150.8	156.0	162.1	147.8	154.4	150.3	152.3	152.8	162.4	183.4	130.3	140.9	*153.6*	*12.8*
2009	164.4	149.1	181.3	168.8	170.7	154.8	160.1	152.2	172.0	154.4	143.5	140.2	*159.3*	*12.5*
Mean (x)	*157.9*	*161.2*	*175.3*	*161.7*	*166.3*	*159.9*	*164.2*	*163.4*	*167.9*	*174.3*	*148.3*	*151.2*	–	
SDev. (σ_X)	*12.5*	*9.4*	*10.8*	*9.4*	*12.3*	*13.6*	*12.9*	*9.3*	*8.2*	*13.2*	*11.6*	*15.0*		

Table 4. Decadal mean monthly ET_0 in Highland, Kitale station, Trans-Nzoia County (Cfa)

Year/Month	1	2	3	4	5	6	7	8	9	10	11	12	Mean (x)	SDev. (σ_X)
2000	158.0	162.7	166.0	128.4	124.7	119.7	111.0	122.7	138.8	127.0	117.4	136.5	*134.4*	*18.5*
2001	128.4	147.7	136.8	123.3	123.3	112.0	113.9	123.2	131.9	125.0	110.4	139.3	*126.3*	*11.3*
2002	134.3	151.4	140.8	129.6	128.0	123.5	133.7	134.6	144.2	134.6	128.1	129.8	*134.4*	*7.8*
2003	150.7	155.4	164.4	131.1	128.5	119.5	125.2	124.9	143.0	142.2	129.1	150.1	*138.7*	*14.3*
2004	151.1	152.6	165.8	125.9	139.4	126.8	133.5	134.8	134.8	146.3	127.3	143.4	*140.1*	*12.2*
2005	157.3	163.2	159.9	146.3	120.4	124.3	128.7	136.7	132.8	141.4	143.9	166.3	*143.4*	*15.6*
2006	164.4	156.9	151.9	139.8	139.3	129.6	130.8	132.4	144.8	150.3	118.2	123.4	*140.2*	*14.0*
2007	150.3	135.1	162.7	141.8	135.4	104.2	119.1	128.9	129.4	143.5	137.0	151.3	*136.5*	*15.4*
2008	155.8	155.1	149.9	141.8	129.2	121.4	122.6	123.7	136.9	132.5	139.7	153.9	*138.5*	*12.9*
2009	152.5	165.0	173.2	123.4	125.5	133.6	133.0	141.3	144.9	140.6	146.1	134.5	*142.8*	*14.3*
Mean (x)	*150.2*	*154.5*	*157.1*	*133.1*	*129.4*	*121.5*	*125.1*	*130.3*	*138.1*	*138.4*	*129.7*	*143.8*	–	
SDev. (σ_X)	*11.0*	*8.8*	*11.8*	*8.5*	*6.6*	*8.5*	*8.3*	*6.6*	*5.9*	*8.3*	*12.0*	*12.8*		

J.M. (2017) who mentioned that the amount of rainfall received in a given region differs from year-to-year. For instance, in Machakos County, the coefficient of variation of 42 and 41 percent for MAM and OND rainfall seasons respectively for KARI Katumani station and 39 and 54 percent for Mutisya Mango Farm station respectively were experienced (Huho, J.M. 2017). Similarly, Ghaedi, S. (2021) noted that patterns of precipitation variability were evident across Iran from one year to another. Consequently, higher variability dominates the arid and semi-arid climatic regions across the world, which are characterized by low, unpredictable, and erratic rainfall amounts.

Spatial variation of mean monthly ET_0 in lowland, Taita-Taveta County (Aw)

Reference evapotranspiration (ET_0) was estimated using FAO 56 standard methodology (Equation 1). Results indicated that decadal mean monthly reference evapotranspiration varied from one year to the other and from one month to the other. This variation was dependent on the seasons of the year since a greater percentage of Kenya exhibits two major rainy seasons, the MAM long rain season and OND, short rain season, both related to the influence of the ITCZ, but differing in the amount of precipitation received and its interannual and inter-seasonal variability (Camberlin, P. and Wairoto, J.G. 1997). For instance, Taita-Taveta experiences two rainy seasons, MAM and OND. The precipitation climatology of countries near the Equator where Kenya lies is heterogeneous due to influences of topography, lakes, and seasonal dynamics of tropical winds (Nicholson, S.E. 2017).

The highest decadal mean monthly value of the reference evapotranspiration was 175.3 ±10.8 mm in March, while the lowest decadal mean monthly value was 148.3±11.6 mm in November for the 10 years of analysis *(Table 3)* during the two rainy seasons. The highest annual mean value was 176.6±10.5 mm/year in 2003, while the lowest was 153.6±12.8 mm/year in 2008 (see *Table 3*). During dry seasons, which have its peak from July to September and December to February experience no precipitation or very little amounts, there were relatively small differences of ET_0 among months and high values of ET_0 as shown in *Table 3.* This implies that ET_0 estimates depend mostly on high temperatures and solar insolation but in cases where ET_0 is larger than precipitation more so in the dry months irrigation is an option to substitute the insufficient amount of precipitation and evaporative requirements by crops (Sadick, A. *et al.* 2015).

Spatial variation of mean monthly ET_0 in highland Trans-Nzoia County (Cfa)

Results from humid Trans-Nzoia County indicated that the decadal mean monthly ET_0 varied from one year to the other and from one month to the other but the estimates were lower than in Taita-Taveta County. This was because of lower temperatures experienced in Trans-Nzoia than in Taita-Taveta County. The highest mean value was 157.1±11.8 mm/month in March while the lowest mean monthly value was 121.5±8.5 mm/month in June *(Table 4).* It was also evident that there were moderate differences among the months.

The mean differences among the months were also moderate with the largest mean difference of 11.1 mm/month between November and December (see *Table 4*). Similar variations were observed by Djaman, K. *et al.* (2018) who stated that there were temporal and spatial variations in the monthly average ET_0 from January to December across Madagascar with January average ET_0 (less than 5 mm/day), the highest more so in regions characterized by hot and dry climates while the lowest ET_0, ranging from 3.27 to 3.70 mm/day, evident in the central-eastern humid region of Madagascar.

Mean monthly reference and real evapotranspiration estimation using soil parameters from the two counties

Results of the estimates indicated variation in ET_0 and ET from two counties. In Taita-Taveta County the differences in mean monthly ET estimates were small and almost followed the same trend varying from month to month and year to year *(Figure 3*, a*)*. Mean monthly ET estimates ranged from 8.0±4.5 mm/month in September to 105.8±50.3 mm/month in January. This was due to varying precipitation amounts and simultaneously soil moisture contents. In Trans-Nzoia County, the differences in estimates were slightly high and indicated a noticeable difference (see *Figure 2*, b). Mean monthly ET (without application of plant constant, *Kc*) estimates ranged from 41.7±32.6 mm/month in March to 126.6±12.2 mm/month in September. Mean monthly ET dependent on the season of the year and varied from one climatic region to the other but greater variation was experienced in arid and semi-arid climates. However, in long and short rainy seasons real evapotranspiration is nearly independent of soil textural characteristics because of adequate precipitation. For instance, in Trans-Nzoia County, precipitation ranges from 1,267 mm to 1,808 mm (Nyberg, J.M. *et al.* 2020) while Taita-Taveta County receives 265 mm in the highlands and 157 mm in the lowlands during long rains (MAM); while during short rains (OND) the range is from 341 mm in lowlands to 1,200 mm in highlands (Mwakesi, I. *et al.* 2020).

Textural characteristics vary greatly from one soil type to the other as stated by Mugo, J.W. *et al.* (2016) in a study in Kitui County of Kenya. During dry spells ET mostly depends on both soil texture and amount of precipitation which vary across different climatic regions (Ács, F. *et al.* 2007). For instance, in Taita-Taveta County, the type of soil was sandy clay loam while in Kitale it was loam (see *Table 2*). This implies that the amount of precipitation received in the lowlands is not sufficient enough to meet the requirements of ET_0 and ET unlike in highlands or mountainous regions where rainfall is reliable. There were some few cases where small differences or equal estimates of ET_0 and ET were equal, for example in January 2001, 2003, and 2007. In this month temperatures as well as precipitation were low. These results concur with Ferina, J. *et al.* (2021) who stated that differences in ET_0 and ET are small when precipitation is adequate and equally large when precipitation decreases. The variability in ET_0 and ET is dependent on soil moisture, recharging of lost soil moisture through precipitation, nature, and type of land cover among other heterogeneous land character-

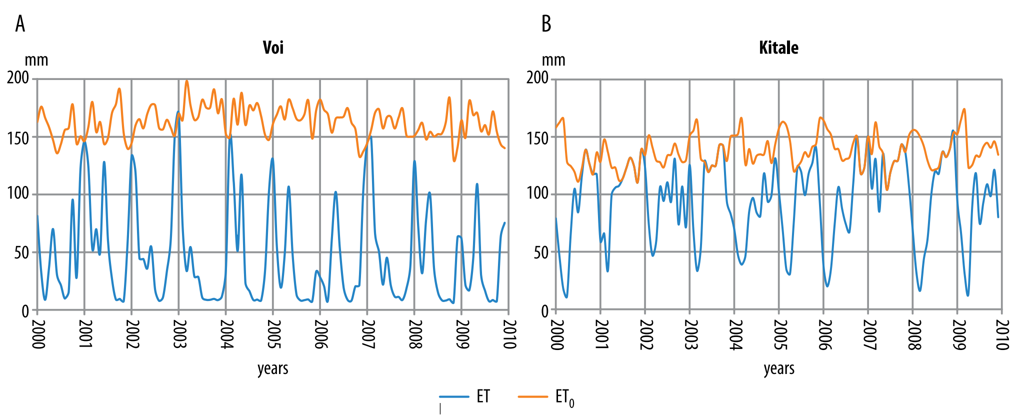

Fig. 3. Mean monthly variability of ET_0 and ET in Voi synoptic station, Taita-Taveta County (a), and in Kitale synoptic station, Trans-Nzoia County (b)

istics. However, its estimation is of greater importance to water and agricultural sectors as well as ecosystem stability and well-being (McColl, K.A. and Rigden, A.J. 2020).

In Taita-Taveta County, Voi station *(Figure 3, a)*, in many instances, *ET* was too low compared to *ET* estimates of Trans-Nzoia County *(Figure 3, b)*. For instance, *ET* ranged from 8.0±4.5 mm/month in September to 105.8±50.3 mm/ month in January. This was because of high temperatures and unreliable precipitation amounts. This increased soil moisture content stress brings a deficit due to aridity conditions of the region and this impacts agriculture and brings potentially adverse effects to the yields hence food insecurity. Contrary to this, in Kitale station (see *Figure 2*, b), Trans-Nzoia County, *ET* was relatively higher and ranged from 41.7±32.6 mm/month in March to 126.6±12.2 mm/month in September and varying annually which also influence maize yield. According to Marshall, M.T. *et al.* (2012), variability in *ET* and maize yield correlations and incompatibility with the awaited growing season are highest in Western Kenya where Trans-Nzoia County lies geographically. There were some few cases where small differences or equal estimates of ET_0 and *ET* were equal, for example in January 2007 because the region receives an adequate amount of precipitation, and the temperatures are usually low. These results are in tandem with Ferina, J. *et al.* (2021) who stated that different climatic regions vary significantly in terms of agricultural essentials, more importantly, soil moisture content, precipitation amount, temperature, and sufficient water. Therefore, the estimation of ET_0 and *ET* is of fundamental importance in the agricultural potential region as well as the other sectors considering their variability.

Daily reference evapotranspiration, real evapotranspiration without and with maize coefficient (ET_{Kc})

Daily results in Taita-Taveta County indicated that, daily averages, ET_0, *ET* and evapotranspiration with maize coefficient, ET_{Kc} was 5.3±0.9 mm/day, 1.6±1.2 mm/day and 1.6±1.2 mm/day respectively. There was practically no significant difference between evapotranspiration without and with maize coefficient as their estimates were almost the same but ET_0 was higher in Taita-Taveta County (*Figure 4*, a) than in Trans-Nzoia (*Figure 4*, b) because of the high temperatures experienced in lowland Taita-Taveta County. The daily maximum value of ET_0 was 8.5 mm/day and was observed on 13 January 2006, while the daily minimum absolute estimate was 1.7 mm/day and recorded on 31 May 2003 in Taita-Taveta County. This was because January is among the hottest months in the dry season of January and February, while May is a month of the long rainy season, hence the variations among values in Taita-Taveta County.

Similarly, in Trans-Nzoia County, the daily maximum absolute estimate of *ET* was 6.2 mm/day on 29 May 2001, whilst the absolute minimum value was 0.0 mm/day on three days: 19, 20 and 21 October 2003. On the other hand, daily evapotranspiration with modified maize coefficients, ET_{Kc} Kc_{ini} (initial period, Kc_{mid} mid-season, the crop growth development period and Kc_{end}, late season period) of 0.3, 0.75, 1.2, and 0.4 and 0.3, 0.8, 1.2, and 0.6 (Allen, R.G. *et al.* 1998) in Taita-Taveta and Trans-Nzoia County respectively. For the Kc_{end}, the modification was done in this study as the average between crop development period and Kc_{end} that was 0.8 and 0.9 in Taita-Taveta and Trans-Nzoia County respectively *(Figure 5)* were used to compute the estimations. As stated by Guerra, E. *et al.* (2011), crop coefficients are fundamentally vital for estimating the evapotranspiration of crops. They computed approximately similar maize coefficients in Kenya of Kc_{ini} of 0.5, Kc_{mid} of 1.0 and Kc_{end} of 0.8. These values were computed for three crop stages, initial, mid-season, and end-season without consideration of the development stage.

The reason for using the maize crop coefficient is because of the importance of soil moisture content to crop growth and development and its deficiency can highly impact the yield of maize crop hence food insecurity in Kenya.

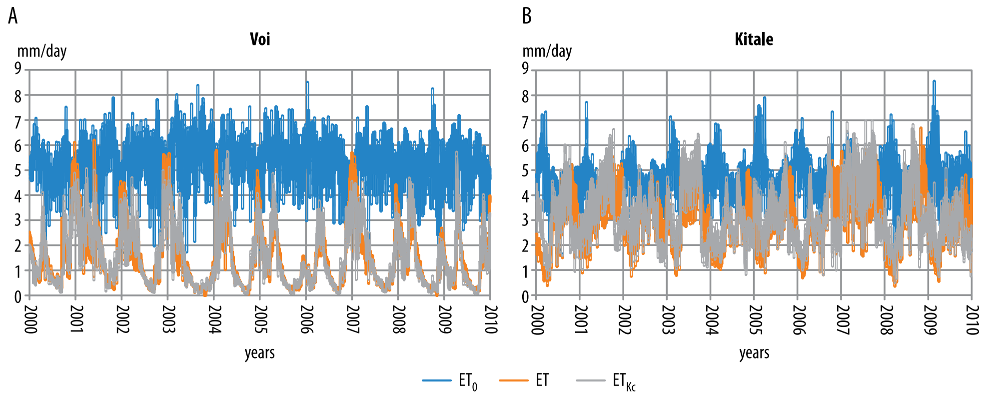

Fig. 4. Daily variability of ET_0, ET and ET_{Kc} in Voi synoptic station, Taita-Taveta County (a), and in Kitale synoptic station, Trans-Nzoia County (b)

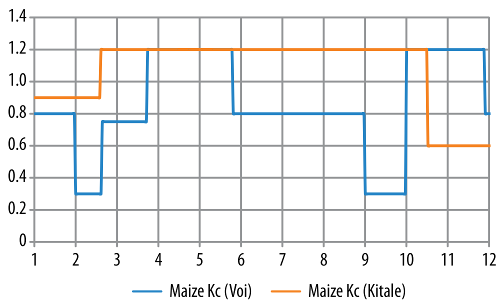

Fig. 5. Maize coefficients in Voi (two rainy seasons), and Kitale (single rainy season) annually

The government's food security depends on the availability of enough quantity of maize to meet food demands. Further, it is the most important and staple food for over 90 percent of population, grown on 1.6 million hectares of land and 80 percent of its farming is practiced by small-scale farmers (Wambugu, P.W. *et al.* 2012). As stated by Shanahan, J.F. and Nielsen, D.C. (1987), despite water availability's importance in every stage of crop development, from germination to harvest, many crops are most sensitive to moisture deficits during the reproductive stages. This occurs mostly during the duration of tasseling, silking, and pollination since water stress during the reproductive stages revitalizes deeper root growth (Mayaki, W.C. *et al.* 1976).

Similarly, soil moisture distress can highly influence real evapotranspiration since if there is a moisture deficiency, evapotranspiration requirements are not satisfied. For instance, Stegman, E.C. (1982) noted that a 1 percent decrease in seasonal real evapotranspiration led to an average loss of 1.5 percent in maize yield, whereas water stress more so during the reproductive stages more so the blister stage (10–14 days after silking) led to a 2.6 percent decline in maize crop yield. This can as well proportionately explain the reduction in maize yield in Taita-Taveta County which experiences two growing seasons (MAM and OND). Daily maximum estimate of ET_{Kc} was 5.7 mm/day on 10 April 2009 while the daily absolute minimum estimate was 0.1 mm/day from 29 August to 28 of September 2003, 2005 and 2006 respectively. This was because April is a month of the long rainy season of Kenya while July, August, and September (JAS) are dry seasons with August and September recording high temperatures in the arid and semi-arid climatic region of Kenya. Daily estimates of Trans-Nzoia County showed that the mean daily average of, ET_0 and ET was 4.5±0.9 mm/day, 3.1±1.1 mm/day and 3.2±1.2 mm/day respectively. These averages were moderately low as compared to Taita Taveta County (see *Figure 3*, b) because these regions received a high amount of precipitation and low temperatures hence meeting the requirements of *ET*. The daily absolute maximum ET_0 for the 10 years (2000–2009) was 8.5 mm/day on 21 February 2009 whilst the minimum absolute value was 1.6 mm/day on 4 July 2007. Similarly, evapotranspiration without and with maize coefficient maximum absolute daily estimates was 7.0 mm/day and 6.6 mm/day on 1 November 2008 and 27 July 2007 respectively. These results are in tandem with those reported by Hobeichi, S. *et al.* (2018) who indicated that evapotranspiration had higher values in the Sahel from September to November.

The analysis also showed the daily absolute minimum values of *ET* without, and with *Kc* were 0.51 mm/day and 0.36 mm/day on the same day (27 March 2008) respectively. The daily, monthly, and annual variations of ET_0, *ET* and ET_{Kc} was due to varying daily, monthly and annual precipitation amounts (see *Figure 2*) and deficiency of precipitation mean soil moisture content and evapotranspiration deficiency hence agricultural drought. This concurs with Marshall, M.T. *et al.* (2012) who indicated that deficits in estimated real evapotranspiration are a direct measure of crop stress and can be integrated into agricultural drought monitoring systems.

Annual comparison of trends of P, ET, ET_0, ET_{Kc} from the two counties

Analysis also shows an annual variation of ET_0 in the two climate regions, with a range of 1,837.6 mm/year to 2,119 mm/year in Taita-Taveta and 1,515.1 mm/year to 1,721.1 mm/year in Trans-Nzoia, and a decadal average of 1,950.7 mm/year in Taita-Taveta County and 1,650.3 mm/year in Trans-Nzoia County. These results are in agreement with Djaman, K. *et al.* (2018) who observed that across Madagascar, annual ET_0 varied from 1,081 mm/year to 2,239 mm/year and averaged 1,620 mm/year. The highest value range of the long-term average annual ET_0 was between 1,891 and 2,111 mm/year on the western coast and northwestern coast (Djaman, K. *et al.* 2018). Further, from *Table 5*, it was evident that higher annual precipitation (*P*) amounts led to higher *ET* and lower annual precipitation amounts led to lower. For instance, in 2003, in Taita-Taveta County, the annual precipitation amount was 212.3 mm and the same year had the lowest *ET* estimate of 447.4 mm/year. This was due to the 2003 drought which was experienced across the whole lower eastern. This result conforms with Yang, Z. *et al.* (2016) who mentioned that the decrease in *ET* is attributed to a decrease in precipitation amounts, and regions with less annual precipitation depict less.

Analysis based on standard deviation (σ) from the annual mean precipitation, *ET*, ET_0, ET_{Kc} was carried out for the whole decade (10 years) for the two counties. A simple F-test (Lim, G. *et al.* 2020) was used to determine whether the standard deviation between the two counties was statistically different. At a significance level (α) of 0.05, results showed that p values of precipitation, *ET*, ET_0, ET_{Kc} from the two counties were greater than 0.05. This means we do not reject the null hypothesis and there is no statistically significant difference between the standard deviation of precipitation, of the two counties. Contrary to the expected results, this outcome implies a similarity of tropical annual precipitation cycles between the two counties and from the two climatic regions (Ilyés, C. *et al.* 2021). A further test of significance by T-test and Mann-Whitney U-test showed that there is no statistically significant difference between the monthly mean precipitation of January, February, March, and November. There exist a statistically significant difference between the monthly mean precipitation of April, May, June, July, August, September, October, and December. These differences and similarities may be attributed to climate variability and change which causes shifts in air and ocean currents circulation linked to ITCZ hence the anomalies (Ayugi, B. *et al.* 2016; Obwocha, E.B. *et al.* 2022) hence change in monthly weather pattern since precipitation distribution is mostly irregular Kenya in time and space. The

Table 5. *Decadal annual mean and standard deviation of annual precipitation (P), reference evapotranspiration (ET_0) and the estimated evapotranspiration (ET) without and with plant (maize) coefficient (ET_{Kc}) from the two counties*

Counties	Indicator	Years										Mean ($\bar{x}$)	SDev. (σ_X)
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009		
Taita-Taveta (Tropical savannah, arid and semiarid)	*P**	696.4	704.8	763.8	212.3	801.4	326.2	765.5	463.0	432.7	576.0	*574.2*	*205.8*
	ET_0	1876.5	1927.1	1939.4	2119.0	1985.5	2031.1	1942.8	1936.2	1837.6	1911.4	*1950.7*	*79.4*
	ET	598.7	737.3	675.9	447.4	677.7	450.8	507.0	604.1	505.4	466.1	*567.0*	*105.9*
	ET_{Kc}	669.9	748.8	667.8	467.2	665.0	461.6	494.2	598.4	510.8	469.9	*575.4*	*106.8*
	ET/ET_0	0.32	0.38	0.35	0.21	0.34	0.22	0.26	0.31	0.28	0.24	*0.29*	*0.06*
	ET_{Kc}/ET_0	0.36	0.38	0.34	0.22	0.33	0.22	0.25	0.31	0.27	0.25	*0.29*	*0.06*
Trans-Nzoia (Humid)	*P**	1014.2	1460.3	1068.2	1335.7	1042.0	1025.5	1282.0	1460.0	1169.9	1138.6	*1200.0*	*174.0*
	ET_0	1612.8	1515.1	1612.8	1664.1	1681.7	1721.1	1681.7	1638.8	1661.5	1713.6	*1650.3*	*60.1*
	ET	1005.6	1229.4	1056.1	1212.1	972.0	1123.7	1045.9	1452.7	1126.4	988.0	*1121.2*	*146.5*
	ET_{Kc}	1088.7	1273.1	1077.6	1325.4	957.6	1135.0	1008.5	1560.3	1145.8	994.6	*1156.7*	*183.9*
	ET/ET_0	0.62	0.81	0.65	0.72	0.57	0.65	0.62	0.89	0.68	0.57	*0.68*	*0.11*
	ET_{Kc}/ET_0	0.67	0.84	0.66	0.80	0.57	0.66	0.60	0.95	0.69	0.58	*0.70*	*0.12*

*mm/year

similarity of the monthly mean precipitation was regardless of the season since it did not follow the seasonal pattern of Kenya.

Conclusions

In this study, we estimated long-term (2000–2009) reference and real evapotranspiration using a one-dimensional Palmer-type soil model for two synoptic stations found in two different climatic regions of Kenya. It was established that:

1. Annual ET_0 estimates were high in Taita-Taveta County with values ranging from 1,838 mm/year to 2,119 mm/year compared to Trans-Nzoia County where its estimates ranged from 1,515 mm/year to 1,721 mm/year.

2. Annual evapotranspiration without (ET) and with maize coefficient (ET_{Kc}) varied in the two climatic regions under study. The estimates ranged from 447 mm/year to 737 mm/year and 461.6 mm/year to 748.8 mm/year in Taita-Taveta County respectively, whilst in Trans-Nzoia the range was from 972 mm/year to 1,453 mm/year and 958 mm/year to 1,560 mm/year respectively.

3. The evaporative stress indices were low in Taita-Taveta County with and without the maize coefficient. It ranged from 0.22 to 0.38 and from 0.21 to 0.38 with and without maize coefficient respectively. This was because of the low amount of annual precipitation and high temperatures. However, in Trans-Nzoia County, evaporative stress indices were high with a range of 0.60 to 0.95 and 0.57 to 0.89 with and without maize coefficient due to varying annual precipitation amounts among the years.

4. The highest evaporative stress index was experienced in Trans-Nzoia County when the annual precipitation was high. For instance, in 2001 and 2007 the annual rainfall amount was 1,460.3 mm and 1,460 mm respectively, and the evaporative stress indices were 0.84 and 0.81 with and without maize coefficient in 2001 and 0.95 and 0.89 with and without crop coefficient in 2007 respectively.

The study concludes that these results are important to different climatic conditions in Kenya which are endowed with various agricultural necessities in terms of topography, amount of precipitation received, and different soil characteristics such as moisture, drainage, and depth among others. The variation in estimated real evapotranspiration in various climatic regions should be applied in farmers' decision-making in their choice of crops to be planted, variety of farming systems, choice of planting seasons, and duration of crops to maturity. Therefore, it is fundamentally important to estimate ET_0, ET and ET_{Kc} with and without specific crop coefficients considering their daily, monthly and annual variability, more so in agriculturally potential regions of Kenya. Further, the study is important for the shifting planting seasons of various crops which differ in terms of soil moisture requirements.

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Population mobility and urban transport management: perspectives environmental quality degradation and sustainable development of suburban Makassar City, Indonesia

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Abstract

The expansion of the area towards suburban areas accompanied by suburbanization has an impact on the conversion of productive agricultural land and transportation movement systems. This study aims to analyse land use change works as a determinant of environmental degradation in suburban areas, the effect of land use changes, socio-economic activities, population mobility and transportation systems on environmental quality degradation, and models for handling land use, population mobility, transportation infrastructure and system management transportation towards sustainable development of suburban areas. This study uses a sequential qualitative-quantitative approach. Data obtained through observation, survey and documentation. The results of the study show that the intensity of land use change coupled with population mobility, in addition to affecting the urban transportation system based on the pattern of origin and destination of travel, also has an impact on the environmental quality degradation of suburban areas. Changes in land use, socio-economic activities, population mobility and transportation systems has an effect in the environmental quality degradation of suburban areas with a coefficient of determination of 95.65 percent.. This study recommends the application of a land use management model, population mobility, and transportation infrastructure towards the sustainability of the suburbs of Makassar City, Indonesia.

Keywords: land use change, population mobility, transportation system, sustainable development

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Introduction

The expansion of the Makassar City area towards suburban areas contributes to changes in land use, transportation systems and population mobility. The change in land use is marked by various development activities being developed, namely industry, commercial activities, services, education and health services. Land use change has specific and cumulative effects on air and water quality, waste generation, climate and human health (Lu, Y. *et al*. 2021; Zhao, Y. *et al*. 2021). Increased socio-economic activities have an impact on population mobility based on the pattern of origin and destination of travel (Graells-Garrido, E. *et al.* 2021; Heine, C. *et al.* 2021). The spatial dynamics of suburban areas which are dominantly developed for housing and settlement development are positively related to an increase in traffic volume on main roads, traffic congestion and disturbances to residents' travel patterns (Nair, DJ. *et al*. 2019; Nozdrovická, J. *et al.* 2020; Surya, B. *et al.* 2020a). Furthermore, the intensity of land use change and population mobility, in addition to having an impact on traffic congestion, also contributes to air quality pollution originating from motor vehicle exhaust emissions. Air pollution not only has an impact on climate change but also affects public health (Mani-

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salidis, I. *et al.* 2020). Increased levels of CO_2 in the air have an impact on public health and affect social stability and economic development (Wu, J. and Pu, Y. 2020; Fears, R. *et al.* 2021). Thus, the complexity of land use and population mobility besides affecting the transportation system also has an impact on environmental pollution (Nugmanova, A. *et al.* 2019; Surya, B. *et al.* 2021a). Development activities that tend to increase in suburban areas cause changes in land cover and a decrease in environmental quality (Hasan, S. *et al.* 2020; How Jin Aik, D. *et al.* 2021). Thus, the spatial designation developed in the outskirts of Makassar City has been identified as having exceeded the carrying capacity of the environment and threatens the sustainability of the ecosystem (Surya, B. *et al.* 2021b).

The distribution of the flow of goods and services coupled with the mobility of the population from the outskirts to the city centre has led to an increase in the flow of transportation movements on the main road corridors of the suburbs. Thus, the city government is faced with the challenge of handling and providing adequate public transportation facilities that are integrated with the land use system (Shen, L. *et al.* 2018; Surya, B. *et al.* 2020b). Furthermore, socio-economic activities that tend to increase have an impact on the complexity of land use and transportation systems in the suburbs of Makassar City. That is, the transportation system and land use are an integral part of the urban system in relation to population mobility (Clement, C. 2015; Rodrigue, P.J. 2020). This tendency is caused by the weak control over the use of space and inconsistency in the implementation of the spatial plan that has been determined (Sadli, M. 2008; Surya, B. *et al.* 2020c). Thus, the complexity of land use and allocation of utilization in suburban areas becomes very important and strategic to be immediately addressed in relation to the expansion of the Makassar City area towards suburban areas.

This study aims to answer research questions, namely: (1) How does land use change work as a determinant of environmental degradation in suburban areas? (2) How big is the influence of changes in land use, socio-economic activities, population mobility and transportation systems on environmental degradation? and (3) How is the model for handling land use, population mobility, transportation infrastructure, towards the management of the transportation system and the sustainability of the development of suburban areas? Thus, the contribution of this study is expected to be the basis and reference for the government in formulating development policies related to land use and transportation system management towards sustainable development of suburban areas for the case of metropolitan cities.

Theoretical background

The tendency of land use change is dominantly influenced by the demands of meeting the needs of urban development, namely housing and settlements, transportation infrastructure and other socio-economic activities. Built-up areas that are developed in suburban areas contribute to land cover and conversion of productive agricultural land (Lee, J. *et al.* 2020; Wang, F. *et al.* 2020). The intensity of land use change has an impact on population mobility towards generation and transportation pull based on the population's travel pattern from the area of origin to the area of destination (Chen, Y. *et al.* 2019; Chemura, A. *et al.* 2020). Thus, the mobility pattern of the urban population is very important to be formulated in the mechanism of transportation planning and urban traffic management (Guo, Y. *et al.* 2020). Land conversion is basically a form of human intervention in land use to meet the needs of its socio-economic activities (Hersperger, A.M. *et al.* 2018; Mandeli, K. 2019). Furthermore, the socio-economic dynamics of the community in relation to changes in land use have direct influence on urban aesthetics, land values and transportation systems towards decreasing environmental quality (Segura, E.A. *et al.* 2020; Tanaka, K. and Hashiguchi, Y. 2020).

Development activities that tend to increase in addition to contributing to land use change also have an impact on population mobility and affect the urban transportation system based on patterns of origin and destination. Increased socio-economic activity in suburban areas has an influence on the spatial social structure, road network system and distribution pattern of urban service functions (Hidayati, I. *et al.* 2019; Surya, B. *et al.* 2021c). Thus, an increase in population mobility followed by an increase in urban activity causes a decrease in the environmental quality of suburban areas (Carrasco, J.C. *et al.* 2021; Ribeiro, P. *et al.* 2021). Development investments carried out through the expansion of urban areas towards suburban areas have an impact on changes in land cover and interactive transportation systems towards the formation of the built environment (Huang, G. *et al.* 2020). Furthermore, the effects caused by the complexity of land use, namely the increase in traffic volume, environmental pollution and public health. These three things require handling and control measures towards the sustainability of suburban areas (Fernandes, P. *et al.* 2019).

Sustainable development is centred on intergenerational justice that rests on the pillars of three different but interconnected dimensions, namely the environment, economy and social (Mensah, J. and Casadevall, S.R. 2019). Cities face increasing environmental, social and economic challenges that threaten the resilience of urban areas (Bush, J. and Doyon, A. 2019). The increasing levels of human population in urban areas and the importance of urban functions pose a number of ecological challenges (Cepeliauskaite, G. and Stasiskiene, Z. 2020). The World Commission on Environment and Development (Brundtland, G.H. 1987) states that sustainable cities are built through caring and paying attention to natural environmental assets, paying attention to the use of resources and minimizing the impact of activities on nature. Sustainability in its broadest sense is the capacity of natural systems to endure and to remain diverse and productive over time (Almusaed, A. and Almssad, A.E. 2018). Furthermore, indicators that can be used to measure the sustainability of development are ecological, economic and social (Branch, M. 1995). Thus, sustainable development is a goal to be achieved towards a balance between economic, social and environmental in order to create a stable and quality society. Quality of life and sustainability i.e., the creation of jobs, reducing inequality, local investment, responsible social practices or environmental protection (Landin, S.A. 2020). The hypothesis built in this study, namely changes in land use, socio-economic activities, population mobility and transportation systems affect the environmental quality degradation of suburban areas.

Conceptual and methodological framework

Land use change is the use of land for the needs of urban activities on a land that is different from previous activities, both for commercial, industrial, and services as well as for housing and settlement development needs. Changes in land use are closely related to government policies in terms of expanding urban areas. Furthermore, population mobility is assessed based on three interests, namely physical, economic and socio-cultural. Population mobility is closely related to the pattern of origin and purpose of travel for work, trade and social purposes, its relevance to socio-economic activities developed at certain locations both in the city centre and in suburban areas. The transportation system is a link between passengers or goods, transportation infrastructure and facilities that interact in a series of passenger or goods movement. Meanwhile, the decline in environmental quality is understood in the context of the non-functioning of environmental components. Thus, the weak control of spatial use in the development of suburban areas coupled with the intensity of land use changes, increased socio-economic activities, population mobility and transportation systems will have an impact on environmental quality degradation.

This research was carried out in the suburbs of Makassar City. The choice of research location was based on the following considerations: (1) Makassar City is the main city in the Mamminasata Metropolitan urban system; (2) The expansion of Makassar City towards suburban areas has an impact on the urban spatial integration of the Mamminasata Metropolitan. This condition is indicated by the presence of the city's main road corridors, including: (i) the Perintis Kemerdekaan road corridor with a road length of 11.93 kilometres that functions to connect Makassar City with Maros Regency, (ii) the Hertasning-Samata road corridor with a road length of 8.76 kilometres serves to connect Makassar City with Gowa Regency, and (iii) the Metro Tanjung Bunga road corridor with a road length of 6.70 kilometres serves to connect Makassar City with Takalar Regency. Furthermore, the population of Makassar City in 2016 was 1,469,601 people, in 2019 there were 1,526,677 people, and in 2021 there were 1,545,455 people. The transfer of land use functions and the increase in socio-economic activities developed in suburban areas are marked by the presence of activities, including: (1) Housing and settlements occupying an area of 2,468.61 ha; (2) Commercial activities occupy an area of 433.88 ha; (3) Industry and warehousing occupy an area of 59.4 ha; and (4) Education and health occupy an area of 182.89 ha (BPS Makassar City, 2021). The suburbs of Makassar City which are the object of research are presented in *Figure 1*.

This study uses a qualitative-quantitative approach sequentially. The case studies in this study were selected with the following considerations: (1) The transportation system for the suburbs of Makassar City is specific; (2) The observed cases have a fairly prominent consistency in the dynamics of development in the suburbs of Makassar City. Thus, to obtain data in the field it is necessary to combine a qualitative-quantitative approach. Observations in this study were used to track data, namely (i) land use changes, (ii) socio-economic activities, and (iii) spatial use patterns in suburban areas. The instruments used in data collection were field notes, periodic notes, checklists and location base maps. This study also uses various documents related to the development of suburban areas of Makassar City. The documents referred to include: (1) Traffic volume data obtained through the Makassar City Transportation Service; (2) Data on land use change and Makassar suburban spatial plans were obtained through the Makassar City Regional Development Planning Agency; and (3) Data on socio-economic activities in suburban areas are obtained through the District Office. The survey in this study used a questionnaire instrument. Measurement of data using an ordinal scale based on the questions posed in the questionnaire. Thus, the questionnaire in this study was used to track data, namely (i) land value and price; (ii) socio-economic activities, (iii) population mobility, (iv) transportation system, and (v) environmental degradation in the suburbs of Makassar City. Respondents who filled out the questionnaire in this study, namely (i) economic actors, (ii) community who carry out mobility, and (iii) local government. Respondents in this study were determined using a purposive sampling technique which the researchers determined based on certain criteria. Determination of the research sample refers to Neyman, J. (1934).

The formulation used is as follows:

$$n_h = \frac{N_h}{N} n \quad (1)$$

where n_h is the sample size of each stratum, n must be allocated according to (proportionally). Sampling is simple random at each stratum, so that the probability $\frac{N_h}{N}$ of each sampling unit in the strata h to be selected as a subsample is $\frac{n_h}{N_h} = F$. Each unit in the population has an equal chance of being selected as the sample. The number of samples in this study was determined by as many as 300 respondents. The suburban transportation system data in this study uses the analysis method of traffic volume, road capacity, and degree of saturation.

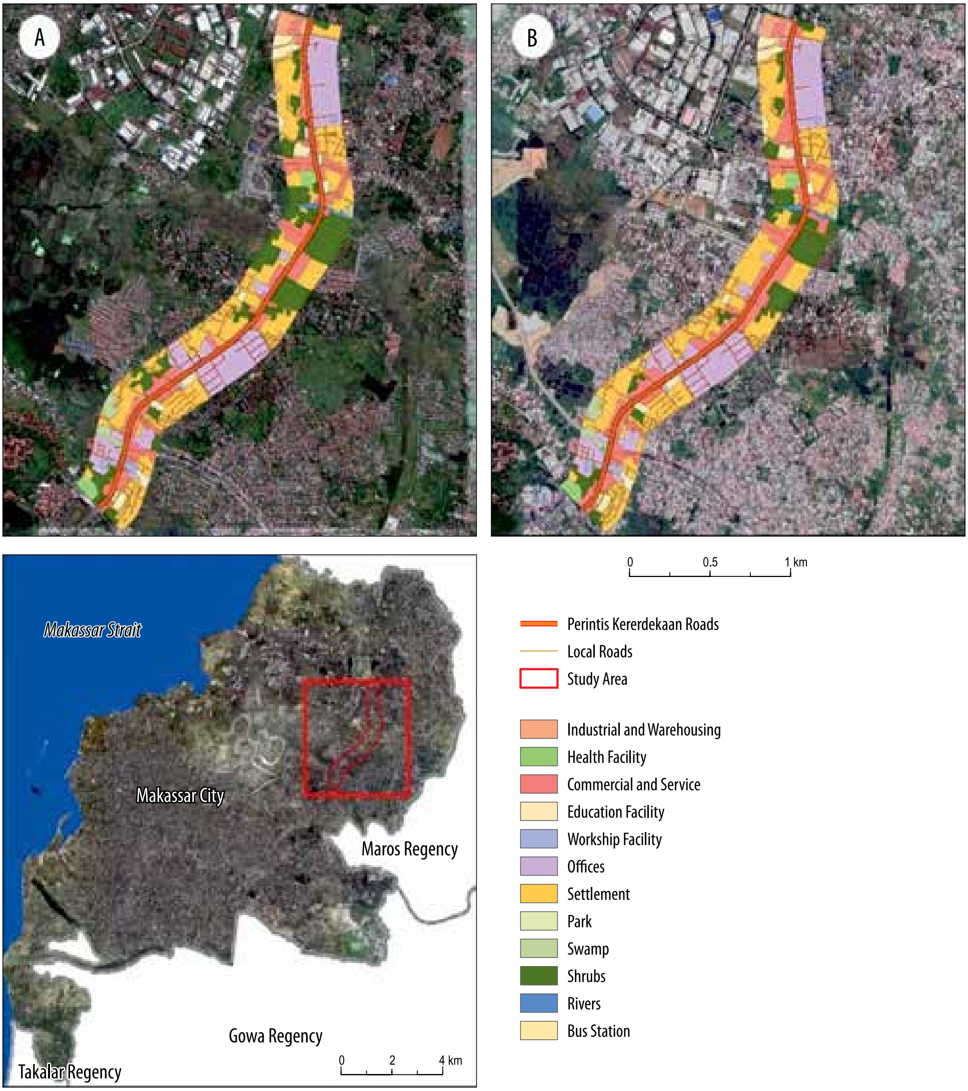

Fig. 1. Research location in the suburbs of Makassar City with land use in 2016 (A) and in 2019 (B). *Sources:* Google Earth Survey Arca Raster 2020, Geospatial Information Agency of Indonesia.

The formulation used is as follows:

$$q = \frac{n}{t}, \quad (2)$$

$$C = Co \cdot FC_W \cdot FC_{sp} \cdot FC_{cs}, \quad (3)$$

$$DS = \frac{Q}{C}, \quad (4)$$

where q is the volume of traffic passing through a certain point, n is the number of vehicles passing that point in the observation time interval, t is the observed time interval. C is the capacity (pcu/hour), Co is the basic capacity (pcu/hour), FC_w is the direction separation adjustment factor, FC_{sp} is the side drag adjustment factor, and FC_{cs} is the city size adjustment factor. DS is the degree of saturation, Q is traffic volume (pcu/hour), and C is capacity (pcu/hour). Multiple regression analysis method is used to analyse the causal relationship of several independent variables, namely land use change (X_1), socio-economic activities (X_2), population mobility (X_3), transportation system (X_4), to the dependent variable, namely the environmental quality degradation (Y).

The formulations used for multiple regression analysis and correlation analysis are as follows:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + \dots b_nX_n + \varepsilon, \quad (5)$$

$$r_{xy} = \frac{n\sum X_i y_i - \sum X_i \sum y_i}{\sqrt{n\sum X^2_i - (\sum X^2_i)^2}\sqrt{n\sum y^2_i - (\sum y_i)^2}} \quad (6)$$

where Y is the dependent variable, a is a constant, b_1, b_2, b_3, b_4 and b_n are the regression coefficients X_1, X_2, X_3, X_4 and X_n are independent variables, and ε is the residual value. Furthermore, n is a lot of data or samples, r_{xy} is the correlation coefficient between variable X and variable Y, $\sum X_i y_i$ is the number of the multiplication between variables X and Y, $\sum X^2_i$ is the sum of the squares of the X value, $\sum y^2_i$ is the sum of the squares of the Y value, $(\sum X_i)^2$ is the sum of the X values then squared, and $(\sum y_i)^2$ is the Y value then squared. Furthermore, implementation of Structural Equation Modelling (SEM) in this study refers to several exogenous variables, including: (1) The land use construct variable is measured by indicators, namely space utilization (X_1), built area (X_2) and spatial function (X_3). (2) The construct variable of population mobility is measured by indicators, namely the means of transportation used (X_4), availability of transportation modes (X_5), origin of travel (X_6) and destination of travel (X_7). (3) The construct variable of transportation infrastructure is measured by indicators, namely the road network system (X_8), road body capacity (X_9), road services (X_{10}), road conditions (X_{11}). Furthermore, the constructs of the endogenous latent variables include: (1) The latent variables of transportation management are measured by indicators, namely accessibility (y_1), generation and attraction of movement (y_2), distribution of movement (y_3), mode selection (y_4), distribution of movement (y_5) and behaviour road users (y_6); (2) The latent variables of suburban development sustainability are measured by indicators, namely environmental (y_7), economic (y_8), and social (y_9).

The SEM analysis method uses the following formulation:

$$\eta = \alpha + B\eta + \Gamma\xi + \zeta, \quad (7)$$

$$\eta - B\eta = \alpha + \Gamma\xi + \zeta, \quad (8)$$

$$(I - B)\eta = \alpha + \Gamma\xi + \zeta, \quad (9)$$

$$\eta = (I - B)^{-1}\alpha + \Gamma\xi + \zeta. \quad (10)$$

where α is the intercept vector, B and Γ is the coefficient matrix and $\zeta = \zeta_1 \cdot \zeta_2 \cdot \zeta_m$ is the error vector in the structural equation, element B presents variable influence η and variable η other, and elements Γ present a direct influence of variables ξ in variable η. It is assumed that ξ not correlated with ζ and $I - B$ is nonsingular. Furthermore, is the intercept vector m x 1, η is the endogenous latent variable m x 1, B is the coefficient matrix of the endogenous latent variable m x m, Γ is the coefficient matrix of the exogenous latent variable m x n, ξ is the exogenous latent variable vector n x 1, ζ structural model error vector relationship between η and ξ size m x 1. Random vector η and ξ not measured directly but through the indicator, namely the variable $Y^T = (y_1, y_2, \dots y_p)$ and $X^T = (X_1, X_2, \dots X_p)$.

Results and discussion

Changes in land use, population mobility and decline in environmental quality

The expansion of the Makassar City area has an impact on changes in land use, increased socio-economic activities and population mobility and transportation systems based on patterns of origin and destination of travel. Population growth and land requirements that tend to increase are positively associated with discrepancies between land use patterns and the designation plans stipulated in the city spatial plan (Khadiyanto, P. 2005;

Surya, B. *et al.* 2021a). Thus, changes in land use coupled with increased social activities are determinant factors that affect population mobility and the transportation system in the direction of decreasing the environmental quality of suburban areas. Changes in land use in the suburbs of Makassar City are presented in *Table 1* which shows changes in land use during the period 2010–2021.

Socio-economic activities that developed in the outskirts of Makassar City were marked by the presence of several activity functions, including: (1) Commercial activities increased by 5.15 percent; (2) Housing and settlement development increased by 1.10 percent; (3) Educational activities occupy an area of 7.65 ha or 3.73 percent; (4) Industrial and warehousing activities occupy an area of 3.06 ha or 1.49 percent. These four activities are the driving force for increasing population mobility and transportation systems in the suburbs of Makassar City. This means that the development of suburban areas will be faced with the challenge of providing land that is integrated with the urban transportation system (Surya, B. 2016; Shen, L. *et al.* 2018). Population mobility which tends to increase will require the support of providing adequate transportation facilities in relation to the mobility of goods and passengers from the suburbs to the city centre. The facts found in the field indicate that two factors that influence the increase in land prices are related to the complexity of land use and transportation systems in the suburbs of Makassar City, namely: (1) Related to the selling value of land in relation to the function of economic activities; (2) Use value land and spatial functions that develop have a direct influence on increasing population mobility. These two factors are positively associated with an increase in the value and price of land economically and affect the transportation system in the suburbs of Makassar City. Thus, distance, accessibility, transportation infrastructure, and economic activity affect the use value and price of land in suburban areas (Hudalah, D. and Firman, T. 2012). Thus, changes in land use and the function of economic activities contribute to changes in transportation characteristics and population mobility based on the pattern of origin and destination of travel and their effect on spatial dynamics and environmental degradation in the suburbs of Makassar City. The characteristics of transportation in relation to land use change are presented in *Figure 2*.

Changes in transportation characteristics in the suburbs of Makassar City (see *Figure 2*, A) are influenced by two main factors, namely economic activities and social activities related to land use. This means

Table 1. Utilization of space on the suburban of Makassar City

Type of activity	Space utilization			
	2010		2021	
	ha	%	ha	%
Settlement	71.39	34.77	73.65	35.87
Offices	42.36	20.63	42.64	20.77
Commercial and services	31.35	15.27	41.92	20.42
Education facility	7.65	3.73	7.65	3.73
Health facility	2.77	1.35	2.77	1.35
Industrial and warehouse	3.06	1.49	3.06	1.49
Bus station	2.27	1.11	2.27	1.11
Worship facility	2.12	1.03	2.12	1.03
Shrubs	36.99	18.01	24.03	11.70
Swamp	3.79	1.85	3.64	1.77
Park	0.37	0.18	0.37	0.18
Rivers	1.21	0.59	1.21	0.59

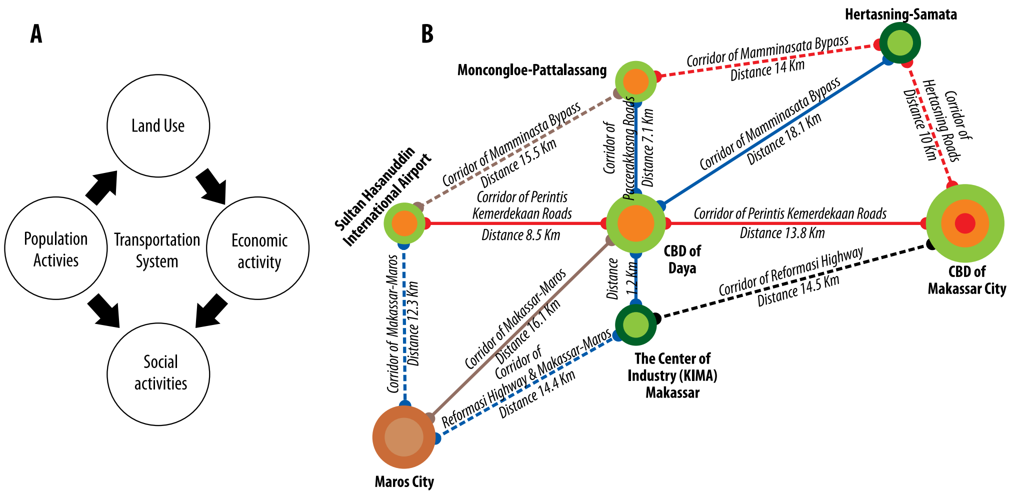

Fig. 2. Socio-economic activities and transportation system. A = Transportation systems and activity patterns; B = Pattern of origin and destination of travel. *Source*: Author's elaboration.

that changes in land use in the corridor are closely related to socio-economic activities developed by the community. Field facts found indicate that three factors are related to socio-economic activities in the suburbs, namely (i) economic productivity, (ii) consumption, and (ii) distribution. These three things are positively associated with the transportation system and environmental degradation. This means that changes in land use and the function of urban activities are closely related to the characteristics of transportation and population mobility based on the pattern of origin and destination of travel and their influence on the spatial dynamics of the suburbs of Makassar City. Four factors affect the urban transportation system in relation to road infrastructure, namely (i) basic capacity, (ii) effective lane width, (iii) distribution direction, and (iv) side barriers. The interpretations proposed (see *Figure* 2, B) are: (1) Population mobility from residential locations to commercial, industrial, educational, workplace and health services; (2) People's travel orientation to the city centre is dominant using private vehicles. The increase in socio-economic activity has an impact on the generation and attraction of transportation. Field facts found indicate that population mobility coupled with land use complexity is positively associated with environmental degradation in the suburbs of Makassar City. The road capacity and degree of saturation on the main road corridor in the suburbs of Makassar City are presented in *Figure 3*.

It shows the relationship between traffic volume, road capacity and degree of saturation in the suburbs of Makassar City. Interpretations can be proposed regarding these conditions, including: (1) The degree of road saturation at the location of the business centre and power plant is 0.450 with a daily traffic volume of 94,220 pcu/hour; (2) The degree of road saturation at the location of the PLTU and Sermani industry is 0.339 with a daily traffic volume of 71,064 pcu/hour; (3) The degree of road saturation at the Makassar Industrial Estate location is 0.266 with a daily traffic volume of 55,766 pcu/hour; (4) The degree of road saturation at the Hasanuddin International Airport is 0.291 with a daily traffic volume of 60,826 pcu/hour. These results confirm differences in daily traffic volume and road network saturation levels. This means that the scale of urban activ-

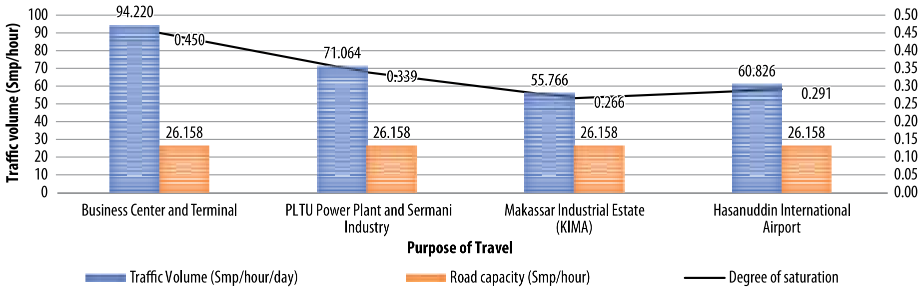

Fig. 3. Traffic volume, road capacity and degree of saturation of main road corridors in suburbs of Makassar City. *Source:* Primary data.

ity affects the traffic volume and the level of saturation of urban roads in the suburbs of Makassar City. Socio-economic activities will affect the availability of urban transportation (Nadi, P.A. and Murad, A.K. 2019; Surya, B. *et al.* 2021b). Air and noise pollution are externality factors generated by road transport and affect environmental quality (Zefreh, M.M. and Torok, A. 2021). The impact of development on environmental quality degradation in the suburbs of Makassar City is presented in *Figure 4* demonstrating the decline in environmental quality in the suburbs of Makassar City.

The interpretations that can be put forward for these results include: (1) The dominant urban activities that contribute to the decline in environmental quality, namely the volume of waste generated by informal economic activities with a value of 9.72 percent; (2) 9.53 percent of the volume of waste generated by formal economic activities; (3) 9.25 percent of waste is generated by informal economy activities and traditional markets; and (4) 9.16 percent generated by industrial waste. These results confirm that the complexity of land use and transportation systems contributes positively to environmental pollution. The transportation system on the outskirts of Makassar City, shows that the complexity of land use has an impact on increasing daily traffic volume, travel distances and inefficient transportation costs. The use of public transportation facilities and private vehicles is an intermediary variable that shows the relationship between land use, travel destination, travel time, and distance based on the mode of transportation used by residents in mobility (Silva, J.A. 2018). The increase in traffic volume and the complexity of land use has an impact on three important things that interact with each other, namely activities, transportation networks and flows. This condition has an impact on increasing air pollution due to vehicle exhaust gases and decreasing environmental quality. In general, air pollution refers to the release of pollutants into the air that are harmful to the environment and health (Zulauf, N. *et al.* 2019). The travel pattern and traffic volume on the main road sections in the suburbs of Makassar City are presented in *Figure 5*.

This figure shows the difference in vehicle volume at the observation location based on the type of activity that develops on the suburban of Makassar City. The proposed interpretations regarding the traffic volume are: (1) The highest traffic volume occurs at 7.00–8.00 (first peak hour), as many as 15,479 at the business centre and Daya terminal, 12,568 at the PLTU and Sermani industrial power plant locations 11,124 in the Makassar industrial area and 10,479 at the location of Hasanuddin International Airport; (2) The traffic volume at the second peak occurs at 16.00–17.00. In this condition, even though there is a reduction in volume, it will not significantly affect traffic jams on the suburban area; (3) The orientation and destination of

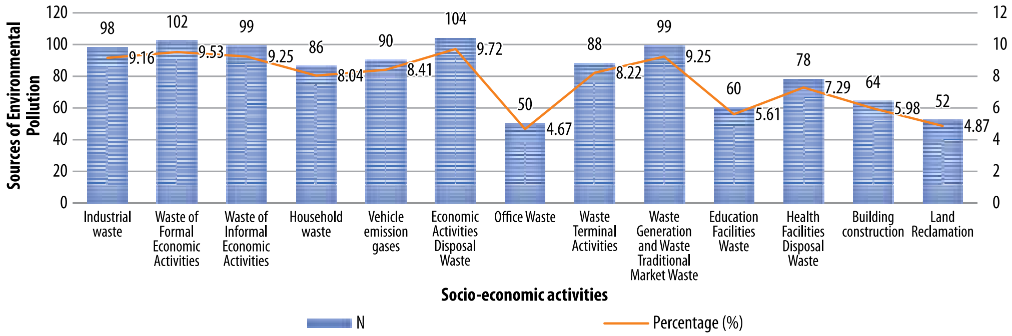

Fig. 4. Decline in the environmental quality of the suburbs of Makassar City. *Source*: Primary data.

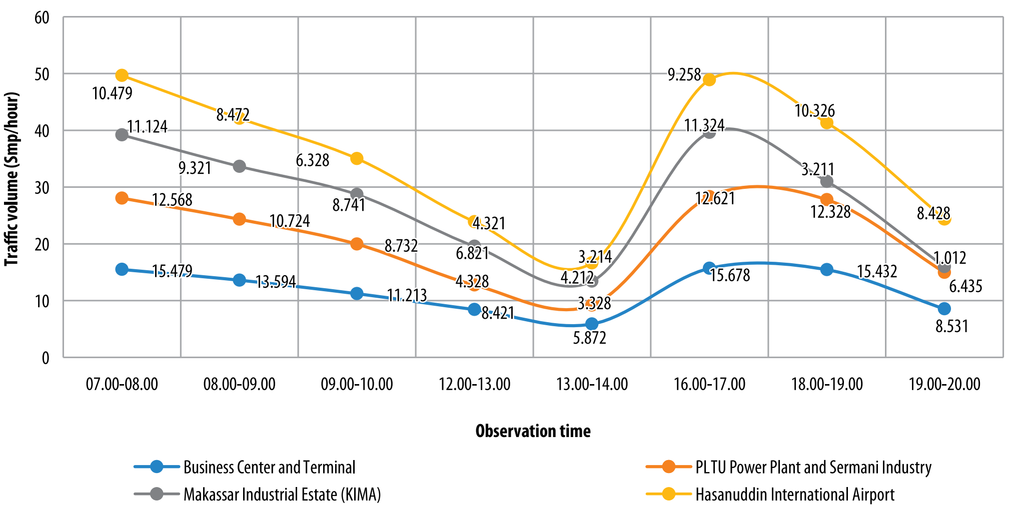

Fig. 5. Traffic volume on the main road corridor in the suburbs of Makassar City. *Source:* Primary data.

transportation movements in the morning are dominated by three main activities, namely offices, education, trade and business centres. Conversely, in the afternoon it is dominated by movement to the area of origin. Increasing traffic is an inherent symptom of vigorous urban development and its prosperity but is concurrently one of the main factors that contribute to the deterioration of the urban environment and the endangerment of the sustainability of urban development (Surya, B. *et al.* 2021c). The mobility of the population from the suburbs to the city centre in relation to the availability of facilities and infrastructure is presented in *Figure 6* showing the mobility of the population in relation to transportation facilities and infrastructure.

Interpretations that can be proposed for these results include: (1) Population mobility in relation to road infrastructure provides an illustration that 60.67 percent is categorized as supportive, 20.67 percent is categorized as

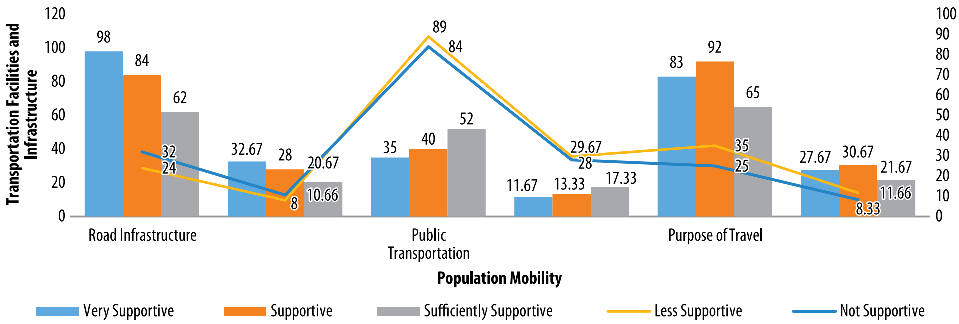

Fig. 6. Population mobility of transportation facilities and infrastructure. *Source*: Primary data.

sufficiently supportive, and 18.66 percent is categorized as not supportive. (2) Population mobility in relation to the availability of public transportation gives an illustration of 25 percent in the supportive category, 17.33 percent in the sufficiently supportive category, and 57.67 percent in the not supportive category. (3) Population mobility in relation to the purpose of the trip gives an overview of 58.34 percent in the supportive category, 21.67 percent in the sufficiently supportive category, and 19.99 percent in the not supportive category. This figure confirms that the mobility of the population from suburban areas to the city centre and vice versa, people tend to use private transportation facilities due to the limitations of public transportation in relation to factors of comfort, security and timeliness to get to their destination. Thus, the function of urban activities and the limitations of public transportation modes lead to dependence on private vehicles in relation to the mobility of residents in suburban areas (Bueno-Suárez, C. and Coq-Huelva, D. 2020).

The facts found in the field illustrate that the increase in socio-economic activities that develop in the suburbs of Makassar City positively associated with land use complexity and transportation system disturbances leading to environmental degradation. The pattern of origin and destination of travel in relation to socio-economic activities in the suburbs of Makassar City is presented in *Figure 7* demonstrating the pattern of origin and destination of travel from the suburbs to the centre of Makassar City.

Interpretations that can be put forward in relation to these results include: (1) Transportation movements related to travel times provide an overview of 21.33 percent with the supportive category, 18.67 percent with the sufficiently supportive category, and 60 percent with the not supporting category. (2) The transportation movement system in relation to movement barriers gives an overview of 25 percent in the supportive category, 22.67 percent in the sufficiently supportive category, and 52.33 percent in the not supportive category. (3) The transportation movement system in relation to the cost of travel obtained an overview of 20.66 percent with the supportive category, 20.67 percent with the sufficiently supportive category, and 58.67 percent with the not supportive category. These results confirm that the travel pattern of the population based on the pattern of origin and destination of movement from the outskirts to the city centre is not effective and efficient in terms of travel time, movement barriers, availability of transportation modes and transportation costs. Thus, travel time, availability of transportation modes and relatively high transportation costs are positively related to the travel pattern of residents from suburban areas to socio-economic activity centres being inefficient and having an impact on increasing air pollution leading to a decrease in environmental quality. The effect of changes in

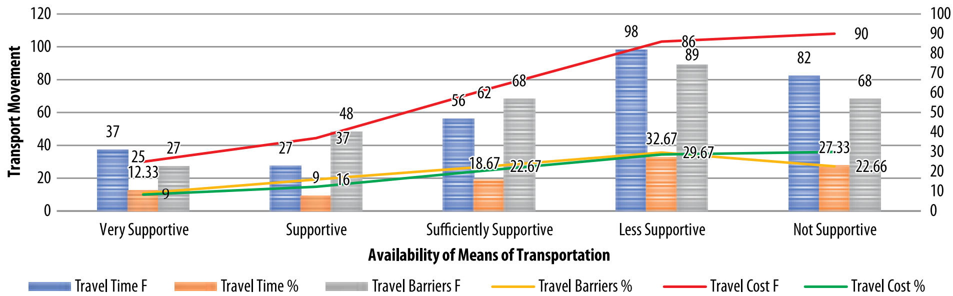

Fig. 7. The pattern of origin and destination of travel from the suburbs to the centre of Makassar City. *Source*: Primary data.

land use, socio-economic activities, population mobility, and transportation system on environmental quality degradation in the suburbs of Makassar City is presented in *Table 2*.

The results of *Table 2* that can be explained include: (1) Changes in land use have a positive effect on the environmental quality degradation; (2) Socio-economic activities have a positive effect on the environmental quality degradation; (3) Population mobility has a positive effect on the environmental quality degradation; (4) The transportation system has a positive effect on the environmental quality degradation. Thus, changes in land use, socio-economic activities, population mobility, and transportation systems simultaneously explain 95.65 percent of the environmental quality degradation in the suburbs of Makassar City. The management model of the urban transportation system and the sustainability of the suburbs of Makassar City is presented in *Figure 8*.

This figure shows a model for estimating land use, population mobility and transportation infrastructure and sustainable development in the suburbs of Makassar City. Interpretations that can be put forward to the model include: First, the variable constructs of land use, population mobility, and transportation infrastructure have a positive effect on

Table 2. Summary of test results for the significance of multiple regression coefficients

Correlation			Coefficient β	Error S_{bi}	t-count	t-table
Land use change to environmental quality degradation (ryx_1)			0.193	0.068	2.972	1.95
Socio-economic activity to environmental quality degradation (ryx_2)			0.148	0.056	2.865	1.95
Population mobility to environmental quality degradation (ryx_3)			0.407	0.098	3.284	1.95
Transportation system to environmental quality degradation (ryx_4)			0.206	0.078	2.893	1.95
Source variant	Sum of squares, JK	Free degrees, db	Average of the sum of the squares, RJK		F-count	F-table $\alpha = 0.05$
Regression Residue	20,642 0,548	7 12	7.548 0.076		88.146	6.78
Total	20,642	19	–		–	–
R	R^2	db1	db2		F-count	F-table
0.978	0.9565	7	12		88.146	6.78

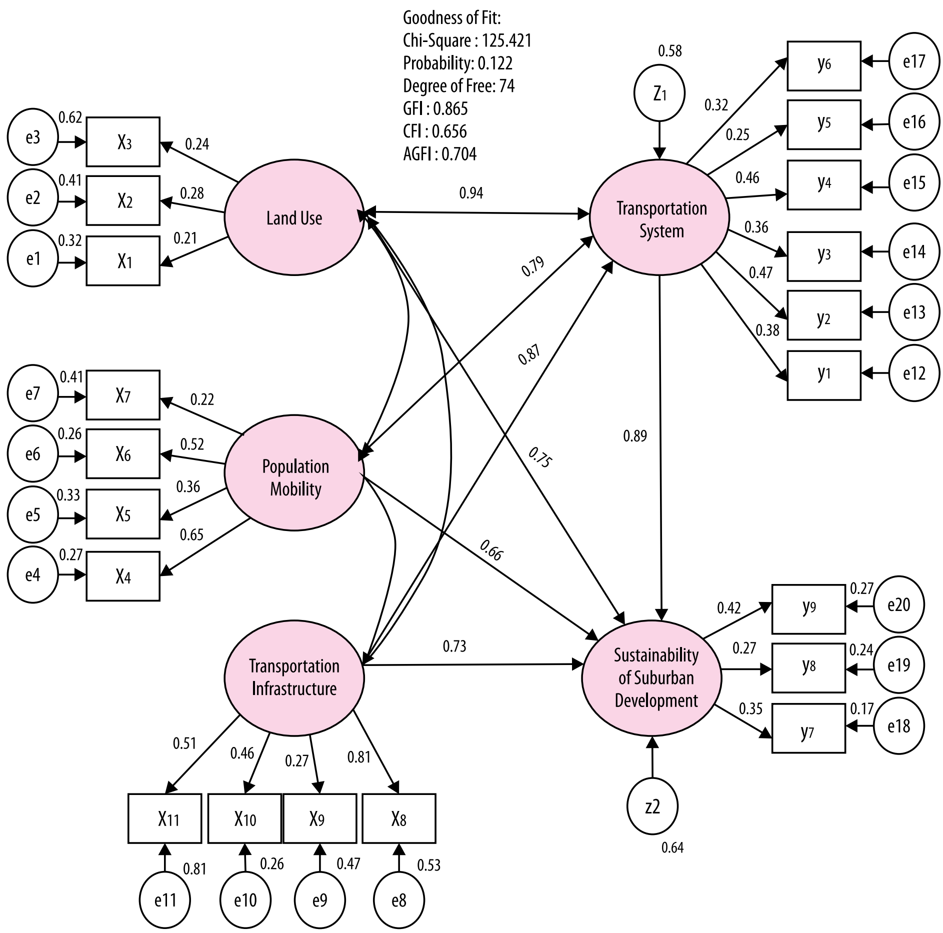

Fig. 8. Urban transportation system model and the sustainability of the suburbs of Makassar City

transportation management and sustainable development of suburban areas of Makassar City. The results of the chi-square test showed a value of 125.421 with a probability of $p = 0.122 > 0.05$, $df = 74$, $GFI = 0.865$, $CFI = 0.656$ and $AGFI = 0.704$. These results confirm that the built model is categorized as a fit model. Second, the total influence of land use on the endogenous variable of transportation management is 0.8836 or 88.36 percent, population mobility on the endogenous variable of transportation management is 0.6241 or 62.41 percent, and transportation infrastructure on the endogenous variable of transportation management is 0, 7569 or 75.69 percent. Third, the total influence of land use on the endogenous variables of suburban development sustainability is 0.5625 or 56.25 percent, population mobility on endogenous variables of suburban development sustainability is 0.4356 or 43.56 percent, transportation infrastructure to endogenous variables the sustainability of suburban area development is 0.5329 or 53.29 percent. The effect of the endogenous variable of transportation management on the endogenous variable of the sustainability of suburban development is 0.7921 or 79.21 percent. Thus, the implementation of the transportation management model will have an impact on the sustainability of the development of suburbs Makassar City.

Sustainability of the suburbs of Makassar City

The sustainability of the suburban area requires efforts to control the use of space and ensure the balance of the process or condition of a system, in relation to the built environment and biological resources as a single system. This means that the sustainability of the suburbs of Makassar City is part of the effort to ensure the sustainability of the ecosystem in order, to maintain function, productivity and ecological diversity. Five basic principles that can be implemented for the

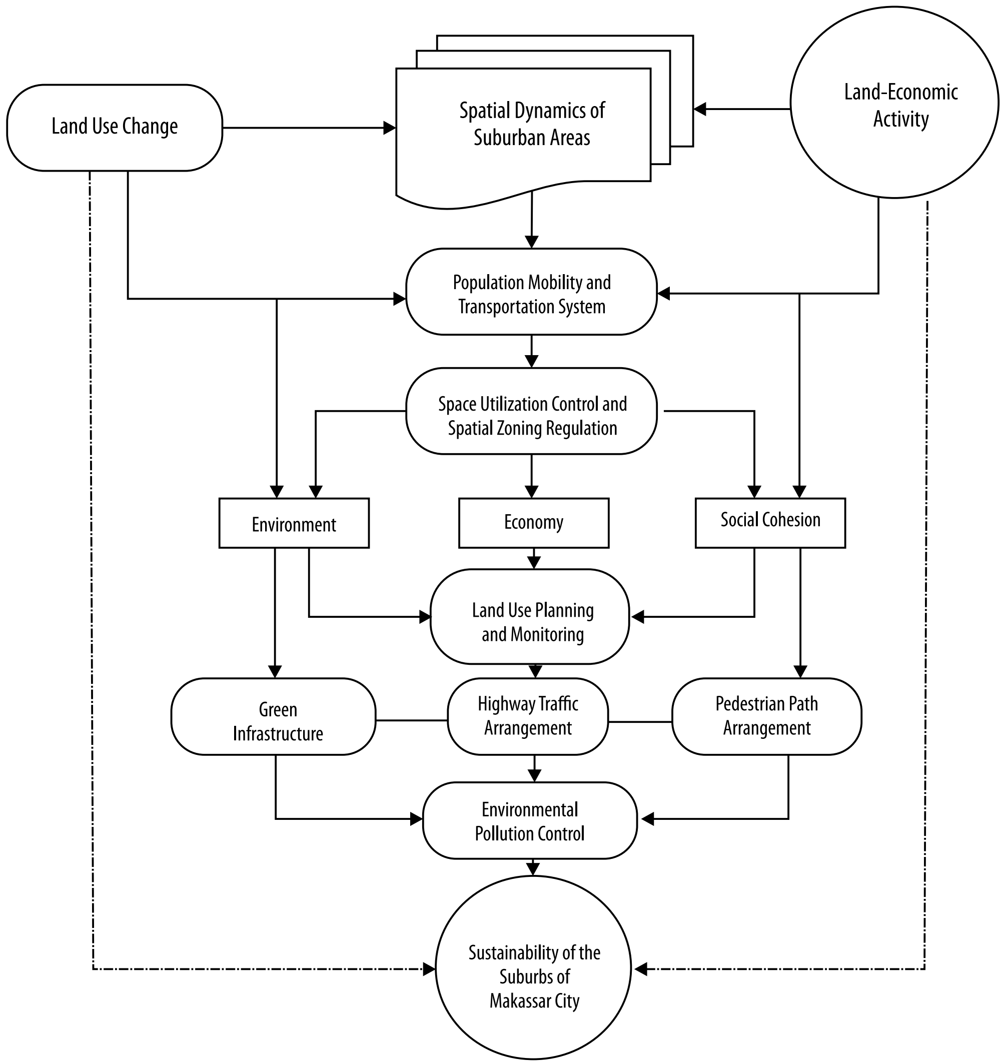

Fig. 9. Sustainability of the suburbs of Makassar City

development of suburban areas towards sustainable development, namely: (1) Capacity, refers to the carrying capacity of the environment as a medium for carrying out community socio-economic activities; (2) Resilience, in terms of interactions between humans and the environment; (3) Adaptive in responding to ecosystem changes; (4) Diversity, in this case integrating the socio-economic interests of the community which is accommodated in a space that does not exceed the carrying capacity of the environment and is integrated with a sustainable transportation movement system; (5) Balance, in this case refers to the balance of the natural environment in relation to the development carried out by the community and the government. This means that the government must take into, account the balance between the expenditure allocated for development activities and the accumulation of human and technological capital to ensure environmental balance towards improving the welfare of the population and the sustainability of the transportation system (Wu, F.C. *et al.* 2020; Surya, B. *et al.* 2020a). The sustainability of the suburbs of Makassar City is presented in *Figure 9*.

Conclusions

The expansion of the Makassar City area has an impact on changes in land use, increased socio-economic activities, population mobility and transportation systems. These three things cause a decrease in the environmental quality of suburban areas. Changes in transportation characteristics coupled with the intensity of land use changes have an impact on air, water and soil pollution. Furthermore, economic activity that tends to increase causes an increase in population mobility based on the pattern of origin and destination of travel and has an impact on increasing traffic volume, slowing vehicles, traffic congestion and high transportation costs. The decline in environmental quality is indicated by the increased potential for environmental pollution due to the intensity of development allocated to suburban areas. Thus, it is necessary to control the use of space, structuring land use and managing the transportation system towards the sustainable development of the suburban area of Makassar City.

The development of the suburbs of Makassar City is oriented to create a balance in the use of natural resources to support sustainable development which is carried out through three main principles, namely (i) future-oriented equality between generations, (ii) the principle of social justice, in terms of fulfilling access and distribution. socio-economic activities towards improving environmental quality, and (iii) responsibility in terms of minimizing environmental impacts and compensating efforts. The implementation of these three principles is realized through controlling the use of space, structuring land use and improving the quality of the environment towards the integration of urban systems.

This study was conducted in a limited scope and only focused on changes in land use, socio-economic activities, population mobility and transportation systems to environmental damage. To complete the results of this study, further research is needed with two main topics, namely: (1) Model of the sustainability of the urban transportation system in suburban areas based on community participation; and (2) Utilization of suburban area space based on the integration of the metropolitan urban system.

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Transformations of place, memory and identity through urban place names in Banská Bystrica, Slovakia

Alexandra BITUŠÍKOVÁ[1]

Abstract

The paper looks at the renaming of streets as a significant aspect of post-socialist change using an example of the city of Banská Bystrica, Slovakia. It discusses politics, processes and practices of (de-re)commemoration in street names, which reflect transformations of memory (remembering and forgetting), identity, heritage, power and resilience related to public space in a post-socialist city. Changing street names creates new connections between the past and the present and reflects political power struggles for control over contested space between various groups that tend to privatise their own history, heritage, memory, identity, places and symbols. The case of Banská Bystrica demonstrates strategies of the street renaming based on the decommunisation of names (done by restoration of the names from older periods or by introducing non-commemorative names), and on commemoration of names based primarily on local (or regional/national) heritage, events and personalities that might become areas of contested heritage.

Keywords: street renaming, urban space, memory, identity, heritage, Banská Bystrica, Slovakia

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Introduction

The objective of this article is to look at politics, processes and practices of the renaming of public spaces, particularly streets and squares in the city of Banská Bystrica in Slovakia in the post-socialist period. In the scholarly literature the most often used term is „street renaming", although it covers also renaming of other public spaces of the city including squares and neighbourhoods or even institutions. In the paper I use the overarching term „street renaming". Based on critical research on practices of street naming and renaming developed and summarised mainly (but not only) by Rose-Redwood, R., Alderman, D. and Azaryahu, M., it focuses on relationships between heritage, memory, identity, location and power (Rose-Redwood, R. *et al.* 2018a, b). Post-socialist transformation started numerous processes of diversification of Slovak society, accompanied also by diversification of memories, identities and symbols. The study deals with challenges of the street-renaming, related to remembering and forgetting in the post-1989 period. As Rose-Redwood, R. *et al.* (2018a, 2) emphasise, the renaming of public spaces plays an important role in the remaking of urban commemorative landscapes. Indeed, various political regimes have been using street renaming as a strategy to show authority, ideological hegemony and symbolic power.

Street names primarily serve the purpose of orientation within the city, but they also have a broader significance. The names which commemorate key events or personalities from local, regional or national history or heritage are a manifestation of political order. They can also become expressions of local or national identity with a powerful symbolic importance (Azaryahu, M. 1997;

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Light, D. 2004). Street renaming is usually connected with a political regime change or other historic milestones. It has an impact on further symbolic transformation of urban space and on the (re)construction of urban memory. Along with monuments, street names (particularly commemorative names, based on local or national history and heritage) 'celebrate that which the governing authorities deem worthy of public remembrance' (Rose-Redwood, R. *et al.* 2018b, 8).

Research objectives and methods

This article discusses politics, processes and practices of (de-re)commemoration in the city of Banská Bystrica in Slovakia on the example of the street renaming, which reflects transformations of memory (remembering and forgetting), identity, location, heritage, symbols, power and resilience related to public space in a post-socialist city. It focuses on the period of the first decade of the post-socialist urban transformation after the political change in 1989, however, it also builds on previous periods as they are crucial for understanding historic discontinuities and disruptions in Central Europe. It also briefly reflects on street-naming in the city in the 21st century.

The main research questions are: What have been the concepts used in the strategy of the street renaming in the early 1990s? Which concepts have been prevailing? How did the process of the renaming take place within the municipality and the City Council? What was the role of the street-renaming advisory body in the process? How did the power relations impact the street-renaming? How did the public participate in the process? Are there any consequences of the selected concept(s) in the street naming in the 21st century?

The paper is based on the results of qualitative ethnographic research carried out mainly in the period of 1990–1995 (participant observation and engaged research, 25 semi-formal/informal interviews with local inhabitants, experts – historians, geographers, architects, linguists and ethnologists, and the city representatives), and the textual analysis of regional newspapers, scientific journals and archives documents. Meeting minutes from the advisory body (The Street-Naming Committee) and from the City Council in the 1990s (archived at the Registry Office of the Banská Bystrica Municipality), as well as regularly published articles of the Chair of the Street-Naming Committee in local and national newspapers (such as *Priekopník*, *Ľudové noviny* and *Národná obroda*) addressing the public in order to encourage their participation in the process, were the main source of the data. My personal ethnographic diary as of a member of the Street-Naming Committee also contributed to the collection and analysis of research data. The nomination to be a member of the committee by the Mayor in the early 1990s led to numerous interactions with various stakeholders, particularly local citizens, municipality representatives and local interest groups. It also helped me to witness the dynamics of power relations in the new democratic state.

In addition, a methodology of spatial ethography was partly used that allowed understaning of people and place relationships (based mainly on participant observation, interviews and analysis of textual documents – Sen, A. and Silverman, L. 2014).

Place, memory and post-socialist change: A theoretical framework

Maurice Halbwachs was one of the first scholars who stressed that the past was reflected and preserved in the built environment – a repository of conscious and unconscious collective memories (Halbwachs, M. 1992). Since Halbwachs, memory and its relation to place and identity has been attracting the attention of numerous scholars from different disciplines. Changing street names creates new links and connections between the past and the present and reflects political power struggles for control over contested space between various opposing groups that tend to 'privatise' their own history, heritage, memory, identity, places and symbols. Both individual and collective memories of the city and its public spaces have a significant influence on the identification of urban inhabitants with their city and their sense of belonging.

Memory has become a popular keyword and topic not only in scholarly literature, but also in the marketing and branding strategies of cities all over the world. It is a consequence of what some authors call a general 'obsession with memory', a 'commemorative fever'or a 'remembrance epidemic' (Hewison, R. 1987; Macdonald, S. 2013). However, memory, especially collective memory is an important bond and a tool for socialisation and communication. It is the individuals as members of various groups who create, share and put forward collective memory through their individual personal memories. Collective memory is always localised and socially constructed within a particular political-economic context and it requires the support of a group in time and space (Halbwachs, M. 1992).

According to Boyer, it is mainly physical artefacts, urban spaces, streets, monuments and architectural forms in which our memory is buried (Boyer, C.M. 1994). Nora who introduced the term *lieux de mémoire* (sites of memory) also stressed that memory is spatially constructed and it is attached to both tangible sites (streets, squares, buildings etc.) and intangible sites (rituals or celebrations) related to the past (Nora, P. 1989). The city is often defined as a physical space, made of squares, streets, parks, neighbourhoods, buildings, monuments, symbols and names of objects and spaces. However, the development of the city is not only in the hands of architects and urban planners, but especially of the people who use it: 'People make places, more than places make people' (Worpole, K. and Knox, K. 2007, 2). The memory of each city resident reflects memories of different physical spaces in different periods. Previous generations´ memories play an important role in the reinterpretation and redefinition of public spaces, reflected in their names. As Alderman notes, (particularly) commemorative street naming and renaming is a vehicle for bringing the past to the present (Alderman, D.H. 2003, 163).

Commemorative names of public spaces (streets and squares) in Central Europe do not have a long history and started to be introduced only at the end of the 18th century replacing descriptive names (mainly names inspired by the geographical place or direction such as Main Square, Lower or Upper Street etc.). A new way of street naming at the end of the 18th century followed a commemorative motivation to name public spaces after persons, events or ideas – usually those who were acceptable and supported by a leading political power (David, J. 2013, 2). Commemorative names reflect important moments of history, local and national heritage (cultural and natural) or important personalities that played a role in local, national or international contexts, however, they are often built on contested narratives and memories. According to Yeoh, street renaming can be seen as 'an uneven, negotiated process of constant mediations, in which people questioned, challenged, or came up with alternative readings of both the forms and meanings of street-names' (Yeoh, B.S.A. 1996). Azaryahu stresses that commemorative street names are a common feature of modern political culture. Together with commemorative monuments and heritage museums, they 'not only evince a particular version of history but are also participants in the ongoing cultural production of a shared past... Potentially contested and eventually challenged, commemorative street names concretize hegemonic structures of power and authority' (Azaryahu, M. 1996, 312).

Dramatic change of physical structures, forms or functions of public spaces can lead to discontinuity and loss of memory, or to what Simmel refers as selective amnesia, which means selective and conscious forgetting in order to cope and survive the overwhelming memories of the past (Simmel, G. 1950). This has been a common case in most post-socialist societies. In this context, van Vree uses the term 'absent memory', described as memories absent from public discourse at a specific moment in time and to emerge at another. He talks about 'social forgetting' (often based on shame, guilt or embarrassment) that can be understood as 'a deliberate or non-deliberate exclusion or dilution of memories through framing, or, even, because of the very lack of proper frames' (Van Vree, F. 2013, 7).

In order to survive, people living in former socialist countries of Central and Eastern Europe had to learn to adopt such strategies of social forgetting by living double identities (public and private), suppressing publically enforced memories of historical events and figures and creating countermemories and counternarratives. In the context of the topic of the paper, the best example of these strategies was using the pre-socialist urban street names in everyday common language instead of using "new" street names introduced by the new communist municipalities.

According to Meusburger, 'the fact that the overwhelming majority of the population in socialist countries had such divided identities and countermemories was one of the main reasons why Central and Eastern European communist systems, despite their military power and seemingly almighty secret services, collapsed within weeks after the development of mass public opposition in 1989' (Meusburger, P. 2011, 58).

A serious discontinuity of collective memory usually happens in the periods of crucial historic changes or natural disasters that can in a short time dramatically change the physical and social environment of the city. The post-socialist (post-1989) governing authorities faced a challenge to (re)build new urban identity upon the heritage of these historic discontinuities. They had to decide what the future vision and identity of the city should be based on. The construction of new identities was first built on the rejection of the socialist past (Light, D. 2004).

Glorious medieval history was seen as the least problematic and most attractive to be marketed by local authorities in the 1990s and the majority of activities that aimed at the revitalisation of urban identities as well as at new marketing of the city have been based on the return to medieval (so called 'golden') history and heritage. It was clear that the socialist period did not fit into the 'nice' historic image of the city. This observation goes in line with the results of Young's and Kaczmarek's research in Polish cities. They observed the return to a medieval 'Golden Age' in many cities in Poland and across Central Eastern Europe. Cities with such history can more easily 'leave out or obscure their socialist pasts, or only refer to a history of resistance to socialism' (Young, C. and Kaczmarek, S. 2008, 56). Similar though not exactly the same development could be seen in the Romanian city of Oradea (in Hungarian: Nagyvárad) – the city with a significant proportion of Hungarian population – where after the collapse of communism many streets received either new or interwar period names, mainly ethnically neutral (Erőss, Á. and Tátrai, P. 2010, 57). The post-socialist urban developments have demonstrated trends towards revitalisation and strengthening of urban identities through the practices initiated mainly by local governments and increasingly also by local inhabitants and activists.

The focus and the locus of research: Banská Bystrica

Banská Bystrica is a medium-size city situated in a mountainous area of Central Slovakia. With almost 80,000 inhabitants, it is the sixth largest city in the country and the administrative centre of Banská Bystrica Region *(Figure 1).*

First urban development strategies in post-1989 Banská Bystrica were built mainly upon the return to history, cultural heritage and commemoration. They included the renaming of streets and squares, reconstruction of the historic city centre, organisation of urban festivals and parades based on historical events, (re)introduction of new symbols and the (de-re)erection of new monuments.

Fig. 1. Geographical position of Banská Bystrica inside Slovakia

All these activities created space for the (re) construction of new collective memory and local identity. Following de la Pradelle we can ask to what extent these activities really addressed local inhabitants´ needs and made them feel proud and identified with their city (de la Pradelle, M. 1996), and/or to what extent they were just a tool for the manipulation of collective memory, celebrating the 'right' heritage and the 'right' moments of history and consciously forgetting less glorious chapters of the city´s history. As Williams stated: 'Such is the desire for communality that only "correct" memories will be tolerated, usually resulting in real history being forgotten. Removed from any political context, the result of urban memory practices is often simply the celebration of attachment to place for its own sake' (Williams, A. 2005). Williams continues that this kind of selection of historical memories could lead to a false urban memory syndrome. He provocatively adds that we can see a demand for collective memory at a time when collective reality has disappeared. Each urban government tries to revitalise urban memories and identities through the engagement of the inhabitants in various activities, but in fact 'we never really see a campaign of local residents spontaneously demanding that their urban memory be protected' (Williams, A. 2005, 3).

Banská Bystrica was founded in 1255 when it became the free royal city (called *Nova villa Bystrice*) by being granted royal municipal and mining privileges by the Hungarian king Béla IV. In 1263, the first magyarised version of the name *Byzterchebana*, later *Beszterczebánya* appeared, at the same time the German settlers (mainly those in mining business) used the name *Neusohl* (Jurkovič, E. 2005, 16). Rich silver and copper deposits and extensive mining sustained the dynamic development of the city in the Middle Ages. In the 14th and 15th centuries, the city was called 'the Copper Banská Bystrica' and flourished as a significant European mining centre with a strong German influence. The medieval city, like many other European cities, developed its economic strength from trade and commerce, based on its multicultural characteristics. The Thurzo-Fugger Company, established in 1495 in Banská Bystrica, has been considered one of the first modern capitalist enterprises in the world, having a monopoly on the trade of copper in Europe and worldwide. The 'Golden Age' of the mining city of Banská Bystrica lasted until the 17th century (Jurkovič, E. 2005).

During its rich mining history, the city – similarly to many other cities in the multi-ethnic Kingdom of Hungary – was characterised by multiethnicity and multiculturality, based on cultures of a number of ethnic and religious groups living in the city (the Germans, the Slovaks, the Hungarians, the Jews, the Roman Catholics, the Protestants, the Greek Catholics etc.). All these ethnic and religious groups left traces in the historical tapestry and memory of the city, however, they have not always been reflected in local toponymy/ urbanonymy. After the decline of mining activities, Banská Bystrica became a centre of crafts, commerce and services. The city witnessed its most turbulent history in the 20th century. Similar to other cities in Central Europe (formerly part of the Kingdom of Hungary and from 1867 the Austro-Hungarian Empire), the city´s population experienced seven major political regimes and states in the 20th century itself, which had a significant impact on people´s memories and identities, on their remembering and forgetting (Bitusikova, A. 2018).

Banská Bystrica has been constructing its new post-socialist image particularly on two selected chapters of its history – on the medieval mining history ('the Copper Bystrica') when the city was one of the biggest world producers and exporters of copper, and on the modern history of the Slovak National Uprising, the biggest anti-Nazi movement in Central Europe during the Second World War in which the city played a crucial role as the centre of the uprising ('the Insurgent Bystrica'). Representatives of 30 countries joined the uprising based mainly on partisian operations in the mountains. Although the uprising was defeated by the Germans, it has remained a symbol of moral victory of the Slovaks who at the time were living in the collaborationist Nazi „puppet state" (Syrný, M. *et al.* 2014). The municipality has been introducing the topic of these two historical periods in most cultural events and festivities organised in the city (City Days; The Radvaň Fair; Cultural Summer; and the Slovak National Uprising commemoration). This approach has been reflected also in the renaming of public places.

Politics, processes and practices of street renaming in Banská Bystrica

The street renaming was one of the very first activities of the new municipality after the political change in Slovakia (then part of Czechoslovakia) in the late November 1989. The original historic street naming or toponymy used to serve primarily the purpose of geographical orientation reflected in names such as Central Square, Lower Street, Upper Street, Capitol Church Street etc. These names were used for several centuries since the foundation of the city (1255) until the end of the 19th century. The development in the late 19th century demonstrated the change towards the importance of commemoration naming based on key personalities and events of the city´s or country's history and heritage. According to Azaryahu, it was a measure of historic revision during periods of political change (Azaryahu, M. 2011, 29). In the post-1948 socialist period, a new wave of street renaming started when majority of streets and squares in Czechoslovakia were renamed using commerative names of the Soviet Union personalities: political figures, Red Army heroes, artists, writers, poets (e.g. Stalin's or Lenin's streets) as well as Russian geographical names, such as Moscow street, Russian street etc.

A number of scholars have written about toponymical cleansing and place renaming in post-socialist contexts (e.g. Azaryahu, M. 1996, 1997; Czapliczka, J. *et al.* 2003; Light, D. 2004; Gill, G. 2005; Kaltenberg-Kwiatkowska, E. 2008; Palonen, E. 2008; Bucher, S. *et al.* 2013; Light, D. and Young, C. 2015a, b, 2018; Basik, S. and Rahautsou, D. 2019), however, most of the studies focused on country capitals (e.g. Budapest, Bucharest, Moscow, Warsaw, East Berlin, Minsk or Bratislava). Research of medium or small size cities in the region of Central and Eastern Europe has been rather rare though it has been slowly increasing (e.g. Erőss, Á. and Tátrai, P. 2010; Stiperski, Z. *et al.* 2011; Cretan, R. and Matthews, P.W. 2016; Mácha, P. *et al.* 2018; Palmberger, M. 2018; Chloupek, B.R. 2019; Rusu, M. 2020). Azaryahu was one of the first scholars who proposed that it was important to broaden the study area to include smaller, provincial cities, too (Azaryahu, M. 2011).

The study of the city of Banská Bystrica aims to fill the gap in such research orientation and on the basis of ethnographic methods to demonstrate specific local approaches to street renaming in a peripheral medium-size Slovak city.

In the city of Banská Bystrica, the most significant processes of street renaming since its foundation in the 13th century were connected with the following periods:

1. The end of the 19th and beginning of the 20th centuries (strengthening of Hungarian power and control over minorities in the Austro-Hungarian Monarchy);

2. Post-1918 (the collapse of the Austro-Hungarian Monarchy and the establishment of the Czechoslovak Republic);

3. Post-1948 (the communist coup and the foundation of the Czechoslovak Socialist Republic);

4. Post-1989 (the collapse of communism and the establishment of the democratic Czecho-Slovak Republic and in 1993 the formation of the Slovak Republic after the dissolution of Czechoslovakia).

It is important to stress that the latest historical chapter – the foundation of the two separate states – the Slovak Republic and the Czech Republic in January 1993 did not lead to any significant changes in place-naming/renaming in Slovakia. This might demonstrate that the 'velvet' split of the two countries with a common history did not have a traumatic impact on collective identity and memory that would lead to symbolic changes of place names – which was not the case in previous historical periods.

When looking at street renaming from a chronological perspective, it is obvious that two periods in the Slovak history when commemorative names were mostly preferred were the periods from the end of the 19th century to 1918 and the period from 1948 to 1989 (the communist period). It seems that political authorities during the democratic periods of the first Czechoslovak Republic (1918–1938) and the post-1989 Czechoslovakia (and the Slovak Republic after 1993) preferred using non-commemorative place names in the processses of renaming, which I understand (based on my direct engagement in the Street-Naming Committee) as an approach or attempt towards a certain stability and resilience in the street-naming in the future.

The renaming of streets and squares in Banská Bystrica has been (throughout the history) most significant in the central historic district of the city, which has been the National Urban Heritage Site since 1955. This is in line with what Gnatiuk and Glybovets emphasise that commemorative names have been generally more common in central parts of a city than in the city´s peripheries, which means that different locations in the city show different symbolic significance and 'naming and renaming of urban space often implies categorization of streets according to the perceived ˝importance" of a person, geographic name, idea or event' (Gnatiuk, O. and Glybovets, V. 2020).

The Banská Bystrica historic city centre: from the Kingdom of Hungary to the end of the Czechoslovak Socialist Republic (1255–1989)

In the city of Banská Bystrica, the historic central square has always been considered the heart of the city and the source of pride for local people, and one of the most beautiful urban squares in Slovakia. The name of the square changed several times throughout history, reflecting political powers as well as the dominant language of the time. For more than 600 years, from the 13th to the 19th century, the square held the German name *Ring* (the Square, known in the local Slovak dialect as *Rínok*). This name was changed in the 1860s to a Hungarian version *Fő tér* (in Slovak

Hlavné námestie – Central Square) and in 1886 to a commemorative Hungarian name *Béla Király tér* (in Slovak *Námestie kráľa Bela IV*. – King Béla IV Square).

After the foundation of the Czechoslovak Republic in 1918, the square gained for the first time an official Slovak name *Hlavné námestie* (The Central Square), based on a local narrative using the simple name *Námestie* (The Square) when referring to the central square despite of its former commemorative names. At the end of the 1920s, with the development of the democratic Czechoslovak Republic led by the President Tomáš Garique Masaryk (who was half-Czech and half-Slovak by origin), the square was renamed *Masarykovo námestie* (The Masaryk Square).

After the establishment of the Slovak Republic (also known as the Slovak State) in 1939 which was a client state of Nazi Germany, the square was given a new name in the process of recommemoration: *Námestie Andreja Hlinku* (The Andrej Hlinka Square), named after the leader of the autonononomist Hlinka's Slovak People's Party from the 1920s to 1930s.

The end of the WW2 with the Red Army and the Romanian Army as liberators of Banská Bystrica on March 25, 1945, clearly marked the further symbolic developments of the central square (Bitušíková, A. 1998). Only a few days after the liberation, a black obelisk made of marble imported from the Soviet Union and dedicated to the WW2 liberators of the city, (however, dedicated only to the Soviet Red Army, and 'forgetting' the Romanian Army liberators) was forced on by the Soviet representatives and eventually built in the lower part of the central square (Bitušíková, A. 2018). The renaming of the main square was a further challenge *(Photo 1).*

The central square was first renamed in the period 1945–1948 as *Námestie Národného povstania* (The National Uprising Square), and after 1949 (up to the present) *Námestie Slovenského Národneho povstania* (The Slovak National Uprising Square). Only twice in history the square had a general, non-commemorative name (*Ring* from the establishment of the city in the 13th century to the 19th century, and *Hlavné námestie* – Central Square from 1919 to 1923). Despite all official names, in everyday local communication only one name has always been used up till the present: '*Námestie*' (The Square), which has been seen as the heart and the symbol of the city by local population. This language is part of understanding of local toponymy and local memory. The common name '*Námestie*' (The Square) clearly defines the place on the basis of an easy identification and orientation without any confusion caused by changes of commemorative names.

The same practice of renaming public spaces referred to the adjacent streets that also changed their names several times. For instance, originally *Untere Gasse* or *Dolná ulica* (The Lower Street) changed to *Spitalgasse, Kossuth Lajos utcza, Malinovského ulica* (Malinovsky Street) until it returned to the old non-commemorative name *Dolná ulica* (The Lower Street) again after 1989 *(Photo 2).*

The ideologically-motivated names of streets and squares bearing usually names of Soviet political or cultural figures or events that were introduced during the socialist period were rarely accepted and used by local population and were only presented in official documents and maps. That was the case of all streets in the central city area. Already mentioned *Malinovského ulica* named after the Soviet marshal Malinovsky was known by local inhabitants only as *Dolná ulica* (The Lower Street*); Ulica Februárového víťazstva* (The Victorious February Street) as *Národná ulica* (The National Street); *Polevého ulica* (Polevoj´s Street named after the Soviet writer) as *Kapitulská* (The Church Street); *Jilemnického ulica* (Jilemnický Street) as *Kuzmányho ulica* (Kuzmány Street); or *Námestie 1. mája* (The May Day Square) as *Strieborné* (The Silver Square) (Rohárik, J. 1995). Many local inhabitants were even not aware of the official (communist) names of the streets in the city centre and used pre-communist names as the main way of communication, geographical orientation, and sometimes also as a sort of resistance against the regime.

Photo 1. Slovak National Uprising Square (formerly Ring, Fő tér, Béla Király tér, Hlavné námestie, Námestie, Masarykovo námestie, Námestie Andreja Hlinku, Námestie Národného povstania) in Banská Bystrica. Photo by Bitušíková, A. 2021.

Photo 2. Entrance to Dolná ulica (Lower Street). Photo by Bitušíková, A. 2017.

Post-1989 period: the processes and practices of street renaming in a new democratic Banská Bystrica

The process of the street renaming in Banská Bystrica was one of the earliest responses to the collapse of communism, as also Light observed in other cities (Light, D. 2004). The renaming of public spaces in post-socialist cities commonly involved processes of de-commemoration and/or new re-commemoration (Azaryahu, M. 1997, 482; Bitušíková, A. 2018, 156) and became important in forming a new identity of many cities.

In Banská Bystrica, on the 19 January 1990, the Street-Naming Committee (*Názvoslovná komisia)* was established as an advisory board commissioned by the Mayor and the District Office to provide expertise in the field of naming/renaming of streets and squares. Its establishment was based on the Act No. 369/1990 that explicitally prescribed the way of functioning of Street-Naming Committees as advisory bodies within local municipalities and the Act No. 517/1990. The first Street-Naming Committee in Banská Bystrica consisted of nine members - historians, urban planners, architects, linguists, ethnologists and lawyers. The members were independent experts nominated by the Mayor that did not represent any political parties or interest groups. I was nominated as one of the members.

The Street-Naming Committee had regular meetings several times a year from 1990 to 1995 (most frequently in the first two years of the 1990s) and its task was to propose and discuss new names for streets and squares based on the expert proposals, discussion and public participation. The first step towards starting the proces of the renamimng was to define key concepts of the new renaming, based on the following principles:

– The Act 93/1970 about names of places and their streets (still in practice at the time);
– To build on historical idenitity of old original street names (often geographically-based);
– To propose new street names based on local/regional personalities or historic events;
– To build on historical and cultural traditions of the city and the region. [2]

Following these principles, the initial criterion of the street renaming was the 'decommunisation' of street names and their replacement with ideologically neutral names (where possible) in order to achieve a certain level of sustainability and resilience. Sustainability and resilience in this context can be understood as a capacity of the city and its residents to resist and avoid name changes in the future and to build on the names that are stable and undisputable, which meant either using non-commemorative names or names reflecting local natural, historical and cultural heritage that was not connected to contested history and memory.

The very first wave of the street renaming was done by a direct restoration of the names from the pre-socialist and older periods, based on geographical orientation. The second important criterion was taking into account the historical identity of public spaces and local topography, and commemorating heritage of the city, the region and the country.

The members of the committee agreed to bring old, locally used names back to the city centre and in particular cases to introduce new commemorative names. At the same time they proposed to use preferably non-commemorative names with a long(er)-term validity in the neighbourhoods further outside the city centre,[3] which is in line with the observations of Gnatiuk, O. and Glybovets, V. (2020).

Despite the approach of the committee, which did not expect any political intervention in their expert recommendations, the renaming of streets and squares in the central area turned into a power struggle for control over space and names between various 'old' and

[2] Minutes from the Street-Naming Committee, 12 January 1990. Archives of the Banská Bystrica Municipality.

[3] Streets and squares in several neighbourhoods were given new names based on geographical identification (often following old topography names), industrial-heritage based names (following older economies of the neighbourhood such as mining or trading), names based on significant objects (such as the Court) or nature (garden, forest, trees, flowers etc.).

'new' groups. As Azaryahu has stated, 'the selection of street names is a political procedure determined by ideological needs and political power relations' (Azaryahu, M. 1997, 481).

All new proposals made either by the committee experts or individual citizens were published in local newspapers and open for public participation and debate, which was a very new idea in the early 1990s. Following this objective, the chair of the committee regularly published new street name proposals in the main local newspaper (*Priekopník*) with the aim to motivate the general public in taking part in a new process of participative street-naming (e.g. Odaloš, P. 1990a, b, c, d, e, 1991a, b, c, d).

Soon after the November 1989, two groups emerged as the most active opponents to any change regarding street renaming: 1. the former communist city representatives, and 2. the Anti-Fascist Fighters Union *(Zväz protifašistických bojovníkov)* members. The former communist officials protested against new names, especially those replacing the names of cities, events or figures of the former Soviet Union or the names of the communist leaders (particularly Lenin). The other group – the former partisans who fought in the anti-fascist Slovak National Uprising during the WW2 – wanted to protect mainly 'revolutionary' names related to the Red Army as the liberator. These two groups managed to stop the renaming of the main square (the Slovak National Uprising Square). The proposal of the expert committee to change the square name to the commonly used *Námestie* (The Square) was motivated by the fact that the name was used by the local population in the local toponymy and local language for several centuries. The expert committee proposed to transfer the name of the Slovak National Uprising Square to another public space in the city, near the Slovak National Uprising Museum, however, after numeorous dicussions between the committee and two opposing groups, the expert committee gave up and agreed to keep the square name from the socialist period. The final argument was based on the fact that the Slovak National Uprising was internationally a highly respected anti-Nazi movement of the WW2, and for these reasons its name was an acceptable and respected name for the central square name.

Another contested site in the renaming conflict was a site square in the castle area next to the central square named after the Soviet Red Army *(Námestie Červenej Armády)* – the army that liberated the city on 26 March 1945 together with the Romanian Army. After long dis-ussions within the Street-Naming Committee and following public discussions, the square was given a new name: *Námestie Baníckeho povstania* (The Miners' Uprising Square), which referred to an important milestone in the medieval history of the city (1525–1526). Soon after the new street signs were installed on all corners of the square, the City Council suddenly rejected the expert committee's decision and the next day new signs were installed, carrying the name *Námestie Štefana Moyzesa* (The Štefan Moyzes Square) *(Photo 3)*, named after the Roman-Catholic bishop and the first chair of Matica slovenská (the cultural institution of the Slovaks in the 19th century). The Street-Naming Committee published a protest in the local newspaper and sent a letter to the Mayor. The City Council responded that the change was done as a response to citizens' protests who lived on the square. In fact, there were no residential buildings on the square, it was only the Roman-Catholic Bishop's Office that intervened in this case and managed to enforce the change of the square name (Odaloš, P. 1990d; Rada MsNV v Banskej Bystrici 1990).

The examples of above mentioned practices demonstrate that the processes of renaming streets and squares in Banská Bystrica were marked by a power struggle between various groups presenting or occupying different power positions that tried to put a stamp of their collective memory, identity and heritage on public spaces and by doing so to gain a symbolic ownership of them.

Michael Rothenberg desribes this as a competitive nature of contemporary public memory when different groups fight for representation in the public sphere and fear that their histories will be blocked out by the histories of other groups (Rothenberg, M. 2009).

Photo 3. The Štefan Moyzes Square. Photo by Bitušíková, A. 2019.

The processes and practices of the street renaming were most turbulent in the first months and years of the 1990s. They showed lack of experiences in managing participatory methods of engaging citizens in local policies and practicies, however, they were the first attempts of involving local inhabitants into local governance.

Power groups from the socialist period, but also new emerging groups (such as the church or other interest groups) were using their influence through the City Council as well as through print media in order to gain a symbolic control over public space. The process of the renaming was more or less finalised within five years after 1989. In Banská Bystrica, by the end of January 1990, the first thirteen streets were renamed in the city centre; by the end of September 1991, another nineteen streets were renamed in the suburbs, and by the end of 1995 – the last large wave of renaming happened – another eight streets were given new names (Forgács, J. 2020). This means that fourty public spaces were given new name out of hundred and fifty public places at the time *(Table 1).*

In the years of the late 1990s, the target of public interest and criticism moved to the introduction of the names of newly developed neighbourhoods, buildings and complexes that rarely respect local topography and toponymy and carry mainly foreign names (such as Europa Shopping Center, Belveder, Antea, Proxima, and so on). This was closely related to the commodification of urban toponymy resulting from privatisation and commercialisation of public places and place naming rights (Light, D. and Young, C. 2015a, b). According to the information from the municipality[4], there have been 290 streets and squares in Banská Bystrica in 2022. The names in recently built neighbourhoods are primarily of non-commemorative nature, based on geography or geology related to mining history.

[4] Interviews in March 2022.

Table 1. Examples of changes of street and square names in central city area

Around 1589 (first city map)	1896–1919	1919–1940s	1950s–1990	1990–
Ring	IV. Béla Király tér	Hlavné námestie; Masarykovo námestie, Námestie A. Hlinku, Námestie Národného povstania	Námestie Slovenského národného povstania	
(no name)	Mátyás tér	Horné námestie, Námestie Červenej armády	Námestie Červenej armády	Námestie Baníckeho povstania, Námestie Štefana Moysesa
Untere Gasse, Spitalgasse	Kossuth Lajos utcza	Dolná ulica, Malinovského ulica	Malinovského ulica	Dolná
Obere Gasse	Bethlen Gábor utcza	Horná ulica, Benešova ulica	Ulica V. Širokého, Horná	Horná
(no name)	Szent István tér	Dolné námestie, Hušták, Námestie S. H. Vajanského	Námestie S.H. Vajanského	
Badengasse	Károlyi Péter utcza	Lazovná, Ulica M. Rázusa	Ulica M. Gorkého, Lazovná	Lazovná
Obere Silbergasse	Heinczmann András utcza	Horná Strieborná	Ulica K. Kalužaya, Horná Strieborná	Horná Strieborná
Untere Silbergasse	Alsó ezüst utcza	Dolná Strieborná	Strieborná, Dolná Strieborná	Dolná Strieborná
(no name)	Ezüst Kapu tér	Strieborné námestie, Námestie 1. mája	Námestie 1. mája	Strieborné námestie
(no name)	Körfal utcza	Katovná	Katovná	
(no name)	Kereszt utcza	Krížna	Ulica J. Wolkra, Krížna	Krížna
(no name)	Deák Ferencz utcza	Súdobná, Ulica A. Hitlera, Stalinova ulica	Stalinova, Obrancov miesu	Skuteckého ulica
Grauer Gasse	Wesselényi Ferencz utcza	Kapitulská, Ulica Š. Moysesa	Ulica Borisa Polevého, Ulica Š. Moysesa	Kapitulská

Source: Roháric, J. 1995.

Conclusions

The renaming of streets during periods of social upheaval and transformation is hardly a new phenomenon. It has happened many times in history and is always related to power, identity and momory. We might witness changes of public spaces and their names all over the world, yet, in post-socialist countries and their cities they showed specific features. According to Verdery, it is mainly the large extent, the sheer number (*of torn down symbols*) and magnitude of the changes that led to radical reorganisation of socialist state systems and spatial and temporal orders in many countries, and – such as in the case of Czechoslovakia – even gave way to new nation-states (Verdery, K. 2000, 6).

The struggle for new identity and memory in the city of Banská Bystrica did not differ significantly from similar struggles in other Central and Eastern European cities. It is mainly narratives and oral histories that differentiate one city from another, stories that produce and reproduce the past and bring it to the present. People have a tendency to return to history, to celebrate what is not there any more, to idealise the past (or selected parts of the past), to remember 'old' places and events with nostalgia. Each of us builds and preserves our own, individual memories based on experiences that have been lived and accepted by a group in certain time and space. These memories are changeable. One of the characteristic features of memory is that it is selective, it may delete unpleasant moments, even rewrite history and lead to what Williams calls a false urban memory syndrome (Williams, A. 2005, 3). This process can be assisted and even enforced by various interest groups that fight for 'their' history, memory, places and symbols, e.g. by former communists or the church in case of Banská Bystrica.

Experience from the former, but also existing totalitarian regimes of Central and Eastern Europe (e.g. Russia or Belarus) clearly shows that collective memory and identity often become a tool of manipulation and power games. Facts and figures are rewritten, changed, deleted or silenced in order to strengthen or change collective identity of certain power groups or to mobilise people against an enemy or opposition. As Šubrt and Maslowski noted, explorations of memory always have important political connotations and implications as numerous passionate discussions about history and identity across Central and Eastern Europe demonstrate (Šubrt, J. and Maslowski, N. 2014, 281).

Official institutions, particularly municipality representatives, try to re-produce collective memory and strenghten the feeling of local identity by reconstructing and re- or decommemorating public spaces, introducing new names (but also erecting new memorials, or organising activities and events), however, they often succumb to the pressures of various groups when it comes to symbolic control over public space. In this article I examined mainly processes and practices of the renaming of streets and squares in the early post-socialist period by presenting empirical material from the medium-size Slovak city of Banská Bystrica. I tried to demonstrate the process of street renaming and power struggles related to it that used heritage, memory and identity as a tool for gaining symbolic ownership over certain parts of history, and I also wanted to emphasise a growing involvement of the public in these processes.

The renaming of streets in Banská Bystrica showed two main strategies. First, it was the decommunisation of names which was done either by the restoration of street names from the pre-socialist periods that were always used by the local population (particularly in the historic city centre) or by the introduction of idelologically neutral new names (especially in the neighbourhoods), based on geography or natural characteristics of the locality or the region (such as Green Street, Sunny Street, Chestnut Street, Tatra Street etc.). Second, the renaming of some streets or naming of newly developed squares or streets followed commemoration of personalities, events or cultural, historical and natural heritage of the city, the region and the country. Unlike in some other post-socialist cities (e.g. Budapest or Bucharest) that used the opportunity to introduce a large number of commemorative names from the pre-socialist periods (mainly from the so called 'Golden Eras' (e.g. Light, D. 2004; Palonen, E. 2008), in Banská Bystrica the ratio of commemorative names remained rather low. The prevaling approach supported by the Street-Naming Committee was the restoration of pre-socialist commonly used names in central city areas and the introduction of non-commemorative names in the neighbourhoods. This might be a difference between country capitals that tend to use more commemorative names in central areas of the city, and smaller or medium size cities that follow different naming strategies, emphasising more local and regional personalities or events, or – more often – non-commemorative names.

At the time of rewriting this study (2022), it was impossible to ignore the Russian aggression in Ukraine that already had serious impact not only on collective identity and memory of the Ukrainians, but also – in line with the topic of this paper – on the renaming of public spaces (Gnatiuk, O. 2018). At the 31st anniversary of the Ukrainian independence (24 August 2022), 95 street and square names in the capital of Kyiv were changed in order to „derussificate" public space (TASR 2022). The stories of renaming go on...

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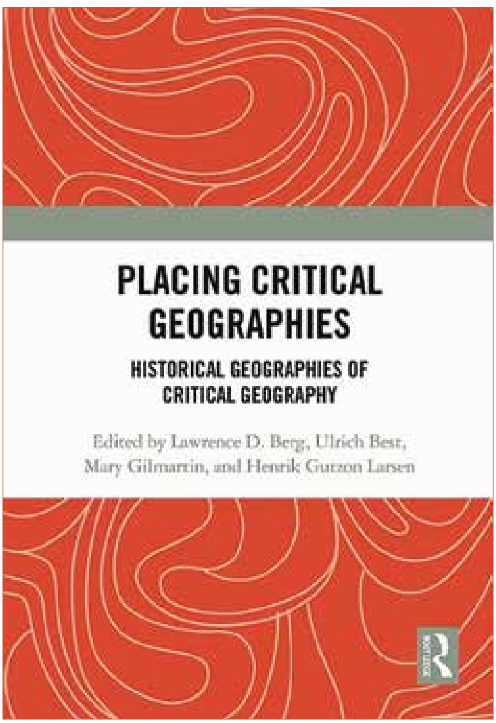
BOOK REVIEW SECTION

Berg, L.D., Best, U., Gilmartin, M. and Larsen, H.G. (eds.): Placing Critical Geography. Historical Geographies of Critical Geography. London and New York, Routledge, 2022. 331 p.

Placing Critical Geography is rather a thought-provoking and inspiring collection of geographically situated histories of critical geographies in various locations around the globe. The editors of the book aimed at grasping differences in the production of critical knowledge in a range of academic settings using Kirsten Simonsen's (1996) conceptualization as their starting point. Accordingly, in compiling the chapters, they adopted the "space as difference" and "space as social spatiality" approaches in order that the chapters can "capture the difference that space makes and the different social relations that lead to different conceptualizations and understanding of the spatial" (Lawrence D. Berg, Ulrich Best, Mary Gilmartin, and Henrik Gutzon Larsen: Chapter 1, p. 4). All the 37 authors offer an insight into the evolvement and shaping of critical geography in mostly nation states and linguistic groups or regions typically as "insiders." Thus, they offer insight into the following locations in the following order: Palestine (and beyond), South Africa, the USA and Anglo-Canada, Latin America, Japan, China, Francophone and German-speaking countries, Ireland, Italy, Nordic countries, Spain, the United Kingdom, Australia and Aotearoa New Zeland.



It is not only the large number and diversity of the chapters that I cannot undertake to summarize them in any way. The stories presented in the book are all specific and complex. I strongly believe that in order to be able to understand "how space matters," all the chapters, the changing economic, social, political and institutional contexts presented, and the personal stories selected by the authors must be studied carefully.

This review is not only partial but also subjective. Not only because of the characteristics of reviews in general, but also because it has a less common form of subjectivity. The (above-mentioned) concept of "space as social spatiality" is partly coming from Henri Lefebvre's interpretation of space (1991), according to which each mode of production leaves its footprint on the production of space. I believe that this alone can create a feeling of "something missing" in readers, namely that ex-socialist Central and Eastern Europe (CEE) is not represented in the volume. That said, I am not going to be the one that voices criticism in connection with that. On the contrary. This book was still in the making well over a decade ago when I was invited to write a chapter on the critical geography of this region. At the time, however, I did not think I could provide information on any meaningful progress compared with the information on the absence of critical geography in Hungary I had shared earlier (Timár, J. 2003). My conviction at the time, namely that the situation was not any different in the region either, was substantiated by a conference of the International Critical Geography Group (ICGG) held in Békéscsaba (Hungary) in 2002 as CEE researchers represented only a small proportion of the 180 participants from 40 countries (Bialasiewicz, L. 2003). However, there has been some discernible change since then. Currently, a change of generations offering some hope and a social turn also reflected in the application of critical social theories are taking place, putting a final end to Soviet-type social geography. Therefore, seizing the opportunity provided by this review, in the conclusion, from among the major issues presented in the book I will cherry-pick specifically those that bear relevance to critical geography evolving in Hungary (hopefully elsewhere in CEE too). I hope such subjectivity will not divert attention from the book, rather it will contribute to the realization of the goal of "placing critical geographies."

Such realization is not confined to a mere descriptive presentation of the individual, locally different trajectories of critical geography. The book can be deemed as a challenge to "the hegemonic history of critical geography" defined by the editors. This kind of history "reduces the multiple and complex histories of critical geographies around the world to a singular story that reinforces Anglo-American hegemony, where critical geography is understood to have originated in the United Kingdom and the United States and 'diffused' outward to the peripheries of academic knowledge production" (Chapter 1, p. 1).

One of the results of the approach disassociating itself from that kind of history is that the chronology of the chapters does not start with the end of the 1960s or the 1970s. Although this period is commonly regarded as a decisive moment in critical geography in most (groups) of the countries studied, the authors go back much earlier, in some cases even to the 19th century, to search for the roots. Linda Peake and Eric Sheppard, who discussed the USA and Anglo-Canada (Chapter 4), also break with earlier traditions. As a result, in addition to/instead of a few better-known predecessor geographers representing radical geography with its roots traced back to 1969 (the year of the publication of *Antipode*), they also present the activities of the forerunners overlooked before. Mary Gilmartin (Chapter 10) raises the issue of a seemingly controversial position of Ireland. She is aware of the fact that if the definition of Anglo-American hegemony is language-based, due to English being used as a de facto first language, Ireland, too, must be considered a part of the core. However, this approach hides Ireland's controversial colonial and postcolonial relations with Britain. Gilmartin mostly reveals the role that these relations play in the production and circulation of critical geography. Koji Nakashima, Tamami Fukuda and Takeshi Haraguchi (Chapter 6) have adopted an analytical method as an alternative to the assessment of critical geography in Japan (Mizuoka, F.T. *et al*. 2005) that has attracted considerable attention and that they also appreciate. One of the components of their alternative approach is a multi-linear history of social, cultural and other related studies instead of a focus on the history of economic geography. Ari Lehtinen and Kirsten Simonsen (Chapter 12) present the in-between status of Nordic critical geography. It is not only between internationalization and situated knowledges, and representation and materiality that such in-betweenness exists. As a number of examples illustrate, in-betweenness also reflects the duality of Anglophone and continental European inspiration.

Finally, it is worth emphasizing here that probably the most comprehensive and consistent argument against "the hegemonic history of critical geography" is Wing-Shing Tang's presentation of the history of critical geography in China (Chapter 7). In so doing, the author introduces an alternative methodology called spatial story methodology where he is helped by the tradition of non-dualistic Chinese *tongbian* thinking, which emphasizes the mutual embeddedness of contradictions. He concludes that critical geography in China is not a "mere variegated version of its western counterpart" (p. 138). It is specific paths that can describe differences best. Challenging, among others, David Harvey, he explains that there are spatio-historical paths other than those characterized by the logic of capital, strong private property rights and free markets. As he puts it: "Because of this, a benchmark of criticality for critical geography that is derived from western capitalism and then uncritically deployed to other contexts, such as China, is not particularly useful or insightful. The crux of the issue is not so much the mere identification and documentation of pluralisms or diversities alongside this benchmark, but rather the need to acknowledge the existence of many more distinctive criticalities that have been derived from disparate, but inter-connected, forces and processes." (p. 138).

The origin of these criticalities is a fundamental question in each chapter. Critical social theories are inspiration, key sources and, at the same time, tools of critical geographical research aimed at understanding and changing the numerous forms of inequality, oppression, socio-spatial injustice, which is also reflected in the individual chapters. The importance of the spatiality of critical geography is reflected in the analyses of the situational embeddedness and travelling of these theories. An excellent argument against "the hegemonic history of critical geography" that would be strengthening Anglo-American hegemony is the fact that the career of Élisée Reclus and his friend Pyotr Kropotkin, two anarchist geographers summarizing the theoretical approach of criticality, started in France and Russia, respectively. In addition to the international impact of their works from over 150 years ago that is still detectable, they also disseminated their knowledge while travelling, even if they did not always meet a receptive audience. Kropotkin, for instance, limited the channels of his professional discourses to his personal relationships with his British colleagues because his principles prevented him from becoming the member of any organization under royal patronage, thus that of the Royal Geographical Society, which offered him membership after his visit to London (Kye Askins, Kerry Burton, Jo Norcup, Joe Painter and James D. Sidaway: Chapter 14). For those who, for linguistic barriers, could not read Blanca Ramírez's (2007) study about this in the original, it would be interesting to learn that Reclus visiting Colombia as an explorer could not earn fame despite his continuous discussions with Francisco Javier Vergara y Velasco, a famous local geographer. Fame only came to him in the 1970s, by which time the geographical profession had become receptive thanks to the French Marxists Pierre George and Yves Lacoste, mainly in Colombia and Venezuela and, to a lesser extent, in Ecuador (David E. RAMÍREZ, Gustavo Montañez, and Petra Zusman: Chapter 5). It was also attributable mainly to Lacoste that, after a long period of marginalization, Reclus's rather diverse works written in the extremely critical spirit of an anarchist were re-discovered and thought further from the 1970s (Rodolphe de Koninck and Michel Bruneau: Chapter 8).

These events lead us to a period when Marxism facilitating critical geography started to gain ground, a fact mentioned by all the authors. This review allows us to highlight from among the analyses few examples (or persons) only. They all mention the impact of the most famous British and American Marxist geographers (in particular David Harvey) that is detectable in nearly all the countries studied. It is sometimes the case that the concepts of the original theorists or Marxist philosophers like Henri Lefebvre reached geographers through their (re)interpretation. However, the book also presents facts like the one according to which a book on the geographical study of the mode of production and territorial structure written by Gerhard Schmidt-Renner, an East German geographer in 1966 proved influential in Denmark quite early (Lehtinen, A. and Simonsen, K.: Chapter 12). For instance, the influence of Lacoste's works mentioned above was not limited to critical geography in Latin America. Making an observation in connection with the Spanish translation of one of his books, Abel Albet and Maria-Dolors García-Ramon (Chapter 13, p. 248) attributed Lacoste's significant impact especially on university students to the fact that "he came from French geography, which was viewed as closer to Spanish geography than Anglo-American geography. (In fact, Anglo-American geography was until recently seen as a 'foreign' tradition.)"

Feminist and, to a smaller extent, queer theories are mentioned in the most consistent manner among critical social theories in the chapters. It is true that the authors do not always focus on the effects of these theories, rather they analyze the history and consequences of "gender geography." Differences in their approaches and narratives can encourage the continuation of international debates on whether (sometimes descriptive and apolitical) gender geography can be regarded as critical geography (e.g., Longhurst, R. 2002). Chapter 13 on Spain definitely answers this question. While Albet and Garcia-Ramon make it clear that a number of Spanish geographers studying gender issues come from radical and Marxist geography, they also state unambiguously that gender geography is "a way of doing critical geography" (Chapter 13, p. 252). At the same time, the authors of the book point out delays in, or the absence of, the social acceptance of feminism and gender issues in a number of chapters.

The presence of anti-colonial/postcolonial/decolonial approaches inspiring critical geography is also context-dependent. I have only chosen three examples to illustrate its specific forms: the topics of critical geography in Palestine are provided by continuous responses to dispossession, denationalization and refusal of rights and presence (Ghazi-Walid Falah and Nadia Abu-Zahra: Chapter 2). The social and political environment created by apartheid is a major source of geography undergoing radicalization in South Africa (Brij Maharaj and Maano Ramutsindela: Chapter 3). In Aotearoa New Zealand, regarding Maori geography, research in the context of colonialism opened up new possibilities for critical geography (Robyn Dowling, Richard Howitt, and Robyn Longhurst: Chapter 15).

In addition to the theorists already mentioned, there are a number of critical geographers or their predecessors from other disciplines presented in the chapters whose theories/concepts enriched critical geography at an international scale. Without an aim of providing an exhaustive list, it is worth mentioning those to whom the authors of the book contribute a whole subchapter: Milton Santos, Mao Zedong, Claude Raffestin, Lucio Gambi, Massimo Quaini, Giuseppe Dematteis, Franco Farinelli, and Gunnar Olsson.

The diversity of the critical theories mentioned here characterizes critical geography in most of the places studied. It follows, therefore, that most cannot point out one single defined school of thought. Most accept this and even think that it is an advantage; however, Askins, K. *et al*. think further about this issue in Chapter 14: "If 'critical geography' is located at the overlap between geography and critical theory, then it is a very diffuse and loosely defined field, and perhaps too diffuse to be meaningful; if there is nothing much outside the category, then how is the category helpful? For many, activism of some kind (whether in the classroom, the academy or beyond) remains an essential component of critical geography, though this insistence may be tempered with a reluctance to exclude those who share similar political goals but don't consider activism to be their forte." (p. 275).

What is certain is that chapters bring activism of this kind into a sharp focus. This is no coincidence because it was mainly (groups of) university students and their campaigns that gave an impetus to the evolvement or even an explosion-like emergence of critical geographies. ('Opening events' often meant the launch of new journals. *Antipode* in the USA was indeed a key source of inspiration. However, as, e.g., the link between *Herodote* in France and *Hérodote/Italia*, its Italian version reveals, it was not only the 'center–periphery' relations that worked in this respect, either [Elena dell'Agnese, Claudio Minca, and Marcella Schmidt di Friedberg: Chapter 11]). Comprising interviews conducted with persons who participated in the events of the day as well, an analysis of critical geography in West Germany provides the most detailed account of the particularly important role of the young generation (Bernd Belina, Ulrich Best, Matthias Naumann, and Anke Strüver: Chapter 9). A story taking place in Rome and leading the reader to the present is an excellent example of connecting theory with practice. Campaigns against the neoliberalisation of universities took the form of occupying the roofs of universities, which was also fuelled by Angelo Turco's conceptualizations of the processes of territorialization (dell'Agnese, E. *et al*.: Chapter 11). Critical pedagogy, action research and cooperation with progressive social movements illustrate relations outside the academia. However, self-criticism was also voiced in connection with this when results were summarised or thoughts about the future were formulated. During this becoming "people's geography" (Peake, L. and Sheppard, E.: Chapter 4) and using produced knowledge to serve disadvantaged and marginalized groups (Falah, G. and Abu-Zahra, N.: Chapter 2; Maharaj, B. and Ramutsindela, M.: Chapter 3) remain an important goal.

Similar and other (e.g., academic) practices of critical geography (launch of new journals, seminars, conferences, regional or wider networks of researchers) seem to take on an increasingly international scale. As this book also proves, there are continuous efforts to put into practice the principles on "internationalism" adopted in Vancouver by approximately 300 geographers and activists, who launched the International Critical Geography Group 25 years ago (Smith, N. and Desbiens, C. 1999).

Finally, in keeping with the promise at the beginning of the review, reading this book from a Hungarian/CEE perspective, based on the lessons I find especially relevant and important, I would like to raise two issues for discussion.

One is related to historical analyses, the circumstances in which critical geographies evolved. As the chapter on China (by Tang, W.) makes it clear, even experience long considered to be a cornerstone or a shared characteristic such as "Marxism can give a significant impetus to the development of critical geography" does not necessarily hold true everywhere. Sovietization, which can also be interpreted within the context of the postcolonial and decolonial theories listed in a number of chapters (Stenning, A. and Hörschelmann, K. 2008; Győri, R. and Gyuris, F. 2012), produced the opposite result in Hungary (Timár, J. 2003). Similar to the situation presented in the chapter on Germany (by Belina, B. *et al.*), i.e., when Marxism and Leninism became a state ideology, it was used to paralyze the essence of criticism. Therefore, I do not think that critical theories and/or practices can be expected to become an integral part of the differing contexts of critical geographies as long as we allow any hegemonic knowledge production to prevail.

The other issue is related to challenges that critical geographers face currently. One of the most thought-provoking lessons of the book is that the neoliberalization, internationalization and "publish or perish" approach of universities in the 21st century also launched conflicting changes. As opposed to the numerous adverse impacts of these processes that many pointed out (e.g., the recent reinforcing of Anglocentrism [Lehtinen, A. and Simonsen, K.: Chapter 12]), the authors assessing the situation in Germany present the evolvement of a paradox situation. They find that thanks to the international relations of critical geographers, this process also generated reputation for them (Belina, B. *et al*.: Chapter 9). However, as a result of a conservative shift, governments in Hungary and a few other countries condemn social research with gender or political content of any kind as undesirable or ideology, i.e., something not scientific (Timár, J. 2019). Therefore, the time does seem to have come for internationalism and coordinated actions as advocated by critical geography. I believe that this book provides knowledge for us that can serve as an excellent tool for the realization of this goal.

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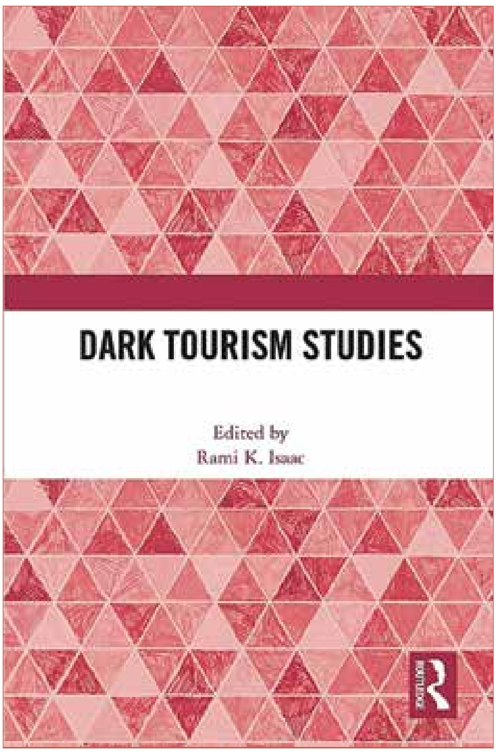
Isaac, R.K. (ed.): Dark Tourism Studies. Abingdon and New York, Routledge, 2022. 132 p.

The ever-increasing competition among tourism destinations results in the emergence of new approaches and products. The tourism industry is taking a second breath after a couple of years of break in the period of the COVID pandemic – this creates opportunities for the new ideas. The so-called dark tourism is one of the emerging fields within tourism, that contributes to the changing field of the industry and impacts the attitudes towards tourism and attractions at the same time. There is a growing popularity and hype of dark tourism in the last decades as it is able to effect the transformation of mindsets and assimilate the framework and scale of crucial moments in human history. Rami K. Isaac is a senior lecturer at the Academy for Tourism at Breda University of Applied Sciences in the Netherlands. His recently edited book is a collection of studies that offers innovative, cutting-edge, and international tourism research that is based on multidisciplinary and transdisciplinary conceptual and empirical ideas. Moreover, throughout the chapters, the authors offer new perspectives and possible research directions for future studies on dark tourism.



According to the editor of the volume, the book aims to stimulate and advance theoretical, conceptual, and practical study on dark tourism and to get a peek at the kinds of original thinking and academic research. Although the concept of dark tourism has existed for 25 years, it is getting more attractive and relevant in present times as research interest is broadening and having popularity among researchers from various fields.

The book consists of 7 chapters. Among them, dark tourism has been covered from different perspectives, such as emotional, ethical, educational, and commemorative aspects. The chapters could be restructured into two sections according to the key concepts. The initial four chapters can be considered studies of the experiences and emotions of dark tourism visitors, and the last three chapters could become a part of edutainment in dark tourism.

As it is highlighted in the book, due to the gap in the research, there is no exact proven relation between dark tourism and heritage in scientific papers. However, they have interdisciplinary connections. The primary purpose of Chapter 1 by James Kennell and Raymond Powell is to assess the association and degree of the overlapping between heritage and dark tourism from the perspective of World Heritage Sites (WHS) perception. Even from the name itself, dark tourism is perceived as negatively affiliated with death and atrocity. Therefore, heritage-oriented scientists dispute in acceptability of dark tourism to WHS studies. There are also some debates on how dark tourism relates to eerie events. However, many dark sites are dynamic and towering structured service landscapes, including World Heritage Sites. The study area of Chapter 1 is Maritime Greenwich, a UNESCO World Heritage Site in London, United Kingdom. Surveys among participants of the research were conducted using the Delphi technique. This study offers a unified perspective on the connection between dark tourism and heritage from a vast collection of heritage tourism stakeholders.

Chapter 2 discusses the gap in the research related to feminine crime in dark tourism. Generally, murder tours worldwide mainly focus on cases where men are the killers and women are their victims. According to the authors (Bailey A. Adie and Esther J. Snell), if female killers are less prevalent in modern murders than male killers are, this must be partially because of how gender and crime are perceived socially and how they are used and portrayed in contemporary society. However, misunderstanding murder's role as a social issue can result from distortion, which can perpetuate false stereotypes. When the killer is unknown, it is fascinating to observe that mystery killers are typically thought to be males. As a result, even in the absence of explicit gender, it is safe to presume that the narratives of these tours have a masculine gender role in mind. Chapter 2 concludes that women are frequently ignored in the activities of murder-related dark tourism, which is not surprising given the academic and criminological link between men and murder. The goal of this essay was not to refute the term 'dark tourism.' Still, it does appear that visiting crime scenes, particularly those of violent crimes, may differ from visiting commemorated tragedy sites like Auschwitz in Poland or Ground Zero in New York. These locations serve as a means of remembering the victims of these incidents. In contrast, violent criminal tourism practices demean the victims and frequently serve as a celebration for the perpetrator. However, the analysis and conceptual basis of Chapter 2 could be broadened in a sense of gender issue as only women's crimes are discussed in this part of the book. Thus, future studies can incorporate a broader analysis of gender issues by researching murders of transgender, two-spirit, non-binary genders and pangender. Furthermore, it would be intriguing to learn whether dark tourism to crime scenes occurs outside of the Western, predominantly English-speaking globe and, if so, whether these locations serve to reinforce local cultural gender norms.

Chapter 3 by Martin MacCarthy and Ker Ni Heng Rigney describes a study that used a variety of qualitative techniques. This research investigates visitors' experiences at the Anzac National Center in Western Australia to comprehend the level of involvement, the emotions connected to it, and the everyday conduct connected to antipodal commemorism. The Anzac National Center, which was inaugurated in 2014, and the area around it are very significant to Australia and New Zealand since this is where soldiers leaving for the Great War of 1914–1918 assembled before their long trip to an unknowable fate. Popular topics in commemorative studies include place and collective social memory. One critique in Chapter 3 is that dark tourism drew large numbers of visitors at the expense of converting the memorial into a theme park. We are demeaning our past, as Daley, P. (2019) warns, by altering the Australian War Memorial into a theme park. However, the spectacular and moving moments in the nation's history deserve to be memorialized. Hirsch, M. (2008) says that memories can be transmitted to the following generation as a 'post-memory' if they are sufficiently painful. Thus, from generation to age, memory continues to be politicized.

The research questions such as "What is the relationship between hero worship and compassion towards guests?" remain unanswered as the authors' initiative seeks to deepen our understanding of dark tourism. What concepts can be applied to the design and upkeep of historical monuments to improve tourists' expectations for immersive Caritas? Is remembrance truly dark tourism, or should the hypername be changed? The authors claim that many respondents concur with the practicality that personnel should be paid and facilities should be maintained. At the same time, some criticize and emphasize the charging of access fees to a sacred site.

As it was mentioned before, the first four chapters emphasize awareness of the experience and emotions of the visitors of dark tourism sites. Chapter 4 strokes on consumer behavior, psychology, services and tourism to comprehend how the feelings and emotions engendered by dark travel experiences lead travellers to reflect on death-related issues and interact in thought methods that in spin empower them to develop insight into dark places and death. Previous studies have been criticized for highlighting motives over the characteristics and effects of dark tourism, particularly their phenomenological and contextual underpinnings. The results of Chapter 4 add value to the field by using a reflective autoethnographic approach to learn more about the experience of dark tourism. This chapter includes a literature review on how emotions relate to dark tourism, methods, analysis, and results with discussion. In this part, the autoethnography approach is a crucial tool. In a narrative research approach, individual experiences are described and systematically examined to comprehend cultural experiences (Ellis, C. *et al.* 2011). As a study site, Ground Zero, Gettysburg Park, and Ellis Island were selected. In terms of the kinds and degrees of emotions elicited and their effects on introspection, critical thinking, and transformation, Ground Zero has been identified as the location with the highest emotional engagement. At the same time, Gettysburg sparked emotions of sorrow over the Civil War casualties as well as an appreciation for the pride of the American people in maintaining their heritage and giving it its unique meaning.

The authors, Marianna Sigala and Effie Steriopoulos concluded that the visitor experience in frightening locations ought to be thematically connected to tales and genuine artifacts with symbolic significance that can arouse intense feelings and thinking and open the door to novel interpretations. Chapter 4 suggests dark site managers must be conscious of the elements and procedures that can elicit a variety of emotions in visitors to settle better and create their services and experiences to provoke suitable feelings in visitors. The authors also provide some proposals for additional investigation. One of these involves determining whether Asian travelers touring Western dark sites have positive or negative emotions and how they can contemplate them and extrapolate creative meanings, and vice versa. Drawing on the results presented in the chapter, future research should look into the function and effects of tourists' interactions and reflections, including those with other visitors and with themselves, dark site artifacts, their story messages, and symbolism.

According to its authors (Brianna Wyatt, Anna Leask and Paul Barron), Chapter 5 was initially written to highlight that edutainment seems underdeveloped and underused amongst researchers in dark tourism. In this context, edutainment means organizing entertainment dark tours through educating people. The influence of the edutainment interpretation of three lighter dark visitor attractions, which are offered as new attractions to explore as part of the dark tourism study, is thus critically examined in this part of the book. This study deepens the knowledge of dark tourism in relation to variety of LDVAs (lighter dark visitor attractions), their interpretation, and the use of dark tourism education initiatives. Dark tourism can allow viewers to connect with a painful past through interpretation by acting as a trigger for emotional values and information enrichment (Kim, S. and Butler, G. 2015). According to surveys, LDVA receives much criticism for trivial entertainment that dilutes historical accuracy by softening and removing narrative and erasure the surroundings (Dwyer, O. and Alderman, D. 2008; Silverman, H. 2011; Stone, P. 2006). Others have responded by asserting that LDVA genuinely educates viewers and satisfies tourists' interest in darker tales from older days through accurate and authentic displays in its amusement programming (Rodriguez-Garcia, B. 2012; Magee, R. and Gilmore, A. 2015; Welch, M. 2016).

In the chapter, three different LDVAs, The Real Mary King's Close in Edinburgh, Sick to Death Museum in Chester, and Gravedigger Ghost Tour in Dublin, were chosen by deliberate sampling as the sites where data gathering was to happen. Each delivered an interpretation using a curriculum that combined education and entertainment with varied approaches to inform, provoke, and engage the audience. The focus groups were asked to answer the question: what is your perception of the design and management of the interpretation of your attraction? The data analysis revealed three other elements that affect how LDVA entertainment and instructional programs are perceived: pop culture allusions, the nature of the material and other alluring features, and competitiveness. The results demonstrate a clear awareness that each LDVA has worked to construct its vision in a way that teaches its audience and provides historically correct and academically sound material, despite the influence of pop culture references and the popularity of edutainment. It was shown that none of the LDVA members intended to change history or stir up violence just for the sake of it. The findings of this study, which looked at how edutainment interpretation affected design, deepen our understanding of dark tourism because they go against many of the publications claiming that LDVAs typically do not consider issues of factual accuracy and most frequently marginalize history through myths.

Chapter 6 investigates the significance of students' educational experiences focusing on the effects of students' visits to gloomy tourist destinations on their internal and behavioural activity. This issue has been studied rarely and incompletely in previous research. As university students are one of the most often targeted audiences for edutainment, the authors have analysed their attitudes in the study. The goal of Chapter 6 is to examine the value of students' education programs in dark tourist spots with an emphasis on the after-visit impacts, which are behavioural activity that is both inwardly and outwardly directed. The research is based on longitudinal data gathered from study tours of various dark tourism destinations in Latvia from 2014 to 2019, which were organized as a part of an undergraduate course. During the research trips, students visited three to four sites associated with the Nazi and communist regimes. Excursions or educational tours are viewed as a method for experiential learning. However, it is important to highlight that the research has a significant limitation due the size of the analysed sample. The number of students and the number of site visits varied annually. As a consequence, each site had anywhere between 12 and 103 replies. Due to this, authors limited data analysis to websites that at least 30 students visited and concluded that visiting dark tourism destinations, which represent the darkest end of the spectrum, generally results in more significant aftereffects than seeing the lighter end. The outcomes of this chapter support earlier research that shows that students regard the tourist destinations with the most educational value to be the darkest. The findings also demonstrate that not all of the dark tourism destinations featured in the tour program successfully stimulated tourists' cognitive and affective responses.

Chapter 7 also describes a study with a case of a mix of educational and dark tourism in Fukushima, Japan. The study consists of two parts: first, examining how educational and dark tourism ideas have evolved in Japan; second, how the Fukushima Hope visitor tour's educational dark tourism component came about. Due to the cultural background of Fukushima, the terms 'peace tourism' and 'hope tourism' are alternatives that avoid the word 'dark tourism' but still incorporate dark tourism elements in the context of educational tourism. Local governments rarely use the phrase 'dark tourism' in Japan. They worry that even though dark tourism includes both 'light' and 'dark', if a place is called 'dark tourism,' it will acquire a bad reputation. Specifically, data and knowledge about natural disasters and their prevention, information and understanding about emergency preparedness, sorrow and prayer for the victims of the natural catastrophe, and landscapes of the afflicted area were utilized to measure the element of education or 'dark.' On the other hand, natural scenery, food and specialty, culture, and attractions, were applied to quantify enjoyment or 'light' factors. The excursion's analysis provided insight into how education and entertainment may be blended and how they can enhance one another to assist the public to acknowledge the area and even promoting it.

Dark tourism is not new, but evolving popularity gives the opportunity for forgotten history to be revised and transferred to the public. The editor of the volume, Rami K. Isaac concluded that multiple types of visitors, such as victims, perpetrators, and observers, must be distinguished. The term 'victims' refers to people who, in some way, identify with victims and take action to seek justice or reparation on their behalf. The 'perpetrators' have a relationship with individuals who perpetrated the crime, even from a distance. The category of 'observers' is more complicated, but it also includes those who are deeply attached while not belonging to any of the categories. According to Isaac, greater research is required to understand the various visitor kinds thoroughly, but this is a highly intriguing topic. Studies included in the book have discussed a lot about the negative and positive emotions and experiences of tourists. *Dark Tourism Studies* proved that there is a significant gap in the research of dark tourism regarding the understanding of the emotional experience of visitors.

I wholeheartedly suggest the volume to everyone interested in dark tourism studies and its contemporary trends. The book is helpful for people who wish to learn about the theories and approaches of dark tourism and obtain inspiration for further research. After going through the book for the first time, I noted that seven researches majorly were about the experiences and emotions of the visitors and the edutainment significance of dark tourism. Thus, the first four chapters belong to a part about the experiences and emotions of dark tourists, and the last three chapters can be included into the education and entertainment section. The book is a fine collection of different aspects of dark tourism studies in terms of gender equality, emotions, experiences, and commemoration.

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CHRONICLE

In memoriam Arild Holt-Jensen (1937–2022)

The sad news arrived to the editorial office of HGB that Arild Holt-Jensen professor of human geography at the Department of Geography, University of Bergen, and old friend of Hungarian geographers, passed away on 2nd of April 2022 at the age of 85. Professor Holt-Jensen grew up in Horten near Oslo, and his road to geography was paved by such childhood memories as the arrival of five volumes of the National Geographic Magazine in his post-box in 1945 after the end of the war, that was ordered by his father before the Nazi occupation, and Thor Heyerdahl's Kon-Tiki expedition in 1947. He became fascinated by geography, explorations and reading maps, thus, it is not surprising that he chose this discipline for his studies and academic career. After graduating in geography at the University of Oslo in 1963 he took an assistant job at the University of Aarhus, Denmark. It was there he met his wife Elisabeth with whom he shared the rest of his life. In 1965 the Holt-Jensen family moved to Bergen, where Arild was employed as lecturer in geography at the University of Bergen, and he served the university for the rest of his academic career. In 1986 he defended his PhD, and in 1991 he was appointed professor in human geography at the University of Bergen and stayed in this position until his retirement in 2008.

Professor Holt-Jensen published numerous books, among them the well-known *Geography: History and Concepts* (Sage Publications) that was first published in 1999, and its fifth edition appeared in 2018. The book has also been published in Spanish, Chinese and Persian. This textbook is an excellent introduction for students to geographical thought with a unique approach that encompasses environmental, historical and social perspectives of geography and the study of human-nature interaction. The book became an essential student companion to the discipline worldwide. Arild was amazingly prolific in several fields of geography, and he published excessively journal articles and book chapters on environmental, urban and regional planning issues.

Arild Holt-Jensen was also very active on the research front, and after the fall of the Iron Curtain he became interested in the mechanisms and outcomes of post-socialist transition in East Central Europe. He coordinated the NEHOM (Neighbourhood Housing Models) project financed by the EU 5th Framework Programme between 2000 and 2004, with 11 partners from eight European countries, including Hungary and Estonia from the post-socialist part of the continent. This project was later followed up by the Nordic Neighbourhood Project, financed by the Nordic Council of Ministers, with 12 partners from seven Northern European countries, including the Baltic States. The main result of this project was the edited volume 'Urban Sustainability and Governance; New Challenges for Nordic and Baltic Housing Policies' published by NOVA, New York in 2009.

His academic achievements were rewarded Modeens Minnemedalj' by the Finnish Geographical Society in 2000. The most significant recognition of his many achievements was the Johan August Wahlberg's medal in gold from the Swedish Society for Anthropology and Geography in 2018. The medal, which was awarded by Crown Princess Victoria at Stockholm Palace, was given for his comprehensive view of geography as a science and his contribution to geography's orientation towards social planning.

Next to his academic achievements Arild was always very active in local and national politics from the start of his university studies: as member of the Norwegian Liberal Party he headed its Environmental Commission between 1968 and 1975, he was member of Bergen City Council (1971–1979) and later served as Chair of 'Landås City District' Board (his local neighbourhood) for 12 years. From 2004 he shifted to membership in Bergen Socialist (Labour) Party. Arild was always very sensitive towards questions of social and environmental justice, which became more and more the centre of his academic interest. He questioned the functioning of neoliberal capitalism with severe criticism. Beyond his outstanding professional achievements as university teacher, researcher and politician Arild was also active in public life, and for many years he was voluntary cabin guard in Turnerhytten in Mount Ulriken, where he made pancakes and coffee for hungry hikers over the week-end. Another hobby he dedicated his free time together with his wife was dancing. He was a great lover of dancing, he was member of the folk dance club at Ervingen and he was always the first on the dance floor during conferences.

Arild visited Hungary regularly after 1998, where he gave lectures and set up collaborations with the younger generations of Hungarian geography. He was always very curious about the political and socio-economic development of Hungary and the troublesome pathway from state-socialism to global capitalism. But he was also open to discuss both global and local challenges and the future of our discipline and Planet Earth. We will all miss his cheerful attitude, generosity and dedication to geography.

Zoltán Kovács

GUIDELINES FOR AUTHORS

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