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Comparison of Daily and Monthly Intra-urban Thermal Reactions Based on LCZ Classification Using Surface and Air Temperature Data

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Abstract

Urban air (T_a) and surface (T_s) temperature patterns depend mainly on the surface cover conditions. WUDAPT methodology was used to create the local climate zone (LCZ) map of Szeged (Hungary) providing detailed information about the structure of the urban area. The seasonal and monthly variations of simultaneous measurements of T_a (urban network) and T_s (MODIS) in different LCZs were analysed for a four-year period. The results show that the largest differences between T_s and T_a values occur in late spring and summer. During the day, the monthly mean T_s was much higher than the mean T_a, while at night, the T_a exceeded the T_s in all LCZs. Linear statistical relationship was also analysed, which concluded that diurnal and nocturnal T_a and T_s are strongly correlated in all LCZs in Szeged.

Keywords: urban heat island; air and surface temperatures; MODIS; urban network

Introduction

Rapid urbanization profoundly affected local climatic conditions, thus investigating the urban thermal environment gained importance in order to better adapt to changing conditions. The phenomenon known as the urban heat island (UHI) effect is a consequence of artificial surfaces and anthropogenic activities. UHI has an impact on the urban environment, including energy consumption, human health, phenological phases, duration of snow cover.

It is essential to distinguish between urban heat islands that are measured in the near-surface air layer (T_a, denoted by UHI) and those measured on the surface (T_s, denoted by SUHI) (Oke et al., 2017). Its magnitude is usually determined by urban heat island intensity, which by definition means an urban-rural temperature difference, although the demarcation between “urban” and “rural” areas is not clearly objective, making it very difficult to compare values reported in the scientific literature. For SUHI monitoring land cover products (Zhou et al., 2013) and night-time light data (Fu & Weng, 2018) are commonly used to distinguish and specify these areas.

Local Climate Zone (LCZ) scheme is a comprehensive classification system, its elements (zones) are ’regions of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometers in horizontal scale’ (Stewart & Oke, 2012). As this framework is able to represent the specific thermal regime of intra-urban areas, more and more studies appear that use the LCZ system in urban climate monitoring (e.g. Unger et al., 2011; Yang et al., 2018). The set of LCZs is divided into two sub-sets:

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there are 10 built-up and 7 other land cover types, so they are very suitable for a fine and exact distinction between environments with urban and rural characteristics.

Several investigations (Bechtel & Daneke, 2012; Bechtel et al., 2015; Lelovics et al., 2014) focused on optimizing LCZ mapping methods and several studies followed them to develop and compare different classification procedures, considering local surface morphology (e.g. Geletič & Lehnert, 2016; Quan et al., 2017; Wang et al., 2018a; Hidalgo et al., 2019). These studies form four main groups: (i) GIS-based (Oliveira et al., 2020) and (ii) satellite-image-based classification, (iii) combined method, and (iv) expert-knowledge-based classification, as discussed in recent comprehensive review studies (Lehnert et al., 2021; Quan & Bansal, 2021).

Remote sensing imagery-based LCZ mapping supplies detailed urban morphology information for thermal characteristics analysis, and the usefulness was proved by a great amount of studies investigating LCZ–T_a relationship (e.g Yang et al., 2018). The mapping of LCZs expanded to many studies that focus on understanding the surface thermal characteristics. Some of them apply airborne measurements to assess the quality of LCZ classification, however it offers the opportunity for only short term detection (Skarbit et al., 2015; Bartesaghi Koc et al., 2018). Using thermal satellite images enabled to assess long-term and seasonal changes of the Ts in different LCZs (Gémes et al., 2016; Geletič et al., 2019), but their temporal resolution was low.

The World Urban Database and Portal Tool (WUDAPT 2021) was developed as an international synergy project to create a global high-resolution database that collects information on the urban form and function of cities worldwide using a universal, simple, and objective LCZ mapping method (Bechtel et al., 2015; Ching et al., 2014; See et al., 2015). Since then, this methodological framework has been successfully applied in mapping and thermal analysis studies. Bechtel et al. (2019a) conducted consistent and comprehensive inter-city SUHI analyses for 50 cities globally from MODIS (Moderate Resolution Imaging Spectroradiometer) and Landsat data. Significant Ts differences were detected within the built-up classes, confirming the suitability of the LCZ system and WUDAPT L0 data for SUHI analysis. However, considerable differences were found in the spatial distribution of SUHIs between cities, which can be explained by phenology, topography, and the influence of neighbouring LCZ classes.

Many other studies confirmed the strong LCZ–T_s relationship in urban regions in wet subtropical areas (Das & Das, 2020) as well as in arid areas (Wang et al., 2018b; Fricke et al., 2020) using WUDAPT methodology. Dian et al. (2020) applied remote sensing data to examine the spatial and temporal structures of T_s, and they concluded that the differentiation of LCZs by T_s depends on the time of the day in the case of Budapest. Du et al. (2020) combined LiDAR and satellite data to study the thermal behaviors of different LCZs and their results show that in Nanjing the thermal reactions of LCZs were more distinguishable by T_s in summer than in other seasons, and building height had a substantial effect on T_s.

Gholami & Beck (2019) revealed a significant relationship between LCZ and T_s on the basis of case studies from 25 cities worldwide with different climatic backgrounds. They investigated the influential drivers of the relationship when applying the WUDAPT concept, and their results demonstrated that latitude, mean and maximum annual temperature were the dominant modifier factors among the examined possible factors.

Another group of research (Beck et al., 2018; Oxoli et al., 2018) focused on the relationship between LCZ classes and air temperature. The analysis by Skarbit et al. (2017) aimed at comparing T_a in different LCZ classes, and their results show that the temperature parameters of compact LCZs exceed those of the other classes. Besides in-situ observations, T_a difference was examined also via mobil measurements (Stewart et al., 2014; Leconte et al., 2015) and high correlation was detected between LCZs and T_a.

In order to better understand the urban thermal environment, some articles aimed at combining T_s and T_a observations, and in parallel, compared the spatial and temporal variability of T_a and T_s, and sought to explore their relationship. Gallo & Owen (1999) investigated the relationship of urban-rural T_a–T_s–NDVI differences and they concluded that T_s is a useful predictor of monthly and seasonal T_a variables for the period from March to June. Yang et al. (2020) quantified UHI/SUHI difference simultaneously with five different indicators in Changchun (China), where light snows occur in winter. According to the results the land cover of the demarcated "urban" and "rural" areas has a substantial influence on UHI/SUHI intensity. Li et al. (2020) analysed the relationship between SUHI and T_a, and their results indicate that T_a has a spatially nonstacionary impact on SUHI.

However, it can be concluded that little effort has been made to investigate the complex relationship between LCZ–T_s–T_a using a large number of thermal remote sensing datasets, allowing detailed daily and monthly analysis of variation.

In this study, we focus on the analysis of thermal reactions between LCZs and the rural areas as well, as within the city using the example of a Central European city (Szeged, Hungary) based on 4-years (2014–2018) of simultaneous satellite and urban station network data sets. Our specific objectives are to:

1. collect MODIS thermal images with clear conditions and separate them according to months as well, as night and day;
2. collect simultaneous air temperature data from the urban station network of Szeged and separate them according to months as well, as night and day;
3. compare the obtained mean monthly (seasonal) diurnal and nocturnal Ts and Ta differences between the urban LCZs and rural areas.

Study area

Szeged (46.25°N, 20.15°E) with a population of 160,000 is the third largest city in Hungary locating on the Great Hungarian Plain (Figure 1a). Szeged is characterised by densely populated urban area with a concentric growth pattern and fragmented suburban areas (Figure. 1b). The core of the city is characterised by midrise buildings, and it is surrounded by warehouses, detached houses with gardens, and blocks of flats in the north-eastern direction. Its neighbouring rural area is utilized for cultivating different crops, but a few groups of trees are also found there. Its climate is Cfa by the climate classification of Köppen (1918) with the highest monthly temperature of 22.7 °C and the annual amount of precipitation of 508 mm (1986–2015, Harris et al., 2014).

Figure 1. The geographical location of Szeged in Hungary and Europe, and its aerial view (https://www.google.com/maps)

Data and methods

LCZ mapping and separating urban and rural areas

The applied mapping method uses freely accessible software (Google Earth and SAGA-GIS) and remotely sensed data (Bechtel et al., 2015), and it provides a globally objective classification (Bechtel et al., 2019b). The first step of the workflow is processing all the 11 spectral bands of Landsat-8 satellite images. The highest quality level Precision Terrain dataset of the Operational Land Imager and the Thermal Infrared Sensor instruments was downloaded from the Earth Explorer user interface of the U.S. Geological Survey (https://earthexplorer.usgs.gov). In order to represent the intra-annual surface changes, cloud-free Landsat-8 images were taken at three different times of the year, namely, on 24.06.2017, 27.08.2017 and 30.10.2017. Secondly, we need to resample the 30–100 m resolution Landsat-8 scenes to a common spatial resolution (100 m) in SAGA-GIS. The next part of the process is to delineate manually the training area polygons of the LCZ classes and the region of interest in Google Earth.

In SAGA-GIS an automated classification of Landsat images was conducted using random forest classification algorithm. If poorly classified areas are detected, we have to improve the training areas, and repeat the classification procedure as many times as necessary. In a final step, a majority post-filtering is performed with a given filter radius size to scan the neighbouring pixels around a central pixel. After testing different radius sizes, we selected 3 pixels in the current study, because this reduces noise, but meanwhile, it does not result in unreasonable generalisation at this city scale. The result of this workflow is an LCZ map of the study area (for more details see Fricke et al. (2020)).

Figure 2 shows the obtained LCZ map for Szeged. Seven different built-up LCZs were distinguished: 2 (compact mid-rise), 3 (compact low-rise), 5 (open mid-rise), 6 (open low-rise), 8 (large low-rise), 9 (sparsely built), and 10 (heavy industry). As it can be seen the built-up density is decreasing beginning from the downtown to the border of the city. The northwestern part of the city covered by LCZ 8 and LCZ 10 is located beyond the urban area (see later).

Around the city 5 different land cover types were detected: LCZ A (dense trees), LCZ B (scattered trees), LCZ C (bush, scrub), LCZ D (low plants), and LCZ G (water). The dominant land cover type of the surrounding area is LCZ D with low plants (Figure 2).

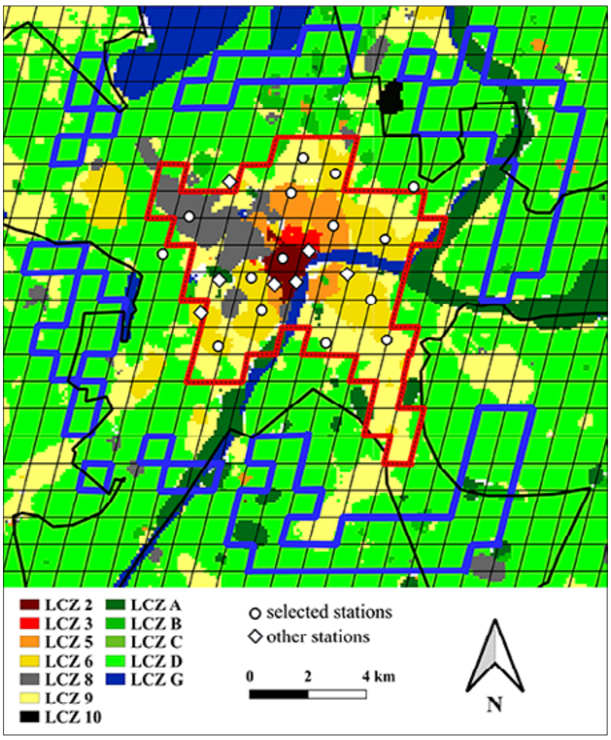

Figure 2. LCZ map shown on the MODIS grid covering the study area with administrative city border (black line), delineated urban (red line) and rural (blue line) polygons in and around Szeged (the elements of the 24-station network are marked by circles and squares)

Some parts of the low plant areas are under agricultural use, which means that they became bare soil temporarily within the year, thus bare soil and low plant areas are merged into LCZ D. As we used multiple satellite images from different dates, the merging of the two zones simplifies the classification.

To make a comprehensive study we identified urban and rural areas using the obtained LCZ map. In QGIS we assessed the ratios of individual LCZ classes for each MODIS tile. Urban and rural tiles are determined by different criteria which are specified in Fricke et al. (2020). We considered tiles as urban tiles if they are covered by mostly built-up LCZs and during selection of rural area we eliminated significant effects of built-up areas, water bodies or substantial topography (Table 1).

Table 1. Specification of urban and rural tiles

Urban	Rural
• include min. 55% built-up LCZs • cells form coherent area • located within the administrative border	• mostly uninhabited • located at least 2 km from the urban boundary • must contain less than 1% of total building surface fraction

Source: Fricke et al., 2020

Land surface (T_s) and air (T_a) temperature

In this paper MOD11A1 (V6) MODIS/Terra and MYD11A1 (V6) MODIS/Aqua Land Surface Temperature and Emissivity Daily L3 Global 1 km Grid SIN products were used to investigate surface thermal properties. Data were obtained from the summer of 2014 to the spring of 2018 for the study area. Sensor MODIS measurements are available from both solar-synchronous satellites Terra and Aqua as part of the American National Aeronautics and Space Administration's Earth Observing System. The MODIS sensor measures radiation in 36 electromagnetic spectral bands with different spatial resolutions (NASA, 1999). T_s retrieved from the raw MODIS radiation data by split window algorithm, which corrects the atmospheric effects using multiple bands on the sensor MODIS (Wan & Snyder, 1999). This method is less sensitive to uncertainty in emissivity over wide ranges of surface and atmospheric conditions resulting in improved data quality.

Both Terra and Aqua images consisted of one day- and one nighttime scenes with acquisition times approximately 9–10 a.m., 8–9 p.m. (Terra), 2–3 a.m. and 12–13 p.m. (Aqua). Since anticyclonic, cloudless weather situations enable us to examine the local-scale thermal patterns, only the images that contained 100% data coverage within the delineated urban and rural areas ofSzeged.

The air temperature (T_a) data came from the urban monitoring network of Szeged, similar to the one in Novi Sad, Serbia (Šećerov et al., 2019). It was established to provide long-term T_a and relative humidity datasets from various parts of the city representing different local environments. The selection and installation of 24 station sites considered the spatial pattern of the LCZs in order to gain representative temperature datasets for these zones (see Figure. 2). 22 stations settled in the urban area of the city, while stations D-1 and D-2 are situated in its rural surroundings (for more details see Skarbit et al. (2017)).

We selected those T_a stations as urban stations, which are located in MODIS cells with more than 55% coverage by a particular built-up LCZ class and we considered D-1 and D-2 stations as representatives of the rural area. The selection provided one station in LCZ 2, two stations in LCZ 5, six stations in LCZ 6, one station in LCZ 8, and three stations in LCZ 9 within the urban area (Figure 2).

Calculation, evaluation and comparison of daily and monthly variation of T_s and T_a

From the measurements of the selected stations, the hourly means of T_a were retrieved for the acquisition times of sensor MODIS. Those stations were selected where the built-up LCZ coverage exceeded 50% in a MODIS pixel. Missing data were filtered out and only the simultaneous measurements of a particular MODIS pixel and its inherent T_a station were taken into account during the further computations. For LCZs (5, 6 and 9) with more than one station, the collected data were averaged. The T_s and T_a data were separated into diurnal and nocturnal groups on the basis of the forenoon/afternoon and night/dawn MODIS images, and the simultaneous T_a data, respectively.

As the first step, we calculated the monthly mean diurnal and nocturnal T_s and T_a differences between urban LCZs and rural areas ($\Delta T_{s(LCZx\text{-}r)}$) and $\Delta T_{a(LCZx\text{-}r)}$, respectively). Then, these mean diurnal and nocturnal values were compared for each month, and the retrieved differences of the thermal reactions of surface and air by LCZs were analysed and explained (see later Figures 3 and 4).

As the second step, the annual variations of T_s and T_a were demonstrated on box plots for LCZ 2 and LCZ D as they respresent the most different (densely built up and rural) land cover (see later Figure 5).

As the third step, linear statistical relationships between all available T_s and T_a values were revealed and evaluated by LCZs (see later Figure 6).

Results and discussion

In this section several analyses were undertaken to reveal the relationship between the different thermal characteristics as well as between these thermal characteristics and LCZ classes.

Comparison of daily and monthly intra-urban thermal reactions

Figure 3 shows the annual variation of diurnal and nocturnal thermal differences measured in surface temperatures between different urban LCZs and the surrounding rural area of Szeged. Figure 4 presents the annual variation of the T_s–T_a differences by LCZs both in daytime and nighttime.

It can be immediately seen in Figure 4, that during the day T_s was much higher than T_a (especially in the warm half-year). At night, the opposite was detected in all zones, with the air being warmer than the surface, although not to the same extent as during daytime. No substantial T_a difference was observed between urban LCZs and rural areas in daytime (Figure 3a). Urban LCZs are mostly cooler by around 1 °C, and the differences are almost constant throughout the year, with a few exceptions (e.g., LCZ 8 in February, LCZ 6 in April).

The largest T_s difference (4.1 °C) was observed between LCZ 2 and the rural area during daytime in June (Figure 3b). While the Ts difference between LCZ 2 and rural area changed by the seasonal variation of the solar irradiation, a relatively slight seasonal variation was observed in T_s in other zones. In September and October, the largest $\Delta T_{s(LCZx\text{-}r)}$ was observed in LCZ 8, which is mostly dominated by large shopping centers and industrial buildings. From late autumn to late winter, there was no considerable Ts-difference between individual LCZs, presumably due to the more insignificant vegetation typical for this period (Figure 3b).

The highest T_s–T_a difference (9.7 °C) was found in LCZ 2 during daytime in May, and T_s was more than 7 °C higher compared to T_a from April to August, while the lowest T_s–T_a difference was observed for LCZ D and LCZ 9, which consist mostly of green areas (Figure 4).

At night, $\Delta T_{a(LCZx\text{-}r)}$ is consistent with the built-up density: the difference increases with building density, so that the largest difference occurs almost throughout the year between LCZ 2 and the rural area (Figure 3c). LCZs 5 and 8 are the second warmest zones followed by the LCZs 6 and 9. The seasonal variation of the nocturnal $\Delta T_{a(LCZx\text{-}r)}$ is relatively large compared to the daytime situation (Figure 3a).

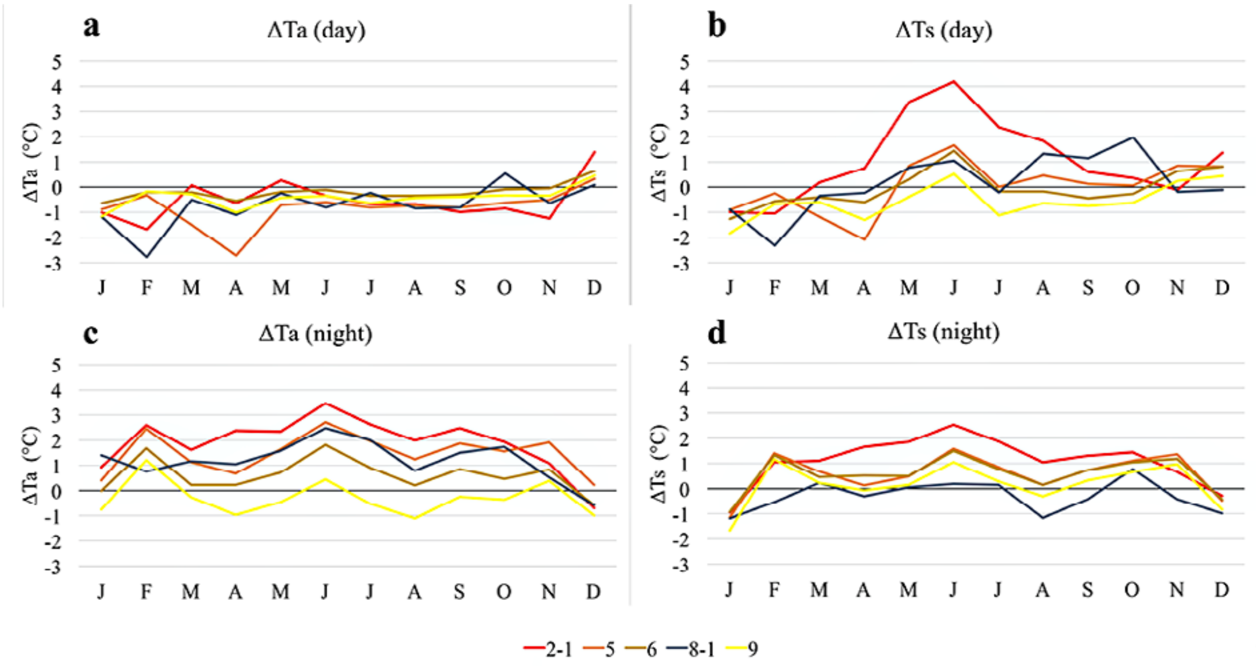

Figure 3. Annual variation of the diurnal (a, b) and nocturnal (c, d) LCZ vs. rural thermal differences detected in surface ($\Delta T_{s(LCZx\text{-}r)}$) and air ($\Delta T_{a(LCZx\text{-}r)}$) temperatures (Szeged, clear days, 01.06.2014 – 31.05.2018)

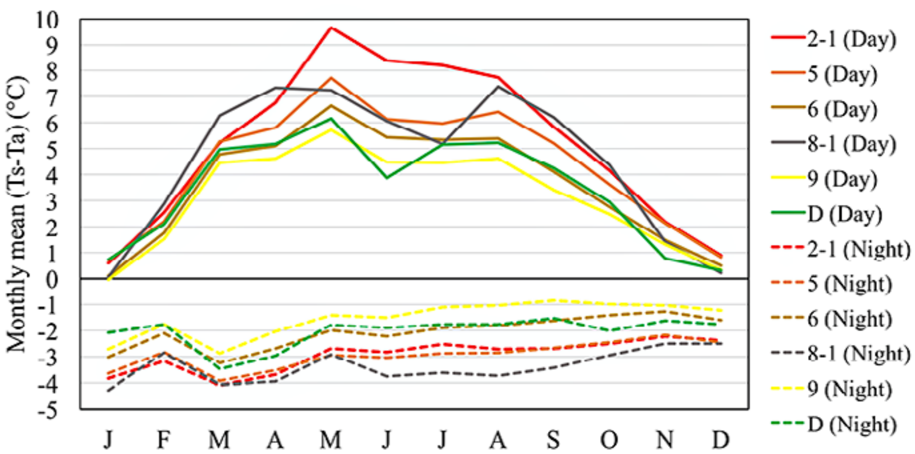

Figure 4. Annual variation of the diurnal and nocturnal T_s–T_a differences by LCZs (Szeged, clear days, 01.06.2014 – 31.05.2018)

Regarding the nocturnal dynamics of $\Delta T_{s(LCZx\text{-}r)}$, there were only small differences between the LCZ classes (Figure 3d). From February to October, the LCZ 2 was at least 1 °C warmer than the rural area, however, the difference exceeded 2 °C also in June.

Seasonal thermal reactions of LCZ D and LCZ 2

The thermal effects of the built-up differences were investigated among the LCZs having the most diverse surface properties (LCZs D and 2), comparing the obtained seasonal T_a and T_s values. In Figure 5, the boxplots of these LCZs show the median values of the measured and seasonally averaged absolute T_s and T_a values as well, as their distribution (showing quartiles and extremes) and outliers (indicated by open circles). It can be clearly seen that during the day, the absolute T_a and T_s values increase with seasonally increasing insolation for both LCZ 2 and LCZ D. In addition, the T_s values are mostly higher than the T_a values during daytime, while the T_a exceeds the T_s at night, regardless of the season.

The diurnal T_a and T_s values show greater variability in spring and autumn than in other seasons as the thin vertical lines between the extremes cover relatively broader intervals (Figure 5). Most outliers were observed in winter in both LCZs, however, the two LCZs' thermal reactions were less distinguishable then. The LCZ D and LCZ 2 are well distinguished during daytime in summer: the T_s values vary between 24.5–44.5 °C and 26.6–46.5 °C in LCZ D and in LCZ 2, respectively.

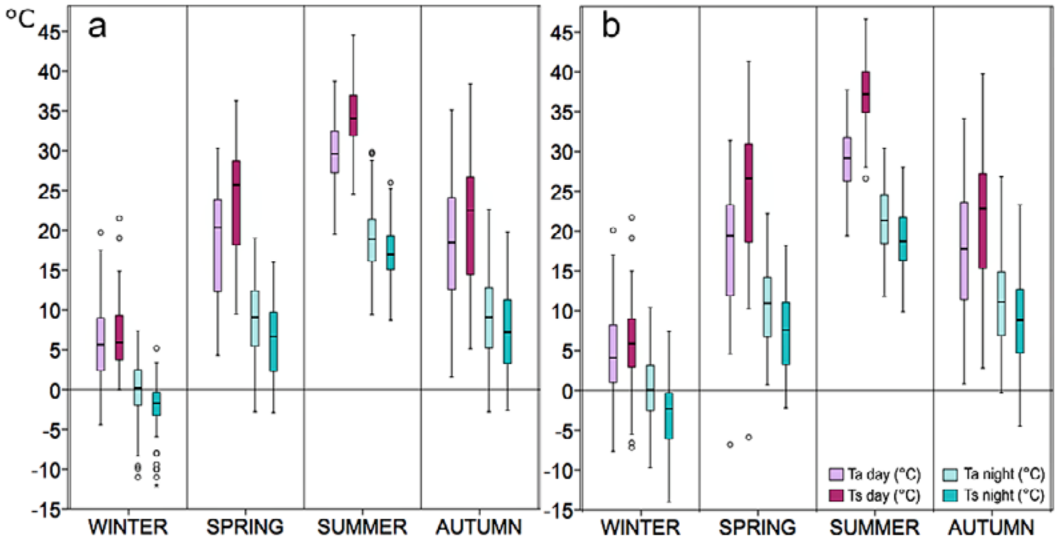

Figure 5. Annual variation of the diurnal and nocturnal thermal reactions of (a) LCZ D and (b) LCZ 2 detected in surface (T_s) and air (T_a) temperatures, as examples (Szeged, clear days, 01.06.2014 – 31.05.2018)

Linear statistical relationships between surface and air temperatures

Figure 6 shows the scatter plots of the correlation between the parallel T_s and T_a records of MODIS and urban stations in each LCZ during day and night. According to these, strong linear relationship can be detected in each LCZ both day and night in the study area. LCZ 5 (Figure 6b), LCZ 6 (Figure 6c) and LCZ 9 (Figure 6e) contain more than one station, which obviously results in more observation pairs than LCZ 2 (Figure 6a), LCZ 8 (Figure 6d) and LCZ D (Figure 6f). The coefficients of determination (R^2) were very high, ranging from 0.92 (LCZ D) to 0.982 (LCZ 5) during daytime, and slightly lower at night, between 0.912 (LCZ 9) and 0.959 (LCZ 2).

Hereher and El Kenawy (2020) also reported strong correlations between the monthly daily and nocturnal T_s and the minimum as well, as maximum T_a values. Similar results were also concluded in many other studies (e.g. Zhu et al., 2013; Chen et al., 2016). The derivation of the diurnal linear regression changed around 0.8, while the nocturnal derivation was above 0.9. The diurnal T_s is generally higher than diurnal T_a, while T_a and T_s values are quite close at night.

Conclusions

This study classified LCZs in and around Szeged using Landsat 8 satellite images based on the WUDAPT method. As a result, 7 different built-up LCZs were recognised in the urban area of Szeged. T_a values are retrieved from the urban monitoring network of Szeged, while the T_s database was provided by MODIS.

Simultaneously measured T_s and T_a values were compared in each MODIS pixel that contained at least one T_a station and had more than 50% coverage of a built-up LCZ. Seasonal and monthly variations in thermal differences in the built-up LCZs were analyzed, and T_s values were generally higher during the day, especially in summer, while T_a at night mostly exceeded T_s in all LCZs. The nocturnal LCZ–rural differences of T_a increased with increasing built-up density, while T_s showed the same pattern, both during day and night. Over the four-year period studied, the highest mean T_s difference (4.1 °C) ***was observed*** between LCZ 2 and the rural area, during daytime in June. Seasonal variation of thermal properties were investigated between LCZ 2 and LCZ D as these LCZs represent the most densely built-up urban and the most dominantly present rural LCZs, respectively. The results show a high thermal contrast, especially in summer and spring during the daytime period. Analysis of the T_s–T_a correlation showed that a strong linear relationship was observed in all LCZs day and night.

Results show that built-up density and the amount of vegetation has a considerable effect on the thermal pattern of the urban and the surrounding areas. Adding more vegetation, replacing artificial surface to natural would decrease local and microscale differences. In addition prefering lower built-up density in urban planning would also mitigate urban heat island effect. Expected increasing global temperature and heat waves associated with climate change will enhance this urban-rural contrast, which has also negative impacts on human thermal comfort and energy

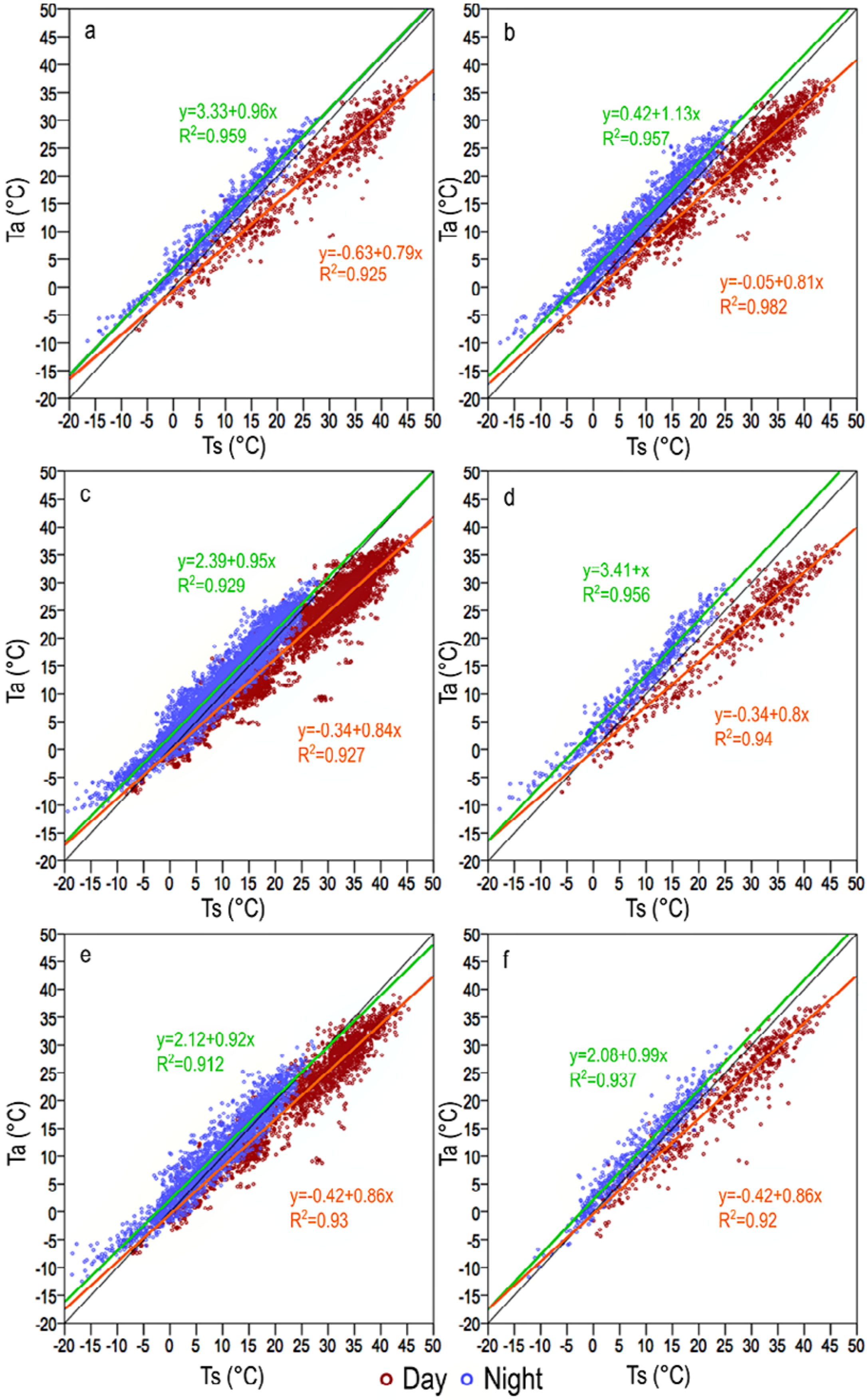

Figure 6. Linear regression relationship (orange lines: day, green lines: night) fitted between surface (T_s) and air (T_a) temperatures by LCZs (a – LCZ 2, b – LCZ 5, c – LCZ 6, d – LCZ 8, e – LCZ 9, f – LCZ D) (Szeged, clear days, 01.06.2014 – 31.05.2018)

consumption. Increasing temperatures will become more intolerable for urban inhabitants in the densely built-up regions of the cities, while people who live in areas of openly arranged buildings will experience less heat excess. For this reason preffering open city structure during urban planning and improving resilient infrastructures by local government would mitigate these disadvantageous effects and it would help in adaptions to ongoing climate change.

This paper was the first step of our extended research on T_s-T_a relationship therefore we examined it only one urban area (Szeged). In the future our aim is to accomplish a larger scale investigation with more cities in Central Europe to find different relationships between the studied thermal variables using statistical models which would enable us to assess the UHI effect also in cities where urban monitoring network is not available.

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Identification of Factors Influencing the Quality of Life in European Union Countries Evaluated by Principal Component Analysis

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Abstract

In the paper we evaluate the quality of life in European Union countries. The introductory database is made up of 19 variables which, in our view, appropriately capture numerous spheres of human life. The reference date for this data, taken from the Eurostat database is April 10, 2021. The Principal Component Analysis that we have used in this paper is not rare in the conditions of multivariate statistics, however, when evaluating the quality of life, it is not much used. Many authors dealing with the topic take advantage of the traditional questionnaire survey and the points-based approach when analysing data. Our objective was to demonstrate that the Principal Component Analysis can be used in evaluating quality of life, especially if it is necessary to evaluate a significant number of variables and select factors with the highest impact. Apart from the main objective - the identification of factors most impacting the quality of life in European Union countries, we also focused on the comparison of countries as per particular main factors and searched for what caused differences between them. Quality of life is also reflected in the subjective perception of responders' happiness. We were concerned to know whether the evaluated data would indicate that the feeling of happiness increases along with prosperity, or does not depend on growing prosperity at a certain stage.

Keywords: Eurostat; European Union countries; quality of life; Principal Component Analysis

Introduction

While many European countries and their societies underwent significant economic, political and social changes in the 1950s, the countries of the former Eastern Bloc accelerated and fundamentally transformed only at the beginning of the 1990s. These cardinal changes resulted in the growth of social prosperity and general economic prosperity on the one hand, however, on the other, did not always result in the growth of people´s satisfaction with their own life.

From this point of view it is not possible to explain the overall level of (un-) satisfaction in a population by material good only, but it is necessary to see the problem in a wider context. The imaginary mathematical equation then comprises also other important spheres using variables such as health, environment, psychological, social, relational sphere etc. The approach that absorbs all these important elements is the concept of quality of life which, according to Macků and Voženílek (2019), represents an extensive field closely

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connected with human existence. It is a focus of many scientific disciplines, social, medical and natural and nowadays attracts numerous researchers. The term is being developed in several academic disciplines, such as economics, psychology, sociology and geography. (Madziková et al., 2015).

Our article concentrates on the quality of life in European Union (EU) countries and we attempt to identify the factors that influence their quality of life the most based on a set of selected indicators from the Eurostat database using Principal Component Analysis (PCA) – one of the methods of Factor Analysis. At the same time we concentrate on comparison of countries or groups of countries according to their similarities or differences from the main factors' point of view and endeavour to establish the causes of these differences.

Theoretical Background

The inconsistency between objective growth and prosperity on the one hand and not always satisfied people on the other, mentioned above, can be explained by the following fact: Progress and prosperity has often been and still is looked at only through the optics of economic growth usually expressed by the complex indicator of gross domestic product (GDP). It is, according to Nohlen and Nuscheler (1992, in Maier & Tödtling, 1998), just one of five elements of development. GDP is very often that factor which is considered the most important and determinant indicator of prosperity and perceived by the lay public as something that needs to consistently "grow". However, in recent years more and more attention has been drawn to its shortcomings and limitations (e.g. Cummins et al., 2003; Matlovič & Matlovičová, 2005, 2011; Sloboda, 2006; Žúdel et al., 2007; Buček et al., 2010; Giannetti et al., 2015; Prasad & Castro, 2018; Figueres & Rivett-Carnac, 2020; etc.). Adler (2009) mentions the following problems when using it: GDP monitors economic progress, but not the progress of people´s prosperity within a society; progress and prosperity of a society as complex quantities cannot be monitored by only one number represented by GDP; GDP does not retain partial components of prosperity of a country; GDP fails in the distribution of income and wealth in a country; although GDP grows, the number of happier and more satisfied people might decrease. D´Agostino et al. (2021) point out that in addition to economic indicators (especially GDP), new innovative indicators are needed to assess social progress which would better reflect various aspects of individual quality of life.

According to several researchers, the policy of each country should focus more on people´s satisfaction with their life and their happiness rather than on the economic growth of the country itself (Sachs, 2012 in Helliwell et al., 2012). Life satisfaction, subjective well-being and happiness in evaluation of quality of life are all emphasized in the works of Glaser et al. (2016), Novianti et al. (2020) and Đerčan et al. (2017). It is confirmed that the level of satisfaction with life does not grow automatically with the growth of prosperity. Mlčoch (2005) states that economists name the relationship between growing material prosperity and stagnating even decreasing subjective happiness as the "Easterlin Happiness-Income Paradox". Similarly, Pacione (2003) warns that quality of life is not necessarily a simple function of material wealth. He calls it the "Prosperity Paradox".

That is why, when assessing countries and regions, it is important to take into consideration the widely understood concept of quality of life and the existence of its two essential dimensions, namely, an objective dimension (public, social, environmental), and a subjective one (individual, personal and private). Quality of life can be understood as a result of the mutual impact of these two dimensions or of the mutual interaction between the external impacts and the internal "environment" of a person (Andráško, 2005; Ira & Andráško, 2007; Ira & Murgaš, 2008; Ira, 2010; Rišová, 2016; Klamár & Gavaľová, 2018). Similarly, Dissart and Deller (2000) wrote that quality of human life depends on exogenous (objective) life factors and their endogenous (subjective) perception. For the first dimension of quality of life, the psychological one, Massam (2002, in Ira & Andráško, 2007) uses alternative names such as individual/personal quality of life, subjective welfare and satisfaction with life. The second dimension, the environmental one, is known variously as urban quality of life, residential quality of life, community quality of life or quality of location.

Based on the above, it is evident that, when assessing quality of life, it is misguided to take into consideration only a one-dimensional economic indicator like GDP, however complex it is. In this context Andráško (2008a) mentions that, to a certain extent, it is a paradox that indicators of economic prosperity and welfare were the ones that stood at the beginning of the growth of "society-wide" interest in quality of life.

Quality of life as such cannot be measured or expressed directly but can be done only indirectly via elements also known as indicators, components, criteria, agents, domains etc. (Murgaš, 2009; Ira & Šuška, 2006; Godor & Horňák, 2010).

Fahrenberg et al. (2000, in Džuka, 2004) defined ten elements of life and individual satisfaction with them: health, work, financial situation, free time, marriage and partnership, relations with children, satisfaction with oneself, sexuality, friends and relatives, and housing. Within a WHO (World Health Organization) project entitled "Measuring Quality of Life" six domains were defined: physical health, mental health, level of independence, social relations, environment, spirituality (religion) and personal persuasion (Ištok & Angelovič, 2012). When evaluating the quality of life in Standard Metropolitan Statistical Areas in the United States Liu (1976, in Dissart & Deller, 2000) used 123 factors and variables that were measured through five different quality-of-life components: economic, political, environmental, health and education, and social. Similarly, Amin et al. (2021) used 4 sub-indexes to assess quality of life in the United States: physical and social environment subindex, economics subindex, health subindex and natural environment subindex.

Several papers have assessed the quality of life in European countries. In the case of 28 EU Member States supplemented by other selected European countries, Macků and Voženílek (2019) evaluated five aspects (economic power and material security, health, social environment, education and environment) and defined 13 indicators. Lagas et al. (2015) used nine indicators to assess regional quality of life in Europe: public services, purchasing power and employment, housing, social environment, natural environment, recreation, health, education, governance. Liargovas and Kratimenou (2020) used a set of the following indicators to monitor the quality of life convergence in the EU: population density, GDP per capita, long-term unemployment, household consumption expenditure per capita and electric power consumption, services, health, education, natural and urban environment, infrastructure. Sanchez-Sellero et al. (2021) classified within the subject matter five dimensions of quality of life: subjective component of governance, public services, environment, general satisfaction with life, and socioeconomic issues. When assessing the quality of life in Slovakia and its regions Ira (2005) grouped the monitored indicators into six dimensions: demographic, material comfort and social securities, household equipment, environment, security, and educational-informational; Ira and Šuška (2006) used a set of 26 indicators in five domains: location and accessibility, housing and household equipment, environment, demographic, and economic; and Murgaš (2009) in three domains: prosperity, deprivation, and human capital.

From the overview above it is evident that when assessing quality of life it is important to couple objective indicators with subjective ones. This has to be done while bearing in mind their character and statistical source.

Methodology

The objective of this article is to identify the factors that most significantly influence the quality of life of people in EU countries.

The object of the assessment was selected indicators (further referred to as features or variables) that were divided into the following groups in keeping with Eurostat methodology (in the thematic part Quality of Life):

- **factors of material living conditions** – net income in PPS (Purchasing Power Standards) (**A**), main GDP aggregated per capita in PPS (**B**), households making ends meet with great difficulty (**C**),
- **productive and other main activities** – persons reporting a work-related health problem (**D**), persons reporting an accident at work (**E**), long term unemployment (**F**), employment rate (**G**),
- **economical safety** – inability to face unexpected financial expenses (**H**), arrears (mortgage or rent, utility bills or hire purchase) from 2003 onwards - EU-SILC (European Union Statistics on Income and Living Conditions) survey (**I**),
- **health** – healthy life years (**J**), frequency of heavy episodic drinking at least once a week (**K**), time spent on health-enhancing (non-work-related) aerobic physical activity-300 minutes or over (**L**),
- **education** – education (**M**),
- **social interactions** – frequency of contact with family and relatives several times a month (**N**), frequency of getting together with friends several times a month (**O**),
- **living environment and physical safety** – pollution, grime or other environmental problems (**P**), noise from neighbours or from the street (**Q**), crime, violence or vandalism in the area (**R**),
- **life satisfaction** – percentage of population rating their satisfaction as high (**S**).

In the case of monitored indicators we used available input data from the Eurostat database mainly covering the situation in 2018, as some of the data were not available for 2019 (or newer). In some of the cases it was necessary to use even earlier data. Therefore, the reference year is given in Table 1 after the name of the variable.

Principal Component Analysis (PCA) was used to identify the factors influencing quality of life in the

EU. Although it is a quite frequently used method of multi-dimensional analysis, it has not been used very much when assessing quality of life so far (applied e.g. in papers by Andráško, 2008b; Macků & Voženílek, 2019). The main advantage of this method is in its analysis of a small number of uncorrelated **principal components** representing the linear combination of original features instead of examining a high number of original features (variables) with complex internal bonds (Bartholomew, 2010). The largest part of information about variability of original features is hidden in the first principal component and the smallest in the last one. The components are arranged in order of decreasing variance (Bartholomew, 2010).

The standard process in Principal Component Analysis is the decrease of dimensionality of the space or the reduction of features so that information does not get lost. The model of principal components is as follows

$X = TP^T + E =$ *data structure + noise*,

where X is the source data matrix, T is the component score matrix, P^T is the transpose matrix of component weights and E is the matrix of residues (see Meloun et al., 2012). The role of PCA is to analyse the product TP^T presenting the data structure instead of the matrix X itself. Matrix E is the noise matrix or the matrix of residues that is not classified by the PCA model.

The principal components have a common beginning that corresponds to the centre of cluster of objects (in this case the states of EU). In order to calculate a suitable number of principal components we employed a table of eigenvalues supplemented by a graphic representation via the **Cattel Index Graph of the Base of Eigenvalues** where the principal components are separated from the unimportant ones (representing the bottom of the graph) by an evident drop. In this practice, the Kaiser criterion is used as well, according to which the factors (principal components) corresponding to eigenvalues higher than 1 are considered to be statistically significant. In order to identify the suitable number of factors, a percent variance criterion is used too. In natural sciences it usually achieves about 95% of covered variance; in human sciences it is about 60% (Meloun et al., 2012).

In our case the PCA has been provided by the help of software Statistica 13.0. After reducing the number of variables, we calculated the component weights and component score.

The Graph of Component Weights (loads) can be viewed as a bridging of the original features and principal components and demonstrates the intensity of dependence between variables and their importance. The graph shows how the original features contribute to the principal components. The features placed close to the beginning are of small importance whereas features with a high level of variability in objects have more significant component weights. In the 2D graph of the first two principal components they are placed far from the beginning of the coordinate system. In cases where the difference in the clarification of the original features between the first and the second principal component is significant, the original features of the high weight in the first principal component will be more important than the features with a high weight in the second. The features placed close to each other on one side towards the beginning with a small angle between the respective position vectors of features have high positive correlation. The features with a 0° angle between position vectors show strong positive correlation, the features of a 90° angle are uncorrelated and those of a 180° angle are negatively correlated (Bartholomew, 2010).

The Graph of Component Score shows clusters of objects (EU countries) of similar qualities from the view of monitored characteristics. The objects located far from the beginning of the coordinate system represent the extremes. From the graph it is possible to identify isolated objects, as well, which can be distant. Normally, the component score is expressed for the first two principal components (Bartholomew, 2010).

The comparison of the graph of component weights and that of component score refers to the coupling between factors and respective objects (EU countries). It helps to understand connections between the closeness of the object and the respective factor.

Results and Discussion

The issue of assessing quality of life is problematic for two main reasons. The first is its content demarcation: so far there has been no generally acceptable definition of it. The second is its measurability: until now, no indicator has appeared that would capture quality of life in its complexity (Holková & Veselková, 2019). The essential problem of the last few decades has been well presented by Macků and Voženílek (2019) who declare that research in the sphere of quality of life has focused on the calculation of aggregated numerical indicators – indexes that in many cases (e.g. Distaso, 2007; Murgaš & Klobučník, 2016) are easily perceivable and comparable but do not enable us to understand wider connections and the core of the evaluated problem.

Our research concentrates on the identification of factors using the PCA method. Thanks to this approach it is possible to perceive the mutual relation between the variable and the object and thereby eliminate the author´s subjective feelings that are often present when assessing quality of life. At present, we can see a certain shift in ways of assessing quality of life as there are papers that see the PCA method as a suitable tool to interpret the results of research – see e.g. Pöldaru and Roots (2014), Singh (2015), Finch et al. (2017). In this context, we can also mention the paper of Rao et al. (2012) who used the Factor Analysis to interpret input parameters for assessing the quality of life index. Generated indexes were further processed to estimate the overall index of quality of life in Uttarákhand, India.

Decrease of the Dimensionality of the Space and Selection of Principal Components

The Cattel Index Graph of the Base of Eigenvalues (Figure 1) shows that a significant breaking of the curve can be seen with number five. The first five principal components clarify 77.8% of variance of the original variables. According to the Kaiser Criterion which identifies significant and insignificant factors we might speculate about six principal components that together clarify 83.2% of data variability. It serves the most reliable results for 20 up to 50 original features. In the case of a lower number of factors, as here, an incorrect tendency to compile too many factors might appear (Meloun et al., 2012) hence a graphic representation in the form of the Cattel graph is essential. As mentioned in Meloun et al. (2012), with regard to the social-scientific character of the data and the objective of assessment, we may consider the threshold 77.8% of covered variance sufficient. To compare, for example in the paper written by Macků and Voženílek (2019), via the robust PCA the authors identified three principal components that cover 68% of variance. The first component explained 27.5% of variance in data, the second 23.9%, and the third 16.8%. When assessing quality of life, Birčáková et al. (2016) accepted eight principal components with total variability of almost 53%. Taking into consideration the number and the character of variables the authors considered it sufficient. Similarly, when assessing the internal structure of Bratislava from the quality of life conditions point of view, Andráško (2008b) also identified eight principal components that involved more than 83% of the total variance of original variables.

After decreasing the dimensionality of space to a 5-dimensional one, the factor loadings were calculated. Values lower than 0.3 (expressed in absolute value) were considered insignificant. Attention was drawn to the variables whose contribution to the relevant factor was the most significant.

Graph of Component Weights or Loadings (Figure 2) shows the first two factors that may clarify the biggest part of variance of the original variables (35.6% of the variability of the original variables by the first factor, by the second factor 18.1% of variability of those uninvolved in the first factor). The variables with a lower level of significance, such as P (pollution, grime or other environmental problems) and D

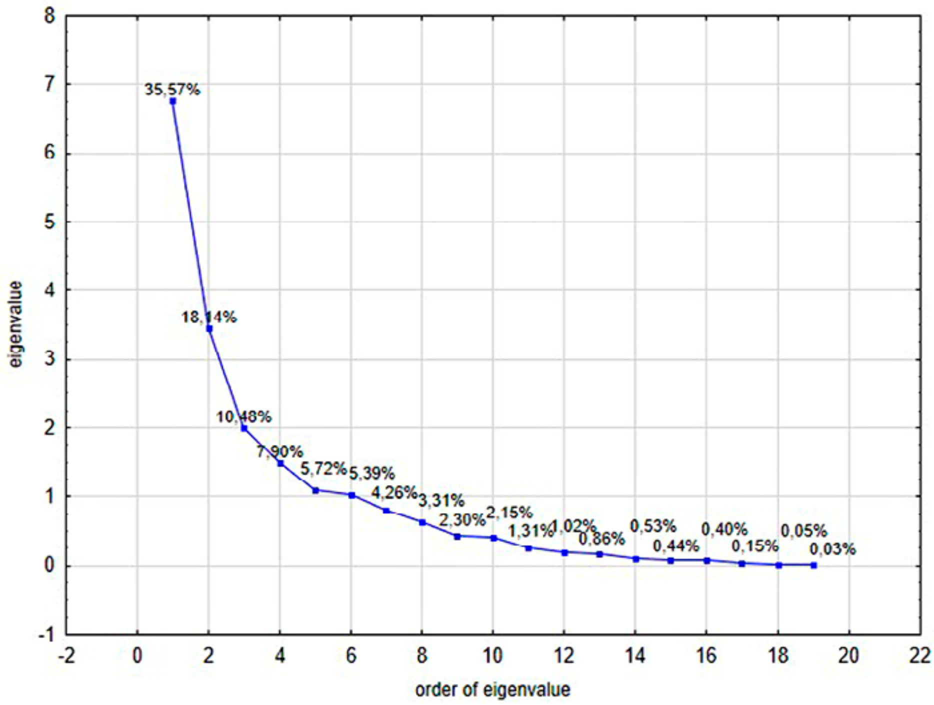

Figure 1. Cattel Index Graph of the Base of Eigenvalues
Source: Own calculation

(persons reporting a work-related health problem) are displayed in the graph of projection of variables closer to the beginning of the coordinate system; variables with higher significance are closer to the circle. The angle between the respective variables indicates the intensity of correlation.

The projection of variables into a factor level made from the first two factors revealed that the highest factor loadings (in absolute value) were identified by variables A – net income in PPS (0.8847, Table 1), L – time spent on health-enhancing (non-work-related) aerobic physical activity - 300 minutes or over (0.8450), and B – main GDP aggregated per capita in PPS (0.8385). Variables C – households making ends meet with great difficulty and I – arrears (mortgage or rent, utility bills or hire purchase) from 2003 onwards, were strongly positively correlated (0.93, Table 3). This was similar in the case of variables A – net income in PPS, and B – main GDP aggregated per capita in PPS (0.92). A close relation was also shown between education and net income or level of GDP (in both cases the correlation was 0.52), what corresponds to findings of Simonescu et al. (2021).

The square of factor loadings expressed the volume of the total variance of a feature explained by a corresponding factor. As much as 69.7% of the clarification of the variance of the original feature expressed by **factor 1** could be observed in variable S – percentage of the population rating their satisfaction as high. Variable C – households making ends meet with great difficulty, reflects worsened economic problems of a family, where the square of the factor loading reached 0.609. This corresponds to 60.9% of the clarification of the variance via factor 1. Even variables E – persons reporting an accident at work, F – long term unemployment, G – employment rate, H – inability to face unexpected financial expenses, I – arrears (mortgage or rent, utility bills or hire purchase), and K – frequency of heavy episodic drinking, have a negligible impact on the mentioned factor; the absolute value of Pearson correlation coefficient in all of these variables is higher than 0.58 and the determination coefficient reached the value higher than 0.33 here (Table 1). Along with the above variables that significantly contribute to factor 1, it would be possible to sum up the observed and name **factor 1** as **material-economic conditions**.

Factor 2 clarifies more than 59% of the variance of variable N – frequency of contacts with family and relatives several times a month, and 57.7% of the variance of variable O – frequency of getting together with friends several times a month, with a high positive correlation (0.69, Table 3). Significant contributions to the factor 2 are also evinced by variables J – healthy life years (0.2063), and R – crime, violence and vandalism in the area (-0.6237) - see Table 1, Figure 3. Also variable F – long term unemployment, makes some contribution to factor 2 (correlation -0.5826). A close interconnection between long-term unemployment (F) and the ability to provide for the family´s essential existential needs (C) is reflected by a high level of positive correlation (0.75). Long-term unemployed persons have substantial problems handling the economic situation and ability to provide for their family. This can be seen from the medium-high negative dependence between overall satisfaction with life (judged based on subjective feelings) and long-term unemployment (-0.44). Despite the fact that the majority of detection of variable I – arrears (mortgage or rent, utility bills or hire purchase) from 2003 onwards, falls to factor 1, this can be partially explained by factor 2 (22.2%), that negatively correlates with variables G – employment rate (-0.58), A – net income in PPS (-0.50), B – main GDP aggregated per capita in PPS (-0.45), and positively correlates with variables C – households making ends meet with great difficulty (0.93), F – long term unemployment (0.67), and H – inability to face unexpected financial expenses (0.55) - see Table 2. Even though factor 2 totally clarifies 38.9% of the variance of variable R – crime, violence or vandalism in the area, according to data analysed, it has almost nothing to do with long-term unemployment (correlation of 0.10, Table 3). Considering and summarizing the facts above, we would name **factor 2** as **social contacts and existential issues**.

Unquestionable contributions to **factor 3** can be seen in variables P – pollution grime or other environmental problems (0.8661), and Q – noise from neighbours or from the street (0.6577) - see Table 1, Figure 3. Both are strongly positively correlated (0.65) and reflect a negative impact on the quality of human environment. Other variables´ contributions to factor 3 are less notable or even negligible. That is why we can name **factor 3** as **environmental issues and quality of environment** in order to sum up our observation.

Factor 4 detects 60.5% of the variance of variable D – persons reporting a work-related health problem, and 37.1% of the variability of variable K – frequency of heavy episodic drinking. Strong episodic alcohol consumption has some influence on occupational diseases (correlation -0.34) and lower alertness at work (correlation of 0.36 with variable E – person reporting an accident at work), but regarding the negligible contribution (0.1159) of variable E to factor 4, we do not see it as significant (Table 1). With respect to the above, we could name **factor 4** as **healthy limitations related to work and alcohol consumption**.

The last factor we identified from a debris graph as a significant one was **factor 5** named **criminality**. It detects 27.5% of the variance of variable R – crime, vi-

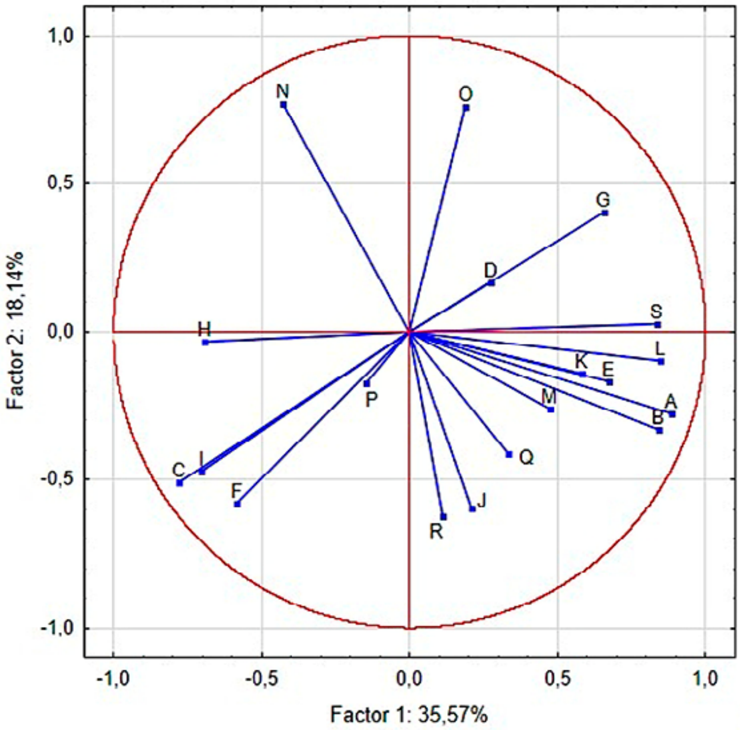

Figure 2. Projection of variables into the factor plane

Notes: **A** – net income in PPS, **B** – main GDP aggregates per capita in PPS, **C** – households making ends meet with great difficulty, **D** – persons reporting a work-related health problem, **E** – persons reporting an accident at work (from 15 to 64 years), **F** – long term unemployment, **G** – employment rate (age level 20-64 years), **H** – inability to face unexpected financial expenses, **I** – arrears (mortgage or rent, utility bills or hire purchase) from 2003 onwards - EU-SILC survey, **J** – healthy life years, **K** – frequency of heavy episodic drinking - at least once a week, **L** – time spent on health-enhancing (non-work-related) aerobic physical activity - 300 minutes or over, **M** – education, **N** – frequency of contact with family and relatives - several times a month, **O** – frequency of getting together with friends - several times a month, **P** – pollution, grime or other environmental problems, **Q** – noise from neighbours or from the street, **R** – crime, violence or vandalism in the area, **S** – percentage of population rating their satisfaction as high (16 years and over)

Source: Own calculation

Table 1. Factors' coordinates of variables according to correlation

Variable	Factors´ coordinates according to correlation				
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Factors of material living conditions					
A - net income in PPS (2018)	0.8847	-0.2761	-0.0572	0.0739	-0.0228
B - main GDP aggregates per capita in PPS (2018)	0.8385	-0.3325	-0.0963	-0.0121	-0.0958
C - households making ends meet with great difficulty (2018)	-0.7803	-0.5091	-0.0950	0.0589	0.1119
Productive and other main activities					
D - persons reporting a work-related health problem (2013)	0.2742	0.1675	-0.1475	0.7775	0.3228
E - persons reporting an accident at work (from 15 to 64 years) (2013)	0.6705	-0.1728	-0.2700	0.1159	-0.3740
F - long term unemployment (2018)	-0.5850	-0.5826	-0.1377	0.2389	-0.2809
G - employment rate - age level 20-64 years (2018)	0.6552	0.4022	0.1632	-0.1589	0.3851
Economic security					
H - inability to face unexpected financial expenses (2018)	-0.6969	-0.0347	-0.2799	-0.3669	-0.0293
I - arrears (mortgage or rent, utility bills or hire purchase) from 2003 onwards (2018)	-0.7050	-0.4717	-0.0987	-0.1151	0.1263
Health					
J - healthy life years (2018)	0.2063	-0.5965	0.3077	0.2315	0.2065

Variable	Factors´ coordinates according to correlation				
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
K - frequency of heavy episodic drinking - at least once a week (2014)	0.5813	-0.1437	0.1651	-0.6091	-0.1671
L - time spent on health-enhancing (non-work-related) aerobic physical activity - 300 minutes or over (2014)	0.8450	-0.0986	-0.1060	0.2237	-0.0895
Education					
M – education (2018)	0.4750	-0.2619	-0.4257	-0.3532	0.3793
Social interactions					
N - frequency of contact with family and relatives -several times a month (2015)	-0.4299	0.7710	0.2183	0.0944	-0.0308
O - frequency of getting together with friends – several times a month (2015)	0.1888	0.7595	0.2820	-0.0845	0.1069
Living environment and physical safety					
P - pollution, grime or other environmental problems (2018)	-0.1469	-0.1736	0.8661	-0.0270	-0.1230
Q - noise from neighbours or from the street (2018)	0.3345	-0.4153	0.6577	0.0795	-0.1951
R - crime, violence or vandalism in the area (2018)	0.1119	-0.6237	0.3049	-0.1187	0.5247
Life satisfaction					
S - percentage of population rating their satisfaction as high (16 years and over) (2018)	0.8350	0.0242	-0.1525	-0.0825	-0.1112

Sources: Eurostat (2021), own calculation

olence and vandalism in the area, almost 15% of the variance of variable G – employment rate, and 14.3% of the variance of variable M – education. As can be easily seen from Table 3, there was only a small correlation (less than 0.22) between these variables.

Quality of Life in Countries of the European Union

The Dispersion Diagram of the Component Score (Figure 4) uncovers the structure of objects, i.e. clusters, isolated and outlying objects or anomalies. The objects placed far from the beginning of the coordi-

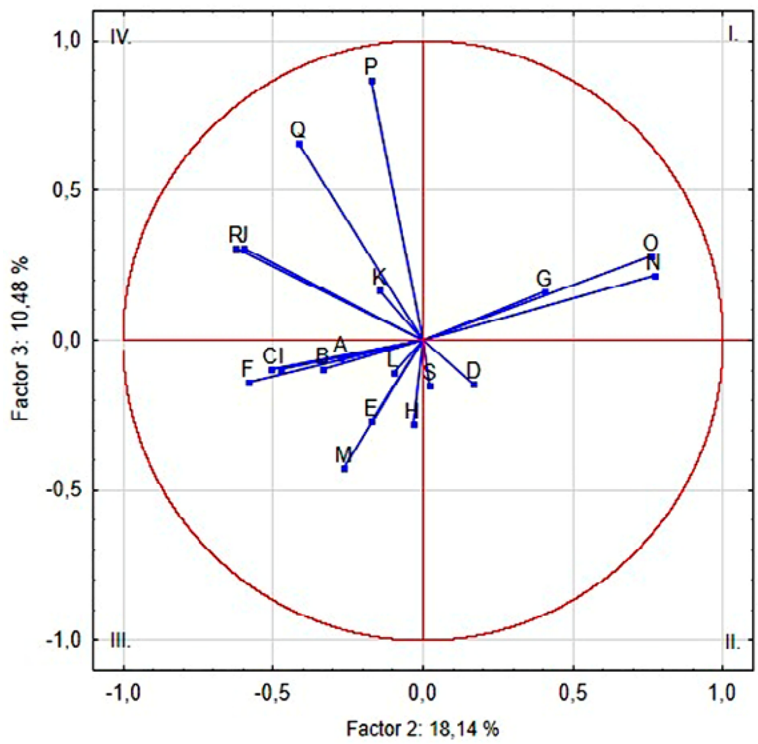

Figure 3. Projection of variables into the factor plane
Note: The description of variables is the same as in Figure 2
Source: Own calculation

nate system in the diagram represent the extremes; the ones that are closer to the beginning are the objects with the most typical properties.

The quality of life in the EU as a whole is best expressed by Portugal and Slovenia and their properties (via the first two factors that have the highest significance).

Economically advanced and developed countries of Northern and Western Europe, such as Finland, Sweden, Denmark, Great Britain, Ireland, Netherlands, Belgium, Luxembourg, Germany and France are characterized by a high level of GDP per capita in PPS what clearly affects the quality of life. Compared to the other EU countries, higher purchasing power is visible here. In the graph of component score (Figure 4) all these countries are located in quadrant I and II. Among these states the highest contributions to factor 1 are from Sweden, Finland and Denmark (Table 2). The above facts also confirm the closeness of vectors of variables A – net income in PPS, and B – main GDP aggregated per capita in PPS, to the named countries if we overlay the graph of component weights with the graph of component score. Within this context Luxembourg leads, its level of main GDP aggregated per capita in PPS reaching 32,060 € and net income in PPS 32,158 €.

Considering the indicator related to alcohol consumption (included in the forth factor affecting the quality of life according to our analysis) the higher percentage within EU countries can be observed by some countries of Western and Northern Europe. The frequency of heavy episodic alcohol consumption is higher especially in Ireland (13.3%), Luxembourg (11.2%), and Finland (11.0%). Among other countries a high percentage is noticed in Romania (10.6%). Compared to the EU average (3.0%), France, Sweden and Finland also record more occupational injuries (Finland 8.7%, Sweden 5.3%, France 5.2%). The correlation value between episodic alcohol consumption and occupational injuries was about 0.36 here. Considering these criteria Ireland is an outlier, because even though it has the highest consumption of alcohol (13.3%), it recorded only 1.5% of occupational injuries. On the contrary, an active approach to health positively influencing quality of life, is declared by as many as 30.4% of Swedes, 29.4% Austrians, 21.9% inhabitants of Luxembourg, 28.2% Finns and 26.4% Germans (see the closeness of variable L – time spent on health – enhancing (non-work-related) aerobic physical activity – 300 minutes or over, to the mentioned countries when overlaying the graph of component weights with the graph of component score). Those people do some aerobic physical activity in order to strengthen their physical condition 5 and for more hours a week.

In the graph of component score (Figure 4) the highest similarity (from the factor 1 and 2 point of view) is visible between Denmark and Austria, Latvia and Hungary, Lithuania and Slovakia. Even though their

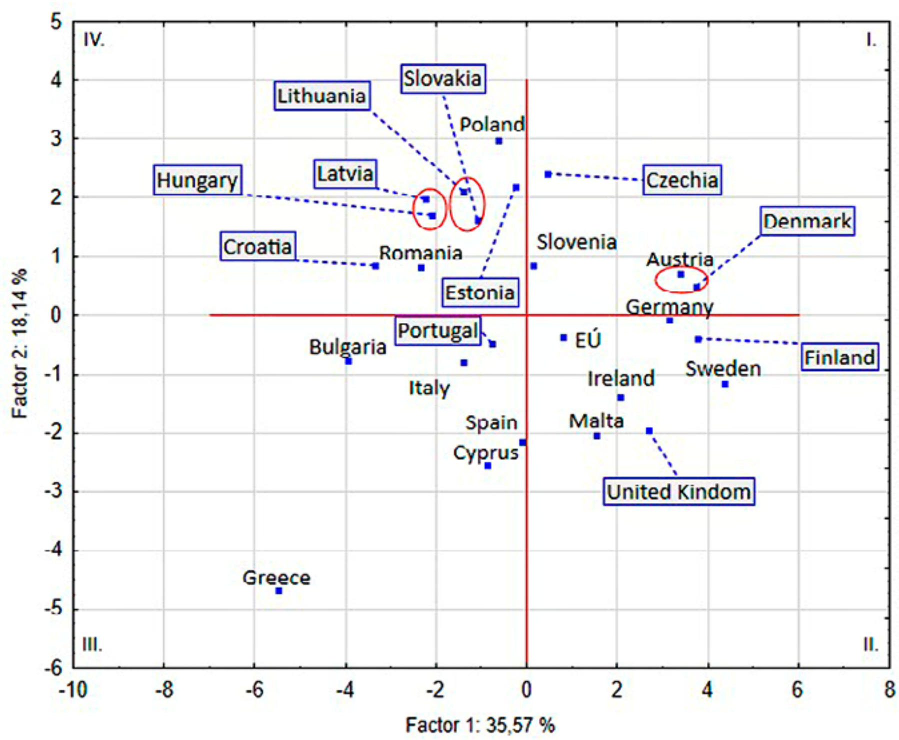

Figure 4. Projection of objects into the factor plane
Note: The graph contains countries with complete data from the Eurostat database
Source: Own calculation

contributions related to factors 1 and 2 are similar, in factors 3 and 4 they are often different.

The biggest contributions (in absolute value) to factor 3 are from Malta and Germany (Table 2). Although the environmental issues apply most to residents of the above countries, they are also important for inhabitants of other countries. As stated in the Communication of the Commission (Oznámenie Komisie, 2019) document, only a few EU Member States (Belgium, Netherlands, Germany, and Slovenia) succeeded in reaching 50% level of communal waste recycling by 2020; more EU Member States (Bulgaria, Cyprus, Estonia, Finland, Greece, Croatia, Latvia, Hungary, Malta, Poland, Romania, Slovakia, and Spain) were in danger of not reaching it in the near future.

Overlaying the graph of component weights with the graph of component score shows certain coherences. This step needs to be taken very carefully, however, when analysing data, as the risk of misunderstanding observed features is high. This relates to different reduction of dimensionality of the space in terms of objects and variables.

The relative closeness of variable F – long term unemployment, is evident in Greece. Apart from a high negative contribution to factor 1, it also has the highest contribution to factor 2 - social contacts and existential issues, of all EU countries (Table 2). In Greece, there was significantly higher long-term unemployment among economically active inhabitants culminating in 2014 (it culminated at 19.5%). Although by 2018 it had dropped to 13.6%, it was still 4.5-times higher than the EU average (3%). The second country with a high level of long-term unemployment was Spain. Even though it was not as high as Greece, its rate of 6.4% was still double the average of the EU as it was in Italy (6.2%). Long-term unemployment as such generally causes serious problems not only in the social sphere in the form of lost self-confidence, work habits, communication, social position, financial income and risk of poverty, but also in the economic sphere: taxes, GDP, loss of savings etc. (Brožová, 2003).

In Greece and Italy, the high level of long-term unemployment was also negatively manifested in their high share of people at risk of poverty or social exclusion. According to Eurostat data (2018a), Greece was in this respect the third worst within the EU with 31.8%, only behind Bulgaria (32.8%) and Romania (32.5%). Italy occupied the sixthworst place (27.3%). Behind Romania (42.6%) and Bulgaria (34.3%), Greece also recorded the third worst score in material and social deprivation with 33.9% (EU average was 12.8%) (Eurostat, 2018b).

In the case of Greece the coherence between variables C – households making ends meet with great difficulty, and I – arrears (mortgage or rent, utility bills or hire purchase) from 2003 onwards, was also visible and reached the highest level of all EU countries (in variable C – 38.2%, in variable I – 43.0%).

Quality of life notably concerns the feeling of happiness, but primarily reflects how people perceive it. In this context, Easterlin´s ideas (1974) were inspirational. His findings revealed that despite the fact national income in the USA almost doubled between 1946 and 1970, Americans became no happier. Easterlin´s ideas were supported by Frank (2005) via his statement that a person will be happier with a yearly salary of 110,000 USD, if everyone else earns 85,000 USD rather that with a salary of 110,000 USD in a society where everyone earns 200,000 USD a year. Layard (2003) remarked that happiness and income are interrelated, but only to the point when the country reaches a specific level of development. If the income of inhabitants reaches a certain level, the feeling of happiness does not increase with growing income.

As many as 45.0% of Irish, 41.3% of Danes, 41.1% of Finns, and also more than 34% of Austrians, Poles and Swedes feel high satisfaction with their quality of life. Unlike Poland, a country of the former Eastern Bloc, the share of highly-educated persons in these countries exceeds 30%.

Satisfaction with quality of life is closely related to length of life in health. This was monitored as the highest in Sweden (72.8 years), followed by Malta (72.7 years) and Ireland (69.4 years).

Although material welfare plays significant role in subjective feeling of happiness, the contacts with friends and family relations are of at least the same importance here. As for frequency of contacts (several times a month), in almost all the EU countries (the exceptions were Croatia (19.5%), Greece (11.2%), Hungary (20.8%), Lithuania (26.6%), and Portugal (13.9%)) contacts with friends prevail over contacts with family and relatives. In countries of Northern and North-Western Europe contacts with friends are far more intensive (e.g. 24.9% contacts with friends versus 10.7% contacts with family and relatives in Netherlands, 29.0% with friends versus 14.9% contacts with family and relatives in Denmark, 18.8% contacts with friends versus 7.4% contacts with family and relatives in Ireland). Compared to the EU average (16.6%), contacts with family are below-average and contacts with friends are above-average (EU average is 23.0%) here. Data concerning meeting friends was compared also on a weekly basis. The highest values were recorded in the countries of Northern and North-Western Europe. Contact with friends is very important for the inhabitants of Scandinavian countries - Sweden and Finland. As many as 51.6% of Swedes (the most in the EU) and 46.5% of Finns state that they meet their friends every week. Regular weekly contact with friends play an important role for more than 47.9% of Dutch, 47.6% of Belgians and 45.1% of Austrians. Regarding weekly meetings with family and relatives the leading positions are occupied by inhabitants of Finland (55.4%), Sweden (54.8%), Belgium (50.9%), Netherlands (48.5%), and Austria (45.9%).

One of the countries characterized by high satisfaction with quality of life is Poland (35.9%). It contributes to factor 2 the most (2.9761, Table 2). Even though the economic strength of some Northern and North-Western European countries, for example Luxembourg (net income in PPS 27,529 € and main GDP aggregated per capita in PPS 32,060 €), Denmark (21,646 € and 25,390 €), Sweden (20,414 € and 23,900 €), Netherland (21,528 € and 24,240 €), is approximately double that of Poland (11,513 € and 14,890 €), family contact several times per month in Poland is the highest of all EU countries (30.4%). However, regarding frequency of contact with family and relatives on a weekly basis (30.2%) Poland did not even reach the EU average (41.2%).

In the graph of component score, which displays contributions to factors 1 and 2 (Figure 4) we can notice smaller clusters of objects (states), what reflects to similar perception of life quality in countries grouped in respective clusters. The first cluster is formed by Slovakia and Lithuania; the second by Hungary and Latvia, the third by Estonia, Czech Republic, and Poland (except for Czech Republic all of these countries can be found in quadrant IV). These Visegrád Group and Baltic countries are connected not only territorially, but also historically (former Socialist Bloc countries), economically and culturally. Moreover, in the case of Slovakia and Czech Republic, they have had a common history as one state (1918 – 1992) and intensive family bonds. Even the subjective assessment of quality of life by inhabitants of Czech Republic and Slovakia is similar – in Czech Republic 29.5% and in Slovakia 27.5%, which is more than twice that of Hungary (only 13.1%). A low percentage of people considering their quality of life to be high was also recorded by inhabitants of Greece (13.5%) and Bulgaria (only 9.5%). We presume that in the case of Bulgaria the situation mainly arises from a lower income, problems to provide for their families and/or the lower purchasing power of its inhabitants (net income in PPS 7,218 €, main GDP aggregated per capita in PPS 10,740 €). In Greece the GDP is higher than the majority of Eastern European countries, but the low overall satisfaction of its inhabitants with quality of life is probably the result of the fact that Greeks lived beyond their means for a long time. The global financial crisis in 2008 resulted in significant austerity measures there that became most evident between 2010 and 2014, and which were often accompanied by the outrage of its inhabitants (Finančný trh (Financial Market), 2021).

According to Easterlin's model, the feeling of happiness in these countries will certainly grow along with increasing income for a certain period of time. Conversely, in those economically strong countries where residents currently show a high satisfaction with quality of life (with the high level of GDP per capita or purchasing power of inhabitants), which are characterized by a higher percentage of university-educated people and also longer healthy life expectancy, the feeling of satisfaction with the quality of life will be the result of non-material factors e.g. frequency of contacts with friends (mainly in Sweden, Finland, Netherlands, Belgium, and Austria) or healthier lifestyle in the form of declared more intensive aerobic physical activities (mainly Sweden, Austria, Finland, and Germany) etc.

Last but not least, we witness some common activities of all EU Member States oriented towards the minimization of risks for climate, human health and biodiversity (Európska komisia (European Commision), 2021) that create a wider framework for the quality of life itself.

Table 2. Factor coordinates of cases according to correlation

Countries	Factor coordinates of cases according to correlation				
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
EU	0.7839	-0.3528	0.5785	0.2467	-0.0493
Austria	3.3867	0.7227	-0.8347	1.9426	0.0022
Bulgaria	-3.9432	-0.7744	0.8959	-0.2041	2.5508
Croatia	-3.3663	0.8610	-2.0393	0.2969	-0.8100
Cyprus	-0.8900	-2.5589	-1.2519	-0.6607	1.3996
Czech Republic	0.4345	2.4259	0.9875	0.4402	0.2811
Denmark	3.7256	0.4970	-0.5028	-0.4608	-0.6379
Estonia	-0.2612	2.1977	-1.0846	-0.9203	0.9642
Finland	3.7714	-0.4012	-1.9613	-1.4376	-1.9725
Germany	3.1451	-0.0778	3.1421	0.2845	-0.4125

Countries	Factor coordinates of cases according to correlation				
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Greece	-5.5049	-4.6889	-0.1521	0.9343	-0.8361
Hungary	-2.0826	1.7140	-0.3765	0.3340	0.2087
Ireland	2.0682	-1.3837	-1.5566	-2.5054	0.4179
Italy	-1.4053	-0.8041	-0.1572	1.2306	-1.0658
Latvia	-2.2427	1.9882	0.2626	-0.6204	0.5320
Lithuania	-1.4061	2.1252	0.2853	-1.4175	0.0283
Malta	1.5451	-2.0412	3.8694	0.1350	-0.5416
Poland	-0.6215	2.9761	0.6533	1.1260	0.4895
Portugal	-0.7851	-0.4666	0.1114	0.6182	-1.2668
Romania	-2.3350	0.8181	1.7071	-1.7568	-0.9246
Slovakia	-1.0849	1.6298	-0.9300	1.1283	-0.7085
Slovenia	0.1344	0.8569	-0.0437	0.0096	-0.3667
Spain	-0.1175	-2.1510	-0.9104	0.5739	-0.4616
Sweden	4.3498	-1.1437	-1.0739	2.6276	1.9284
United Kingdom	2.7017	-1.9683	0.3819	-1.9446	1.2511

Notes: The table contains only EU countries for which we were able to obtain information for all 19 variables. The greatest contributions to factors (in absolute value) are highlighted in blue.

Sources: Eurostat (2021), own calculation

Conclusion

The aim of the article was to identify the factors that most influence EU inhabitants′ quality of life, analysis of the input data revealing that **material-economic conditions** (marked as factor 1), **social contacts and existential issues** (factor 2), **environmental issues and quality of environment** (factor 3), **health limitations concerning work and alcohol consumption** (factor 4) and **crime** (factor 5) have the biggest impacts. Projecting the variables into a factor plane we gained a picture of their importance, contribution to the factors as well as relevant correlations:

The maximum positive correlation (0.93) was shown between households making ends meet with great difficulty, and arrears (mortgage or rent, utility bills or hire purchase) from 2003 onwards; substantial correlation was also observed between main GDP aggregated per capita in PPS, and net income in PPS (0.92). A high value was also recorded between social contacts and net income expressed in PPS, as well as level of GDP per capita monitored on a monthly basis. Considering frequency of contacts with family and relatives several times a month, and frequency of getting together with friends several times a month, on a weekly basis, a strong positive correlation between net income in PPS and frequency of contact with family and relatives (0.62) was also recorded, as was the case with contact with friends (0.66). A significant positive correlation was also seen between main GDP aggregated per capita in PPS, and already mentioned variables related to social contacts.

The feeling of subjective satisfaction with quality of life positively correlates with the amount of net income expressed in PPS (0.72) and level of GDP per capita (0,71) achieved mainly by inhabitants with a higher level of education. In terms of monitored economic indicators, the economically strongest EU countries are Luxembourg and Denmark. The highest share of inhabitants with tertiary education is in Ireland (40.5%).

In the graph of factor score, Greece performed as outlier (considering factors 1 and 2). The closeness of the vector of long-term unemployment refers to its economic problems. Those culminated in 2014, but were still noticeable in 2018, when Greece had 4.5-times higher unemployment rate than the EU average.

Quality of life is substantially influenced by the social securities. While short-term unemployment may cause a certain feeling of increased quality of life for a certain period of time though having more time for oneself and hobbies, long-term unemployment causes deprivation and a feeling of dissatisfaction with one's life. Unemployment is greatly reflected in the inability to provide for one's family and handle unexpected financial expenses. Clearly, people with higher income handle unexpected financial problems more easily and devote more time to active support of their health e.g. aerobic physical activity.

But a subjective feeling of happiness does not often originate in material welfare, but is more the result of social bonds, especially family relations and contacts with friends. In almost all EU countries (excluding Croatia, Hungary, Greece, and Portugal) the frequency of meeting friends prevailed over contact with family (monitored on a monthly basis). But when monitoring the frequency of contacts on a weekly basis, contacts with family prevail over contacts with friends. The exceptions are Great Britain, Spain, Ireland, Greece, Cyprus, and Bulgaria. The calculation of the factor score serves to identify similarities between individual states. Portugal, Slovenia and Ireland had the most typical properties (from the aspect of all five factors) and are closest to the EU average. The states of Northern and Western Europe, which prefer contacts with friends, are, compared to the former socialist countries, economically more developed and show a higher level of GDP in PPS.

To sum up the above, quality of life is related to a feeling of happiness and primarily reflects how people perceive it. The analysed data points to the fact that the subjective perception of happiness (as presumed by Easterlin) grows along with material values (see Bulgaria, Greece and Romania and other countries of the former Eastern Bloc). It also partially indicates that if the level of economic development exceeds a certain point, quality of life will carry on increasing thanks to non-material values, such as a healthier and more active lifestyle as a result of physical activity or the need of adequate education, which also showed positive correlations. Even though the sample we analysed did not prove that the perception of happiness depends on a community way of life with frequency of contacts on a monthly basis, when analysing contacts with family and relatives on a weekly basis, we see that the community way of life played an important role. We also confirmed that the frequency of contacts on a weekly compared to monthly basis influences much more the territorial differentiation between individual states. While family bonds were more intensive in former socialist countries, the inhabitants of the countries of Northern and North-Western Europe preferred contact with friends. The feeling of happiness associated with more intensive social contacts was even intensified by alcohol consumption here.

In our article we drew attention to the fact that the PCA method can be considered an appropriate tool for assessing quality of life, notably when it concerns selection of factors or territorial connections between the factors and the countries of selection. However, perception of happiness remains, to a great extent, a subjective category.

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Annex

Table 3. Correlation table

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
A	1	0.92	-0.55	0.24	0.58	-0.29	0.38	-0.56	-0.50	0.32	0.44	0.81	0.52	-0.58	0.00	-0.08	0.36	0.22	0.72
B	0.92	1	-0.47	0.18	0.65	-0.19	0.33	-0.41	-0.45	0.27	0.50	0.73	0.52	-0,57	-0.02	-0.13	0.42	0.27	0.71
C	-0.55	-0.47	1	-0.17	-0.38	0.75	-0.67	0.55	0.93	0.09	-0.41	-0.56	-0.19	-0.02	-0.48	0.09	-0.09	0.27	-0.61
D	0.24	0.18	-0.17	1	0.20	-0.11	0.23	-0.31	-0.24	0.08	-0.34	0.36	0.05	0.11	0.14	-0.21	0.02	-0.04	0.22
E	0.58	0.65	-0.38	0.20	1	-0.13	0.29	-0.43	-0.33	-0.03	0.36	0.70	0.30	-0.40	-0.12	-0.22	0.23	0.01	0.55
F	-0.29	-0.19	0.75	-0.11	-0.13	1	-0.80	0.43	0.67	0.16	-0.38	-0.31	-0.16	-0.10	-0.51	0.17	0.00	0.10	-0.44
G	0.38	0.33	-0.67	0.23	0.29	-0.80	1	-0.44	-0.58	-0.15	0.30	0.47	0.41	0.00	0.42	0.00	0.18	0.04	0.38
H	-0.56	-0.41	0.55	-0.31	-0.43	0.43	-0.44	1	0.55	-0.40	-0.28	-0.64	0.01	0.22	-0.17	-0.04	-0.27	-0.14	-0.54
I	-0.50	-0.45	0.93	-0.24	-0.33	0.67	-0.58	0.55	1	0.02	-0.23	-0.45	-0.05	0.01	-0.37	0.14	-0.13	0.28	-0.51
J	0.32	0.27	0.09	0.08	-0.03	0.16	-0.15	-0.40	0.02	1	0.20	0.14	0.05	-0.47	-0.32	0.18	0.33	0.46	0.17
K	0.44	0.50	-0.41	-0.34	0.36	-0.38	0.30	-0.28	-0.23	0.20	1	0.36	0.30	-0.33	0.14	0.04	0.27	0.22	0.63
L	0.81	0.73	-0.56	0.36	0.70	-0.31	0.47	-0.64	-0.45	0.14	0.36	1	0.40	-0.41	0.08	-0.12	0.28	0.06	0.64
M	0.52	0.52	-0.19	0.05	0.30	-0.16	0.41	0.01	-0.05	0.05	0.30	0.40	1	-0.46	-0.17	-0.26	-0.02	0.21	0.43
N	-0.58	-0,57	-0.02	0.11	-0.40	-0.10	0.00	0.22	0.01	-0.47	-0.33	-0.41	-0.46	1	0.69	0.16	-0.30	-0.46	-0.32
O	0.00	-0.02	-0.48	0.14	-0.12	-0.51	0.42	-0.17	-0.37	-0.32	0.14	0.08	-0.17	0.69	1	0.07	-0.15	-0.20	0.24
P	-0.08	-0.13	0.09	-0.21	-0.22	0.17	0.00	-0.04	0.14	0.18	0.04	-0.12	-0.26	0.16	0.07	1	0.65	0.24	-0.28
Q	0.36	0.42	-0.09	0.02	0.23	0.00	0.18	-0.27	-0.13	0.33	0.27	0.28	-0.02	-0.30	-0.15	0.65	1	0.34	0.16
R	0.22	0.27	0.27	-0.04	0.01	0.10	0.04	-0.14	0.28	0.46	0.22	0.06	0.21	-0.46	-0.20	0.24	0.34	1	-0.33
S	0.72	0.71	-0.61	0.22	0.55	-0.44	0.38	-0.54	-0.51	0.17	0.63	0.64	0.43	-0.32	0.24	-0.28	0.16	-0.33	1

*Notes: **A** – net income in PPS, **B** – main GDP aggregates per capita in PPS, **C** – households making ends meet with great difficulty, **D** – persons reporting a work-related health problem, **E** – persons reporting an accident at work (from 15 to 64 years), **F** – long term unemployment, **G** – employment rate (age level 20-64 years), **H** – inability to face unexpected financial expenses, **I** – arrears (mortgage or rent, utility bills or hire purchase) from 2003 onwards - EU-SILC survey, **J** – healthy life years, **K** – frequency of heavy episodic drinking - at least once a week, **L** – time spent on health-enhancing (non-work-related) aerobic physical activity - 300 minutes or over, **M** – education, **N** – frequency of contact with family and relatives-several times a month, **O** – frequency of getting together with friends - several times a month, **P** – pollution, grime or other environmental problems, **Q** – noise from neighbours or from the street, **R** – crime, violence or vandalism in the area, **S** – percentage of population rating their satisfaction as high (16 years and over)*

Source: Own calculation

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Biometeorological Conditions During Hot Summer Days in Diverse Urban Environments of Banja Luka (Bosnia and Herzegovina)

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Abstract

Intensive urbanization and global warming are impacting the health and well-being of urban population. Nevertheless, urban environments with different designs will have different micro and local climate conditions. This study used data from micrometeorological measurements performed in different urban spaces (downtown, urban park, riverside) in Banja Luka, Bosnia and Herzegovina, on hot summer days in June 2021. Air temperature, relative humidity, wind speed, and globe temperature were measured and Mean Radiant Temperature (Tmrt), Psychologically Equivalent Temperature (PET), and modified Psychologically Equivalent Temperature (mPET) were calculated for each location. Results show that the downtown is the most uncomfortable area in terms of the highest Ta, Tg, Tmrt, PET, and mPET values registered at this location. The urban park is the most comfortable area with the lowest values of Tg, Tmrt, PET, and mPET. Relative humidity is the highest at the riverside and the lowest in downtown. Furthermore, riverside had lower average Ta during summer daytime compared to urban park and downtown likely due to the synergy between river cooling effect (evaporation and sensible heat transfer) and tree shade.

Keywords: Urban climate; outdoor thermal comfort; heat stress; urban park; riverside; downtown

Introduction

Urban population is under substantial thermal stress during the extreme temperature events such as heat wave (HW) (Milošević et al., 2016). Nevertheless, their outdoor thermal comfort varies depending on the urban location and its design. Measurement of meteorological parameters of humans provides necessary data to understand the interactions between atmospheric processes and human health (Anderson et al., 2020). In situ and mobile measurements of climate elements are popular approaches to assess the local and microclimate conditions in diverse urban or natural areas (Konstantinov et al., 2018; Dian et al., 2019; Paramita and Matzarakis, 2019; Milošević et al., 2020; Syafii, 2021; Žiberna et al., 2021; Lehnert et al., 2021a; Skarbit et al., 2017; Alonso and Renard, 2020a). In addition to short-term measurements, long-term climate data is

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a valuable resource for obtaining trends and changes in climate and bioclimate parameters (Trbić et al., 2017; Popov et al., 2019; Popov et al., 2018; Konstantinov et al., 2020; Varentsov et el., 2020; Konstantinov et al., 2021; Lukić et al., 2021; Nimac et al., 2021; Allen and Sheridan, 2018). Another approach is to apply urban climate modeling for assessing urban climate characteristics and providing input for the creation of sustainable and climate-sensitive cities under current and future climate change (Bokwa et al., 2019; Castillo et al., 2021; Liu et al., 2019; Cugnon et al., 2019; Wang et al., 2019; Ramadhan et al., 2021; Gál et al., 2021; Bajšanski et al., 2015).

With global changes in climate, making cities climate-proof is becoming increasingly critical (Jänicke et al., 2021). Urban form and design affect the outdoor thermal comfort (OTC), by influencing air temperature, humidity, solar radiation, and wind speed and direction (Webb, 2016). Factors as vegetation and water bodies (Lai et al., 2019; Milošević et al., 2017), urban morphology (Bajšanski et al., 2015; Jamie et al., 2019), ventilation (Tablada et al., 2009), and surface materials (Santamouris et al., 2011; Manavvi and Rajasekar, 2021), are important in determining OTC. Accordingly, the understanding of urban microclimate is imperative to facilitate climate-sensitive city planning and design (Jänicke et al., 2021). In pursuit of urban sustainability, livability and circularity, cities are increasingly using nature-based solutions (NBS), such as urban parks, due to their enormous potential in addressing climate adaptation and mitigation in cities (Langergraber et al., 2021; Pearlmutter et al., 2021; Atanasova et al., 2021; Castellar et al., 2021).

Urban areas are complex and the heat wave risk on the population is not uniform (Savić et al., 2018). For example, previous research has shown higher mortality during heat waves compared to other days (Arsenović et al., 2019a; Arsenović et al., 2019b). Projections have also shown that Earth's climate will warm together with increases in the percentage of the world's elderly population (Vecellio et al., 2021) which requires special attention in developing climate comfortable urban neighborhoods. In this perspective, among the most serious impacts of climate change in Central Europe are recognized more frequent and severe heat waves (Geletič et al., 2020). Climate projections are demonstrating that heat waves will occur more frequently and will become more severe in Europe (Fischer and Schär, 2010; Jacob et al., 2018) and are likely to increase during the twenty first century (Leconte et al., 2020). The increase in temperatures and intensity of heat waves has already been recognized in Bosnia and Herzegovina. For example, the highest annual temperature increase occurred in Banja Luka (0.5 °C per decade) probably due to influence of the urban heat island (Trbić et al., 2017). Nevertheless, there is a lack of local and microclimate measurements in the cities of Bosnia and Herzegovina, making them unprepared for the current and projected increases in air temperatures and heat stress.

The present study fills this research gap by providing micrometeorological measurements during hot summer days in diverse urban environments of the city of Banja Luka, Bosnia and Herzegovina. Obtained data on the micrometeorological conditions and OTC of urban dwellers in Banja Luka can be valuable for the urban design and planning. To the best of authors knowledge, this is the first micrometeorological measurement campaign and study performed in the cities of Bosnia and Herzegovina. The following tasks were performed:

- Measurement of micrometeorological conditions in diverse urban environments (downtown, urban park, riverside) in Banja Luka during hot summer days in 2021;
- Spatial and temporal analysis of micrometeorological and OTC data obtained during the field measurements in Banja Luka; and
- Discussion of obtained results and provision of urban climate information for the city of Banja Luka in order to track the heat and develop appropriate mitigation guidelines.

Study area, data and methods

Study area

City of Banja Luka is located in Southeast Europe, in the northern part of Bosnia and Herzegovina (B&H) (Figure 1). City coordinates are 44°46`N and 17°11`E with absolute elevation of 163 m. Banja Luka is the capital of Republic of Srpska (one of two entities in B&H) and the second largest city in the country with population of about 200,000 people (based on census from 2013) and built-up area of about 56 km². In the last 25 years, the city developed quickly, which means that some districts with low buildings have been transformed to multi-story buildings. With rapid urbanization more and more urban areas are being characterized as densely built-up zones with residential mid-rise (four-to-eight stories) buildings or administrative/commercial high-rise (more than eight stories) buildings. Based on this, a substantial modification of climatic characteristics in the city can be expected, due to a combination of intensive urbanization and current climate changes, and this is man-

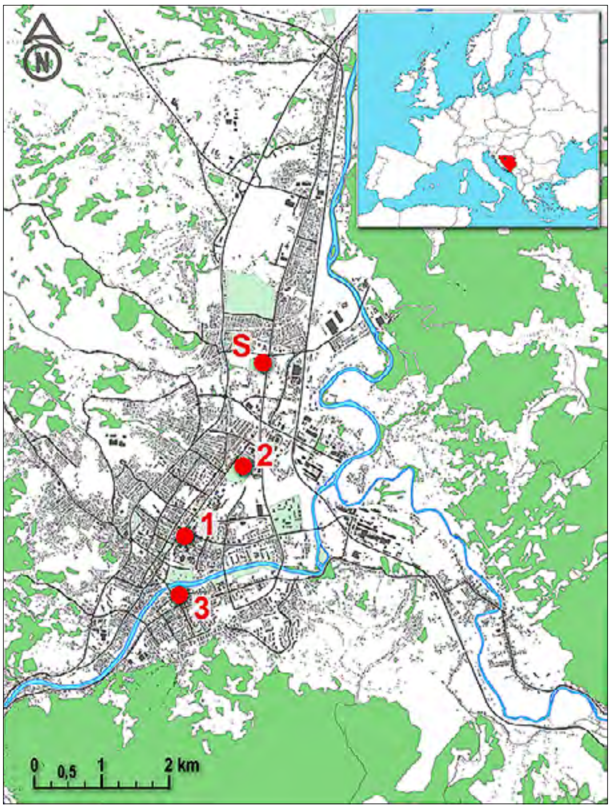

Figure 1. Location of Banja Luka in B&H (black dot) and measurement locations: 1) Downtown; 2) Urban park; 3) Riverside; and S) Official weather station

ifested through longer and more intense heat waves with extreme temperatures, more intense droughts, pluvial floods, more frequent thermal discomfort, etc.

Methods

Micrometeorological measurements

Micrometeorological measurements have been performed at three locations in Banja Luka on three hot summer days (from 22nd to 24th June 2021). Field work conditions were hot with maximum daily T_a of about 39 °C, no precipitation, low cloud cover, low wind speed, and intense solar radiation (Republic Hydrometeorological Service of Republic of Srpska, Bosnia and Herzegovina, 2021). Measurements were conducted at three urban sites with different design: a) downtown (densely urbanized "grey" area), b) urban park (natural "green" area), and c) riverside (natural "blue-green" area near the Vrbas River) (Figures 1 and 2). The three locations are popular pedestrian and/or relaxation areas in the city.

Three Kestrel 5400 Heat Stress trackers (Figure 2, right) were used to obtain one-minute measurements of air temperature (T_a, in °C), relative humidity (*RH*, in %), wind speed (v, in m s^{-1}), and globe temperature (T_g, in °C) during each day in the period 9-18 h (Central European Summer Time - CEST). Measured values were averaged into 10-minute means for the statistical analysis. The Kestrel Heat Stress Trackers were deployed at least 15 minutes before the start of the measurement in order to allow the sensors to equilibrate to the atmospheric conditions. The equipment is calibrated in accordance with the manufacturer's specifications. Sensors' accuracy and range are given in Table 1.

Table 1. Accuracy, resolution and range of Kestrel 5400 Heat Stress Tracker sensors used for human-biometeorological measurements in Banja Luka (Bosnia and Herzegovina)

Sensor	Accuracy (+/-)	Resolution	Range
Air temperature	0.5 °C	0.1 °C	-29.0 to 70.0 °C
Relative humidity	±2%RH	0.1 %RH	10 to 90% 25°C non-condensing
Wind speed	Larger of 3% of reading, least significant digit or 20 ft/min	0.1 m/s	0.6 to 40.0 m/s
Globe temperature	1.4 °C	0.1 °C	-29.0 to 60.0 °C

Banja Luka has a *Cfb* climate (temperate climate, fully humid, warm summers, with at least four months of average air temperature above 10 °C) based on the Köppen-Geiger climate classification system (Kottek et al., 2006; Trbić 2011). The mean annual air temperature is 11.3 °C and the mean annual precipitation is 1.036 mm (1961-2020 period). Since 2003, heat waves have occurred more frequently in B&H, mostly during the summer. Multiple intensive heat waves have occurred in Banja Luka in 2007, 2012, 2015, 2017, 2019, and 2021.

Calculation of biometeorological indices

For the estimation of OTC, Mean Radiant Temperature (T_{mrt}), Physiologically Equivalent Temperature (PET) and modified Physiologically Equivalent Temperature (mPET) were selected. T_{mrt} can be calculated from the measured values of T_g, T_a and v as follows (Thorsson et al., 2007):

$$T_{mrt} = \left[\left(T_g + 273.15\right)^4 + \frac{1.1 \cdot 10^8 \cdot v^{0.6}}{\varepsilon \cdot D^{0.4}} \cdot \left(T_g - T_a\right) \right]^{1/4} - 273.15$$

(1)

Figure 2. Locations of micrometeorological measurements in Banja Luka (Bosnia and Herzegovina) in the period 22-24 June 2021: 1) Downtown; 2) Urban park; and 3) Riverside

where, *D* is globe diameter (mm) and *ε* is globe emissivity.

Based on the calculated values of T_{mrt}, measured T_a, *RH, v*, and default values for personal characteristics, we calculated 10-minute average PET and mPET values for all sites. A new thermal index, named modified Physiologically Equivalent Temperature (mPET) has been developed by Chen and Matzarakis (2018) for the application in different climates. The mPET enhanced the evaluation of humidity and clothing variability and has been improved against the weaknesses of the original PET. The calculations were performed using the RayMan microclimate model (Matzarakis et al. 2007; Matzarakis et al. 2010). PET and mPET estimates were used to assess OTC in Banja Luka based on the physiological stress classes for humans specifically developed for Europe (Matzarakis and Mayer, 1996) (Table 2).

Table 2. PET index threshold values for thermal sensation and the physiological stress level of humans (after Matzarakis and Mayer, 1996).

PET (°C)	Thermal sensation	Physiological stress level
<4.1	Very cold	Extreme cold stress
4.1 – 8.0	Cold	Strong cold stress
8.1 – 13.0	Cool	Moderate cold stress
13.1 – 18.0	Slightly cool	Slight cold stress
18.1 – 23.0	Comfortable	No thermal stress
23.1 – 29.0	Slightly warm	Slight heat stress
29.1 – 35.0	Warm	Moderate heat stress
35.1 – 41.0	Hot	Strong heat stress
>41.0	Very hot	Extreme heat stress

Results and Discussion

Background weather

The background weather conditions during the micro-meteorological measurements were acquired from the official weather station in Banja Luka. It can be noticed (Figure 3, Table 3) that the weather was hot with maximum T_a of about 39 °C and minimum of about 18 °C. Relative humidity was low during daytime (30-40%), while it increased substantially during nighttime. The weather was calm with low wind speeds (0.9 m s^{-1} on average) and low cloud cover (1.4 on average). This weather was ideal for the development of micro-meteorological differences inside the city.

Table 3. Statistics on the weather conditions in Banja Luka (Bosnia and Herzegovina) during the measurement period (22-24 June 2021)

Statistics	Ta	RH	v	N
average	28.5	62.8	0.9	1.4
max	38.7	97.5	2.6	8
min	17.7	34.4	0	0
range	21.0	63.1	2.6	8

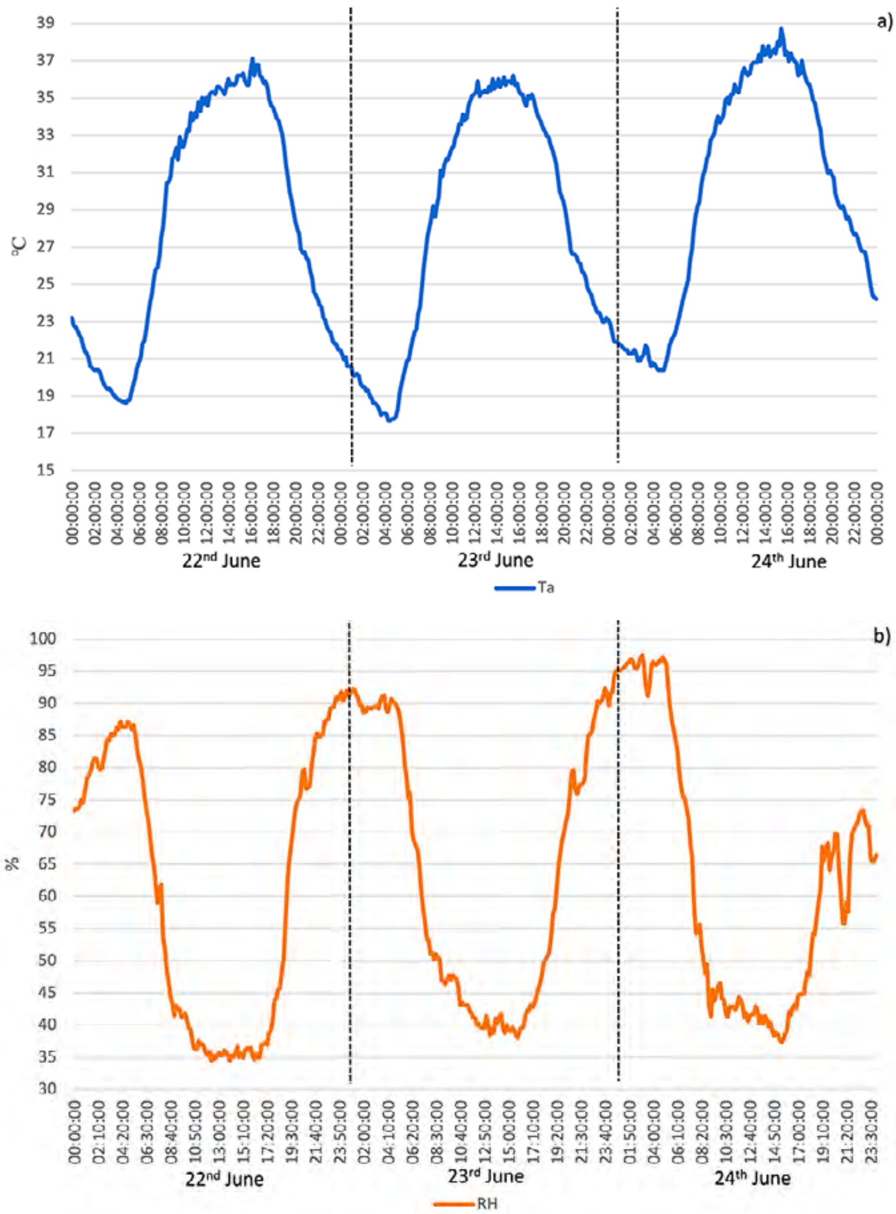

Figure 3. Weather conditions in Banja Luka (Bosnia and Herzegovina) in the period 22-24 June 2021: a) T_a and b) *RH*

Micrometeorological measurements

Air temperature

The highest average T_a (35.5 °C) was recorded in downtown, while similar values of about 33-34 °C were recorded in urban park and at the riverside (Table 4). Extreme temperatures (T_{max} and T_{min}) were also highest in the most urbanized location (downtown), while urban park had lower T_{max} and higher T_{min} values compared to the riverside. The river location had the largest temperature range (12.9 °C) and highest standard deviation (3.2 °C) compared to other locations (Table 4).

10-minute T_a differences between locations provide detailed insights into the temporal variability of air temperature in Banja Luka (Figure 4). The most intensive intra-urban T_a differences of about 5-6 °C occur between hot downtown and cooler urban park and riverside in the morning hours, especially between 9 AM and noon. In the afternoon, T_a differences between downtown and other locations swiftly decrease to about 1-2 °C and sometimes can go to below 0 °C (around 5-6 PM), indicating the occurrence of a slight urban cool island in the downtown. This could be the consequence of the shadowing effect from buildings surrounding the measurement location in the downtown (see Figure 2). Urban park had about 1 °C higher T_a compared to the riverside throughout the day, except for a few hours in the afternoon (Figure 4). The measurement locations at the riverside and in the urban park were under a tree; however, the proximity of the river could additionally lower T_a at the riverside compared to the urban park location. In general, differences in air temperature decreased in the afternoon between the locations and this could be due to the shading effect and less intensive heating in the afternoon hours (Milošević et al., 2021).

Similar to this study, previous studies have shown that the highest temperatures are usually found in more urbanized areas of the city. For example, Oliveira et al. (2021a) showed that more compact areas of Lisboa, Portugal, had the highest temperatures and these temperatures were proportional to the background air temperature change. The heat wave periods with hot weather are especially characterized with strong nocturnal urban heat island (UHI) as shown in Szeged, Hungary (Unger et al., 2020). During daytime, temperature differences in urban areas are mainly linked to shading. For example, Top et al. (2020) showed that urban park in Ghent (Belgium) is overall characterized by lower temperatures with up to 1.0 °C lower mean T_a during summer daytime when compared to the downtown located 2 km away. Gál et al. (2021) pointed out that urban green spaces generally cool the environment, although their cooling potential differs depend-

Table 4. Main statistical characteristics of air temperature (T_a), globe temperature (T_g), relative humidity (*RH*), wind speed (*v*), Mean Radiant Temperature (T_{mrt}), Physiologically Equivalent Temperature (PET) and modified Physiologically Equivalent Temperature (mPET) in diverse urban environments of Banja Luka (Bosnia and Herzegovina) in the period 22-24 June 2021 (measurement period 9-18 h CEST).

Element	T_a			T_g			*RH*			*v*			T_{mrt}			PET			mPET		
Location	D	P	R	D	P	R	D	P	R	D	P	R	D	P	R	D	P	R	D	P	R
Average	35.5	33.9	33.6	43.9	36.2	39.9	35.7	39.0	41.4	0.7	0.6	0.7	55.6	39.7	50.2	45.6	36.7	41.5	41.4	34.7	38.4
Max	39.0	37.7	38.9	49.9	44.0	49.7	50.5	52.4	58.0	1.6	1.4	1.6	75.4	47.4	74.8	53.2	42.4	54.4	47.2	39.3	48.9
Min	28.8	26.8	26.0	31.0	28.7	26.2	29.8	29.5	33.0	0.0	0.0	0.0	31.0	29.9	26.2	30.9	27.8	26.5	29.8	27.4	26.5
Range	10.2	10.9	12.9	18.9	15.3	23.5	20.7	22.9	25.0	1.6	1.4	1.6	44.4	17.5	48.5	22.3	14.6	27.9	17.4	11.9	22.4
St Dev	1.8	2.6	3.2	4.4	3.1	6.7	3.4	4.3	4.8	0.4	0.3	0.4	11.3	4.2	13.3	5.5	3.5	7.9	4.2	2.9	6.2

NOTE: Abbreviations of measurement locations are as follows: D - Downtown, P - Park, R - Riverside.

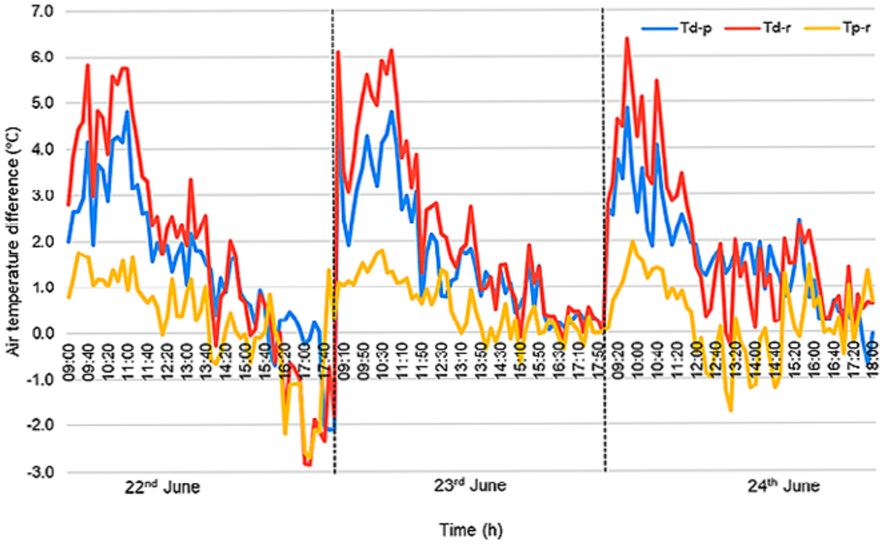

Figure 4. Temporal variation of T_a in Banja Luka (Bosnia and Herzegovina) in the period 22-24 June 2021 (measurement period 9-18 h CEST). NOTE: T_{d-p} represents air temperature difference between downtown and urban park; T_{d-r} represents air temperature difference between downtown and riverside; and T_{p-r} represents air temperature difference between urban park and riverside

ing on the characteristics of green areas, such as size of the urban park. Heat reduction potential of trees also depends on the location of trees and is species specific (Morakinyo et al., 2020). Tan et al. (2016; 2017) also indicated that the cooling effect of urban trees is highly associated with Sky View Factor of the location. Urban cool islands can also occur in densely built urban areas during the daytime in summer due to shadowing and it was typically around –1 °C in Szeged and –2 °C in Novi Sad (Lelovics et al., 2016). The river cooling effect also has an important role in reducing urban heat through evaporation and transfer of sensible heat, as shown by Park et al. (2019). The study of Jacobs et al. (2020) showed that afternoon air temperatures was reduced by a maximum of 0.6 °C in the surrounding spaces of urban water bodies in the Netherlands. Our study showed that the riverside location was most of the time cooler compared to other locations (downtown and urban park) during the summer daytime (Figure 4).

Relative Humidity

The highest average *RH* values are observed near the river (41.4%), followed by urban park (39.0%). In contrast, the lowest average *RH* was noticed in city center (35.7%). The highest maximum and minimum *RH* values are also registered near the river, thus leading

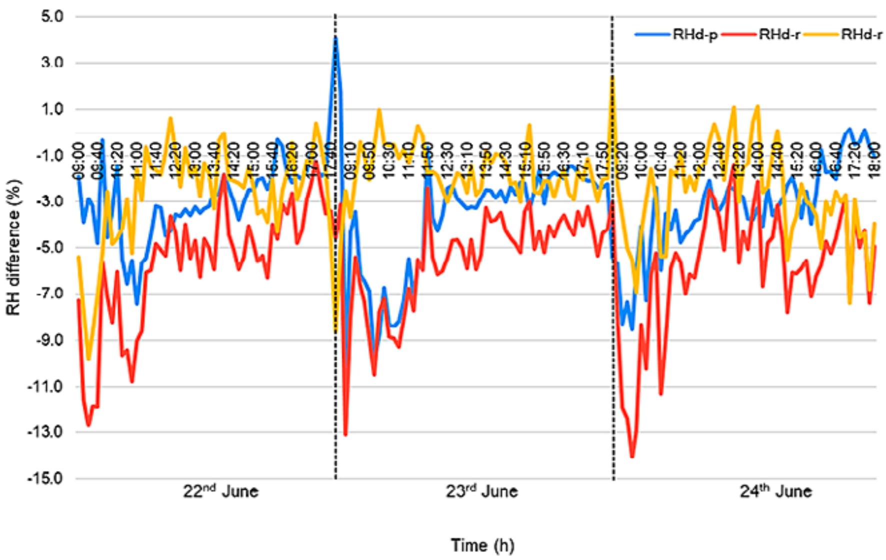

Figure 5. Temporal variation of *RH* in Banja Luka (Bosnia and Herzegovina) in the period 22-24 June 2021 (measurement period 9-18 h CEST). NOTE: RH_{d-p} represents relative humidity difference between downtown and urban park; RH_{d-r} represents relative humidity difference between downtown and riverside; and RH_{p-r} represents relative humidity difference between urban park and riverside

to larger range and standard deviation of *RH* at this location (Table 4).

Temporal variation of RH shows prominent differences between the locations during the morning hours (Figure 5). For example, city center in the morning had up to 14% lower RH compared to the riverside and up to 10% lower *RH* compared to the urban park. As the day progresses, *RH* differences are less prominent between the locations. The least prominent differences in *RH* occur between riverside and urban park, although the river location had higher *RH* values during most of the day (Figure 5).

Results from previous studies showed that lower humidity and urban dry island (UDI) often occurs in densely urbanized areas in summer daytime and during heat wave in Novi Sad, Serbia (Dunjić et al., 2021). Similar results were obtained in Ghent, Belgium, where the lowest *RH* was noticed at the urban location during heat wave, while the highest *RH* was reached at the rural location (Top et al., 2020). Yang et al. (2017) also pointed that *RH* decreases with the increase in urbanization.

Wind speed

During the measurement period, v were low at all locations (0.6-0.7 m s^{-1}) (Table 4). There were no significant v differences between the locations as the measurement period was characterized with sunny and calm weather. Urban park had only a slightly lower *v*. As the differences in v were not significant between the locations, we did not provide a detailed analysis of wind speed in Banja Luka.

In general, air movement in the built-up environment is reduced in comparison to rural areas (Arnfield, 2003) or it can be locally increased by urban canyon effect. More open urban sites in Ghent, Belgium, had highest v, especially during daytime compared to less open locations, such as urban parks (Top et al., 2020). Nevertheless, local climate change adaptation in cities must account for the synergies between regional air temperature and wind (Oliveira et al., 2021b).

Globe temperature

The highest values of T_g are measured at downtown which, on average, has 4 °C higher T_g values compared to riverside and 7.7 °C compared to urban park (Table 4). Also, in the downtown are registered highest maximum and minimum T_g values. The urban park is the most comfortable urban area during the measurement period with lower average T_g compared to the riverside.

Temporal variations of T_g show that substantial intra-urban differences occur in the period from 10 AM to 2 PM when downtown is substantially hotter with up to 14-15 °C higher T_g compared to urban park and riverside (Figure 6). In the morning hours, urban park is slightly warmer compared to riverside. On the contrary, as the day progresses towards the afternoon, riverside becomes warmer compared to urban park and downtown. This suggests that riverside location was in the shade before noon, however, was sunlit and directly irradiated during the late afternoon. These results highlight the key role of radiation in the spatial and temporal variability of thermal exposure in moderate-climate urban areas during summer days (Geletič et al., 2021). Nevertheless, it must be noted that smaller black globes commonly used in Kestrel

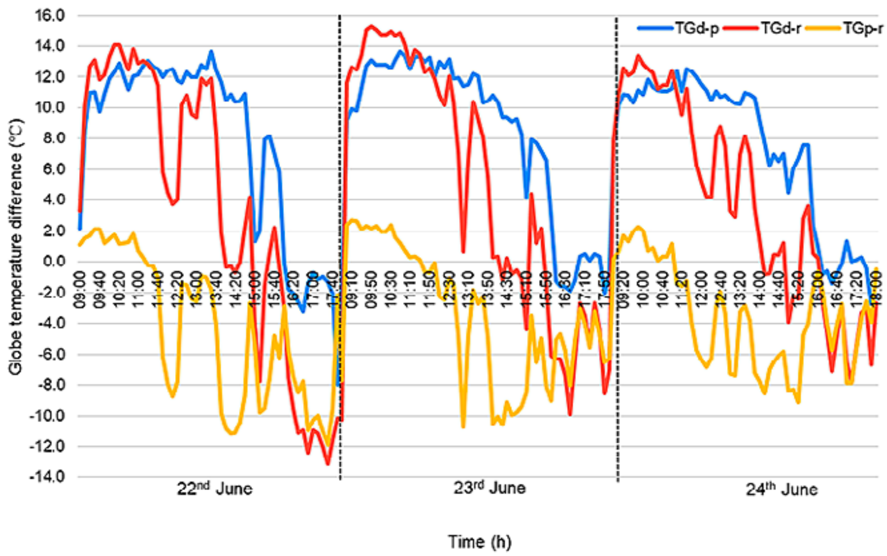

Figure 6. Temporal variation of T_g in Banja Luka (Bosnia and Herzegovina) in the period 22-24 June 2021 (measurement period 9-18 h CEST). NOTE: TG_{d-p} represents globe temperature difference between downtown and urban park; TG_{d-r} represents globe temperature difference between downtown and riverside; and TG_{p-r} represents globe temperature difference between urban park and riverside

Heat Stress Trackers tend to overestimate T_g in the sun due to the globe overheating (Kántor & Unger 2011; Middel et al. 2016).

Calculated outdoor thermal comfort conditions

Mean Radiant Temperature

The most intensive intra-urban differences were registered for T_{mrt} values. On average, downtown had T_{mrt} of 55.6 °C, followed by riverside with T_{mrt} of 50.2 °C. On the contrary, urban park had substantially lower average T_{mrt} of 39.7 °C. Thus, urban park was able to mitigate average T_{mrt} by about 16 °C and 10 °C compared to downtown and riverside, respectively. The maximum T_{mrt} peaked over 70 °C in downtown and at the riverside, while it remained below 50 °C in urban park (Table 4).

Temporal variation of 10-minute T_{mrt} values indicate that downtown has substantially higher T_{mrt} values compared to riverside and urban park throughout the day. Around noon, city center has about 35 °C higher T_{mrt} compared to urban park and riverside (Figure 7). Nevertheless, in the period 4-6 PM, riverside becomes the warmest part of the city with substantially higher T_{mrt} compared to downtown and urban park. It can be also noticed that in the morning hours until about 11 AM, urban park has higher T_{mrt} compared to riverside. These changes in T_{mrt} values between the locations indicate the influence of the shading effect that varies over time depending on the urban design at each location.

The parameter governing OTC on warm, clear-sky days is radiation and its effect on OTC is accounted for by T_{mrt} (Gál and Kántor, 2020). Spatial and temporal variation of T_{mrt} is driven by exposure to solar and longwave radiation, which depends on local patterns of shading, v, air humidity and T_a (Aminipouri et al., 2019). In Ghent, Belgium, the largest intra-urban differences in T_{mrt} are registered in summer with on average a 7.0 °C higher T_{mrt} at more urbanized location compared to the urban park (Top et al., 2020). Although daytime T_{mrt} can reach an extreme level at exposed locations (65–75 °C), mature shade trees can reduce it to 30–35 °C in Szeged, Hungary (Kántor et al., 2018). Trees in Tempe, Arizona, USA, were also able to reduce afternoon T_{mrt} up to 33.4 °C (Middel and Krayenhoff, 2019). The results from our study are in accordance with the results from Szeged and Tempe as trees in urban park in Banja Luka, Bosnia and Herzegovina, decreased T_{mrt} up to 37.5 °C around noon during hot summer day (Figure 7). T_{mrt} varies substantially between locations throughout the day for all seasons in Tempe, Arizona, USA. This variability is mainly driven by the availability or absence of shade that impacts the incoming shortwave radiation (Crank et al., 2020). Another study from Middel et al. (2021) showed that not all shade is the same in terms of decreasing T_{mrt}. That study showed that during the day, at solar noon, and peak T_a, shade from urban form reduced T_{mrt} most effectively, followed by trees and lightweight structures in the City of Tempe (USA). However, it must be noted that many issues can arise due to slow response times, shape, inaccuracies in material properties and assumptions, and color (albedo, emissivity) inconsistencies between sensors used to obtain T_{mrt} (Vanos et al., 2021).

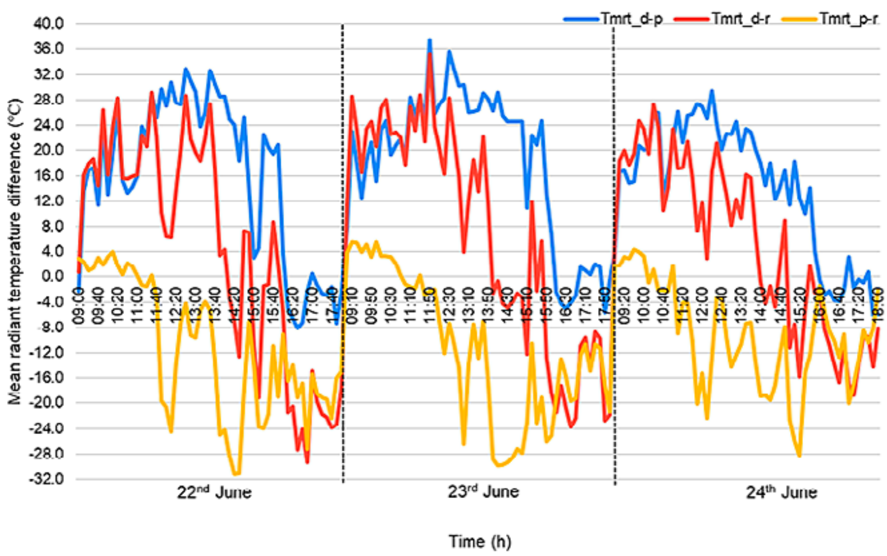

Figure 7. Temporal variation of T_{mrt} in Banja Luka (Bosnia and Herzegovina) in the period 22-24 June 2021 (measurement period 9-18 h CEST). NOTE: $T_{mrt\_d\text{-}p}$ represents Mean Radiant Temperature difference between downtown and urban park; $T_{mrt\_d\text{-}r}$ represents Mean Radiant Temperature difference between downtown and riverside; and $T_{mrt\_p\text{-}r}$ represents Mean Radiant Temperature difference between urban park and riverside

PET

The highest average PET values are registered in downtown (45.6 °C), followed by riverside (41.5 °C). On the contrary, the lowest average PET values were registered in urban park (36.7 °C) (Table 4). This indicates that downtown and riverside were under extreme heat stress conditions, while strong heat stress conditions prevailed in urban park (see Table 2).

Temporal variation of PET showed similar results as T_{mrt}. In other words, downtown has substantially higher PET values compared to riverside and urban park throughout the day. In the period 2-4 PM, downtown has about 17 °C higher PET values compared to urban park and riverside and these differences decrease towards the late afternoon (Figure 8). In the period 4-6 PM, riverside becomes the most thermally uncomfortable part of the city with more than 10 °C higher PET compared to downtown and urban park. This is possibly a consequence of direct solar radiation at riverside in the afternoon, while downtown and urban park are in shade from buildings and trees, respectively. It can be also noticed that in the morning hours, urban park has higher PET compared to river location.

Previous studies have shown that during the daytime, the highest thermal loads are present in more urbanized areas, while the most comfortable are areas with dense trees (Milošević et al., 2016). Kovács and Németh (2012) found that compact midrise zone of Budapest has average PET values higher by 3 °C when compared to the suburban areas with more greenery. Similar to our results, higher PET values were obtained for built zones in Oberhausen (Germany) during the hot days (Tamax > 30 °C) when compared to sparsely built and dense trees zones (Müller et al. 2014). During the daytime period of heat waves, the urban park in Ghent, Belgium, was the most comfortable area because it was able to effectively mitigate heat stress compared to more urbanized locations (Top et al., 2020). In other words, citizens experienced extreme heat stress during daytime of heat waves with highest average PET reached at the semi-open downtown location in Ghent; on the contrary, the urban park had a 4.4 °C lower mean daytime PET when compared to the downtown (Top et al., 2020). The differences in OTC values in Czech cities confirm substantial cooling associated with high vegetation (trees), while the measurable cooling effect of low vegetation was negligible and quite low around water fountains, spray fountains, and misting systems (Lehnert et al., 2021b). The maximum PET in our study peaked over 50 °C in downtown and at riverside (see Table 4). Similar maximum PET values were also obtained in Ghent downtown and industrial areas (Top et al., 2020), as well as in compact midrise area of Szeged, Hungary (Unger et al., 2018).

Frequency analysis (%) of different grades of physiological stress (see Table 2) in downtown, urban park and riverside is shown in Figure 9. It can be concluded that downtown and riverside are under the impact of extreme heat stress during majority of the day (72% in downtown and 57% at riverside). On the contrary, only 6% of the time in urban park is characterized with the extreme heat stress (Figure 9). In urban park, moderate and strong heat stress occurs during majority of the time (in total 91%). The frequency analysis

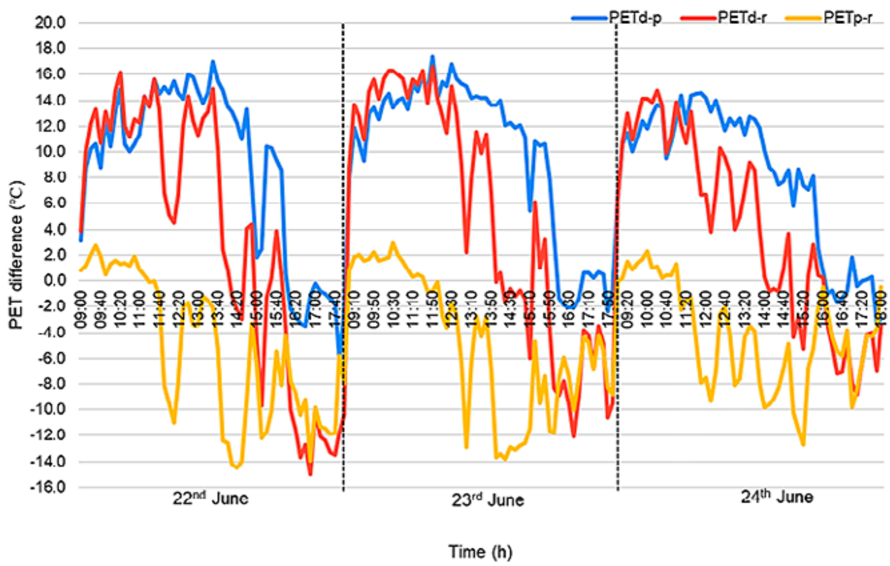

Figure 8. Temporal variation of PET in Banja Luka (Bosnia and Herzegovina) in the period 22-24 June 2021 (measurement period 9-18 h CEST). NOTE: PET_{d-p} represents Physiologically Equivalent Temperature difference between downtown and urban park; PET_{d-r} represents Physiologically Equivalent Temperature difference between downtown and riverside; and PET_{p-r} represents Physiologically Equivalent Temperature difference between urban park and riverside

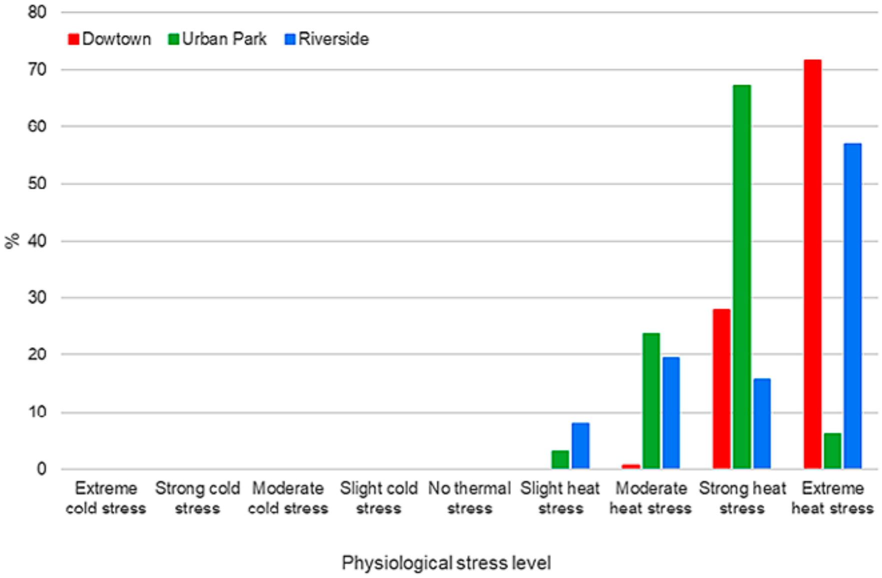

Figure 9. Frequency analysis (%) of different grades of physiological stress (based on PET values) at locations in Banja Luka in period 22-24 June 2021 (measurement period 9-18 h CEST)

revealed that the urban park in Ghent, Belgium, also experienced three to four times less frequent extreme heat stress compared to the downtown areas. This shows the importance of shading to improve the OTC for pedestrians during daytime (Top et al., 2020). The most built-up zones of Brno, Czech Republic, were also registered as the most uncomfortable areas of the city (Geletič et al., 2018).

mPET

The highest average mPET values are noticed in downtown (41.4 °C), followed by riverside (38.4 °C). On the contrary, the lowest average mPET are noticed in urban park (34.7 °C) (Table 4). This indicates that extreme heat stress is registered in downtown, strong heat stress at riverside and moderate heat stress in urban park (see Table 2). When compared to PET, mPET results indicated that modification in the original PET index led to the decrease in the physiological stress level by one category at riverside (from extreme to strong heat stress) and in urban park (from strong to moderate heat stress).

Temporal variation of mPET showed that maximum differences between downtown and other loca-

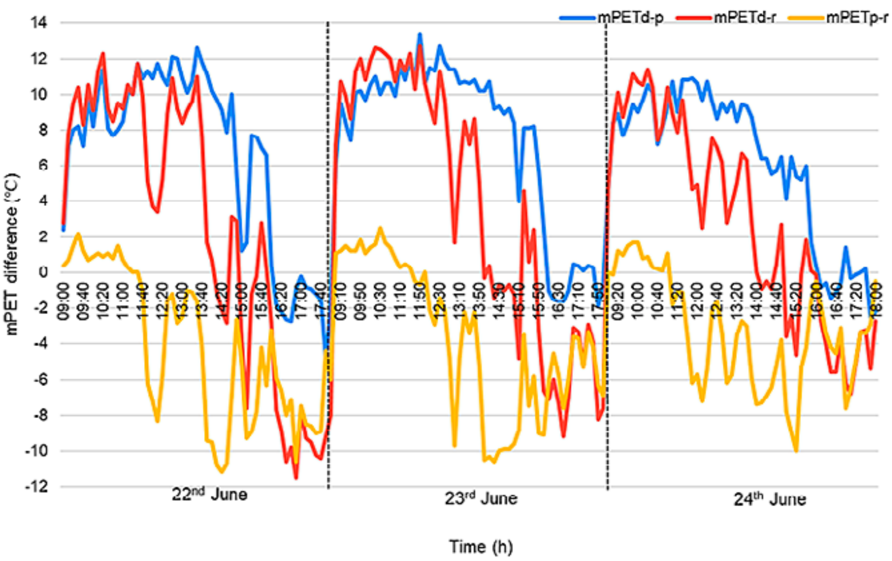

Figure 10. Temporal variation of mPET in Banja Luka (Bosnia and Herzegovina) in the period 22-24 June 2021 (measurement period 9-18 h CEST). NOTE: $mPET_{d-p}$ represents modified Physiologically Equivalent Temperature difference between downtown and urban park; $mPET_{d-r}$ represents modified Physiologically Equivalent Temperature difference between downtown and riverside; and $mPET_{p-r}$ represents modified Physiologically Equivalent Temperature difference between urban park and riverside

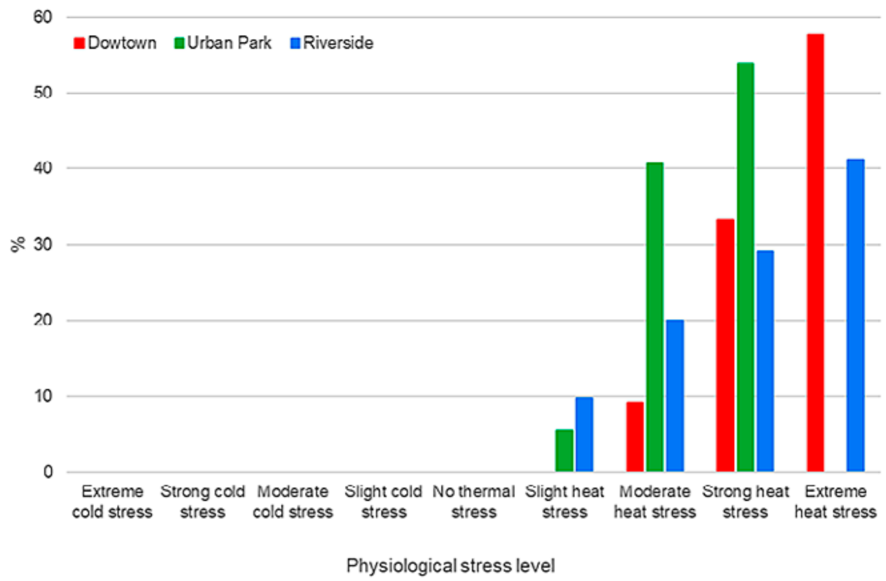

Figure 11. Frequency analysis (%) of different grades of physiological stress (based on mPET values) at locations in Banja Luka in period 22-24 June 2021 (measurement period 9-18 h CEST)

tions were somewhat smaller (up to 13 °C) when compared to PET differences (which were up to 17 °C) (Figure 10). Substantial higher mPET in downtown prevailed until 2-3 PM. Afterwards, riverside had higher mPET values compared to other locations as it was sunlit in the afternoon. Only in the morning period, urban park had slightly higher mPET compared to riverside. It probably continues during most of the night, as suggested by Geletič et al. (2021).

Frequency analysis (%) of different grades of physiological stress at locations in Banja Luka based on mPET values is shown in Figure 11. Extreme heat stress levels are prevailing in downtown (58%) and at riverside (41%). Nevertheless, this is a decrease in the frequency of extreme heat stress occurrence by 14% in downtown and by 16% at the riverside when compared to PET frequencies at these locations. In addition, strong heat stress is dominating in urban park (54%), which is a decrease of about 13% when compared to frequency of this heat stress level based on PET values. This indicates that clothing variability brought by mPET calculation in the RayMan model can lower the heat stress levels at studied locations.

Results from Pecelj et al. (2021) showed the applicability of PET and mPET indices as indicators of biothermal conditions necessary in urban planning, public health systems, tourism and recreation purposes. Increase in frequency and intensity of heat waves and hot weather are direct consequences of climate change with a higher risk for urban populations due to UHI effect. Reducing urban overheating is thus a priority as well as identifying the most vulnerable locations and people to establish targeted and coordinated public health policies (Alonso & Renard, 2020b). For this purpose, a continued monitoring and improvement of heat intervention is needed due to projected changes in frequency, duration, and intensity of heat events combined with shifts in demographics, making heat a major public health issue now and in the future (Sheridan & Allen, 2018).

Conclusions

Up to now, OTC research from Bosnia and Herzegovina mainly focused on the examination of climate potential for tourism development (Dunjić, 2019). Our study investigated OTC conditions in Banja Luka and confirmed conclusions from previous studies that showed the importance of small-scale micrometeorological measurements, the outcomes of which can be incorporated into climate-responsive urban design (Kántor et al., 2018b; Milošević et al.; 2022).

Nevertheless, detailed spatial and temporal climate data from diverse urban environments is often lacking in urban planning process and practice. This study showed that diverse urban environments (downtown, urban park, riverside) have diverse biometeorological conditions during hot summer days in Banja Luka, Bosnia and Herzegovina. Downtown area is the hottest area with up to 5-6 °C higher air temperatures compared to urban park and riverside. More importantly, downtown area has up to 35 °C higher T_{mrt}, up to 17 °C higher PET and up to 13 °C higher mPET compared to urban park and riverside. This shows that the local population is more often under extreme heat stress in the downtown than in other more natural locations such as urban park and riverside. Of all the locations, urban park is the most comfortable with 9 °C lower average PET compared to downtown and 5 °C lower average PET compared to riverside. When mPET is used, the differences are smaller, but the urban park remains the most comfortable urban area. The highest RH is noticed at the riverside, while urban dry island occurs in the downtown due to lack of vegetation and abundance of impermeable surfaces. Riverside has somewhat lower average T_a during summer daytime compared to urban park which is likely due to the combined effect of river cooling and tree shading near the river in Banja Luka. This kind of research based on field measurements during extreme heat conditions can provide detailed temporal and spatial climate information for the local authorities and guide their efforts in mitigating extreme heat at the right place and at the right time.

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Using Geostatistics to Generate a Geological Model of a Sandstone Petroleum Reservoir in Southern California

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Abstract

A variogram-based two-point geostatistical approach was applied to generate a geological model of a petroleum reservoir. The geology consists of a sandstone formation with uniformly inclined rock strata of equal dip angle structurally trapped by surrounding faults. Data exploration of electrical well logs using univariate/bivariate statistical tests and data transformation tools demonstrated the data to be statistically suitable for ordinary kriging and sequential Gaussian simulation. Three directions were defined as part of the variogram and the data were interpolated resulting in a 3D subsurface representation. Validation included performing a leave-one-out cross-validation for each well and statistical comparison of multiple realizations generated from a computed stochastic model. The results display a reliable geological model which indicate a direct causation of the continuity trends from the bedding attitude of the regional fault trap.

Keywords: Reservoir Characterization; Ordinary Kriging; Conditional Simulation; Geostatistics; GIS; Petroleum Geology; Los Angeles Basin

Introduction

Reservoir characterization includes estimating the distribution of subsurface properties of a geologic system, which is essential for improving resource management, production development and field operations (Gorell, 1995). Reliable geologic outputs obtained from geostatistical models are used in a variety of important practices such as calculating production rates, remediating contaminated aquifers, estimating the recoverable reserves (i.e., oil, gas or water), drilling new boreholes and determining hydrocarbon migration (Deutsch, 2006). An important question for reservoir characterization is to determine the extent of geological continuity. This report demonstrates how to generate a geological model using two-point geostastistics and thereby revealing the geological continuity.

Interpolation of subsurface data involves predicting values of specific variables at unsampled locations based on the measurements obtained from known locations using statistical principles, thereby creating a continuous surface of the geologic domain (Journel, 2000) (Dubrule & Damsleth, 2001). The inclusion of geological features depends mainly on the depositional environment and defines the overall geological architecture of a given reservoir (Ebong et al., 2021). Different geological settings may require different geostatistical approaches in order to construct an appropriate model that honors the character of the reservoir with the greatest possible accuracy (Ebong et al., 2021; Caumon, 2010). The assumption of stationarity is important in geostatistics, and it is defined in practice as local

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data averages within a spatial domain that are approximately constant (Elfadil et al., 2018). Assuming stationarity for a particular area requires that the model developed from the sampled data be applicable within the specified area of stationarity (Kelkar & Perez, 2002). In the context of this investigation, the area of stationarity defined by the continuity boundaries for the subsurface field is the reservoir. In reservoir analyses this assumption is necessarily subjective because of the inherent uncertainties in the subsurface and the scarcity of data which prevents researchers from being certain about the geology of a region in which there is limited subsurface data (Kelkar & Perez, 2002).

In cases where geological structures are continuous enough throughout the reservoir, even if minor inconsistencies exist in some locations within the field, it is assumed to be appropriate that the reservoir can be modeled as a whole using variogram-based modeling (Nobre & Sykes, 1992). Kriging is a widely used, conventional estimation technique based on a linear estimation procedure expected to provide accurate predictions of values within a volume, over an area, or at an individual point within a specified field (Kaur & Rishi, 2018). In earth science, kriging is a favored interpolation approach compared to other methods because of its ability to include the anisotropy that rock layers of a sedimentary material exhibit in geological formations. Thus, models that are obtained via the use of kriging have more resemblance to the true field geology (PetroWiki, 2020). This is in part because the linear-weighted averaging methods used in kriging techniques depend on direction as well as orientation, instead of only depending on distance as other interpolation methods do. Kriging is explained by the following expression:

$$Z^*\left(\vec{x}_p\right)=\sum_{i=1}^{n}\lambda_i Z\left(\vec{x}_i\right)$$

where $Z^*(\vec{x_i})$ = value at a neighboring location , $(\vec{x_i})$, λ_i = weight of neighboring value and $Z^*(\vec{x_p})$ = estimated value at the unsampled location (Uyan & Dursun, 2021). The estimation procedure calculates the weights λ_i (assigned to neighboring locations, which depend on the spatial relationship between unsampled points and neighboring values as well as the spatial relationship between neighboring points (Uyan & Dursun, 2021). The relationships are obtained via the use of a variogram model.

Ordinary kriging is by far the most used kriging approach that allows for the local mean to vary and be re-estimated based on nearby (local) values, thereby easing the assumption of first-order stationarity (Satish Kumar & Rathnam, 2020). Ordinary kriging is better suited for this type of analysis because a true stationary global mean value for data in a reservoir is typically unknown. It cannot be assumed that the sample mean is the same as the global mean because in any real reservoir the local mean within a neighborhood in the field can easily vary over the spatial domain (Kelkar & Perez, 2002).

Another approach to characterize reservoirs is the use of conditional simulation techniques. One of the distinguishing factors of simulation methods is that the variance observed in the data is preserved by relaxing some of the constraints of kriging, as opposed to only preserving the mean value as is done in interpolation (Kim et al., 2020). Conditional simulation is a type of variation of conventional kriging, but it is a stochastic modeling approach that allows for the calculation of multiple equally probable solutions (i.e., realizations) of a regionalized variable by simulating the various attributes at unsampled locations instead of estimating them (PetroWiki, 2016). A 'conditional' simulation is conditioned to prior data, or in other words, the raw data measurements and their spatial relationships such as a variogram are honored (Kelkar & Perez, 2002). This approach helps represent the true local variability by providing several alternate equiprobable realizations, thereby helping to characterize local uncertainty (Caers & Zhang, 2004). This is one of the most useful properties of a conditional simulation because all models are subject to uncertainty, in particular, geological models because they are based on partial sampling. This is especially true for a reservoir model due to the several different sources of uncertainty (Kelkar & Perez, 2002).

Provided that the true value of an attribute is a single number, but that exact value is always unknown, the practice in statistical modeling is to transform the single number into a random variable, a variate, which is a function that specifies its probability of being the true value for every likely outcome (Kelkar & Perez, 2002) (Kim et al., 2020) (Caers & Zhang, 2004). During each individual run the corresponding realization starts with a unique random 'navigational path' through the discretized volume providing the order of cells (or points) to be simulated (Kim et al., 2020). Because the 'path' differs from each realization-to-realization, the results provide differences throughout the unsampled cells which yield the local changes in the distribution of rock properties throughout the reservoir that are of interest for accurate geological representations. Running several realizations produces several values per variate, allowing for a graphical representation of the results and an approximation of the variates (Olea et al., 2012). It is assumed that the geologic facies vary smoothly enough across the reservoir (typical depositional setting of shallow marine reservoirs), as opposed to sharp changes in the shape of the sedimentary body.

Sequential simulation methods are some of the most widely used in practice where unsampled locations are sequentially and randomly simulated until all points are included (Elfadil et al., 2018). The order and the way that locations are simulated determine the nature of the realizations. Sequential Gaussian Simulation (SGS) is one of the most popular techniques, it assumes the data follow a Gaussian distribution (Kim et al., 2020). Because SGS is best suited for simulating continuous petrophysical variables it is deemed most appropriate for this study.

Both ordinary kriging and SGS are well proven approaches to characterizing a reservoir. A useful approach is to use both and compare and contrast the results. When including the simulation approach, the natural variability of the local geology counters the blunt smoothing effects of kriging (Kim et al., 2020). The novelty of this study is the combination of conventional kriging and conditional simulation of borehole data points for sandstone model evaluation. The goal of this investigation is to create a model to be utilized for reservoir engineering and help the development of the oilfield by identifying the best target areas to drill and perform oil recovery practices.

Study Area and Geology

Study Area

This project evaluates the Michelin sandstone reservoir within the Abacherli lease of the Mahala oil field in the eastern edge of the Los Angeles Basin of Southern California, situated within the Chino Hills along the Chino fault (Figure 1). The reservoir surface area consists of hills dissected by deep canyons with elevation changes from approximately 500 feet (152 meters) to 1,200 feet (366 meters) above sea level. The Chino Hills were formed by uplift of the two regional geologic faults, Whittier and Chino. The sedimentary basin of Los Angeles consists primarily of coastal lowlands and Upper cretaceous-cenozoic rocks in the surrounding hills (Madden & Yeats, 2008) (Figure 2).

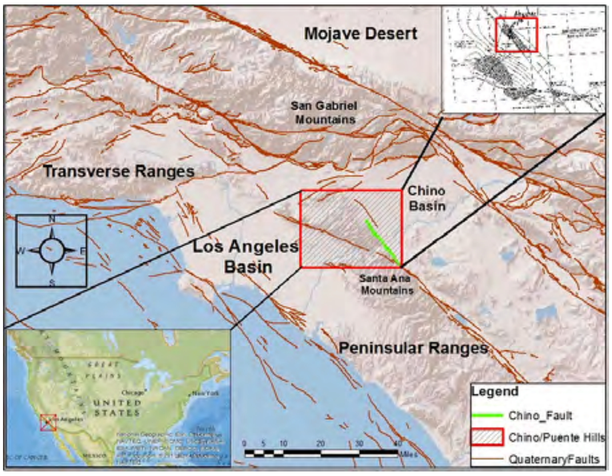

Figure 1. Location map of the study area region

Geology

Compressional forces from the Chino fault resulted in deformation creating the Mahala anticline structure (Madden & Yeats, 2008) (Figure 3). The structure is an asymmetric northwest-trending breached anticline extending over 3 miles (4.83 kilometers) in length (Dorsey, 1993). The anticline is thrust-faulted by the chino fault, which trends to the northwest and has a dip range between 50-70° to the southwest (Olson, 1977). The Chino fault thrust sliced and segmented the northeastern-most limb of the Mahala anticline fold dividing the area into a hanging wall above the fault and a footwall below the fault (Madden & Yeats, 2008) (Figure 4). This local mechanism is responsible for formation of the updip fault trap for the oil accumulation of the Michelin reservoir. The reservoir itself is a tilted homocline with steeply but uniformly dipping beds to the northeast with an approximate strike of 315°. The reservoir dip angle ranges between 40-70° with an average of 60°, and the dip angle is largest closer to the fault and decreases with distance from the fault. Two northeast-southwest trending sealing faults seal the reservoir at its northern and southern edges (Figure 5).

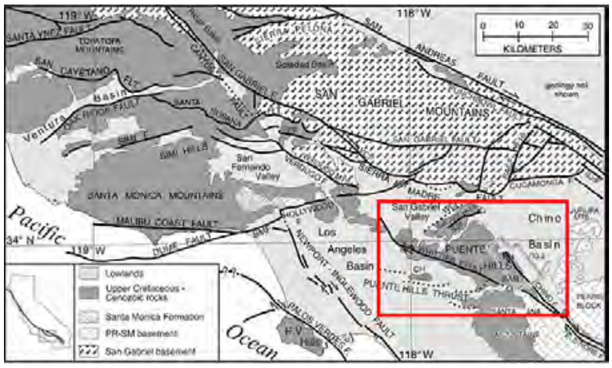

Figure 2. Geological overview of the Los Angeles Basin (Madden & Yeats, 2008)

The depositional environment is marine to moderately deep marine with sediment being deposited via the transport mechanisms of the sea and rivers, and with major subsidence and deposition occurring between the Upper Miocene until the Lower Pleistocene epochs (Yerkes et al., 1971). The strata range from Late

Cretaceous to Holocene, with the oldest Cretaceous section underlain by a basement rock of Mesozoic age consisting of granodiorite and associated plutonic rocks of the Southern California batholith from a depth of 5,000 feet (1,524 meters) to 7,000 feet (2,134 meters) (Olson, 1977). Following the law of superposition, it is expected that the layering order of the sedimentary rocks will follow the sequence on the stratigraphic column. However, the movement of the thrust fault has reversed the normal order by pushing up rocks of a lower layer over rocks of a higher layer, so older strata southwest of the Chino fault, such as the Yorba shale member thrust over younger Sycamore Canyon sand member to the northeast. At present, the overthrust hanging wall block above the fault contains the lower permeability shaly member, and the footwall block, including the Michelin reservoir, contains the higher permeability oil-rich sand (Olson, 1977). The "Michelin Zone" reservoir is predominantly a sandstone facies with some interbedded thin layers of silty and shaly sands underlain by poorly consolidated basal conglomerates (Dorsey, 1993). Observations of the lithology include tan to brown sand with a fine to coarse grain size, white to light gray and dark gray ultrafine grain size shale and siltstone, and pebble to cobble size, hard, poorly consolidated conglomerates in a calcareous matrix (Dorsey, 1993). The production sands are estimated to have an average permeability of around 500md and a porosity of 27% (Dorsey, 1993). The available isopach map (Figure 5) helps illustrate the stratigraphic thickness of the formation and reservoir boundaries.

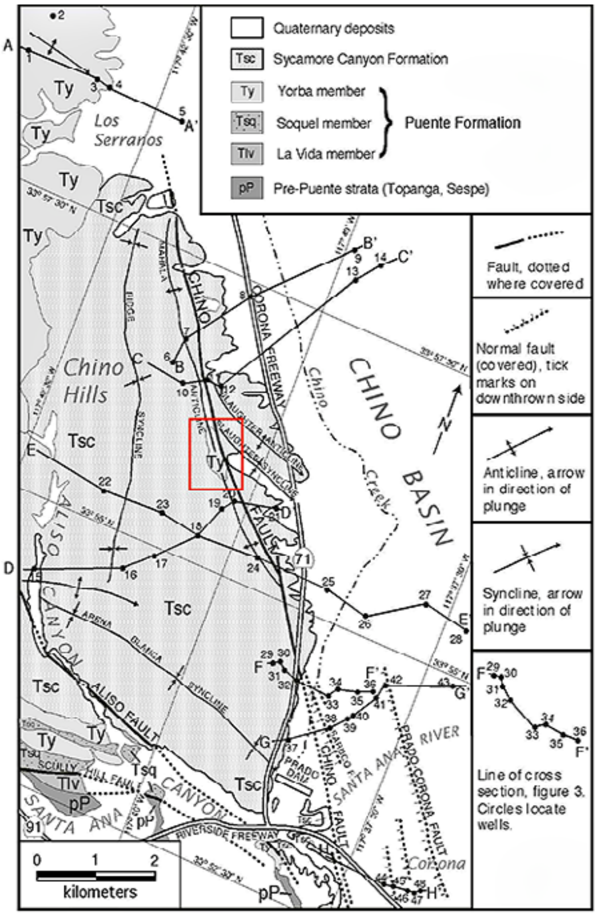

Figure 3. Geological map of the Chino Hills (Madden & Yeats, 2008)

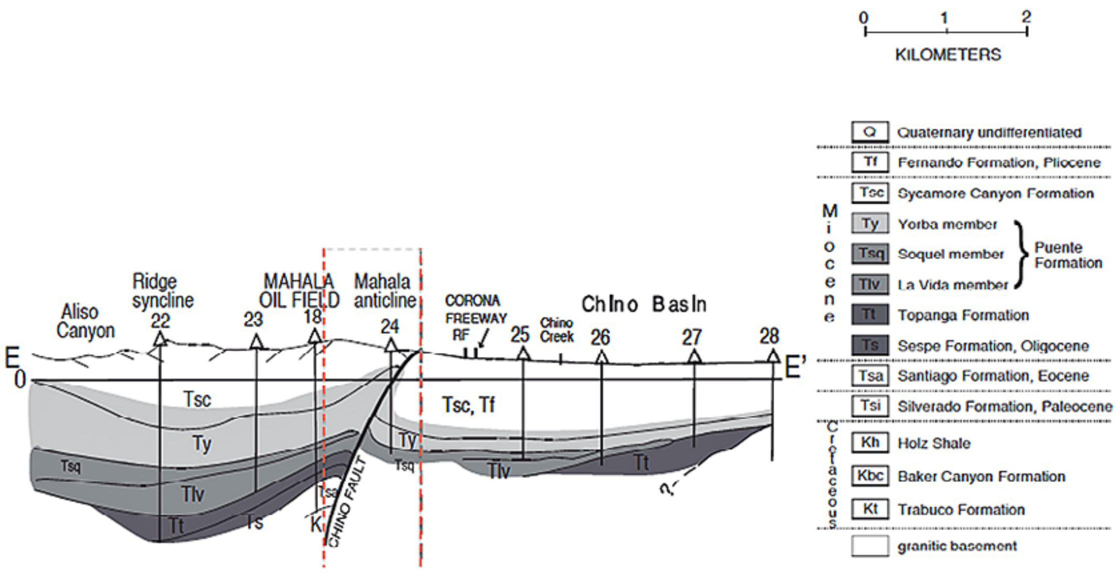

Figure 4. Cross-section of Chino fault study area for line E-E' of Figure 3 (Madden & Yeats, 2008)

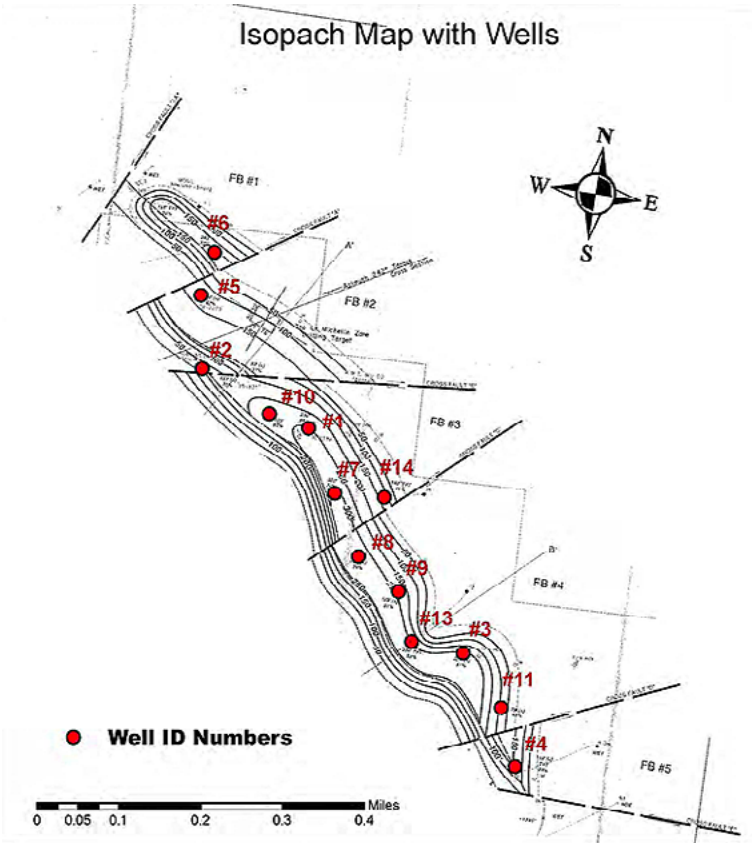

Figure 5. Isopach map of the Michelin Zone reservoir with drilled wells (Dorsey, 1993)

Data and Methods

Data

The data consisted of electrical logs for thirteen wells given as resistivity values ("R") measured in ohms (Ω) and spontaneous potential values ("SP") measured in millivolts (mv). The electrical logs used in this study were performed by Schlumberger Limited and the wireline services produced a continuous dataset for each of the boreholes with intervals of 10 feet (3 meters).

A 3D cross-section of the lithological boundaries inferred from the log data. (Figure 6).

An ultra-high-resolution point data set was generated based on the available isopach map. Due to the very large size of the point data set (>1.5 million

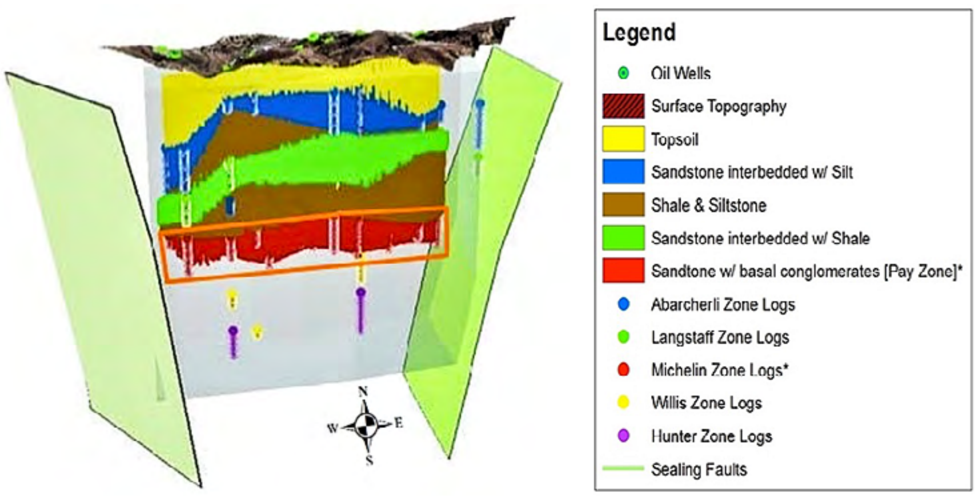

Figure 6. 3D Well Log Stratigraphic Digitization Model. Orange box depicts study area reservoir illustrating the boundaries for all interpolated and simulated models (seen in Figures 8-13)

points) running all simulations was computationally demanding, taking a total time of over one month for completing 101 realizations using a Dell XPS-8300 desktop with a Windows 7 professional 64-bits operating system.

Methods

Since ordinary kriging and conditional simulation methods are modeled by a Gaussian process, univariate and bivariate statistical tests were performed to determine if the data required transformation. The data values were inputted into the geostatistics modeling software (Figure 7 (a-b)), and a Probability Density Function (PDF), Cumulative Distribution Function (CDF), QQ-plot and a scatter plot were constructed. Colorbars indicate range of SP and R values.

The PDF and CDF outputs of the raw SP dataset followed an acceptable normal distribution. Therefore, further transformation for this dataset was not deemed necessary. The PDF and CDF of the raw R dataset displayed a significant positive skew to the right and thus were not normally distributed. It was therefore necessary to transform this dataset to normality. The R dataset was transformed to a normal distribution by using a histogram transformation tool.

The Q-Q plot of both the SP and original R probabilities plotting their quantiles against each other compares the shapes of the two probability distributions and allows to better determine if the data is close to a normal distribution. For the compared probability distributions to be normal, the plotted points should lie within a straight line. The closer all points are to a straight line, the closer the samples are to a normal distribution. The original graph illustrates that there is a significant offset, indicating a clear deviation from normality. The Q-Q plot of the SP dataset with the normally transformed R dataset illustrates a linear relationship between the two variables where the points plot across a straighter line indicating a more normal distribution.

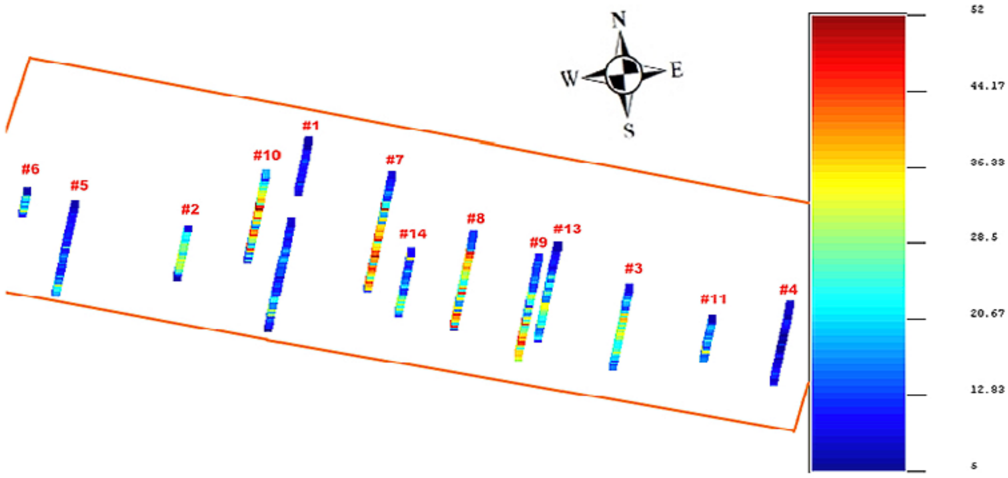

Figure 7a. R Well Data Logs with well ID numbers within study area boundary

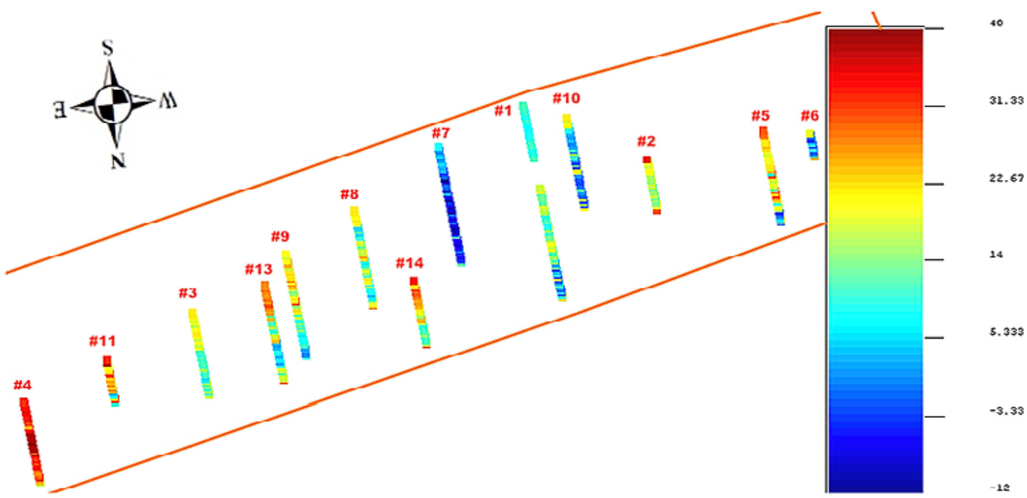

Figure 7b. SP Well Data Logs with well ID numbers within study area boundary

To establish the variogram parameters, the data was first input into the modeling software and the lag components that define the distance and the directional components that define the direction/orientation were selected. The three lag distance components are: 1) number of lags, 2) lag separation and 3) lag tolerance and the four lag direction components are: 1) azimuth, 2) dip, 3) tolerance and 4) bandwidth.

A useful technique to help estimate the parameters is to restrict the maximum distance at which the variogram is computed while retaining enough data points for a reliable estimate for that given distance. A common approach to select that restricted distance is to use half of the maximum possible distance within the region of stationarity and use it as the lag distance (Kelkar & Perez, 2002). Because a variogram is symmetric, this approach still ensures that all pairs on either side of a given location are included in the model. In addition, another common approach is to use approximately half the distance of the lag separation as the lag tolerance (Babish, 2000). These lag assumptions are not necessarily applicable to every case, since the conditions (geologic structure, well geometry, depositional settings) of different reservoirs may require significantly different lag parameters. However, since the wells in this field are oriented in nearly a straight axis, the well spacing is consistently distributed at closely uniform intervals, and the total area of the field is of modest size, this entire reservoir system is treated as a whole, and these factors and assumptions are applied in the variogram analysis.

Lag distance is equal to the number of lags times the lag separation. The maximum distance between any two well data points is 4,300 feet (1,311 meters), therefore the maximum lag distance the model was initially targeted to have was around 2,150 (655). After several attempts with the given directions, a lag number of 39 and a lag separation of 55 provided promising preliminary variogram plots. A lag tolerance half the value of the lag separation was targeted, so the value selected was 27 (55 ÷ 2= 27.5)) rounded down to the nearest whole.

Four components define the directionality of the variogram: azimuth, dip, tolerance, and bandwidth. The azimuth and dip, analogous to geologic strike and dip, are two important components reflecting the major axes in a 3D environment, and the tolerance and bandwidth help further refine the directions of interest to accommodate the intended directionality of the field. By adjusting the variogram azimuth, dip, tolerance, and bandwidth, it is possible to capture the structural geology of the field (strike, dip, rake, plunge) and hence end up with a true volumetric estimation that resembles the geological structure. A general direction was first established by selecting the azimuth and dip, and then the tolerance and bandwidth were adjusted until a variogram structure was identified. Three variogram directions were established: a vertical direction, an omni-directional and a major direction in the horizontal axis which followed the geological strike of the reservoir.

The first direction established was the vertical direction with an azimuth of zero, a dip of 90°, a tolerance of 5° and a bandwidth of 200. The second direction established was omnidirectional with an azimuth of 0°, a dip of 0°, a tolerance of 91°, and a bandwidth of 200. The third direction established was the horizontal direction aligned along the strike of the reservoir with an azimuth of 120°, a dip of 10°, a tolerance of 40°, and a bandwidth of 500. The interpreted variogram structure for each dataset in each direction was fitted with the best fit function. After several attempts adjusting the variogram design for both datasets in terms of the specific modeling components and variogram parameters, a final best-fit variogram model was established for each dataset.

As part of the interpolation, the variance was also mapped, identifying the areas with higher or weaker variance. Cross-validation of the results involved leaving one data location out and performing the estimation to predict the value at that excluded location, repeating the process by removing one different well location at a time, then re-running the estimation until all the well values have been interpolated. Once the predicted values were obtained for the data at all the well locations, they were compared to the known values to help determine the accuracy of the model.

The uncertainty throughout the field was characterized by examining the differences among the multiple equiprobable realizations, which display the local variations. In this matter, if uncertainty at a particular location is relatively small, then a number of images should display similar simulated values at that location. Conversely, if uncertainty at a particular location is relatively large, then a majority of images should display the differences in simulated values at that location.

Since the primary objective of performing a stochastic simulation is to create a model for the probability distribution of the unknown variables and because the variables are conditioned to the data, which is assumed to be a true representation of the subsurface geology, then their values are reasonably expected to fall within the limits of the simulated probability distribution. Summary statistics performed on the simulation output provide a measure of the uncertainty of the model, and specific statistical calculations on the suite of realizations provided estimated probabilities. Calculating the median of the resulting multivariate distribution from all the realizations yielded a map with the highest probability of representing the true model. This probability model was compared to the predicted (kriged) model, and the similarity provided a degree of confidence. In addition to the median probability (i.e., P50), the P10 and P90 quantiles provided uncertainty ranges in the simulated median value, and thus more confidence that the true expected mean value falls within the simulated range.

Results

The correlation coefficient between R and SP was -0.665. This strong negative correlation follows the trend expected in a petroleum field since large positive R spikes and large negative SP deflections are clear indicators of permeable hydrocarbon-containing formations.

A total of 53 realizations of SP distribution across the field using Sequential Gaussian Simulation (SGS) were generated. Six randomly selected SP SGS realizations are illustrated (Figure 8).

A total of 48 realizations for R distribution across the field using SGS were generated. Six randomly selected R SGS realizations are illustrated (Figure 9).

The calculated median (P50), as well as the P10 and P90 maps for R were generated (Figure 10). Higher R values shown in red in Figure 10 are scattered, but a cluster is apparent in center area of reservoir.

The calculated median (P50) as well as the P10 and P90 maps for SP were generated (Figure 11). Higher

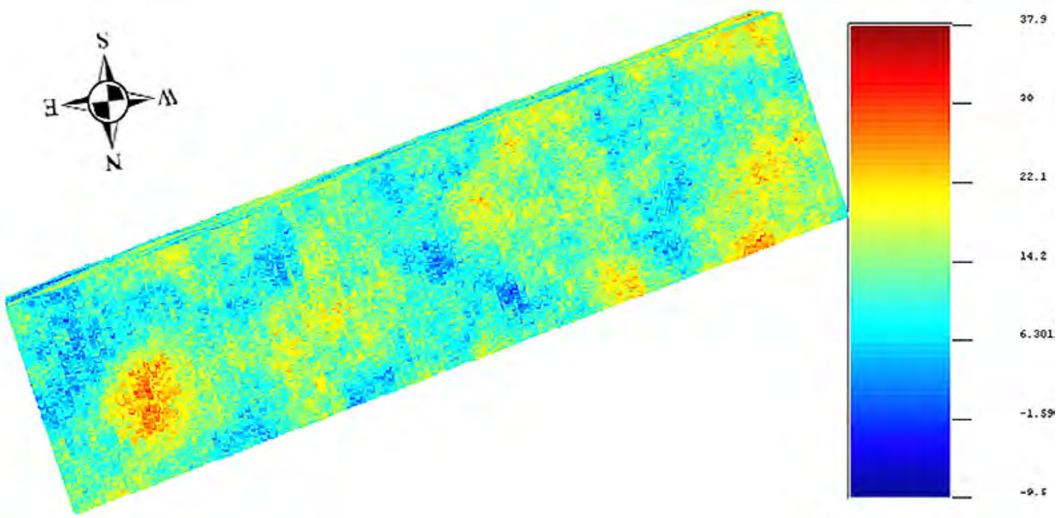

Figure 8a. SP Realization Example #1

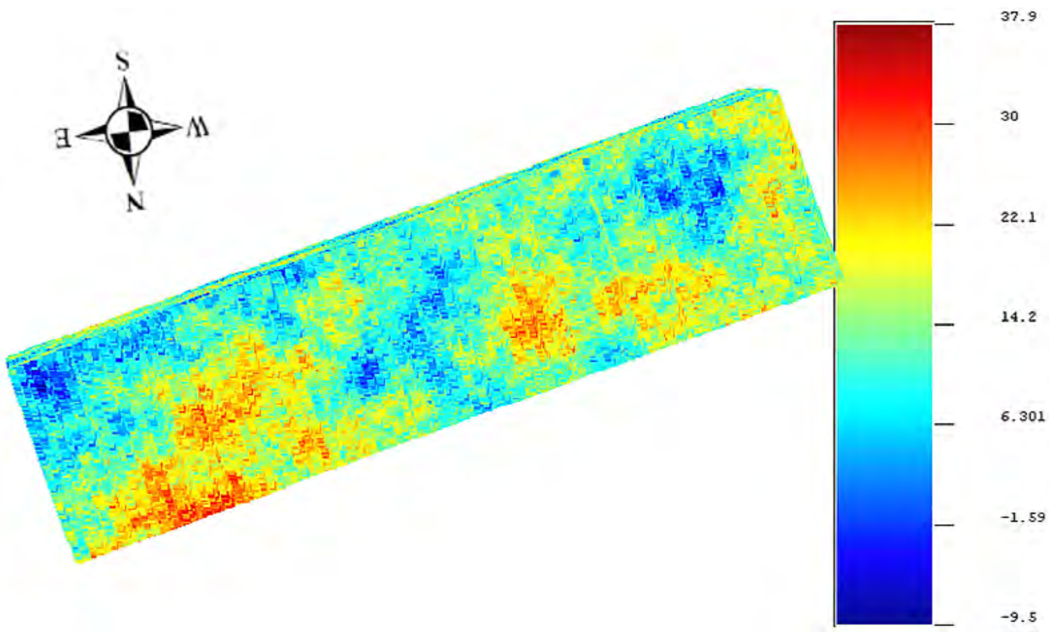

Figure 8b. SP Realization Example #2

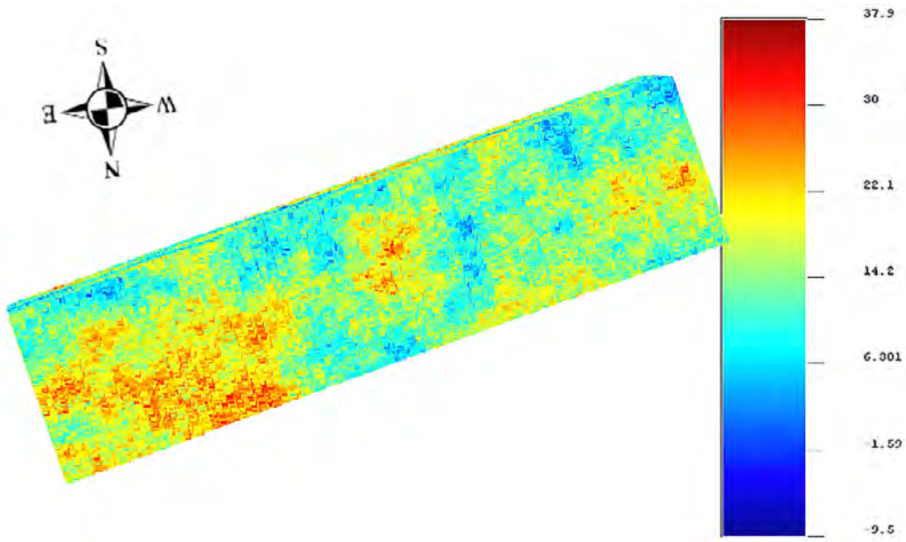

Figure 8c. SP Realization Example #3

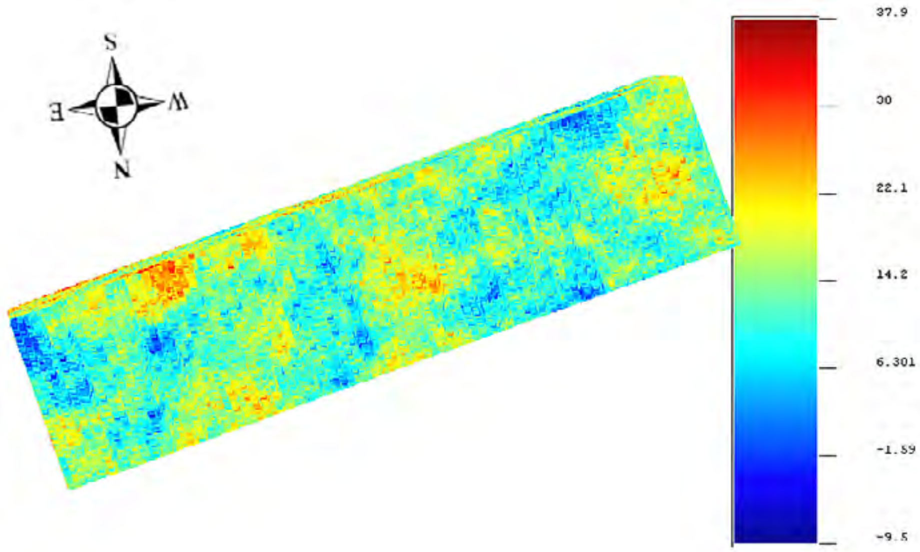

Figure 8d. SP Realization Example #4

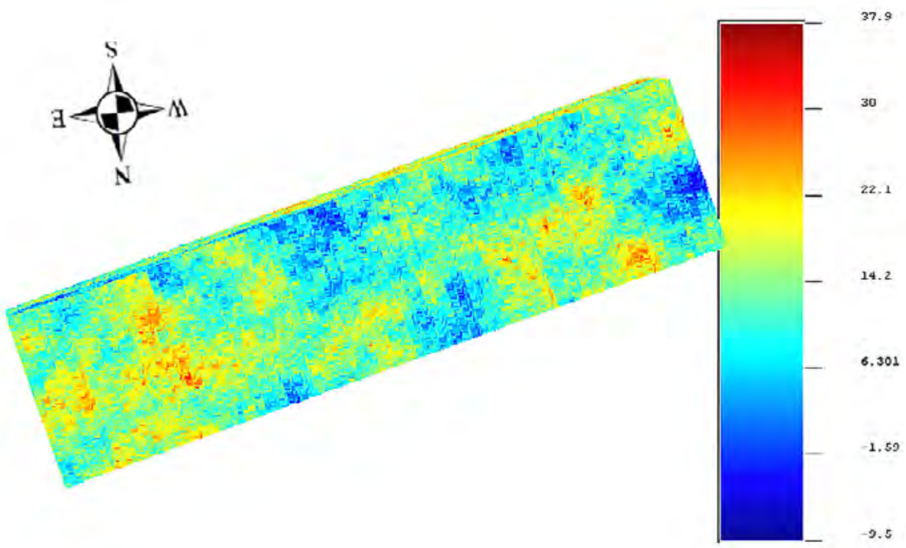

Figure 8e. SP Realization Example #5

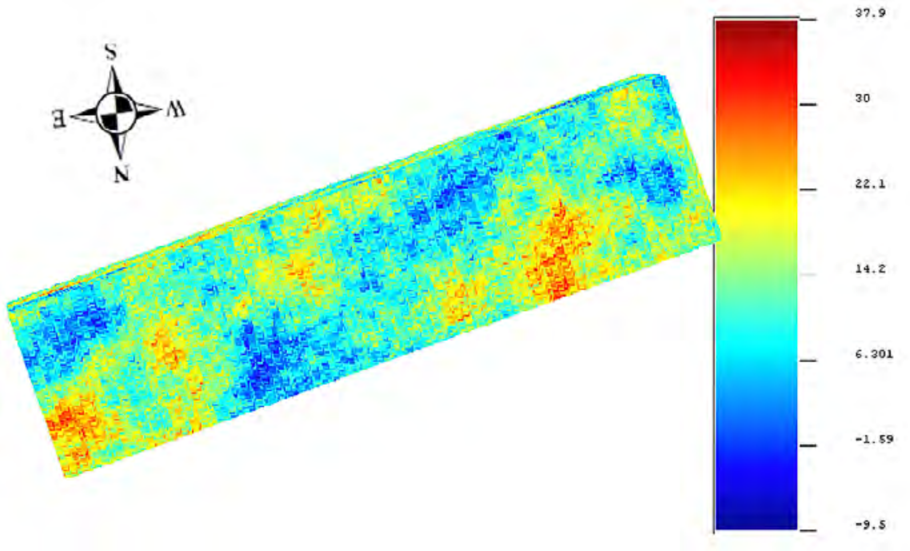

Figure 8f. SP Realization Example #6

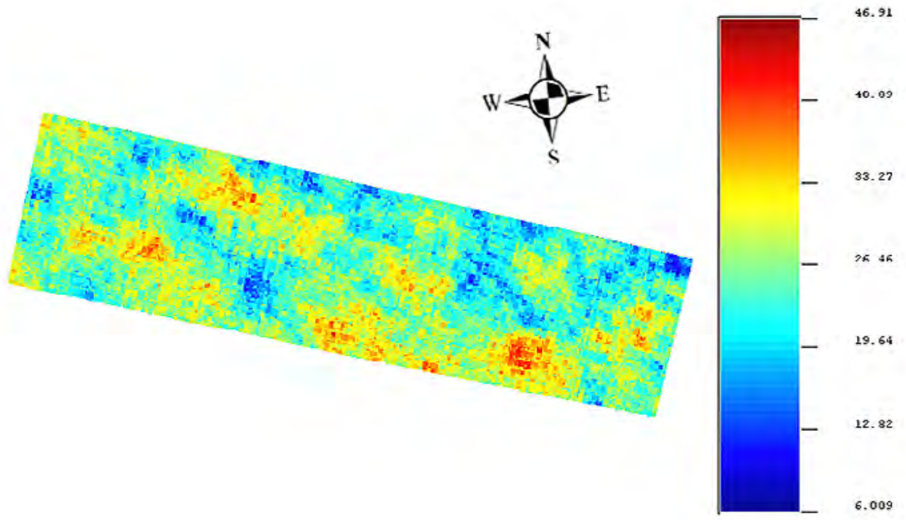

Figure 9a. R Realization Example #1

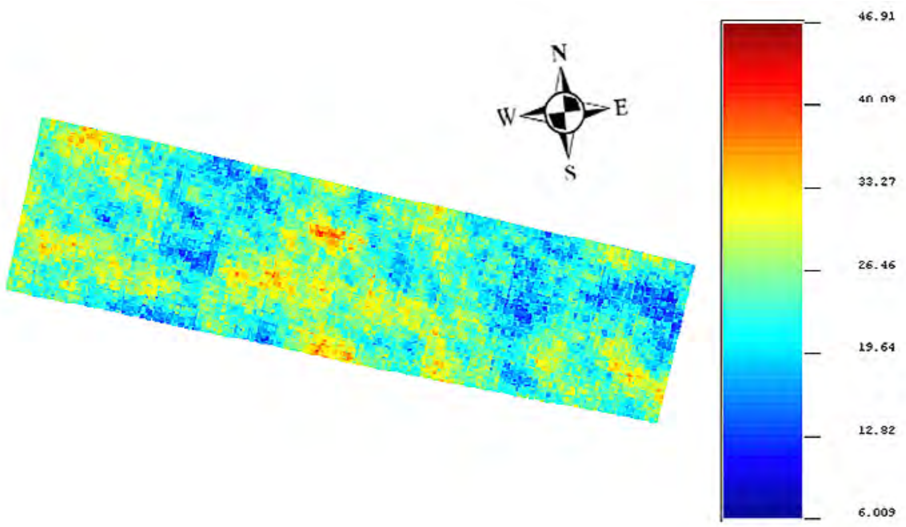

Figure 9b. R Realization Example #2

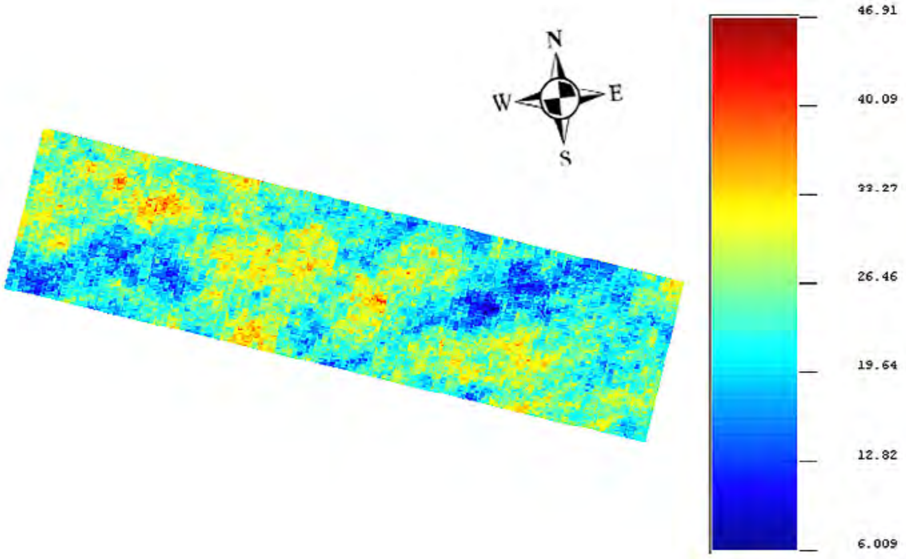

Figure 9c. R Realization Example #3

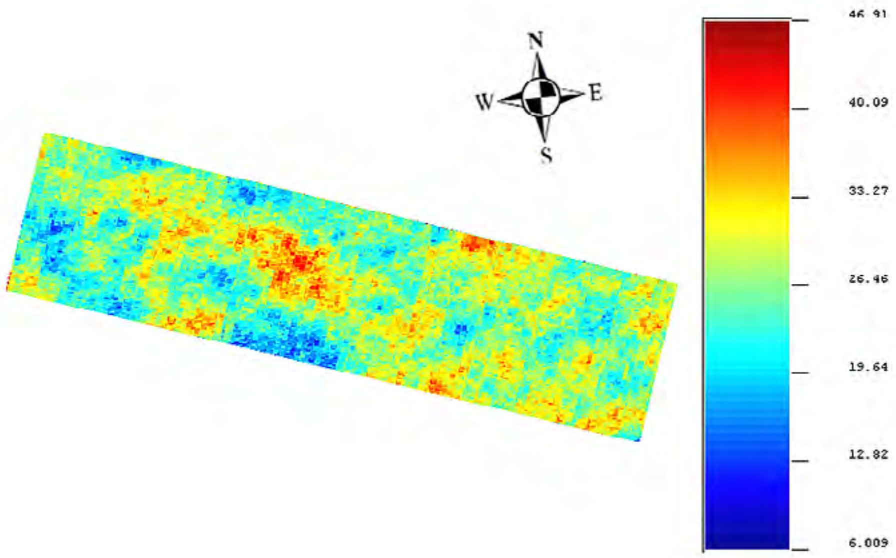

Figure 9d. R Realization Example #4

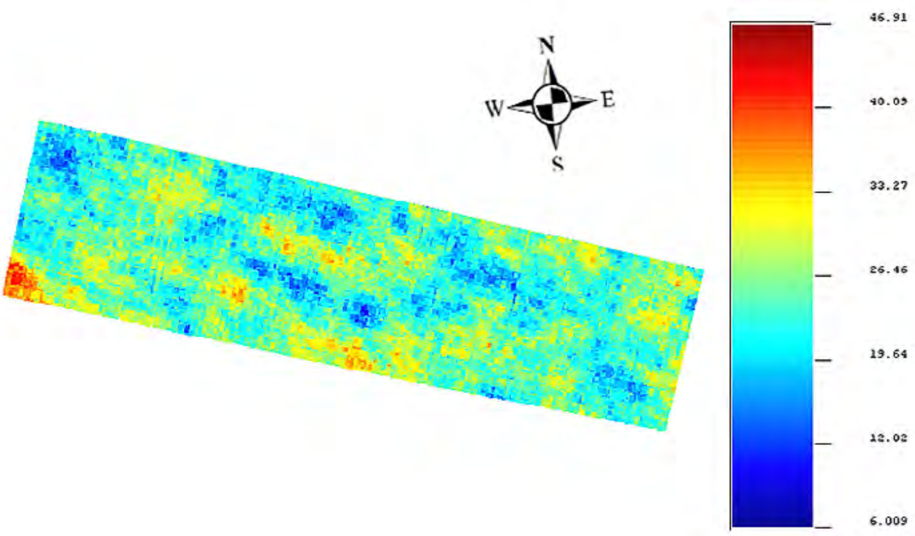

Figure 9e. R Realization Example #5

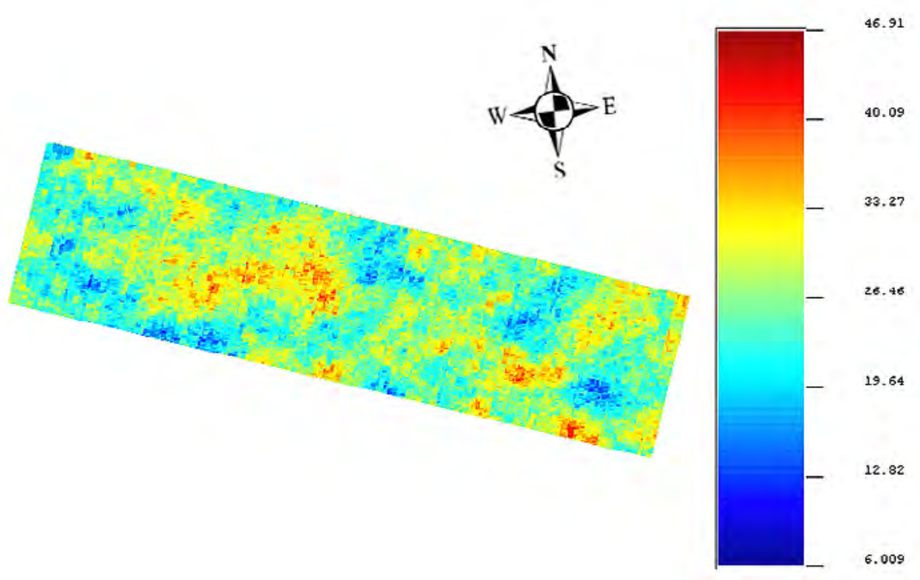

Figure 9f. R Realization Example #6

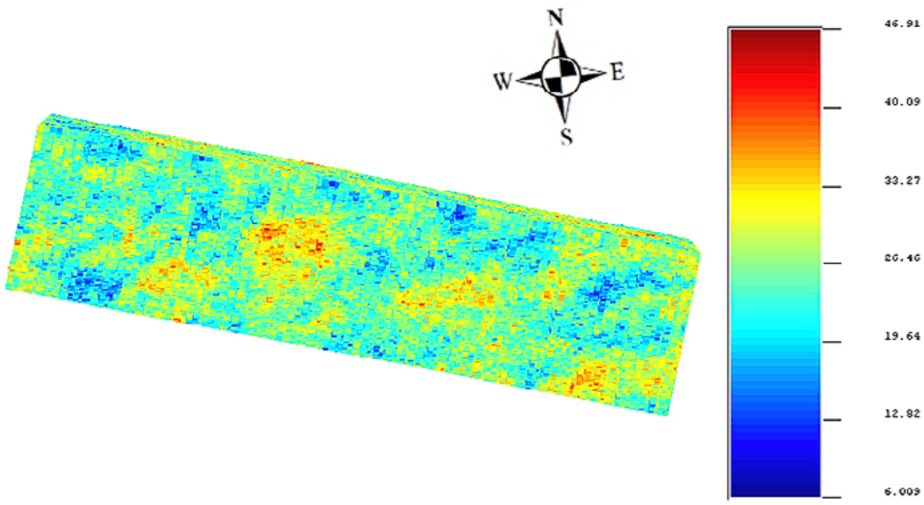

Figure 10a. R P50 model

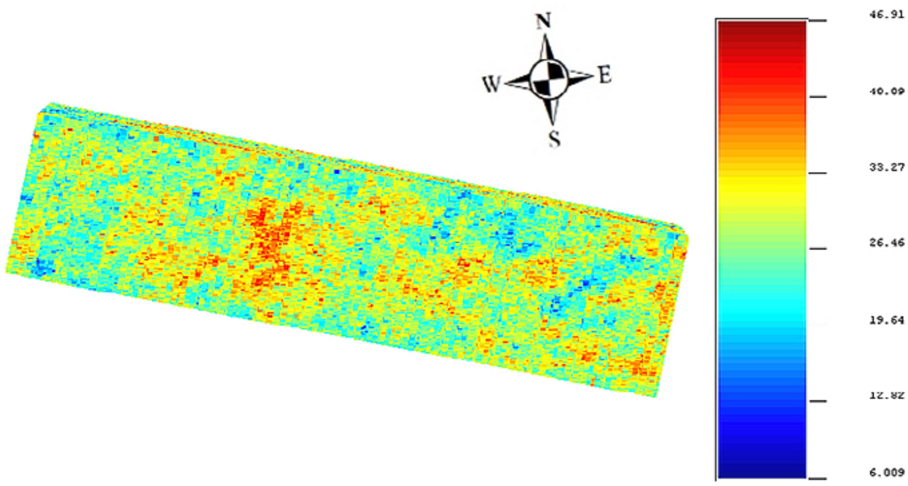

Figure 10b. R P10 model

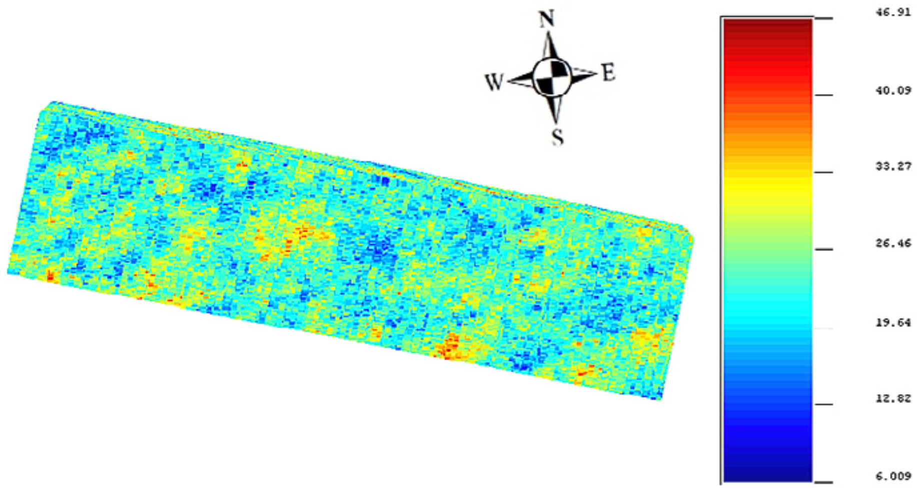

Figure 10c. R P90 model

red SP values are evident in the southeastern area of the reservoir, while scattered, lower blue SP values are apparent in the center area as well as near the top of the southeastern area, especially in the P50 and P90 models.

The models were interpolated, and their derived variance maps were generated for both R and SP datasets (Figures 12 and Figure 13).

In Figure 12, higher R values in red are evident in the middle of the reservoir, and decrease outward from the middle to the edges of the reservoir, and the variance is less in middle and gradually increases (with darker shades) towards the corners.

Lower SP values indicated in blue are centered in the middle, top section of the reservoir, and gradually decrease toward opposite edges. Higher SP values in red are concentrated in the southeastern section of the reservoir. The variance is low in the southeastern section and towards the center of the reservoir, while it increases in the top corners (Figure 13).

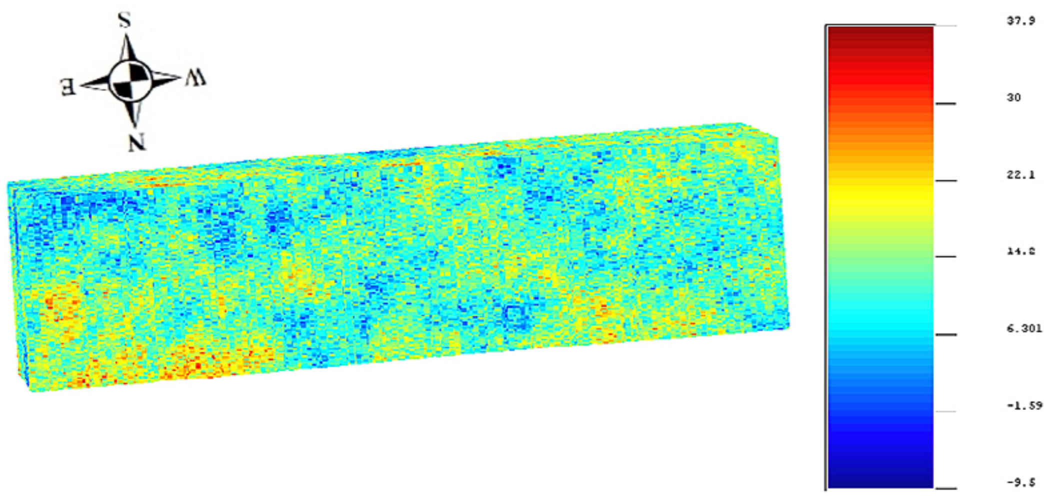

Figure 11a. SP P50 model

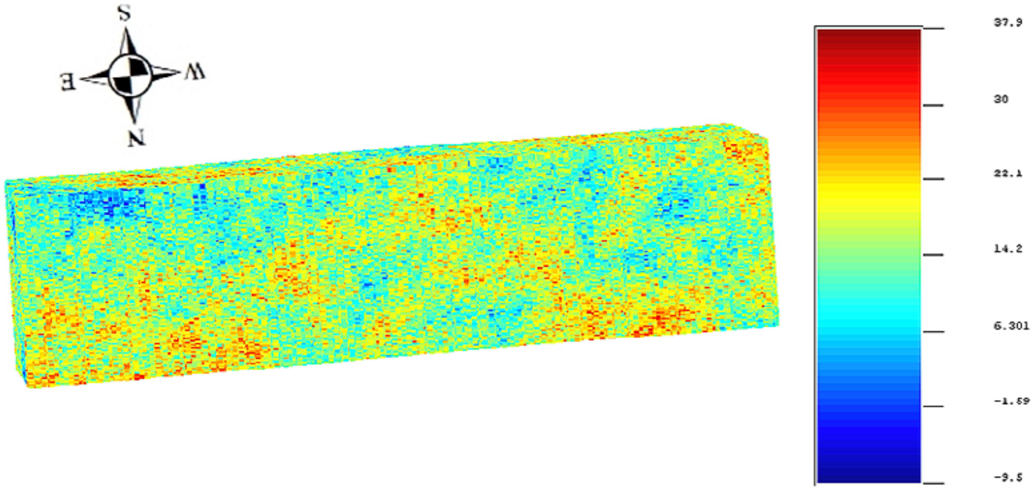

Figure 11b. SP P10 model

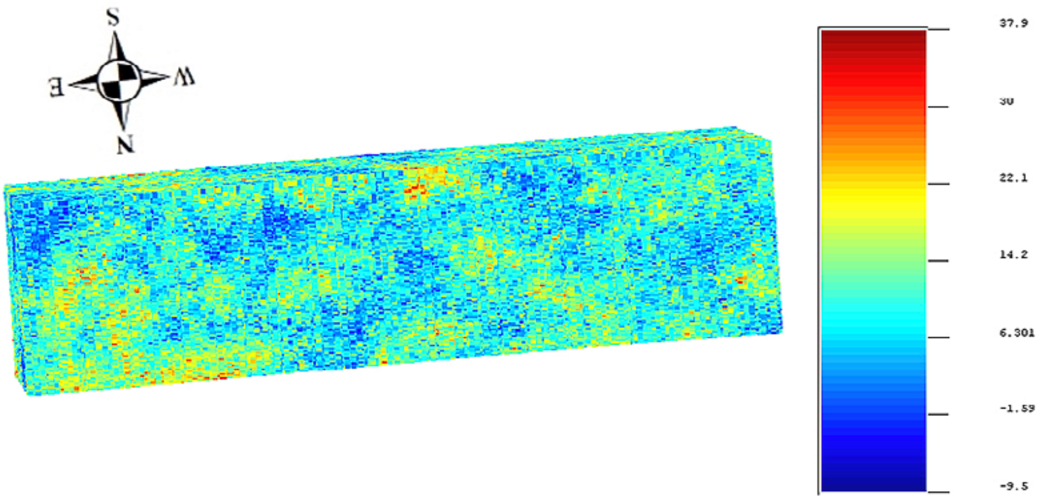

Figure 11c. SP P90 model

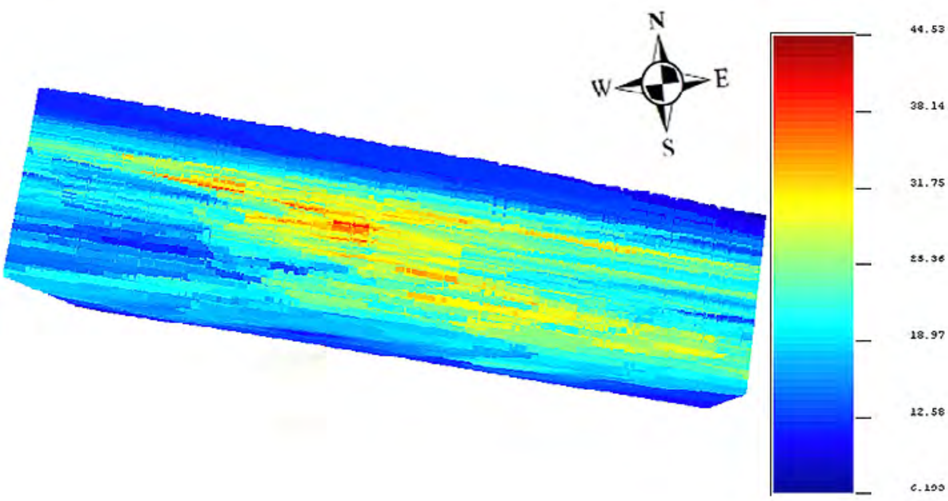

Figure 12a. R kriging map

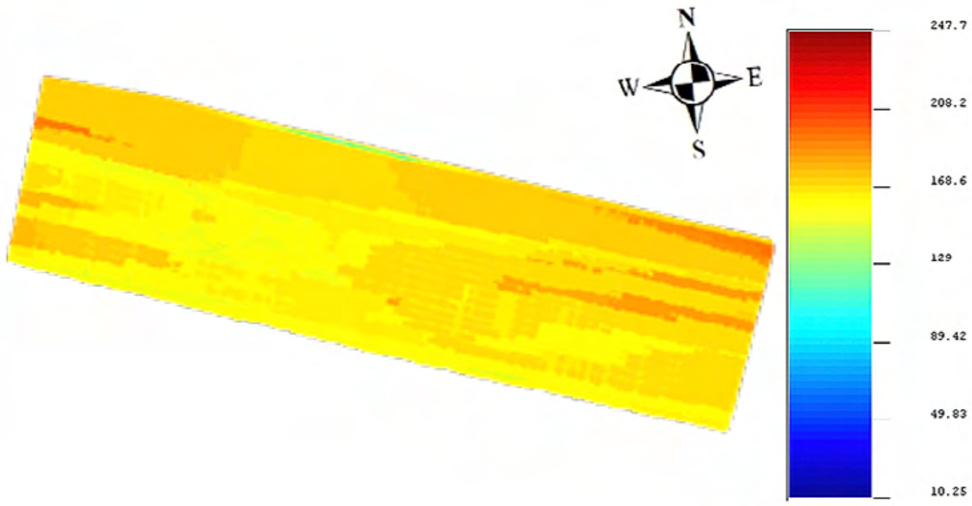

Figure 12b. R variance map

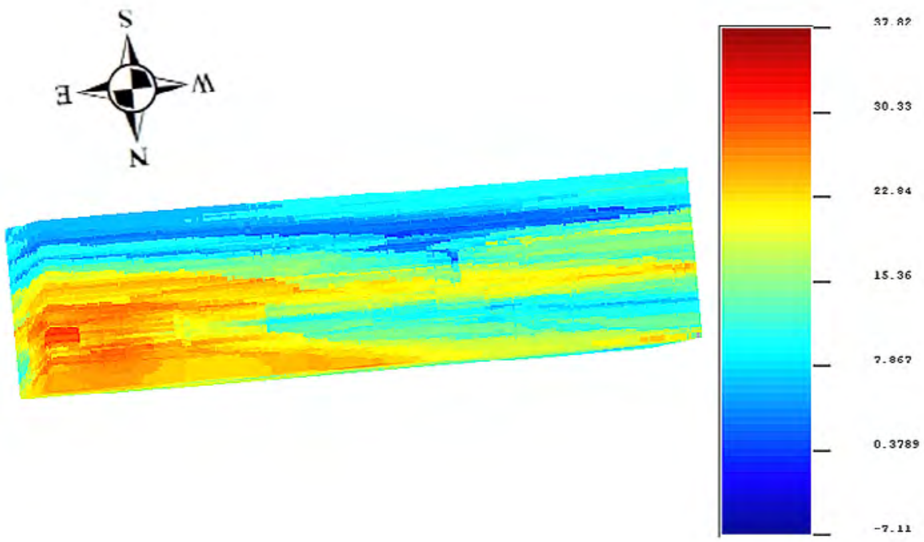

Figure 13a. SP kriging map

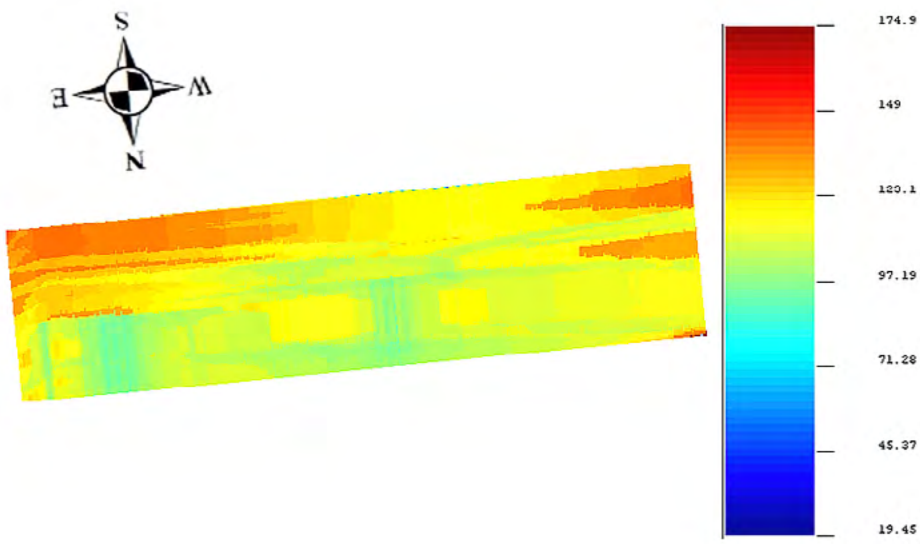

Figure 13b. SP variance map

Discussion

The vertical variograms for both datasets exhibit periodic behavior, which represents cyclical sedimentary processes. This is known as the "hole effect" and is typically experienced when modeling variograms in the vertical direction. In depositional environments, sediment is deposited in layers during geological events, thus this repetition of cycles will be reflected in the vertical continuity of the layers in the field. In these variograms, the transition from one stratum to another can be clearly defined. Interpretation from both vertical variograms indicates that the formation is continuous up to around 350 feet (107 meters) and then becomes discontinuous but regains continuity at greater distances. This trend is expected to continue throughout different depths across the reservoir. The fitted vertical variogram functions only include those values up to 350 feet because it is useful to only capture the extent of the continuous data. In addition, the average thickness of the producing formation is only 378 feet (115 meters), so most of the vertical extent is included by modeling to 350 feet. The fitted functions of the other two directional variograms were plotted to include as many of the data points as possible. A few local outliers were excluded in order to obtain a reasonable structural variogram model. Overall, the trend of the field appears to be well captured in the variogram models.

Since all the realizations honor the same constraints because they are coming from the same distribution, it is not possible that one realization is more likely to occur than any other. Therefore, the apparent differences between realized images are representative of the local uncertainty and visualizing their variability provides a reasonable assessment of uncertainty. Provided the distribution is representative of the real field then the true reservoir values are expected to fall within the bounds of the distribution while the calculated statistical summaries of the simulation (P10, P50, P90) illustrate the probabilities of occurrence.

The cross-validation included the observed data plotted with the estimated data versus subsea depth. All the plots include low, medium, and high-value thresholds as well as horizontal error bars of the standard deviation of the observed data.

Comparing the kriged R model with the simulated R P50 model, it appears that the overall trend generally remains consistent between both models except for a few small patches in the upper half of the field. Comparing the kriged SP model with the simulated SP P50 model, it appears that most of the continuity is also well preserved, especially in the lower half of the field. However, small to moderate dissimilarity appears within the upper half of the field. The dissimilarities that are most apparent occur mainly near opposite edges, which is probably due to the lack of data from boreholes drilled near the edges. Greater uncertainty is expected near the corners because the edges are further away from the observed values. The P10 and P90 maps appear to show a modest margin of probability in the distribution in which the P50 median falls between the lower and upper quantiles. The noticeable differences apparent in both datasets in the upper half of the models are probably related to more significant geological variability in the upper half of the reservoir.

Standard deviation error bars help provide a "tolerance range" in the cross-validation to better gauge interpolation accuracy. Well#1 had the largest error in the R dataset, followed by the southernmost well#4. Although these wells plot in a consistent manner close to the observed values, most of the calculated values fall outside the bounds of the standard deviation. The estimated values for the rest of the wells in this dataset appear to plot reasonably close to the observed values. Close examination of the R results revealed that the estimations for all the wells between well#1 and well #4 (i.e. in the lower half of the field) appear to plot slightly better than all of the wells north of well #1 (i.e. in the upper half of the field).

Well#7 had the largest error in the SP dataset, plotting outside the bounds of the standard deviation. Most of the other wells within this dataset also plot reasonably close to the observed values. Nevertheless, some significant differences were noted, including well #4 (located at the southern edge) and well #6 (located at the northern edge) which both show significant deviation. The "dataset outlier" for SP is well #7 and for R values is well #1. The same field observation is noted in both the R and SP results, where all the wells in the lower half (south of their respective "dataset outlier") provide slightly closer approximations relative to all the wells in the upper half (north of the dataset outlier).

The relatively larger margin of error of the two wells at the edges can be attributed to their more isolated locations compared to the other wells. The clustered borehole locations have more conditioning data and so are expected to provide slightly more accurate estimates. Given a general consistency between the kriged and simulated models, in addition to the same general trend expressed from the cross-validation of both datasets. It can be assumed that the southern half of the field, from well #4 up to somewhere between well #7 and well#1, is very continuous and the upper half, from well #1 to well#6, is slightly less continuous. The results of this study indicate that the reservoir is intact with a well-defined continuity trend mimicking the geologic attitude of the field. As can be seen from similarities between the northwest-southeast direction and the omni-direction variograms, the continuity in the study area is preferential in the plane parallel to the geological strike. Because all the wells are preferentially directed along this plane, there is inherently more certainty in the data obtained in this direction (northwest-southeast) compared to the perpendicular direction (southwest-northeast). Furthermore, because of the continuous thrust faulting that extends the reservoir along the strike and thins the geologic units along the perpendicular plane, it is expected that the trend along the plane perpendicular to the strike will be less continuous. Similarly, because a coherent continuity trend is captured in the vertical direction, the uncertainty in this direction is minimal.

Other similar studies have been conducted on oilfield reservoirs, yet with notable differences compared with the study described herein. For example, Gringarten and Deutsch, 1999 describe proper use of variogram modeling but do not illustrate conditional simulation evaluations. Sabouhi et al. (2019) conducted variogram-based modeling of a hydrocarbon field using sequential indicator simulation rather than sequential gaussian simulation. Masaud and Meddaugh, 2019 conducted reservoir characterization via geostatistical modeling but due to facies heterogeneity, use of a pillar gridding technique to establish a structural framework, and use of a conceptual facies model were warranted.

Conclusion

A geologic model was created using a two-point geostatistics approach that characterizes the distribution of electrochemical properties. The study area represents a conventional sandstone oil reservoir. Evaluation of the data obtained from electrical logs warranted ordinary kriging and sequential Gaussian simulation as appropriate methods for the analyses. A best fit variogram function incorporating geological and statistical assumptions was defined and used for the analyses. Results included 3D models and multiple equiprobable realizations of the geological continuity of SP and R. With respect to associated uncertainties, the confidence level in the models is preferential relative to the direction where it is strongest vertically, then parallel to the geologic strike, and then perpendicular to strike. Validation procedures included cross-validation and calculating the P10, P50, and P90 quantiles to assess local uncertainty and variability. By comparison and evaluation, it can be concluded that the results provided a practical reservoir model. Although the structural continuity of the reservoir appears to retain general consistency throughout the field, there is an apparent continuity trend where the northern half of the reservoir becomes slightly less continuous relative to the southern half. It is assumed that this small to modest change reflected from the field continuity is due to geological phenomena attributed to the localized thrusting of the Chino fault.

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A Community-based Approach to Mainstream Human-Nature Interactions into Coastal Risk Governance: A case of Katrenikona, India

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Abstract

Coastal rural communities, being intricately associated with their ecological settings, are often highly vulnerable to climate change. Amongst the many approaches of reducing the coastal vulnerabilities and achieving climate change adaptation, a potential solution is to improve risk governance through integrated coastal zone management. The coastal risk governance signifies not only the actions of the state but also of other stakeholders, especially the local communities. Community-based approaches have also for long been advocated for effective adaptation and mitigation against climate adversities. While human-nature interactions can significantly influence disaster risks, this research makes an attempt to understand various decisions and choices that a coastal rural community makes based on such interactions to mitigate and manage the climate-induced adversities. Through structured interviews, this research first identifies the significant domains that reflect on the prevailing human-nature interactions, after which the choice modelling technique is utilized to comprehend the community priorities for better climate risk governance, with a specific focus on coastal rural settlements of Katrenikona (Andhra Pradesh, India). The application of this methodology resulted in the formulation of a baseline for local coastal governance, which can be useful for informing various levels within local governments. The baseline consists of an assessment of the different community resilience domains derived based on the prevailing interactions of local communities with their surrounding ecological elements and measured by indicators of local coastal governance. The concept and method for measuring coastal risk governance based on community preferences are potentially replicable, and it can help to track the progress towards longer-term coastal management and local climate adaptation goals. At the same time, it can be turned into a self-evaluation tool to assist the local governments in reflecting on pertinent pathways involving community actions for effectively managing various climate risks and ecological impacts.

Keywords: Coastal Risk Governance; Human-Nature Interactions; Community-based Approach

Introduction

From 1999 to 2019, the disaster occurrences around the world have sharply increased by 74.45% (EMDAT, 2019), as compared to the previous couple of decades. Among the main lands, Asia tops the world at 45.1% in categories of disaster occurrence as well as the number of people killed (50.5%) and the incurred econom-

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ic damages (49.5%) (ARDC, 2019). The anthropogenic activities, steering climate change, are quoted as few of the main reasons that have been instrumental in changing the intensity and frequency of disasters (SR15, 2018). Among other terrain, coastlines are in particular noted to be highly vulnerable to the consequences of climate change due to their close association with the oceans (IPCC SROC, 2019) and are exposed to a variety of disasters such as sea-level rise, cyclonic storms, tsunamis, etc. Coastlines are valuable assets to any region not only in terms of ecosystem services they provide but also due to the livelihood and economic opportunities they attract (Martínez et al., 2007). Recent studies have shown that the exposure of coastlines worldwide to disasters is expected to surge (Bathi & Das, 2016). Coastlines being highly complex systems (Jozaei et al., 2020), any decision taken as a part of recovery after disasters can change the future path of the resilience of that system (Allison & Hobbs, 2004; Gunderson & Holling, 2001). Housing the growing population, livelihoods, and a major share of socio-economic activities, the resilience of rural coastal settlements is faced with several challenges, since the local population predominantly depends on marine ecosystems for their daily survival (IPCC SROC, 2019). These settlements are often exposed to multiple disturbances, in the form of tropical cyclones (for instance, the Indian cyclones Amphan 2020, cyclone Fani 2019, etc.,), floods due to abnormal rainfall (Godavari Floods of India 2020), tsunamis (Indian Ocean tsunami 2014) and stormwater surges (Prince et al., 2020). Such catastrophic events impact the communities in several ways, and in some cases forever change the local footprint, infrastructure, and economy of the areas affected. Depending on the human-nature interactions locally, such events may have profound implications on natural resources and in turn on the people (Bajaj, 2020; Stern, 2007). As a response, many communities choose local-level adaptations to disasters, which has an influence on the overall coastal risk governance (Dronkers & Stojanovic, 2016).

Governance, in general, is understood as the interaction of a government and its citizens; in a sense that citizen participation also provides inputs to strengthen the governance at different levels (Moore et al., 2011). However, there is often uncertainty and ambiguity with respect to the interventions in planning decisions through this approach (Moser et al., 2012). Decentralization of coastal zone management to promote community-based approaches has been widely discussed in Asian countries, with an objective to cooperatively maximize the performance of delegated authority for managing coastal zones (UNFF, 2009). Countries like Malaysia are still between classic deconcentration and coercive devolution where the flow of power is directed from upper to lower levels in a diversified manner. Contrarily, Indonesia and the Philippines have been in the cooperative devolution and devolved experimentation stages where two-way partnerships with more concern to local capacities, resources, and solutions have been considered (Siry, 2006). In India, coastal settlements are governed at various levels by strategically designed policies included in the Integrated Coastal Zone Management Plan (ICZM), National Disaster Management Plan (NDMP), and regional development plans. Although the necessity to expand the scope of community-based efforts and communities to identify local risk reduction measures and implement them is highlighted in NDMP 2019, the community participation at present is still limited to short-term disaster preparedness and contingency planning (NDMP, 2019). Consequently, the local-level adaptive measures in the long term often mesh with the already existing national policies and make their implementation challenging (Sethi et al., 2021). At the same time, the inclination of communities towards adopting local-level adaptive measures emphasizes the need for amendment of existing disaster risk management strategies, which is possible through effective coastal risk governance.

Over that background, this study aims to understand the local perspectives of adaptation and contribute to governance by prioritizing community choices. This research particularly addresses the research question pertaining to the priorities of the local people, as to among the given choices leading to resilience, what would the natives prioritize? In doing so, this study emphasizes on application of choice experimentation using selected parameters in coastal rural settlements for mainstreaming human-nature interactions into coastal risk governance, followed by the interpretation of priorities of local communities which can act as an input for coastal risk governance. A case study of rural settlements along the coast of Andhra Pradesh, India which is a highly vulnerable (Prince et al., 2020) and heterogeneous region regarding social, economic, and environmental factors, has been selected for the purpose of this study.

Overall, this paper comprises five sections, including the introduction (Section 1). Providing a theoretical background, Section 2 defines the role of human-nature interactions in coastal risk governance and adaptation. Section 3 introduces the case of the selected coastal settlements and gives an overview of the adopted research methodology. The study results are presented in Section 4 along with critical discussions. Section 5 highlights the key conclusions and the future scope of research.

Theoretical background

Interacting closely with each other, human societies and nature have patently co-evolved within unique bio-cultural systems (Bergamini et al., 2013). Humans are interconnected and dependent on nature in many ways that are often complex (Liu et. al., 2007) and disasters result from the slightest disturbances in these complex interactions (Shaw, 2010). Understanding these complex interactions, therefore, paves way for reduced disaster risk and global sustainability (Liu et al., 2020). Particularly in fragile systems like coastal areas where the environment and its natural resources are conditioned by the actions of the society (Plag & Jules-Plag, 2013), the human and the natural systems emerge as overlapping components forming a holistic complex socio-ecological system (Schouten et al., 2009). The inherent definition of human-nature interaction in such systems varies over time based on governance decisions (Seymour, 2016). Greater changes observed in human-nature interaction indicate the transformation of that system, increased uncertainty, and a possible risk of disaster (Hossain et al., 2020). Different approaches have been evolved to deal with uncertainties, particularly after the events of disasters, and one of those prominent approaches is adaptation.

By choosing an adaptive approach, human behaviour deviates from its original state of response (Winterhalder, 1980). Hence, adaptations are often recommended as a part of recovery plans (IPCC, 2012). Disaster researchers and policymakers recognized the necessity to address adaptation concerns within disaster risk reduction strategies as a part of the Hyogo Framework for action: 2005-2015 (UNISDR, 2009). The United Nations Framework Convention on Climate Change (UNFCC, 2007) defines adaptation as the “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities”. It can either be a specific action, a systemic change, or an institutional reform (Shaw, 2010). Adaptation can be both beneficial as well as it can moderate the loss that would have been incurred otherwise, thus minimizing the adverse effects and maximizing the opportunity concerning the unmanageable climatic stressors (Le, 2019). In thecase of rural coastal communities, depending on the magnitude of human-nature interactions, adaptation options can have profound effects on the resilience and sustainability of the system (Garmestani et al., 2019). However, the adaptation aspects at a smaller scale are usually difficult to govern and mainstream into decision making, and the rural communities too, are often disadvantaged because of various reasons like little formal education, poverty (Lade et al., 2017), isolation, and vulnerability to disruption. This results in their opinions being unheard and concerns unaddressed in decision-making and policy development. In such cases, decisions and their successful strategic implementation become questionable, especially when the strategies do not suit the communities’ needs.

This research particularly builds on the developed understanding that adaptation after disasters can abruptly affect human-nature interactions. The interactions in this context are considered as the interdependencies of social and environmental parameters. Considering the role of human-nature interactions in disaster risk and the gaps in governance in context of coastal areas, this study is aimed at preparing a framework that is community-based and mainstreams human-nature interactions for improving coastal risk governance. The framework proposed mainstreams human nature interactions into rural development planning with the understanding that by considering the interactions, ambiguity in decision making over adaptations can be reduced. The context of “mainstreaming” was to internalize the human-nature interactions into development decision-making and inform policy decisions on ecological conservation and human development through community participation.

Materials and methods

Study area

The east coast of India, along the Bay of Bengal, often faces tropical cyclones, storm surges, tsunamis, sea-level rise, heatwaves, and heavy rainfall, making many important cities and settlements vulnerable. In the state of Andhra Pradesh alone (location shown in Figure 1), which has a coastline of 972 km, almost 29 million people are vulnerable to a variety of disasters. Among the vulnerable population, 3.3 million reside within 5 km of the coastline (Prasad et al., 2020). For this research, two coastal rural settlements from Katrenikona Mandal, surrounding the Godavari delta region, were selected namely, Balusutippa, population 5468 (Figure 2) and Magasanitippa, population 576 (Figure 3).

Earlier, various studies have demonstrated that handling floods around the coastal region often poses a lot of challenges and calls for integrated solutions to comprehensively address the arising issues (Habibi et al., 2021). The Godavari estuarine region is the second-largest estuarine region in India (Satapathy et al., 2007). Katrenikona Mandal, situated in the East Godavari River estuarine ecosystem constitutes the second largest area of mangroves, along the east coast of India, providing significant ecological and economic benefits and livelihood services to the local communities. The selected settlements of Magasanitippa and Balusutippa are remotely located in Katrenikona Mandal, and often witness a frequent rise in sea level which inundates their major land areas. Fishing and plantations, followed by traditional occupations such as aqua-farms are the major livelihood sources for both the settlements. The communities in these settlements substantially rely on natural ecosystems for their primary income, particularly the ecosystems supporting diverse local fisheries including mollusks, fishes, prawns, and crustaceans (mangrove crabs, yellow crabs) (Figure 4). Both the settlements are often influenced by the impacts of climate change, urbanization, and industrialization due to natural oil resources available in their surroundings. Being located within the mangrove forests, the selected settlements have poor road connectivity and are largely disconnected from the neighbouring areas. Waterways are the only means of transport for these settlements and high levels of illiteracy were also observed in both the settlements during the surveys.

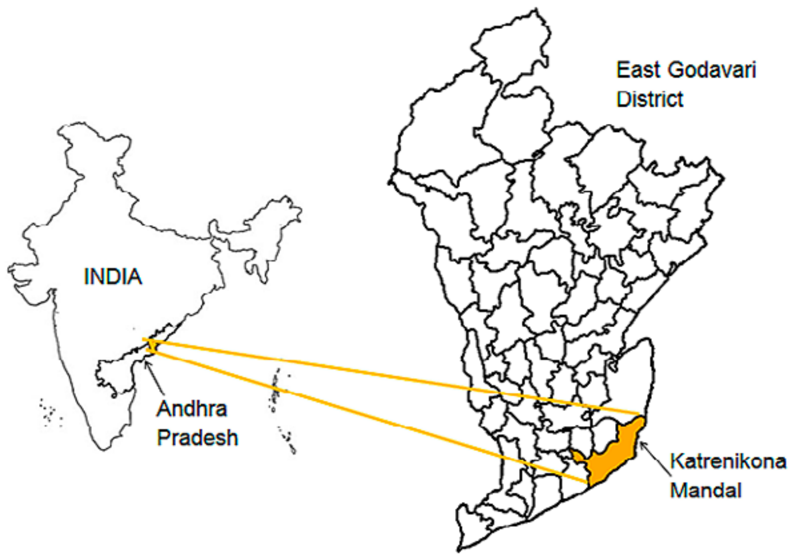

Figure 1. Location map of Katrenikona Mandal in India
Source: Authors

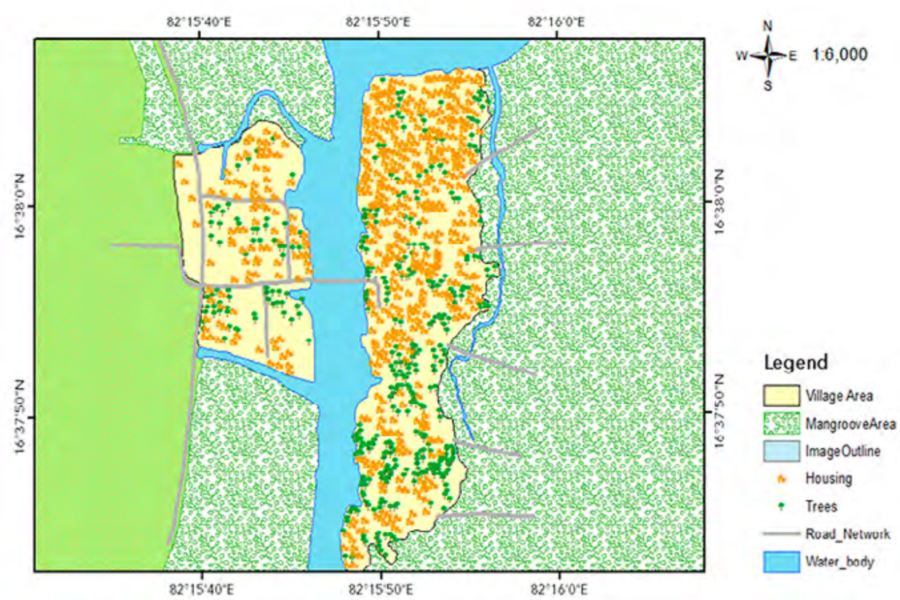

Figure 2. Case study settlement 1: Village of Balusutippa
Source: Author, based on Google imagery and ground surveys

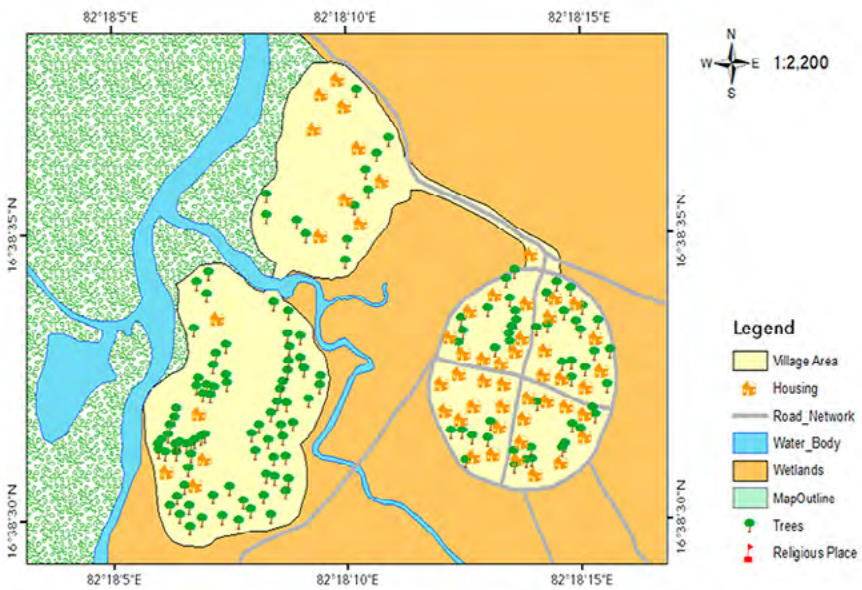

Figure 3. Case study settlement 2: Village of Magasanitippa
Source: Author, based on Google imagery and ground surveys

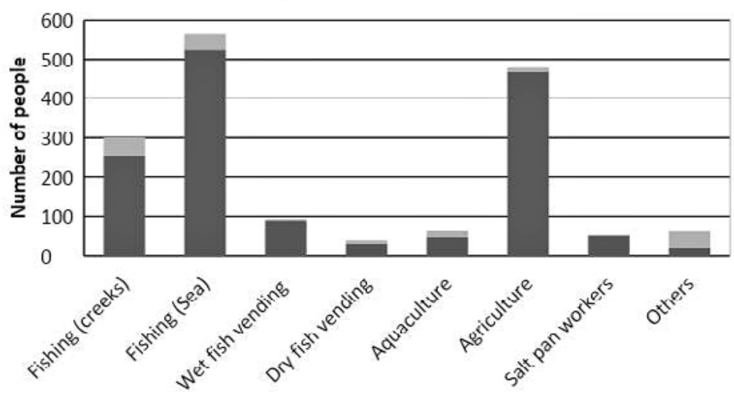

Figure 4. Major sources of income in Balusutippa and Maasanitippa
Source: Author, based on primary surveys

During cyclone 7B in 1996, both the selected settlements suffered substantial losses. However, over the past decades, owing to the effective warning and evacuation systems by the Government of India, there has been a considerable reduction in the number of casualties from cyclones (Marchand, et al. 2008). However, it is important to note that there is no accountability for the loss of ecological systems that communities have been traditionally dependent on for their livelihood. As a result, rural communities are increasingly becoming vulnerable to various climate disasters and are forced into a poverty trap.

Unfolding parameters

An indicator-based framework (Deshkar, et al., 2019) considering five dimensions and four indicators under each dimension has been applied to further this research. The immediate drivers in the system and their causal factors are critical to look at as separate entities because of the existing complexity in the system and various perspectives in place (Young, 2002; Lambin et al., 2003). The human-nature interactions, on the other hand, are subjected to change due to fluctuations in the system (Seymour, 2016). For this purpose, five potential dimensions that influence human nature interactions had been identified and considered for this study, which include Ecosystem Services (ES), Ecosystem Governance (EG), Livelihoods (L), Socio-Culture (SC), and Natural Hazards (NH). Choice-sets were broadly evolved under these sets of dimensions. The four indicators under each dimension were case study-specific and dynamic parameters identified on a situational basis (as shown in Figure 5). Indicator selection considered two primary interests, namely, the interdependence of humans on nature or nature on humans.

Ecosystem services, defined as benefits obtained from ecosystems, (Millennium Ecosystem Assess-

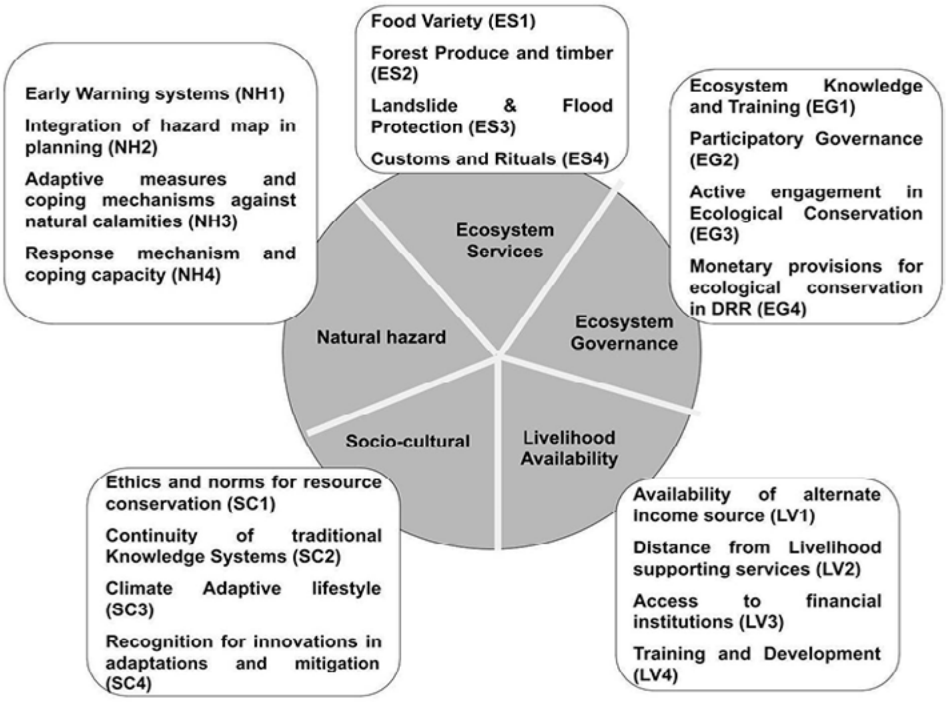

Figure 5. Dimensions influencing human-nature interactions and their relevant indicators
(Modified based on Deshkar et al., 2018)

ment Report, 2005) were bifurcated as indicators in terms of food variety; forest produce; water recharge and flood protection; and customs and rituals. Adequate food variety was also considered as an indicator of diversity. Further, Ecosystem Governance refers to the processes of decision-making involved in the control and administration of the environment and natural resources. The human population as a subsystem of a larger ecological system was referred to as the socio-cultural dimension in this context. Then, a person's livelihood has been understood as their means of securing the necessities namely food, water, shelter, and clothing. Building on the understanding that a shift from nature-based livelihoods to non-nature-based livelihoods can change the system properties and hence the disaster risk, shifting to a non-nature-based occupation is often suggested as an adaptation. The parameters influencing choice for nature-based livelihoods include the availability of alternative income sources (Thekaekara et al., 2013), distance from livelihood support services, access to financial institutions, training, and development (Dhanya et al., 2013). Therefore, the respective indicators as mentioned in Figure 5 have been selected for this study. Natural hazards, described as events beyond human control (Palm, 1990), have varying effects on humans, leading to increased vulnerability (Adebimpe, 2011). However, there are certain measures to reduce the impacts of natural disasters on the human systems. For instance, the early warning systems, integration of hazard maps in planning, adaptive measures and coping mechanisms against natural calamities, response mechanisms, and the community capacity to mention a few. Correspondingly, these were the indicators chosen under the dimension of natural hazards.

Choice experimentation

Perception-based studies are often used to demonstrate the social outlook over a particular issue which gives feedback to the adaptive measures and provides an evidence base to planning. Recent studies related to resident-perception towards environmental quality in Pathumthani, Thailand reveal that understanding local preferences could very well support the sustainable growth of cities (Iamtrakul & Chayphong, 2021). Therefore, the choice experimentation method is chosen to determine the coefficients of key attributes that contribute to disaster risk resilience. The survey format designed for the study comprises of two sections, the first of which includes a set of questions related to the socio-economic conditions of the residents and the second one entails the choice sets for all the study aspects. In the choice-based survey, the respondents were given two generic alternatives for each choice set, derived using two contradictory phases for four defined variables. The choice sets were shown to respondents and by analysing how they make preferences for different sets within a particular aspect, the implication of the individual indicators was evaluated. The estimated utility functions showed the perceived value of the indicator and how sensitive the community perceptions and preferences were for a change in their resilience. These evaluations were then used to create models that helped to determine the best-suited development options from the community perspective. As there were four indicators defined for each of the five aspects, the study defined two contradictory phases for each indicator, the positive aspects being denoted by '1' and negative aspects by '0'. The combinations were done using the binary method in a way that no two choices were the same (as shown in Table 1). The choice sets were arranged in a different combination of the selected variables based on which the respondent had to select a preferred choice.

Table 1. Formation of choice sets for variables within one aspect

S.NO.	CHOICE A	CHOICE B
1	0 0 0 1	1 1 1 0
2	0 0 1 0	1 1 0 1
3	0 0 1 1	1 1 0 0
4	0 1 0 0	1 0 1 1
5	0 1 0 1	1 0 1 0
6	0 1 1 0	1 0 0 1
7	0 1 1 1	1 0 0 0

Source: Based on Deshkar et al., 2019

Data collection

The questionnaire was designed to facilitate choice modelling through the conduct of a choice experiment aimed at answering the basic research question: "Which of the following do you think should be the major priority for decision making in the region?" and the same was explained to the community. The disaggregated data for this research was obtained using choice modelling questionnaires during community consultation. It was conducted in the form of a survey involving 46 participants, in July 2016 for both the settlements. The sample of the participants in the workshops was identified through stratified random sampling, which included members of the local community based on their livelihoods and relation to mangrove fishery resources. For the ease of communication and improving interest, visual graphics were used for the choices displayed to the participants. The basics for the preparation of the questionnaire and understanding the scenarios in the village were obtained through a reconnaissance survey. The process of collecting the raw data during the community consultation survey comprised a display of the complete set of indicators to the respondents and analysis of how they make preferences between the given services. The implicit valuation of the individual elements making up the service was also determined. Considering the existing illiteracy and the duration of the process, a suitable format that combined text and a pictorial approach (Abley, 2000) was adopted. The survey questionnaires were explained to the community during a community consultancy survey, via display sheets, making it easier for the participants to intercept their choice of preference. After the end of the choice experimentation, a group discussion among the participants was conducted in the form of an interview to understand the reason behind their priorities. The study data was based on preferences among alternative combinations and was gathered through a group research survey. The final selected choices were the key intervening points (leverage points) to influence design actions.

Statistical analysis

The statistical analysis is based on logistic regression of different variables. The coefficients obtained by logistic regression are usually challenging to interpret because of the non-linearity and the complicated algebraic translations. Amongst all the choices of transformation, the log of odds is one of the easiest ways to understand and interpret the coefficient values and hence chosen for this study. An interpretation of the logit coefficient which is usually more intuitive is the "odds ratio". The relation p/(1-p) (where p is the probability of occurrence of an event in the design period). So, if we consider the exponent constant (e=2.72) and raise it to the power of the coefficient we get the odds ratio. The interpretation of the odds ratio can be done as one unit difference in predictor X corresponding to a multiplicative change of 'e to the power of coefficient in the odds of Y'. Thus, the exponentiated values of the coefficients (Odds Ratio) were calculated. Coefficients obtained through the logit model in R provided the basis for interpreting the statistical significance of each variable. The values of vectors of community resilience components were estimated for both the settlements.

Results and discussion

Livelihood Aspect of Resilience

Under the dimension of livelihoods, 'the alternate sources of income' (LV1) is revealed to have the highest odds ratio as compared to other sub-parameters of 'livelihood' (refer to Figure 6). This finding implies that the local people perceive that the alternate sources of income play a major role in strengthening resilience in their socio-ecological system. From the results, the local preferences for an alternate source of income also attest to the risk of the ecologically-based occupations particularly in this region, and the low livelihood security. Specifically, the community members engaged in fishery-based occupations highlight the need for more effective policies on the conservation and the protection of natural resources and their quality. Building resilience to livelihoods is a complex policy issue, especially in highly nature-dependent systems. It involves a large and intertwined set of policies, and the involvement of multiple departments, to decide which alternative livelihoods are to be provided, so as to maintain the system in a stable state.

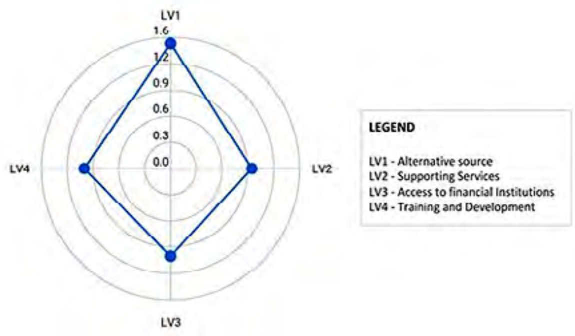

Figure 6. Odds ratio for livelihood parameters

Further, a few of the underlying reasons behind the highest priority given to alternate sources of income are identified to be the degrading fish catch per person, since the past decade, which is also mentioned in the works of Maheswarudu (2014); the low-income levels for people dependent on the ecosystem services due to lack of diversity in incomes and the geographical remoteness limiting the options of alternate livelihood income sources. Anneboina et al., (2017) and Ravikanth and Kumar (2017), have also previously underlined the mangrove-fishery linkage, considering fisheries as the main source of livelihood to many people of this area and in overall India, which relates factual in the study. The availability of alternative income improves the property of diversity and hence resilience in a socio-ecological system (Mallick, 2019). The diversity existing in a social-ecological system and the types of livelihoods reflect the interrelationships and sustainability in the coastal rural settlements.

Ecosystem Services Aspect of Resilience

Within the dimension of Ecosystem Services, the 'food variety' (ES1) has been locally considered to be the most important factor (refer to Figure 7). Earlier, Brown et al. (2008) have pointed out that the coastal poor tend to prioritize provisioning and regulating services, which is also found partially valid in this research. Though the highest priority was given to provisioning services, the next priority was given to regulating services and the least to cultural services. Considering the existing scenario, there is a severe salinity existing in the study region (Ramasubramanian et al., 2004), providing no option for the growth of a variety of food products. The next important sub-factor is highlighted to be the 'forest produce and timber'. As Dahdouh-Guebas et al. (2006) observed in the case of mangrove resource use, 97% of their sample accepted the rules of the forest department, to not access the mangrove timber from the forest, while some of the samples disliked the rule of high fines if the wood was to be collected. However, people in the study region argue that due to their isolated geographic location, accessing LPG was difficult. They also mention that the wood they prefer would be dried timber since they use it for cooking purposes only and they know the value of mangrove protection from cyclones. Though the selected settlements have access to resources like mollusks, river fish, and mangrove crab, access to mangrove timber is completely considered illegal. According to the recognition of the Forest Rights Act, (2006) accessibility to forest resources has been allowed based on the co-existence of the tribes with the forests in India.

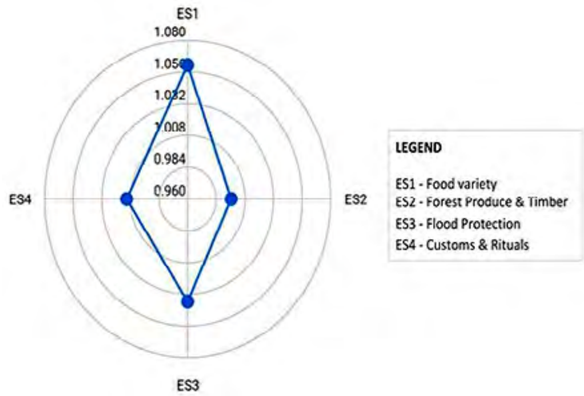

Figure 7. Odds ratio for Ecosystem Services Aspect of Resilience

Although a similar situation exists, the law states the access only to the scheduled tribe's community, the marine livelihood people are not legally allowed to access the forest resources, especially the dried mangrove firewood, which is also one of the critical observations in this study. A need to focus more on this area is also identified through this study to promote sustainable use of mangrove timber and improve community-based forest management. The high salinity in soils is identified to be a barrier to the improvement of ecosystem services. Around 90% of the selected survey samples pointed out the industrialization, specifically the oil and natural gas-based industries in the region, is the main reason behind the outmigration of the fishes, which could also be a point for further investigation.

Socio-cultural Aspect of Resilience

For the indicators of social-cultural dimension (refer to Figure 8), the highest preference was given to 'recognition for innovations in adaptation and mitigation' (SC4), followed by ethics and norms for resource conservation (SC1). Firstly, the recognition for innovations in adaptation and mitigation is another important parameter that encourages adaptation in the community. The community strongly believes that recognition would encourage innovation in adaptation and mitigation among the communities. Perhaps, the study results are also in line with the earlier study conducted by Gunderson (2010), which emphasizes 'episodic learning', as a need for the creation of new approaches to solving problems revealed by an ecological event. Innovations in socio-ecological systems in terms of livelihoods, lifestyles, etc., after a disaster event in these areas, should be recognized and encouraged, as they may improve the capacity of social-ecological systems against any adverse situations. The priority for recognition of innovation reflects the presence of already existing innovations, which must be recorded and recognized at some level of governance. Secondly, the ethics and norms existing in a community determine resource conservation at a smaller scale. For example, the community has a norm of not going for crab catching during the full moon day, which as an ethic had been followed for generations. Also, they are not supposed to catch a juvenile mangrove crab. The government norm of banning fishing during certain seasons allows the fish to reproduce and hence resources are conserved. Thus, the priorities justify the contribution to resilience in socio-ecological systems.

Ecosystem Governance Aspect of Resilience

During the choice experimentation process, the participants have recognized more importance for the sub-factor of 'ecosystem knowledge and training' (EG1) in the group of Ecosystem governance, followed by participatory governance (refer to Figure 9). Notably, training workshops were occasionally conducted by the Government of India through non-government organizations, for the conservation of biodiversity in the region as well as for the employment of localities as tour guides. A well-designed training session for the ecosystem knowledge for various age groups as well as various stakeholders is found to be necessary, as the communities mentioned the need for such knowledge and training. The National Disaster Management Plan (2019) considers vocational training and skill development as one of the strategies for disaster risk reduction. However, due to prevailing illiteracy in the region, the strategy did not suit the people.

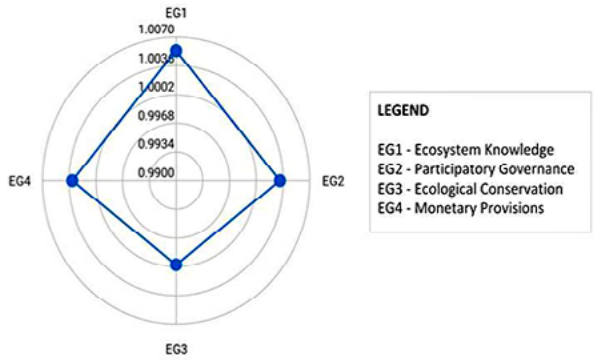

Figure 9. Odds ratio for Ecosystem Governance Aspect of Resilience

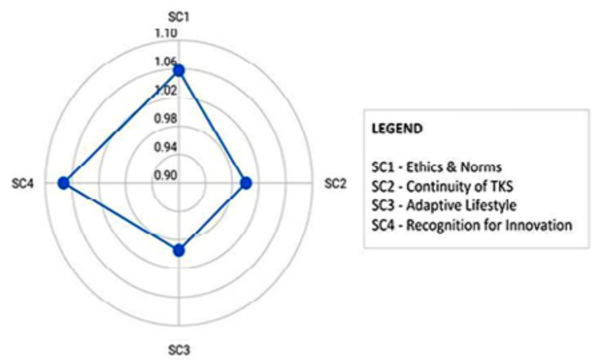

Figure 8. Odds Ratio for Socio-Cultural Aspect of Resilience

Natural Hazards Aspect of Resilience

It is to be noted that the 'Natural Hazards' dimension was given the lowest priority for its contributions to resilience in selected coastal settlements. This also implies that the existing practices, namely the evacuation, warning, and help received from the government at the time of disasters were considered to be adequate by the communities. Though some of the participants mentioned that river floods removed the salinity existing in the soils after a storm surge, the validity of the contribution of natural hazards component in the socio-ecological systems remains to be explored. Within the group of natural hazards (refer to Figure 10), the highest importance is given to adaptive measures and coping mechanisms against natural calamities. Also, the duration of early warning systems and their accuracy determines the vulnerability reduction. The present early warning systems could protect the lives of people, but it is important to note that the natural resources are still at risk, ultimately keeping the recovery of socio-ecological systems in question.

Further, the access to mangrove-based resources to the marine fishery communities and chances for improvement of community-based forestry remains to be investigated further. Also, this research has identified a need for immediate implementation of 'recog-

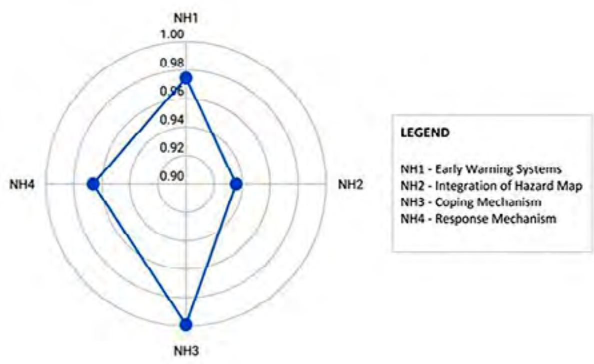

Figure 10. Odds ratio for Natural Hazards Aspect of Resilience

nition for innovations', innovations being one of the important properties for resilience in the socio-ecological systems. Since, at a community level, adaptation is highly preferred, it is important to dynamically take the necessary actions.

Based on the statistical analysis, the values so achieved through the logistic regression indicated the levels of significance for each component to resilience as shown in Table 2.

Community Preferences for Coastal Risk Governance

The results derived through this study underscore the priorities of local communities concerning various parameters that can improve resilience in the system. The overall schematic diagram for community preferences for resilience in selected coastal rural settlements is shown in Figure 11. The study results highlight that the strengthening of 'nature-based livelihoods' is the most significant factor that can contribute to the resilience in these coastal rural settlements (Figure 11). It has been chosen as a priority for planning and disaster risk reduction from a community perspective. The same has also been simultaneously explored through secondary data and further discussion with local communities. In both the villages, the locals believe that the prior focus on livelihoods with the appropriate governance of natural resources

Table 2. Level of significance of each of the selected parameters:

Level of Significance	1	2	3	4	5
	Livelihoods	Environmental Governance	Ecosystem Services	Socio- Cultural	Natural Hazards
1	LV1	EG1	ES1	SC4	NH3
2	LV3	EG2	ES3	SC1	NH1
3	LV4	EG4	ES4	SC2	NH4
4	LV2	EG3	ES2	SC3	NH2

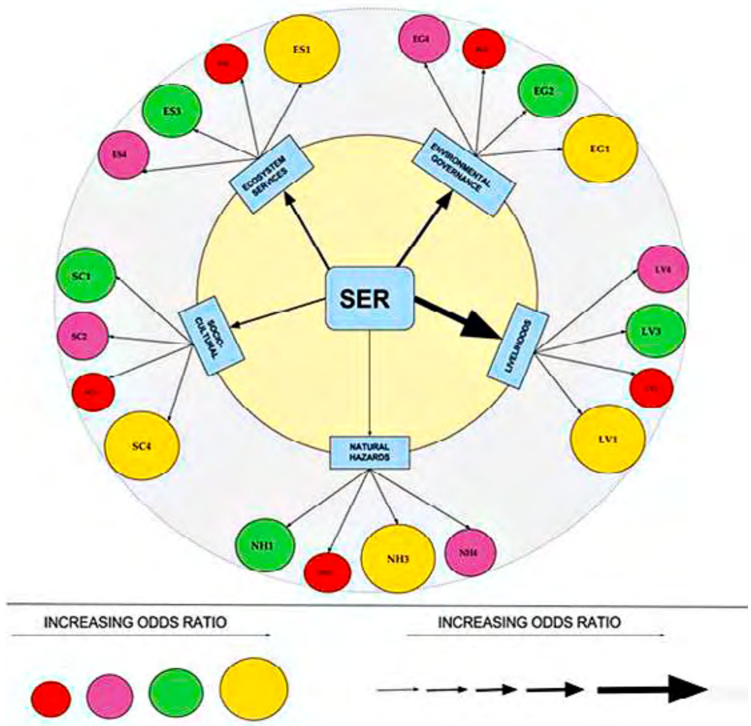

Figure 11. Schematic diagram for identified community preferences in Katrenikona

Table 3. Local priorities and their directions to future resilience and sustainability

Dimensions	Current status and contribution to resilience	Chosen Priority-based Directions of dimension for resilience and sustainability	Chosen Priority for the parameter	Chosen Directions for resilience and sustainability
Nature-based livelihoods	Decreasing and hence low contribution to resilience	↑	Alternate sources of income	↑
Ecosystem Services	Decreasing due to increased frequency of climatic stressors and pollution.	↑	Food variety	↑
Socio-Cultural	Decreasing - however, belief in tradition is not high. Technological and scientific methods are preferred.	↓	Recognition for innovations	↑
Ecosystem Governance	Stable	↑	Ecosystem Knowledge and training	↑
Natural Hazards	Normal.	↑	Adaptive measures and coping mechanisms	↑

would positively fortify the resilience in these coastal villages. Since nature-based livelihoods are worst affected during a disaster, strengthening them with modern technology or diversifying them is their idea for gaining resilience.

One of the arguments of mainstreaming human-nature interactions into development planning is that the funds need to be utilized effectively by focusing on parameters with changing human-nature interactions. By focusing on varying human-nature interactions, it is ultimately leading to reducing disaster risk and thereby resilience. For performing choice experimentation, this research has tried to understand the priorities of the local community for gaining resilience. Not all the priorities chosen by local communities can be sustainable. So, there is a need to examine their choices for consideration before mainstreaming into development planning. This process aligns the local level adaptation with global goals. Also, focussing on improving strategies through community preferences in these human-nature interactions could help reduce conflicts among stakeholders. Based on the derived research findings, Table 3 discusses local priorities and their directions to future resilience and sustainability.

Conclusion

Through conducting a choice experiment with the local people in selected coastal rural settlements of Katrenikona Mandal, this research has tried to uncover the priorities in the resilience components of human-nature interactions. Due to the illiteracy in selected communities, remoteness, and hurdles for use of technology, the conduct of the study was highly restrained, for instance, the language barrier due to which the visual display sheets were used for choice experiments. However, with improved technology, a similar method can be utilized at larger scale using software application aid. The use of animations or regional visuals can also create interest and overcome the challenges of conducting such a kind of data collection. Moreover, this paper essentially proposes the possibility of choosing human-nature interactions as a common measurable factor for achieving resilience. It also enables connecting among various levels. The paper supports the fact that changes in human-nature interactions occur predominantly at a local level and can be influenced by the decisions taken by the local communities. However, it is also important to note that any changes above or below the local level can influence the changes in human-nature interactions. The rapid pace at which the coastal systems are changing requires governance and management strategies that are robust to uncertainty. This study stresses the role of community opinions in decision-making. However, opinions of communities in coastal risk governance are limited to risk assessment and experience. Evidence from the discrete choice experiments performed reaffirms that the communities' preferences can have a high impact on resilience as well as the transformation of the system. This paper sets the groundwork for working towards the possible desired trajectories in a system, as a way of interpreting changes in the community decisions and adaptations for future change under increasing uncertainty with a focus on variations in human-nature interactions. It also influences how decision-making can be mainstreamed into policy planning, hence contributing to improved coastal risk governance.

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Impact of the Circular Economy on Quality of Life – A Systematic Literature Review

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Abstract

The circular economy (CE) is a multidisciplinary approach focused on achieving the sustainability of the whole society. This review aims to reveal the potential impact of the circular economy on quality of life. This systematic review analyzes studies dealing with the concept of circular economy and quality of life. The methodology process included a keyword search and three selection steps. A total of 39 studies were included in the analysis. We define four topics that emerged from the literature review i) urban sustainable development; ii) waste management; iii) material production and iv) human well-being. All these topics emerged in the literature dealing with issues of circular economy and its impact on the quality of life. We assume that it is implied that every step towards circular economy contributes to the life quality, but there is an evident lack of studies that measure that impact. In Serbia, a small number of researchers were involved in this topic, although it represents one step towards the objective of improving the state of the environment. This review of the literature should serve as a starting point for future research.

Keywords: circular economy; quality of life; the Republic of Serbia; sustainable development

Introduction

The concept of circular economy (CE) has been developed in the second half of the 20th Century (Winans et al. 2017). The knowledge of scientists from many fields of science contributes to the development of this concept (Dunjić, 2020). The concept of circular economy is one of the many concepts focused on achieving the sustainability of the whole society. However, no concept has been so widely accepted by the public, nor has it been given its place in the legislation. In December 2015, the European Union adopted the Action Plan for the Circular Economy (CE), and thus, for the first time, such a concept was regulatory adopted (Vujić, 2017; Dunjić, 2020; European Commission, 2015). The circular economy consists of the principles of 3Rs (reduction, reusing, and recycling) (Wu et al., 2014) and the extended model 6R (reusing, recycling, redesign, remanufacturing, reduction, recovering) (Jawahir & Bradley, 2016). Prieto-Sandoval et al. (2018) propose four key components that form the essence of defining the circular economy: 1. minimal demand for resources, 2. a multidisciplinary approach, 3. sustainable development, and 4. innovation. The transition to a circular economy directly affects production, employment, education, finance, and makes a change in the orientation of public policies (Webster, 2017). The concept of CE is designed as a customized model with economic, environmental, and social benefits (Clube & Tennat, 2020). Circular Economy is a required concept for society at present. If managed well, a Circular Economy can provide environmental welfare and economic advantages (Remøy et al., 2019). In the past, reuse and service-life extension were exclusively a strategy in case of scarcity or poverty, and as a result, they yielded products of poorer quality. To-

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day, they are signs of good resource management and intelligent governance (Ellen Mac Arthur Foundation, 2013). Many business leaders, politicians, and economists in Europe are embracing the circular economy to increase growth and profit, and create new jobs (Ellen Mac Arthur Foundation, 2015).

United Nations adopted the 2030 Agenda for Sustainable Development with its 17 goals that lead to the sustainable development of crucial elements that enable the cohesion of the quality of life of the population and the protection of the environment (United Nations, 2015). The European Green Deal is a new growth strategy that leads to the transformation of the EU into an equitable and thriving society, with an innovative, energy-efficient, and competitive economy where there are zero emissions of greenhouse gases in 2050 and where economic growth is divided from resource use (European Commission, 2019). The European Green Deal is supposed to improve the quality of life of citizens and future generations by providing fresh air, clean water, preserving and restoring ecosystems and biodiversity, renovated, energy-efficient buildings, healthy and affordable food, more public transport, renewable energy, and up-to-date clean technological innovation, longer-lasting products that can be repaired, recycled, and re-used, new jobs, globally competitive and adaptable industry (European Commission, 2019). The circular economy contains ideas about sustainable and long-term disposal of energy and resources (Svenfelt et al., 2019), focusing on positive society-wide benefits (Clube & Tenant, 2020). In the 20th century, modern industry was built on energy obtained from fossil fuels and uncontrolled unsustainable exploitation of natural resources. This has led to the pollution of all spheres of our planet (Scheel, 2016), which led to a significant impact on the quality of life of the world's population. The focus of the CE should be goals such as improving the quality of life, health, and well-being (Ribeiro et al., 2017).

Quality of life (QOL) has multiple characteristics, which is why there is no universal understanding of the quality of life that can be applied in all scientific fields (Čanković et al., 2011; Mirkov, 2016). The World Health Organization (1997) defines the quality of life as the perspective of each individual about life and the value system in which he lives concerning his expectations and possibilities. It is a broad concept that encompasses physical and mental health, social relationships, and personal beliefs. Satisfaction with the quality of life conditioned is the breadth of the gap between personal aspirations and the real possibilities for their realization in each social context (Mirkov, 2016).

Is it possible to achieve a sustainable society and quality of life without economic progress? It is necessary to adopt and implement adequate strategies to answer this question (Svenfelt et al., 2019). In 2008, the Government adopted the Strategy of Sustainable Development of the Republic of Serbia. To achieve sustainable implementation of the strategic goals it is necessary to implement the strategy first at the level of local self-government (Gómez-Álvarez Díaz et al., 2017) to improve the quality of life of the local population. In the Republic of Serbia, municipalities have adopted strategies or action plans for local sustainable development (eg. Subotica, Prijepolje, Kuršumlija, Loznica, Pećinci, Požarevac, Bogatić, Malo Crniće, Pirot, Stara Pazova, Apatin, Niš, Tutin), hence implementation is ongoing very slow. Serbia is currently following a linear economy model. An insufficient proportion of awareness about sustainable development and the circular economy is identified by the lack of an educational body that would deal with the circular economy and legislation. This structure does not support the development of new systems that would encourage the transition to a circular economy (Mitrović et al., 2017). The main goal is to establish a balance between the economy, society, and the environment (Službeni glasnik Republike Srbije br. 57/2008).

The United Nations and the European Union are helping Serbia embark on the path of adopting and implementing the concept of a circular economy. The Ministry of Environmental Protection of the Republic of Serbia adopted the document "Roadmap for the Circular Economy in Serbia" in April 2020. They connected four economic sectors: the processing industry, agriculture and food surpluses and food waste, plastics, and packaging construction. Recommendations are indexed for decision-makers, companies, and citizens (Ministry of Environmental Protection of the Republic of Serbia & United Nation Development Program, 2020).

This review aims to reveal the potential impact of the circular economy on quality of life. The review is focused on scientific papers published between 2003 and 2021 that studied the impact of the circular economy on the quality of life of the population. We aim to summarize the results of the previous work in the field, identify the gaps that emerge, and provide insight into how many studies consider the quality of life when discussing the circular. We also want to investigate the situation in Serbia regarding the circular economy and its impact on the quality of life. If we move from a linear to a circular economy, will the quality of life of the population of Serbia change for the better?

Methodology

This section describes the process of identification and analysis of literature on the topic of circular economy and quality of life. The process involved the identification, collection, and analysis of scientific articles.

The academic research database WoS (Web of Science) is used to search and segregate relevant scientific articles. As for the article type, we considered only original articles, review articles, and early access. The search keywords were developed as recommended by Pullin and Stewart (2006) to be sensitive enough to cover relevant articles, and specific enough to limit the number of irrelevant search results. „Circular economy“ was selected as the main keyword phrase, along with the term „quality of life“, emerging in the form of the title, abstract, or keywords of the articles. The two terms were used together, in order to provide specific results that are relevant to the main aim of this review. The number of articles returned from each step of the process was recorded and included in the PRISMA flowchart (Figure 1). Articles were then filtered twice to exclude irrelevant articles for the topic. The search was limited to the period between 1 January 2003 and 30 September 2021, because the first paper which contains the phrase „circular economy“ found in the WoS database is from 2003.

The literature selection process consisted of three steps:

In the first step of the review process, we used the term "circular economy" as the main keyword phrase in the Web of Science database, emerging in the form of the title, abstract, or keywords of the article (filter I). It resulted in 10,185 articles. Then, we included the term „quality of life“ together with the term "circular economy". This combination of keyword terms significantly reduced the number of articles to 50 records.

Afterward, we applied the filter regarding the document type, limiting the search to only research articles and review articles (early access included), while conference papers and editorial materials were excluded. Applying the article type filter (filter 2) excluded 14 records and resulted in 36 relevant articles.

In the third step, we screened the titles and abstracts of all 36 articles to identify the articles that rather mention the quality of life, but do not essen-

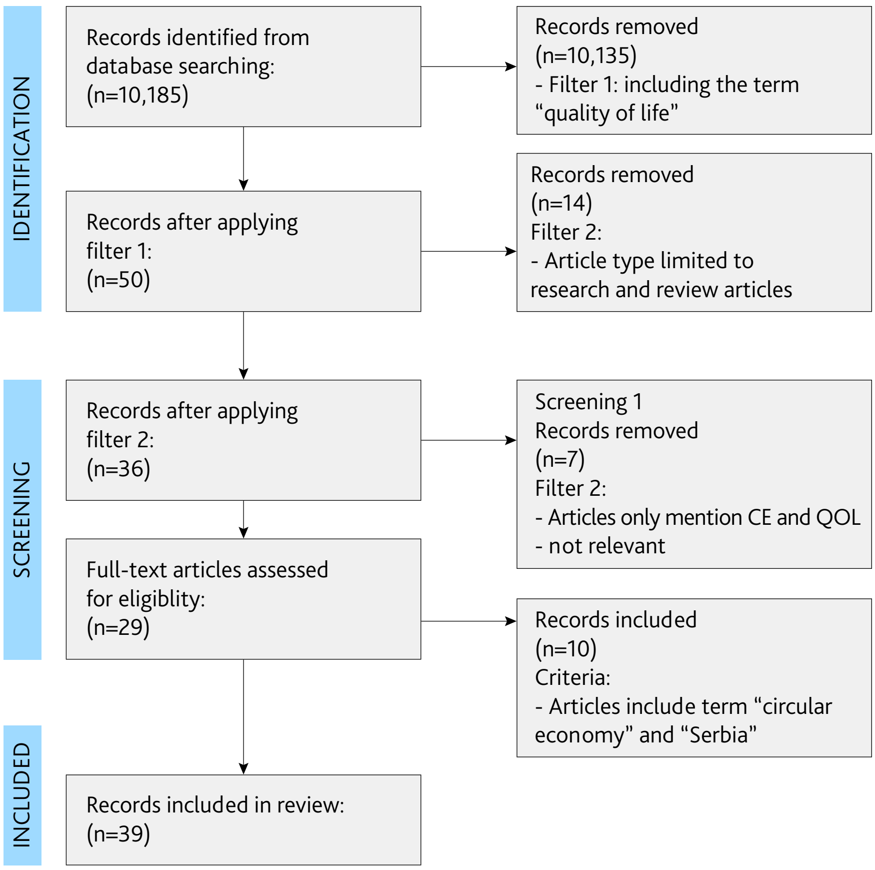

Figure 1. PRISMA flow diagram of the literature identification and review process using initial keywords and WoS database

Source: Moher et al. 2009

tially deal with this topic. This led to the further exclusion of seven articles, so the 29 remaining articles were considered relevant.

The number of 10,185 papers indicates the prevalence of the term circular economy (CE) and its extensive use. Scientists from many fields implement the concept of CE in various branches of science that reflect the importance and popularity of the CE concept in the 21st century. The significant reduction of records after including the term "quality of life" together with "circular economy", indicates that not many articles access the specific impact of the circular economy on quality of life, but rather consider it as implied. The Web of Science database contains studies related to the integration of the circular economy in Serbia. However, during the initial search, the WoS database did not recognize them as primary. We wanted to investigate the situation in Serbia as well, so we performed another round of searches. After another round of search of the Web of Science database, ten studies that include the term "circular economy" and "Serbia" were identified and analyzed. The final stage of the review process includes 39 articles.

Results and discussion

The analysis of the results included screening and review of full articles. After a detailed review of all articles, we have singled out four different areas that consider the concept of the circular economy in terms of its impact on the quality of life. These areas are:

- urban sustainable development,
- waste management,
- material production, and
- human well-being.

By analyzing the keywords, we conclude that the term "circular economy", is the most often combined with the term "sustainability". This term is the most often used in several examples as "sustainable development", "sustainable consumption" and "sustainable city". The following terms are "quality of life", "fundamental human needs" and "well-being".

The number of studies that are focused on circular economy and its impact on the quality of life is constantly increasing (figure 2). However, the focus areas are changing over time. The first studies were mostly focused on urban sustainable development as a result of the implementation of the circular economy concept. Sustainable development, especially in urban areas, continued to be one of the main areas of interest when discussing the circular economy and quality of life to date. However, a second most significant area of interest is waste management, which is to date often considered to be important in the concept of circular economy and quality of life. The third emerging area

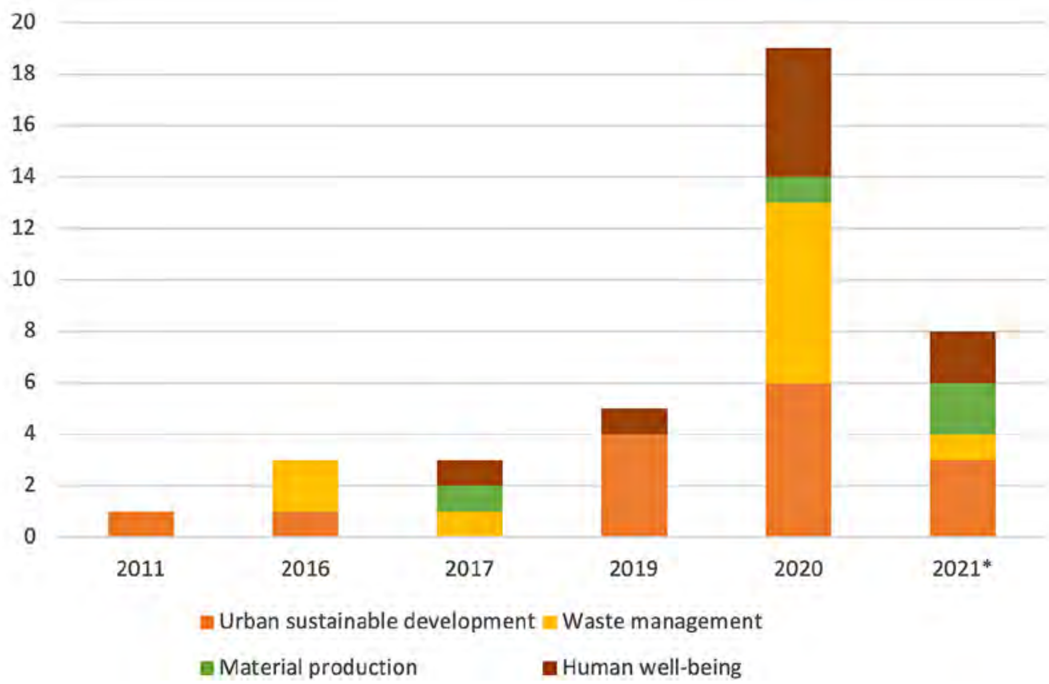

Figure 2. Distribution of research papers and studies included in review
** Included studies published until 30 September, 2021*

of interest is production and materials which appears in the recent articles. The fourth area of interest regarding the circular economy and quality of life is human well-being, which tends to raise the major concern among research articles in recent years.

Urban sustainable development

Sustainable development is often tackled by the articles dealing with circular economy and quality of life, mostly in urban areas. They access different aspects of sustainable development, such as education, built environment, water supply, transportation, economy, etc. Cities occupy approximately 2% of the world's surface, and approximately 60% of the world's population lives in them. Improving the quality of life of citizens is the main idea that should be realized in urban areas (Khudyakova et al., 2020). Cities need to be sustainable because the significant consumption of resources is in cities and will be in the future. Sodiq et al. (2019) highlight the principles that cities should adopt to become or remain sustainable, education in line with sustainable development, use of renewable energy sources, sustainable management of natural resources, sustainable buildings, transport, food waste, population growth, and water safety. Kosanović et al. (2021) implement the principles of circular economy in architecture and construction, to access its potential to increase thermal insulation in residential houses in Serbia, and that way improves the quality of life of residents. Säumel et al. (2019) provide a literature review about the "Edible City" solution. "Edible City" solution represents urban agriculture and food production. This concept contributes to economic, sociocultural, and environmental benefits for citizens comprehending green jobs, reduced pollution (air, water, land), better public health, and quality of life. Drábik et al. (2020) investigate attitudes and behavior of environmentally friendly consumers in Slovakia. They analyze individual ways of consumption and waste policy through the regions in the Slovak Republic concerning environmental preservation. They concluded that purchasers scarcely buy eco-products, because of the high price and deficient distribution of these products. According to Yerznkyan and Fontana (2020), another essential factor in the sustainable development of a city and meeting the quality of life is adequate water supply. Yerznkyan and Fontana (2020) assume that achieving sustainable urban development is impossible without introducing the principles of the circular economy through the latest technologies for innovative water supply. Ecologically sustainable development of the urban economy must have the capacity to reuse treated wastewater and automatic irrigation systems.

Certain cities in Europe seek to implement different programs to achieve sustainable development. For example, Cerreta et al. (2020a) suggest the adoption of strategies and innovative solutions that are in line with the principles of urban development of the European Union is necessary to re-establish the sustainable relationship between the port and the city of Naples (Cerreta et al., 2020a). Cerreta and associates (2020b) propose a methodological approach to landscape design for strategic planning of unresolved territories using the concept of the circular economy. Cuomo et al. (2021) propose living laboratories to be pointer tools for connecting cities and implementing local policies to improve the world's circular economy, which would lead to reduced consumption and improved quality of life. A common goal shared by cities, which can be achieved through dialogue on living labs, was conceived as a new tool of innovative policies to address the challenges of the environment and the health of citizens (Cuomo et al., 2021). Cibulka and Giljum (2020) examined the effects of sustainable development on economic growth and concluded a link between resource use and quality of life. They are convinced that it is necessary to increase efficiency in industrial production to achieve sufficient consumption because the planetary limits have already overreached.

The transport sector emits about a quarter of total greenhouse gas emissions and contributes to climate change. According to Leal Filho et al. (2021), the global focus is on electric cars and public transport, but sustainability cannot be achieved without using clean energy obtained through the circular economy. Mathews (2011) notifies that capitalism has reached extremes and is necessary to move to the concept of a circular economy, which would lead to an improvement in the quality of life without destroying resources and the biosphere. He believes that the green economy will dominate in the middle of the century unless it is blocked by political interests. Swedish scientists (Svenfelt et al., 2019) investigate four sustainability scenarios – i) collaborative economy; ii) local self-sufficiency; iii) automation for quality of life, and iv) circular economy in the welfare state. Scenarios show that there is an approach to thinking about the future beyond what is contemplated. According to them, it is essential to observe the consequences of adopting a correct perspective and thinking about alternatives. They also emphasize the necessity to prepare for a future without economic growth if economic expansion continues or stops. Consumption needs to be decreased to approach sustainable production and consumption. Alternatives should be considered according to current events and policies and analyzed with the potential consequences.

Scheel (2016) proposes the SWIT model (Creating Sustainable Wealth Based on Innovation and Tech-

Table 1. Studies of urban sustainable development identified in this literature review

Study	Geographical area	Research field
Mathews 2011	world	Economy
Cibulka and Giljum 2020	world	Economy
Scheel 2016	world	Economy
Sodiq et al. 2019	world	human capital development, economy management and environmental protection
Yerznkyan and Fontana 2020	world	water management
Leal Filho et al. 2021	Europe	transportation
Bucea-Manea-Ţoniş et al. 2021	Serbia, Romania	Business
Kosanović et al. 2021	Serbia	Architecture
Fauré et al. 2019	Sweden	climate changes
Drábik et al. 2020	Slovakia	consumption and waste policy
Svenfelt et al. 2019	Sweden	Economy
Säumel et al. 2019	Rotterdam, Oslo, Heilderbeg, Andernach and Havana	urban agriculture
Cuomo et al. 2021	Turin	environment and citizens health
Cerreta et al. 2020a	Naples	spatial planning
Cerreta et al. 2020b	Naples	spatial planning

nology). This model is framed on the design of sustainable capital, but with the preservation of natural resources, economic competitiveness, and quality of life in the community.

Sweden has committed itself to becoming fossil fuel neutral by 2050. The combustion of fossil fuels contributes significantly to the release of greenhouse gases. However, emissions also come from imports and are generated during production processes - such as food production, cement production, land cultivation, and air transport. Fauré et al. (2019) proposed less consummation of meat in the diet and switch to veganism and vegetarianism; and switch to cycling or use public transport such as rail, to preserve the environment. Bucea-Manea-Ţoniş et al. (2021) believe that the application of the principles of circular economy, in the Serbian economy would lead to a transition - to modern industrial production. It is necessary to introduce innovations that would bring Serbia closer to developed European countries.

Waste management

When we talk about the development of cities in the modern world and the concept of the circular economy, it is inevitable to discuss waste management, as one of the key drivers of the circularity of materials. This is achieved by employing different treatment strategies, that would bring materials back into the cycle (reuse, recycle), or gain some other benefit from waste, simultaneously diverting it from landfills (material/energy recovery, waste-to-energy systems). Therefore, a number of studies deal with circular economy and waste management strategies. Robeiro et al. (2017) present the projects that have been developed in the city of Guimarães (Portugal) to convert waste into energy. These projects also involve dealing with social issues (repairing medical equipment for families and gathering food for social institutions) that affect the quality of life in the city (Robeiro et al. 2017).

Zorpas (2020) points out how important it is for citizens to be involved in the implementation of waste management strategies. They argue that children of school age should learn about the importance of proper waste disposal, the generation of a smaller quantity of waste, and reuseing waste as a resource. They also state that civic authorities need to initiate regulatory relief measures such as fewer waste taxes, free parking in public spaces, free tickets for cultural events, etc. to assure their citizens to adopt any proposed solution. Construction waste accounts for a large share of waste in the European Union (EU) and across the globe. Colangelo et al. (2020) assume that proper management of construction waste and recycled materials — including established handling of hazardous waste — can have crucial benefits in terms of sustainability and quality of life. They argue that the recycling of concrete to produce secondary raw materials should be accelerated, and that way contributes to a circular economy. Maschmeyer et al.(2020) focused on fish waste and its processing to reuse and obtain biomaterials. The process of processing fish bio-waste affects the reduction of ocean pollution. Fishmeal and oil obtained from fish bio-waste are used to feed livestock, so the use of waste as a resource will increasingly affect the global improvement of the environment and quality of life.

Zając and Avdiushchenko (2020) apply the Dynamic Stochastic General Equilibrium Models (DSGE) outline to reproduce the contemplate impact of escalated resource efficiency on the regional economy. The model undertakes that part of current consumption is restored to producers in the form of repositories that are reused. They measure the parameters of the proposed model for Lesser Poland, a region in southern Poland. There is a positive effect on the economy by improving resources which will contribute to the quality of life of the region's population. This study shows that one component of recycled material is merit four components of unprocessed material. The model also estimated the monetary value of renewable consumption at 48.1% of the value of original materials. Russia is trying to solve one of the biggest environmental problems - car tire waste, by introducing a recycling program (Khudyakova et al. 2020). Serbia faces a lack of adequate waste management, insufficient recycling of large amounts of waste, lack of modern technologies, and lack of finances (Ilić and Nikolić, 2016), which affects the possibilities for introducing the circular economy concept. According to Stevanovic-Carapina et al. (2016) hazardous waste disposal is one of the significant problems in Serbia. There are still no facilities for treatment, which leads to inadequate hazardous waste management. It is necessary to create conditions for the treatment of hazardous waste, to preserve the environment and human health, and consequently provide the conditions for circular economy implementation (Stevanovic-Carapina et al. 2016).

Denčić-Mihajlov et al. (2020) conclude that state subsidies have an imminent impact on the recycling of cars and refrigerators in the Republic of Serbia, especially in electronic waste recycling. Management of different types of waste in Serbia was investigated in the context of the circular economy. As the main problem in Serbia, it is stated that a very low share of waste is recycled – e.g. PET bottles (11%) (Schmidt et al. 2020) or lubrication oil (less than 20%) (Dudjak et al. 2021).

Table 2. Studies of waste management identified in this review

Study	Geographical area	Research field
Zorpas 2020	world	waste management strategies
Colangelo et al.2020	European union countries	construction waste
Maschmeyer et al. 2020	Europe	marine bio-waste
Schmidt et al. 2020	Austria, Germany and Serbia	pet bottle recycling
Khudyakova et al. 2020	Russia	waste recycling
Ilić and Nikolić 2016	Serbia	waste treatment
Stevanovic-Carapina et al. 2016	Serbia	solid waste management
Denčić-Mihajlov et al. 2020	Serbia	waste recycling
Dudjak et al. 2021	Serbia	waste lubrication oil
Zając and Avdiushchenko 2020	Lesser Poland (region)	renewable consumption
Robeiro et al. 2017	Guimarães (Portugal)	waste valorisation

Material production

Even though raw materials represent the basis for any kind of economy, not many records emerged within the concepts of circular economy and its impact on the quality of life. However, the studies that did emerge are dealing with various types of raw material production and the importance of their efficiency in terms of the quality of life. For example, the excavation and processing of copper and zinc significantly contribute to environmental pollution and global climate change. However, the entire world industry needs these metals. Nilsson et al. (2017) researched the carbon footprint of zinc and copper production. The conclusion is that metals produced from secondary sources emit a minor carbon footprint, but variations can be large scaled. They also state that more investigation is needed to furnish sustainable solutions in a circular economy. Silk produced in Brazil is one of the most competitive in the world. Barcelos et al. (2021) investigate the influence of circularity on silk production from silk cocoons. Circular measures have been proposed to increase production and switch to sustainable energy sources. These measures contribute to the preservation of the environment and have a positive impact on the quality of life of all producers (Barcelos et al., 2021). Research conducted in South Banat (Serbia) indicates that the cultivation of certain crops (sorghum) can lead to sustainable biogas production, using energy obtained from renewable sources, using circular economy measures (Rakascan et al. 2021; Milanović et al. 2020).

Table 3. Studies of material production identified in this review

Study	Geographical area	Research field
Nilsson et al. 2017	world	Metal production
Barcelos et al. 2021	Brasil	Silk production
Rakascan et al. 2021	Serbia	Biofuel production
Milanović et al. 2020	Serbia	Biofuel production

Human well-being

Human well-being is the focus of many studies, given that global trends are often affecting the health or environment of humans. In this review, several studies tackle some aspects of human well-being within the concept of the circular economy. Clube & Tenat (2020) investigate how much the CE concept has an impact on human needs. They assume that it is necessary to switch to a less wasteful way of production and consumption and argue that the role of the economy is to improve the quality of life of people by meeting their needs.

Food quality and quantity have a substantial impact on the quality of life. Mazzocci and Marinno (2020) proposed an advanced agricultural policy for Rome, which improves the quality of food, social relations, and the quality of life of citizens. The proposal includes actions for the reorganization of the purpose of the territory of the city, by relocating the plant for more sustainable food production in the context of the circular economy (Mazzocci & Marinno, 2020).

Díaz et al. (2017) indicate the importance of implementing the Economy for the Common Good model, using strategies. That leads financial interests towards the common good at the municipal level and improves the quality of life for all citizens rather than maximizing profit for companies. Understanding science can be a problem for ordinary citizens, so Eckelman and Laboy (2020) tried to bring science closer to the entire population through art. Their goal was to reveal the main problems we face, such as the impact of excessive consumption on the environment. Industrial ecology handles these influences and could provide changes in the environment and the quality of life of all citizens. They argue that the quality of the environment is closely related to the quality of life of citizens, but both depend on sustainable development. Huttmanová et al. (2019) conclude that there is an impact (of the mentioned factors) on the quality of life and health of the population (based on a detailed analysis of economic, social, and environmental factors). The study is based on data from 2000 to 2017 for the countries of the European Union (EU-28). The results showed that the quality of life of citizens should be in the first place - during the implementation of reconstruction projects in cities. The circular economy has a role in preserving the quality of life of EU citizens. Jaszczak et al. (2021) were involved in projects of cities revitalization in northeastern Poland. In the conversation with local experts and on the analyzed statistical data, they conclude that environmental, cultural, and historical aspects have minimal importance and social and economic aspects of life in the city are more important. During the implementation of these projects, attention was drawn to the importance of renovating public spaces in cities. The potential of these cities is reflected in the favorable geographical position and rich cultural and historical heritage, but that potential is still untapped. They concluded that long-term sustainability can be accomplished through the work and influence of community-based organizations. Based on research in India, Papageorgiou and associates (2020) conclude that good governance within community-based organiza-

Table 4. Studies of human well-being identified in this review

Study	Geographical area	Research field
Eckelman and Laboy 2020	world	industrial ecology, art
Pencarelli 2020	world	tourism
Clube and Tenat 2020	world	human needs
Huttmanová et al. 2019	European union countries	quality of life
Papageorgiou et al. 2020	India	social issue
Díaz et al. 2017	Spain	economy
Demirović Bajrami et al. 2020	Serbia	tourism
Jaszczak et al. 2021	Warmia and Mazuri region (Poland)	town revitalisation
Mazzocci and Marinno 2020	Rome	urban agriculture

tions and financial assistance (in the form of loans) are crucial factors in mitigating socio-economic poverty and positively affecting the quality of life of the local population. If the concept of the circular economy is implemented, poverty could be reduced to a minimum and thus improve the quality of life of citizens. Tourism is considered a less intensive industry concerning environmental pollution, but mass visits certainly affect pollution. However, the preservation of resources and restrictions on the issue of visits contributes to the maintenance of attractiveness for a long duration and contributes to sustainable development and the circular economy. The current era of digital technologies and the transformed economy affect the lives of citizens. The development of tourism has significantly contributed to the quality of life and influenced the field of the circular economy. Smart tourism in a sustainable way emphasizes the quality of tourist destinations. And upgrade the quality of life of all actors in tourism (Pencarelli, 2020). Based on the analysis of the attitudes of the rural population in Serbia, Demirović Bajrami et al. (2020) conclude that the rural population is interested in the sustainable development of tourism, which will also improve their quality of life. Touristic destinations must preserve their natural and cultural values from overcrowding.

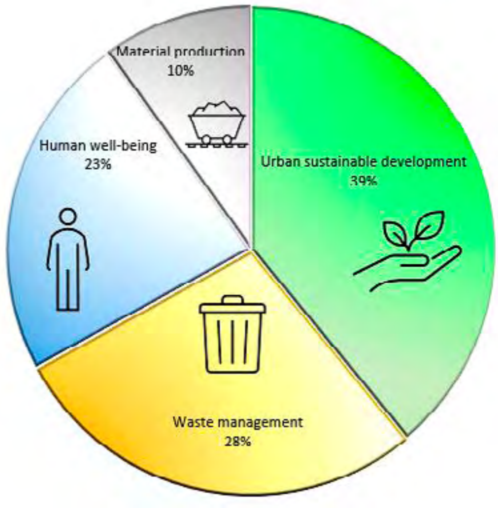

Figure 3. Percentage distribution of the studies reviewed by research field

The state of circular economy in Serbia

The concept of circular economy leads to resource savings, raw material and energy efficiency, environmental protection, and improvement in the quality of life. Fundamental elements that support circular economy development are recycling, green public purchase, encouraging small and medium enterprises. The Serbian economy has the potential to develop a circular economy if the situation improves in the field of recycling and energy (Ministry of European Integration of The Republic of Serbia 2019). The Sustainable Development Goals are derived from the Millennium Development Goals and recognize that the fight against poverty is associated with economic growth and industrialization, targeting several societal needs including health, education, social protection, and a healthy environment and climate-resilient communities (Government of the Republic of Serbia, 2017).

In the period up to 2020, Serbia has made insignificant progress in achieving the sustainable development goals of the Agenda 2030. The notable improvement includes the goals SDG3 (Ensure healthy lives and promote well-being for all at all ages), SDG9 (Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation), and SDG15 (Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss). No progress has been made towards the SDG11 - Make cities and human settlements inclusive, safe, resilient, and sustainable (Babović, 2020). Based on the analysis of monitoring the indicators of all 17 Sustainable Development Goals, Serbia has a long way to go before the complete transition from a linear to a circular economy.

Members of the project Legal Support to Negotiations (PLAC III) and the Ministry of Environmental Protection of the Republic of Serbia in November 2019 organized a conference entitled "How to achieve a circular economy?" An ex-ante analysis of the conclusion of the circular economy should provide a foundation for drafting public policy documents that will enable the development of the circular economy in Serbia (Ministry of European Integration of The Republic of Serbia 2019). Vasiljević and Petrović (2020) provide a detailed overview of the state of the circular economy in Serbia. They concluded that the state of the circular economy in Serbia is in an unenviable position. The circular economy in Serbia has not been implemented in practice yet, but experts from several fields are dealing with this topic(Ilić &Nikolić, 2016; Stevanovic-Crapina et al. 2016; Milanović et al. 2020; Denčić-Mihajlov et al. 2020; Demirović Bajrami et al. 2020; Schmit et al. 2020; Dudjak et al. 2021; Rakascan et al. 2021; Kosanović et al. 2021; Bucea-Manea-Țoniş et al. 2021).

Proposals for improving the current state of the circular economy in Serbia:

1. Develop a stimulating environment for establishing a model of the circular economy.
2. Establishment of a stable and sustainable system of financing circular economy programs.
3. Strengthening public awareness through support to scientific, educational, and professional institutions and professional organizations in creating and implementing programs of regular and additional education for the circular economy; Cooperation with independent associations and citizens' associations to help and support to the implementation of measures to establish a model of the circular economy.
4. Institution structure and legislation - Establish an independent institution that could effectively coordinate and oversee the implementation of policy implementation plans in cooperation with other stakeholders (Vasiljević & Petrović, 2020).

Implementation of a circular economy is a challenging process for developing countries because it requires significant financial, legislative, and human capacity. Therefore, this concept is criticized as too idealistic and unachievable in developing countries. It is impossible to create a society that does not fabricate waste and recycles it indefinitely. There are still no reliable data on the contribution of the circular economy to collective social well-being and quality of life (Corvelec et al. 2021). The linear economy still has its place in developing countries. The introduction of the circular economy requires citizens who can pay for its establishment. The circular economy needs to be established gradually (Vujić, 2017).

Conclusion

Transition to a circular economy requires ecological transformations and innovations to extend the product lifecycle, get other quality products from waste and address the needs of environmental resilience despite the tendency towards economic growth (Scheel, 2016; Prieto-Sandoval et al., 2018; Maťová et al., 2020; Zając and Avdiushchenko, 2020). The European Green Deal instigated a combined strategy for „a climate-neutral, resource-efficient and competitive economy" (European Commission, 2020, 2). Beneficial impact of a circular economy leads to a better quality of life (Szczygieł, 2020). However, we must be aware that this is a long-term process that will require a lot of investment and effort, both in economic terms and in transforming the habits and consciousness of the population. The question is, will it be profitable for producers? Boyer and associates (2020) claim that individual consumers rather decide to buy electrical products that are made entirely from recycled materials - instead of new products. According to Remøy et al. (2019) of learning from each other - to improve the level of development of the circular economy in cities is very important to avoid mistakes and achieve a higher level of the quality of life.

In this review, we assessed the articles regarding the circular economy and its potential to impact the quality of life of the population. Even though it is quite a popular topic lately, a relatively small number of studies are considering circular economy in the context of its possibility to impact the quality of life. We assume that it is implied that every step towards circular economy contributes to the life quality, but there is an evident lack of studies that measure that impact. However, we define four topics that emerged from the literature review i) urban sustainable development; ii) waste management; iii) row material production and iv) human well-being. All these topics emerged in the literature dealing with issues of circular economy and its impact on the quality of life. In Serbia, a small number of researchers were involved in this topic, although it represents one step towards the objective of improving the state of the environment. On the condition that we orientate our economy towards a circularity, the quality of life of the population in Serbia would improve. However, for the present, we still cannot speak with certainty about such a performance, because the transition process is very long, and Serbia is at the very beginning of that path. The authors considered it necessary to contribute to research on this topic. This review of the literature should serve as a starting point for future research.

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