STRATEGY FOR SUSTAINABLE URBAN DEVELOPMENT OF THE CULTURAL ROUTE IN SKOPJE, REPUBLIC OF NORTH MACEDONIA

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Abstract

Strategy for sustainable urban development of cultural buildings along the Cultural Route identifies urban mapping strategy for restoring circulation by activating social aspects and developing cultural activities at the cultural buildings, monuments and urban squares located along the Cultural Route in Skopje. The methodology of this scientific paper is based on the urban mapping methodology which aims to identify and analyze spatial, cultural architectural and social characteristics of the Cultural Route Case Study of the cultural buildings as nodes for sustainable strategy of development of the City Skopje. This study contributes to the creation of a comprehensive and inclusive cultural places and buildings towards contemporary and incoming features of the inhabitants and visitors of Skopje and the Republic of North Macedonia. With the strategy for urban development of the cultural buildings at the Cultural Route as an urban placemaking strategy, identified is new structural revival of intensive urban life, by providing increased circulation and movements of visitors and tourists, emerging cultural and educational activities and events. Within the proposed dynamic models of architectural and urban solutions strategy of the Cultural Route, urban network identification and uniting museums along the cultural route, provided would be inter-connections between cultural institutions and public places in the field of culture, architecture and artistic activities.

Key words: *Architectural Design, Sustainable Urban Development of Cultural Route, Urban mapping of cultural buildings*

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1. INTRODUCTION

The significance of the culture at the Cultural Route in the City Skopje demonstrates the fundamental concept of architectural-urban solution of the Cultural Route in Skopje, the urban mapping concept of connecting and integrating cultural activities, which serve as a guidance towards efforts to protect and preserve culture for future generations [1]. The transmission of messages and legacy from history, culture and the past is essential for the continuation of future generations ideas and concepts. According to Alvin Toffler: "Learning from the past, should be understood as culture of understanding the present. Cultural buildings can be seen as places 'enclaves of the past' and also 'enclaves of the future'." People must engage with culture through architecture, arts, music and aesthetics, in order to comprehend the world. This allows people to walk along the Cultural Route in Skopje that broadens perspectives towards its cultural surroundings developed in different historic periods of time [2]. The core concept of the research is founded on the idea to create a complex system that includes all cultural institutions and placemaking cultural activities at the Cultural Route in Skopje. At the same time, the Cultural Route should serve as a platform to initiate discussion and dialogue about the cultural interactions of artifacts with the city of Skopje and the Republic of North Macedonia. The architectural and urban concept of the Cultural Route recommends and encourages decision-makers and stakeholders to invest in the development of cultural, tourist and other economic sectors by engaging in different types of public national and international cultural activities. Modern changes in technique and technology demand a shift in cultural perspective in new network museum connections in a digital context [3].

2. METHODOLOGY

2.1. Case Study of the Cultural Route in Skopje

The urban mapping methodology in this research aims to identify, document, and analyze spatial, cultural architectural and social characteristics of the Cultural Route in Skopje. The mapping serves as a research and design tool, enabling the visualization of spatial dynamics, cultural values, and user experience within the urban fabric.This research adopts an interdisciplinary and mix-methods of urban mapping approach, combining qualitative, visual and participatory methods to interpret the complex layers of the Cultural Route. The hypothesis of the research defines Cultural Route in Skopje which acts as a dynamic spatial and cultural corridor that reveals how urban heritage, public space usage, and community narratives intersect to shape contemporary urban identity; by applying multi-layered urban mapping and participatory methods, hidden values, neglected nodes, and opportunities for inclusive regeneration can be identified and activated.

Research methods used in the study consist of urban mapping and spatial documentation, with GIS (QGIS, ArcGIS), Google Maps. The process includes: mapping of the spatial layout, land use, built environment, and circulation patterns, as well as identifying nodes of cultural placemaking activity, architectural heritage and cultural landmarks. The objective and aim of the study is to provide visualization of the physical structure and layering of cultural assets and spatial dynamics. The aim of the study is to identify Cultural Route's urban nodes with social integration and placemaking strategy circulation of visitors. To

achieve this, institutional and organizational coordination of existing cultural institutions is required, as well as planning of new cultural activities and contents, which are necessary for allocation of financial resources in culture. According to the current research of the urban-sociological standpoint at the Cultural Route in Skopje, most of the visitor's circulation is noticed during the working hours, and this is due to the presence of primarily commercial, catering, crafts and office buildings, with no residential or business buildings.

2.1.1 Methodology of Urban Mapping along the Cultural Route in Skopje

According to the renowned urban planner Kevin Lynch, the idea of placing focal points or nodes, will attract an extra concentration of people and public visitors [4]. Defining an axis of movement connects numerous focus points nodes, linking them together into one integrated system. Along the Cultural Route in Skopje, visitors can have artistic, cultural or educational experience that is both relevant, unambiguous and accessible to everyone. The cultural route has several connections that are integrated into process of valorization of the cultural values in relation to the rest of the city's natural and created factors. By defining urban mapping strategy it is expected that the Cultural Route will continue to increase the number of visitors, through incorporation of different types of artistic and cultural events [5].

The urban dialectic in architectural space encourages inter-relational coordination. There is consistency in the interconnection and communication of culturally significant content. These interrelations are mutually connected at a higher level, which is referred to as the urban mapping development strategy [6]. The study analysis the urban-spatial context of the Cultural Route, from Museum of the City of Skopje to the Museum of Macedonia and Museum of Contemporary Art at Skopje Kale, passing through square Macedonia and Old Skopje Bazaar complex, in order to ensure development by setting a level of valuation of cultural resources within the Cultural Route's scope. The objective is to provide conditions and develop a urban sustainable strategy for architectural-urban solutions at the Culture Route that includes museum facilities, cultural facilities and open public spaces that can be used for architectural, art and cultural activities [7]. The Cultural Route's urban mapping project defines placemaking strategy which will ultimately enable visual display of cultural contents: exhibitions, musical performances and concerts, talks, shows, events, and concept of building spiritual and cultural connections between people at the Cultural Route. This provides access and utilization of educational content by establishing venues for gatherings where people can communicate at a higher level, by establishing cultural habits through cultural workshop activities and display of data using culturally-related promotional materials. Identification of the urban mapping strategy of the Cultural route, will provide possibilities for exploring cultural heritage and historical sites in the Republic of Macedonia and the city of Skopje, providing growth of cultural tourism by engaging materials towards visitors and travelers, updating route activities with official cultural data from theaters, museums, galleries, and other cultural buildings [8].

The methodological analysis of the network of Cultural Route enables connection of cultural buildings in an urban context, which will be important in terms of: planning cultural activities, organization of cultural events, planning circulation of visitors in the urban spatial matrix defined through the Cultural Route, defining the trajectory of movement of cultural users and tourists in an urban context, defining visit to several museum complexes in the city,

planning the time interval of their visits to the cultural architectural buildings, opportunities for planning and development of exhibition spaces, architectural space planning by architects, museum professionals and users, tourists and visitors [9]. Spatial distance analysis between the cultural buildings at the Cultural Route in Skopje, defines relatively small distances of 100 - 500 m walking communication diagram [10], and pedestrian streets communication between the cultural buildings on the Cultural Route in Skopje without crossing the vehicular traffic with pedestrian circulation, the time required for movement of pedestrians from one building to another ranges from 10-15 minutes, with morphology of the terrain which has favorable accessible configuration of the terrain. For the full realization of the urban mapping strategy, it is optimal to analyze the principle of functioning of the Cultural Route in Skopje, by analyzing the placemaking nodes by incorporating the Old Skopje Bazaar into the development of the Cultural Route as an important economic and institutional urban area [11].
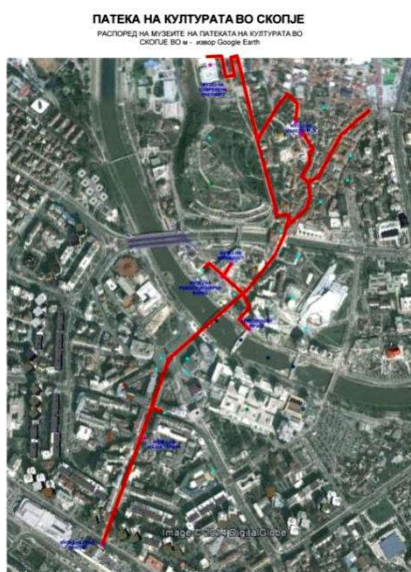

Figure 1. Cultural Route in Skopje by Mapping Cultural Institutions (Source:Author)

The strategy of urban mapping of the Cultural Route in Skopje enables: virtual mapping of cultural institutions in the city of Skopje through using the principles of modern information and communication technologies and dynamic concentration of cultural buildings in the network, increasing cultural activities in the context of revitalization of cultural buildings in long period located at the virtual network, attracting stakeholders due to growing interest of general popularization of touristic visits to cultural buildings and cultural events, involvement of project managers who will organize networked cultural activities, by increasing the interest of media, actualize presentation of the city on a regional, national and international cultural level, defining target group of national and international visitors and tourists from educational institutions, such as high schools and universities and cultural centers [12, 13]. Identification of museum buildings as cultural buildings at the Cultural Route in Skopje are defined as national and local museums, where national museums are: NI Museum of Macedonia Skopje, NI Museum of Contemporary Art Skopje, NI Museum of the Macedonian Struggle for Statehood and Independence Skopje, NI Museum of the Holocaust Skopje, NI Art Gallery

Skopje, NI Memorial House of Mother Teresa Skopje, NI Archaeological Museum of Macedonia - Skopje, and local museums are: Museum of the City of Skopje. Strategy for urban development of the cultural buildings should include the following aspects that need to be addressed: complete protection and revitalization of the existing, newly built and historical buildings of the Old Skopje Bazaar, construction of trade facilities and other business and commercial facilities next to the museums and their connection with the core of the Old Skopje Bazaar, visual presentations, panoramas and virtual reality for all cultural institutions on the Cultural Route, organization of simultaneous creative workshops in all cultural buildings for making jewelry, crafts organization of simultaneous cultural events, manifestations and performances, architectural workshop for traditional construction, creating information and communication technology network by entering all the information about the old and new cultural buildings, posting mapping of cultural buildings and route around Old Skopje Bazaar.

3. RESULTS

3.1 Defining Focal Points of Cultural Contents along the Cultural Route

Strategies for sustainable urban development of the cultural buildings at the Cultural Route in Skopje define strategic placemaking cultural activities that will promote culture [14]. Defining focal points at the Cultural Route in Skopje represents: cultural buildings, museums, historical sites along the Cultural Route in Skopje. Skopje City Museum is the beginning point of the Cultural Route in Skopje, located in the historic Old Railway Station, which was largely wrecked after the 1963 earthquake. Its location in the central city center provides convenient access to different types of visitors of cultural services. It should envision different cultural activities: info-center for the Cultural Route by obtaining information, catalogs and maps for movement along the route, information on pedestrian and car access, descriptions of significant objects on the route and cultural-historical monuments, accompanying activities at each point, video information, and the purchase of discount cards for museums and monuments. The Memorial Center of Mother Teresa represents a historical exhibition of the life and humanitarian work of the worldwide famous historical person born in Skopje Mother Theresa. The ARM Cultural Hall which can host different types of cultural and artistic events and musical concerts, along the Cultural Route in Skopje. Theatre for Children and Youth can host different types of outdoor performances on the Cultural Route in Skopje. Macedonia Square and the city fountain is a central city urban space located on the Cultural Route, a location which can provide organization of many political, cultural, social events, space for socialization in Skopje. Stone Bridge represents the historic structure of the bridge and its surrounding area on both banks of the river Vardar, which offers excellent venues for a variety of cultural events, religious performances and tourism attractions. The new pedestrian Art Bridge in front of the Macedonian Opera and Ballet, represents pedestrian circulation between the two existing cultural buildings. The Old Theater, Museum of the Revolutionary Independence, Museum of the Holocaust, Church of St. Dimitria, Ibni Pajko and other buildings on Karpošovo Uprising Square define another urban cultural complex which can host many cultural activities. This urban mapping identifies complex which has a large

concentration of cultural buildings, that can provide cultural placemaking activities to tourists and visitors. National Gallery of Macedonia Daut Pasha Hamam, Macedonian Opera and Ballet and Philharmonia, located on the left bank of river Vardar, is highly appealing cultural location to artists and art enthusiasts, where many art exhibitions and other cultural activities can take place (outdoor artist painting, art sale exhibition, concerts and theater performances). Macedonian Opera and Ballet activities can take place on the plateau in front of the building.

Figure 2. Cultural Heritage Buildings at the Cultural Route in Skopje, Skopje Old Bazaar, Museum of N. Macedonia in Skopje, Kurshimli Han in Skopje, National Art Gallery Daut Pashin Hamam (Source: Macedonia Timeless)

The entrance to the Old Skopje Bazaar can be defined by the elevated plateau of the Department Store Most, as an attraction point for visitors and tourists to visit the Old Skopje Bazaar. Kapan Han as cultural node can include new tourism and visitor materials with cultural and restaurant activities. Skopje Kale has two functional units: archaeological and recreational. The archaeological section will be node interesting for researchers, while the recreational section can be designed for the relaxation of Skopje's inhabitants and visitors. Skopje Kale site should be connected not only physically to the Cultural Route, but also as an integrated component of the Cultural route. Church Saint Spas is frequently visited due to visits to the church, iconostasis, and Goce Delcev's cemetery. The historic Skopje Old Bazaar represents significant Skopje's shared cultural heritage and history, which dates back almost a millennium. On the Cultural Route, its architectural entity offers an opportunity for urban cultural revival. This area of the city is rich in layers of cultural life, history and art. It also serves as an example of coexistence and shared cultural past throughout many centuries. The concerts, exhibitions, seminars and art displays can be planned in order to bring this area of the city back to its former historical glory. Skopje's Old Bazaar should have a clear visual display of placement of mapping and information boards directing visitors to museums and cultural-historical landmarks as necessary information along the Cultural Route through the Old Skopje Bazaar [15]. The development of the pedestrian route and the vehicle access in the southern portion of Skopje Kale will improve access to the Museum of Contemporary Art. This location offers stunning views of the City Skopje. Outdoor performance stages and

amphitheaters are proposed to be built in the sculpture park, with the option of hosting cultural events. The Old Post Office, Mustafa Pasha Mosque provide great opportunities for cultural events of different types and character. They would be used for educational, commercial religious and other cultural events. Suli Han, Bezisten and National Gallery Cifte Hamam are historical buildings that provide excellent venues for a variety of cultural events. Suli Han and Bezisten can be transformed for art, architecture, and other traditional conservation activities. Suli Han is the location of the Faculty of Fine Arts and it is acceptable to link the organization of these workshops. It also includes the Museum of Old Skopje Bazaar, where visitors can learn more about the Bazaar's history, trades, and merchandise. Cifte Hamam is the National Art Gallery in Macedonia, with amazing remains from the architecture of the historic building in Skopje. Kurshumli Han at the Skopje Old Bazaar is the historic structure which offers an amazing venue for hosting cultural events of various types and styles. The Lapidarium, which features a vast collection of stone monuments from many locations and eras, is situated inside Kurshumli Han. The Museum of Macedonia as cultural building represents Macedonian culture. The Museum of Macedonia's structure is a modern architectural interpolation into the historic core of the city. Instead of presenting the items in the traditional manner, the museum focuses on showcasing the identity of the Macedonian people. The museum is more than just a collection of objects, relics, and works; it also represents museum and cultural place of people, tourists and visitors [15]. The museum should provide gathering place for cultural heritage and the advantages of presenting cultural activities with digital multimedia technology. It should be representing location for meeting point of visitors, as networking place for friends of museum and culture. Museum of Contemporary Art and the plateau in front of the Museum of Contemporary Art in Skopje represent the possibility for organization of several cultural activities with viewpoints towards Skopje and the river Vardar. The concept of the project is to encourage communication between cultural activities, exhibitions, performances, learning, socializing and collaboration, adaptable to allow cultural dialogue and discourse between tourists and visitors [16].

4. DISCUSSION

4.1 Cultural Placemaking Strategy at the Cultural Route in Skopje

For the full realization of the urban mapping strategy and optimal functioning of the new idea of the Cultural Route in Skopje as European City of Culture 2028, it is important to plan placemaking strategy by incorporating of Old Skopje Bazaar as economic and institutional urban area for the development of the Cultural Route; building retail, residential, business, and commercial facilities near museums in Old Skopje Bazaar according to the urban regulations for revitalization. The proposed content will help the economic growth of the regions of the city around the Cultural Route and construction of a strong economic base for future operations, by creating sociologically integrative environment for all visitors. Complete preservation and restoration of historic structures in accordance with the planned protection system, as long as they remain inside the existing boundaries of the Old Skopje Bazaar. The goal is to establish protection and preservation guidelines according to the regime of valorization of cultural buildings. It is especially crucial to present cultural items and

monuments, in order for them to actively display content at the Cultural Route [17]. Museum activities that are already present in the Cultural Route, should continue to plan and organize cultural activities within the network of the cultural institutions at the Cultural Route in Skopje, therefore providing a platform for the development of cultural tourism in the City and in the Republic of North Macedonia. Through the development of the Cultural Route and connecting all cultural institutions in one system and network, a new type of tourism with a cultural component will emerge, taking up a significant portion of the entire tourist offering in the city of Skopje. The type of tourists visiting the Cultural Route will also influence the types of spaces that should be additionally created at the Cultural Route. As a result, there would be responsibility for infusing culture into tourism. Several measures can be defined in order to improve the invertarization, valorization and protection of the cultural activities at the Cultural Route: reconstruction of historic buildings, creating a web page with cultural object information for improved information for visitors, in addition to implementation of the onsite visual displays, panoramas, and virtual reality created for all objects on the Cultural Route [16]. The following placemaking interventions should be planned at the Cultural Route: performance venues for mass meetings at the open space on the location Skopje Kale, representation of old traditional crafts and workshops, souvenir shops, educational program activities, jewelry and traditional weaving workshops, placement of explanatory mapping signposts along the Cultural Route and entrances to all cultural facilities should be renewed and emphasized. Engaging a multidisciplinary team of professionals and experts should provide a full comprehension of all evaluated aspects of the cultural facilities, restaurants, hotels, shops, cultural buildings and facilities, cafeterias, and services, enabling various solutions to the new contents of the Cultural Route in Skopje.
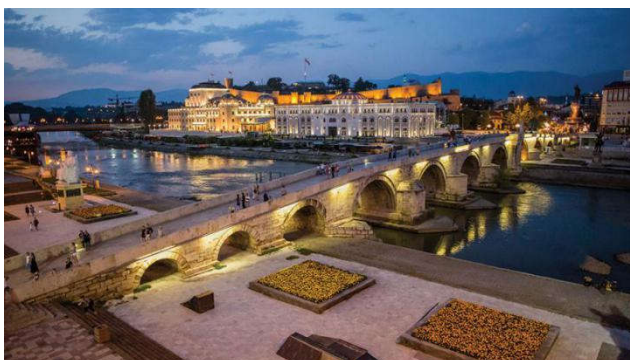

Figure 3. Museums of Macedonian Independence and National Theater in Skopje, Cultural Route at the Stone Bridge in Skopje (Source: Macedonia Timeless)

As a result of the research, it is expected to explore and define the application of modeling in the planning of the current and future development of the cultural buildings and museums, in the virtual development of the city, by defining the existing and future programming factors that influence the development of the cultural buildings, defining factors in the process of modeling of the spatial organization, location and relational connection of the cultural buildings in the network and defining the degree of influence of the development cultural buildings on the virtually created development of the city of Skopje.

5. CONCLUSION

The case study of the Cultural Route in Skopje demonstrates the value of a multidisciplinary approach that integrates spatial analysis, sensory perception, and community participation to better understand and interpret complex urban heritage systems. Through urban mapping methods—including GIS documentation, sensory and ambiance mapping, participatory workshops, and archival research—this study revealed that the Cultural Route is not a static heritage corridor, but rather a dynamic and evolving urban spine that reflects both historical memory and contemporary urban challenges. The implementation of this urban strategy at the Cultural Route will significantly revive cultural activities and urban life while also increasing visitors and tourists through cultural and educational events. This paper provides conditions and the strategy for an architectural-urban solution of the Cultural Route that will include proposed actions towards cultural and museum facilities, as well as open public spaces that can be used for art and cultural purposes. Actualization of cultural activities by visitors and tourists will result in the enhancement and development of their content and capacities. In conclusion, the study confirms that the Cultural Route in Skopje holds great potential as an active framework for inclusive urban regeneration, educational programming, and cultural activation. Future strategies should build upon the insights gained through this research to implement targeted interventions that preserve cultural heritage while enhancing public accessibility, experience, and participation. This methodological approach bridges the gap between technical planning and cultural storytelling, offering a dynamic basis for sustainable urban regeneration and policy innovation. The strategic urban concept embodies cornerstone concept of the project, which encourages communication between cultural activities, exhibitions, performances, learning, socializing and collaboration. The Cultural Route concept should be adaptable enough to allow for cultural dialogue discourse between tourists and visitors.

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Research paper

SENSITIVITY ANALYSIS OF REFERENCE EVAPOTRANSPIRATION TO KEY CLIMATE VARIABLES IN AN URBAN AREA

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Abstract

Evapotranspiration is a key parameter of the agrohydrological systems and is critical factor for water resources planning. The objective of the study is to analyze the sensitivity of the monthly reference evapotranspiration (ET_0) to climate variables. Data were used for Nis urban conditions, for the period from July 2022 to December 2024. Sensitivity analysis was based on the calculation of sensitivity coefficients for four meteorological parameters: minimum and maximum air temperature (T_{min} and T_{max}), wind speed (U_2) and solar radiation (R_s). The ET_0 values were defined using the FAO 56 Penman-Monteith method. The results of the sensitivity coefficients showed that the two variables – R_s and T_{max} have the greatest influence on ET_0, with the values of coefficients of 0.423 and 0.374, respectively. The analysis showed that T_{min} has the lowest influence on ET_0, in defined conditions.

Key words: *Reference Evapotranspiration, Sensitivity Analysis, Urban Area*

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1. INTRODUCTION

Evapotranspiration is one of the most important components of the balance between water and energy in urban conditions. Its importance is especially recognized at green infrastructure solutions, where it represents part of an effective strategy for negative urbanization consequence mitigation. Reference evapotranspiration (ET_0) depends on meteorological parameters and location, i.e. only meteorological variables have a direct impact on ET_0 [1].

According to [1], the Food and Agriculture Organization at the United Nations strongly recommends the FAO 56 Penman-Monteith equation (P-M) for defining ET_0. This equation belongs to a combined group of methods, i.e. a group of physically based methods that combines energy and mass transfer. The method is reliable for defining ET_0 in different climatic conditions, and this fact is confirmed by using the P-M method for the calibration of other methods, especially those with a limited number of input data [2-4].

The spatial variability of the land cover causes different microclimatic conditions, especially in an urban area. These conditions usually include a change in the surface heat flux and complex wind patterns. Urban vegetation heterogeneity and different structures, together with the variability of meteorological parameters, affect accurate urban ET_0 estimation [5]. For these reasons, it is necessary to define the degree of meteorological parameter influence on ET_0, i.e. it is necessary to conduct a sensitivity analysis.

The sensitivity analysis is used for the identification of the most important variables in the model and for the establishment of the error effect of the input data on the model outputs. There are different types of methods for defining the sensitivity analysis, i.e. there is no general procedure for the estimation of sensitivity, so the interpretation and comparison of the results from literature can be a challenge [6-9].

Sensitivity analyses for the ASCE Penman-Monteith equation were done for several meteorological factors (wind speed, air temperatures, vapour pressure deficit and solar radiation) in the different regions of the United States [10]. The daily basis was the level for the calculation of sensitivity coefficients. Authors concluded that ET_0 was mostly sensitive to changes of the vapour pressure deficit, while it was not sensitive to minimum temperature changes, at all locations. Also, the analyses of other variables showed significant variations of sensitivity between locations.

The analysis of reference evapotranspiration to the changes of climatic parameters, based on the daily data, was conducted in China (Jiangsu province) [11]. The analyzed area was covered with 60 stations, and the data covered a period from 1961 to 2015. Overall, authors indicated that actual vapour pressure was the most important parameter for ET_0. Wind speed was separated as the parameter to which ET_0 is not sensitive. The analysis of the seasonal influence of the parameters on ET_0 revealed that it was the most sensitive to changes of air temperature and sunshine hours during the summer period.

The monthly analysis of the sensitivity of climatic factors to ET_0 trends was performed in Iran by using a qualitative detrend method [12]. The territory of Iran was observed by five synoptic stations for the period between 1963 and 2007. The main factor which affected the significant positive trend of ET_0 was relative humidity, i.e. relative humidity and sunshine hours at Tabriz station, and minimum temperature, relative humidity and wind speed at Mashhad.

The paper covers the sensitivity analysis of reference evapotranspiration to the key meteorological variables (air temperature, wind speed and solar radiation) using the sensitivity coefficients and sensitivity curve method.

2. METHODOLOGY

2.1. Study Area and Data

The study area in the paper is one urban area in Nis, South-eastern Serbia. The climate in Nis is humid subtropical with continental influences. The main characteristics of this climate are average high temperatures during the summer period and moderately cold winters. The sunniest month during the year is August, while February is the driest month. Moderate precipitation is characteristic of Nis, with an average annual amount of 607 mm. There are approximately 134 days with rain and 40 days with snow cover during the year.

The automatic weather station, installed in the urban area of Nis with coordinates 43°19' N and 21°56' N and an elevation of 197.2 m a.s.l. was used for data collection. The station is equipped with sensors for the measurement of air temperature and relative humidity (HC2S3-L Temperature and Relative Humidity Probe, Campbell Scientific), wind speed and direction (05103-5 Wind Monitor RM Young, Campbell Scientific) and solar radiation (CS300-L Pyranometer, Campbell Scientific). Datalogger (CR1000 Measurement and Control Datalogger, Campbell Scientific) is used for the management and operation of the station. The analyzed period is based on the average daily data on a monthly basis, from July 2022 to December 2024.

2.2. The FAO 56 Penman-Monteith Method

The FAO 56 Penman-Monteith method was used for the calculation of reference evapotranspiration [1]:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \tag{1}$$

where:
ET_0 – reference evapotranspiration [mm day^{-1}]
R_n – net radiation at the crop surface [MJ m^{-2} day^{-1}]
G – soil heat flux density [MJ m^{-2} day^{-1}]
T – air temperature at 2 m height [°C]
U_2 – wind speed at 2 m height [m s^{-1}]
e_s – saturation vapour pressure [kPa]
e_a – actual vapour pressure [kPa]
e_s-e_a – saturation vapour pressure deficit [kPa]
Δ – slope vapour pressure curve [kPa °C^{-1}]
γ – psychometric constant [kPa °C^{-1}]

2.3. Sensitivity Analysis

Sensitivity analysis represents the technique that defines the influence of variables on ET_0. For this study, the sensitivity analysis is based on the dimensionless relative sensitivity coefficient [13]:

$$SC = \frac{\Delta ET_0}{\Delta CV} \frac{CV}{ET_0}$$

(2)

where:

ΔET_0 – relative change of ET_0 with respect to variable changes

CV – climate variable, the base value before change

ΔCV – relative change of CV

ET_0 – reference evapotranspiration, the base value before change

The variables analyzed through the sensitivity process are minimum and maximum air temperature (T_{min} and T_{max}), wind speed at 2 m height (U_2) and solar radiation (R_s). The calculation procedure was done by changing one variable in the ET_0 calculation, while the others were fixed. The relative changes of variables cover the range of $\pm$ 20%, with an interval of $\pm$ 5% (-5%, -10%, -15%, -20%, 5%, 10%, 15%, 20%). All the calculations were done on a monthly basis.

The SC value, positive or negative, implies that the ET_0 value will increase or decrease as the CV increases. The relative effect of the analyzed CV will be larger on ET_0, with the larger SC value. In order to have the most precise assessment of sensitivity, the classes of SC values were proposed by [14] according to the degree of sensitivity, table 1.

Table 1. Sensitivity classes

Sensitivity coefficient	Degree of sensitivity
$0.00 \leq |SC| < 0.05$	small to negligible
$0.05 \leq |SC| < 0.20$	medium
$0.20 \leq |SC| < 1.00$	high
$|SC| \geq 1.00$	very high

3. RESULTS AND DISCUSSION

The values of monthly sensitivity coefficients for all the analyzed variables are shown in Figure 1. The figure clearly indicates that there are large fluctuations in all variables. Temperature sensitivity coefficients show a similar pattern. The SC values for T_{max} are higher than those for T_{min}, i.e. ET_0 is more sensitive to T_{max} than to T_{min}, which is reasonable because T_{max} values are always higher than T_{min} and have a greater influence on the ET_0 equation. Based on Figure 1, it is obvious that $SC(T_{min})$ has the lowest values of all the other variables (ET_0 is not sensitive to the changes of T_{min}). This conclusion is supported by the numerical value of the unique SC of 0.087 for the entire analyzed period. The analysis of the average monthly SC values recognizes September as the month with the highest $SC(T_{min})$ values of 0.142, while February has the lowest values of $SC(T_{min})$ (0.008). According to the values of average yearly SC for T_{min} and T_{max}, 2022 stands out as the year with the greatest P-M equation sensitivity to temperature changes, i.e. 0.112 and 0.396, respectively. According to the unique $SC(T_{max})$ value of 0.374, it can be concluded that the ET_0(P-M) equation is highly

sensitive to T_{max}. This sensitivity is especially expressed during the autumn months of October and November, with $SC(T_{max})$ values of 0.465 and 0.458, respectively.

The sensitivity coefficients for U_2 exhibit an opposite correlation than those for temperature. This statement is supported by the numerical values of $SC(U_2)$ on an average yearly and monthly basis. Yearly $SC(U_2)$ determines 2024 as the year with the highest sensitivity to U_2 (0.168). A monthly analysis of the SC reveals that the winter session is the most sensitive to U_2, especially in February (0.289). The results of $SC(U_2)$, with an average value of 0.157, define U_2 as the parameter with a medium influence on the ET_0 equation.

The behavior of $SC(R_s)$, on a monthly basis, deviates from the other analyzed parameters. According to Figure 1, there are especially noticeable peaks at $SC(R_s)$ during the summer periods, which is reasonable considering the intensity of R_s during this period. The average monthly $SC(R_s)$ exhibits the highest values in June and July, with 0.771 and 0.753, respectively. November is the month with the lowest sensitivity of ET_0(P-M) to the R_s variable (0.060). The results of the average yearly $SC(R_s)$ show that, in 2023, R_s had the highest influence on ET_0 (0.429) of all the other years. It can be concluded that the ET_0 equation has a high sensitivity to R_s, based on the average $SC(R_s)$ of 0.423. The final comparison of the average SC values for the entire analyzed period determines the prominence of R_s as the variable to which ET_0 is the most sensitive, followed by variables T_{max}, U_2 and T_{min}, respectively.
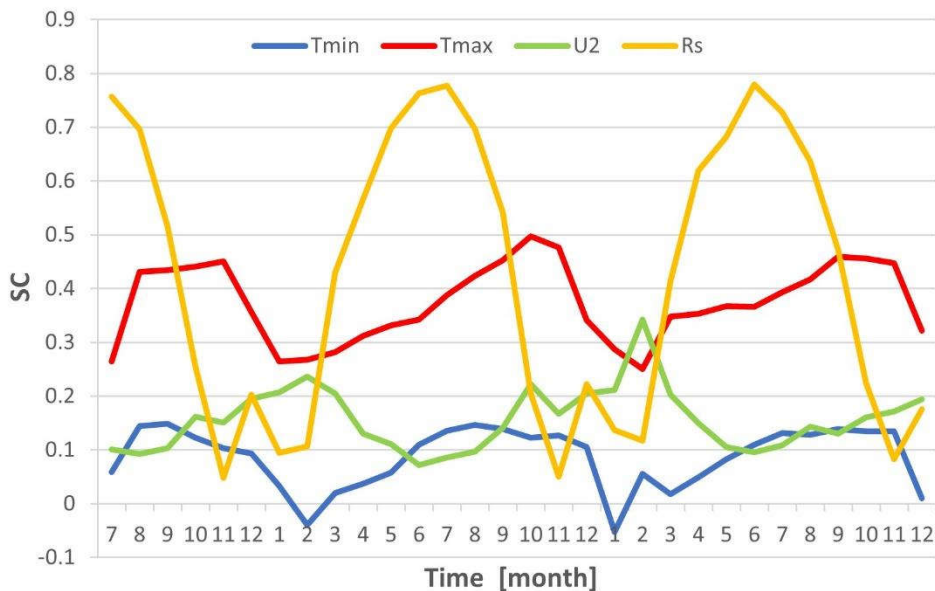

Figure 1. Sensitivity coefficients on a monthly basis

Table 1 represents the percentage change of ET_0 due to the relative change of meteorological variables. The relative change of variables includes T_{min}, T_{max}, U_2 and R_s, used for the calculation of ET_0. The visual relationship between the change of ET_0 and the variables is presented in Figure 2 in the form of the sensitivity curve. According to Figure 2, there is a linear sensitivity relationship, with a positive trend, between the relative changes of ET_0 and the variables. What is more, based on Table 1 and Figure 2, it can be concluded that the changes of T_{max} and R_s have a greater influence on the ET_0 changes than other variables do. The negative relative changes of T_{max} and R_s are almost the same, while there is a small

difference between the positive changes. The influence of U_2 change on ET_0 is relatively low, i.e. lower than that of T_{max} and R_s. This result is expected, considering the urban conditions and their impact on U2 (trees, houses and other urban obstacles).

Table 1. Change of ET_0 (%) considering the change of meteorological variables

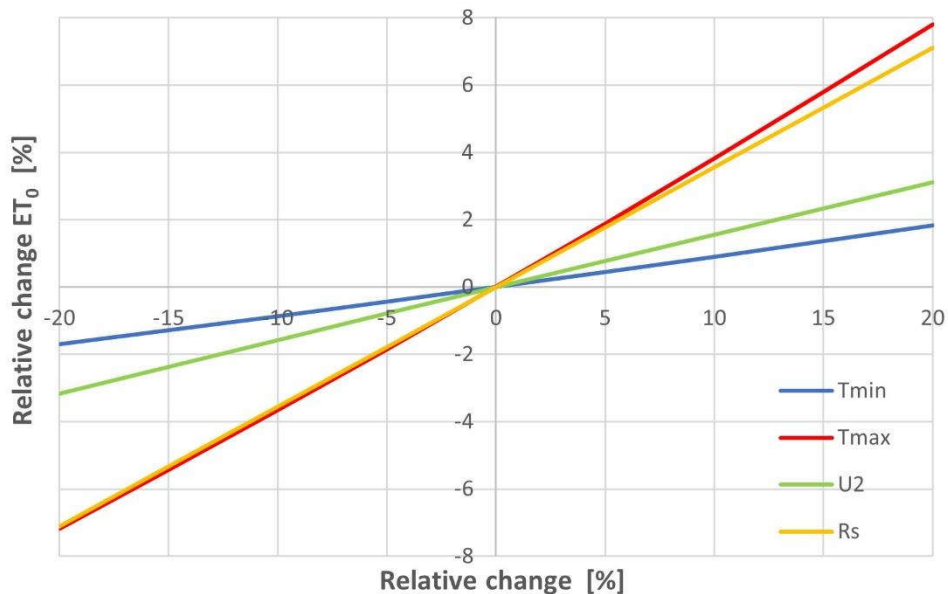|	-20%	-15%	-10%	-5%	5%	10%	15%	20%
T_{min}	-1.696	-1.283	-0.863	-0.435	0.443	0.895	1.355	1.825
T_{max}	-7.179	-5.436	-3.660	-1.849	1.888	3.816	5.788	7.806
U_2	-3.161	-2.365	-1.573	-0.785	0.781	1.559	2.334	3.104
R_s	-7.111	-5.333	-3.556	-1.778	1.778	3.556	5.333	7.111

Figure 2. Sensitivity curve for four meteorological variables

4. CONCLUSION

The sensitivity of reference evapotranspiration on key meteorological variables was conducted in one urban area of Nis. Reference evapotranspiration was observed using the FAO 56 Penman-Monteith equation and the mentioned key variables included in the equation calculation, which are T_{min}, T_{max}, U_2 and R_s. The sensitivity analysis was based on the sensitivity coefficients and sensitivity curve method, where the influence of variables was separately analyzed. All the relative changes of variables have demonstrated the linear connection with the relative change of ET_0. The results revealed that the P-M equation is highly sensitive to the changes of T_{max} and R_s, while T_{min} caused the lowest changes, i.e. sensitivity of the equation. The monthly values of SC showed that there is a high variation in the changes of variables, especially in terms of the variations of R_s.

Further study will be oriented towards the connection of the sensitivity analysis with the dependence and uncertainty analysis. Moreover, the urban areas of Nis will be analyzed using the data from more positions.

ACKNOWLEDGMENTS

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