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GIS MODELING OF METEOROLOGICAL AND HYDROLOGICAL VARIABLES FOR THE PURPOSE OF REGIONAL AND SPATIAL PLANNING - CASE STUDY OF THE CITY OF SARAJEVO

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ABSTRACT
GIS Modeling of Meteorological and Hydrological Variables for the Purpose of Regional and Spatial Planning - Case Study of the City of Sarajevo
This study aims to combine a review of the main climatic and hydrographic features of the City of Sarajevo, which provide knowledge and insight into the basic principles of assessing climate and water potential of a particular geospace through GIS modeling of spatial data. This analysis acquired an application of current GIS modeling technologies and Remote Sensing technology in the valorization of hydro-meteorological variables of geospace.The study is conceived in two parts, one which refers to cartographic representations and explanations of the meteorological variables of the area of the City of Sarajevo whilst the second part combines cartographic representations and explanations of important hydrographic variables of the observed geospace. For the purposes of this study, the following methods were used: analyzes, syntheses, statistical method, comparative method, and especially important cartographic ones, by which the previously analyzed objects were visually presented in the form of cartographic attachments.

KEY WORDS
GIS, GIS modeling, meteorology, hydrology, regional and spatial planning, Sarajevo

1. Introduction

One of the most important strategic advantages of GIS in relation to other programs for modeling geographical phenomena and processes is reflected in the fact that it greatly facilitates and simplifies the process of spatial planning decisions. Two perspectives on developing better decision support capabilities of GIS can be identified, one based on analytical problem solving and another based on integration of GIS and specialized analytical models. According to the first perspective, GIS should offer modelling, optimization, and simulation functions required to generate, evaluate, recommend, and test the sensitivity or problem solution strategies. The model-based approach represents an alternative and an extension of a toolkit approach embodied in the current generation of GIS software offering enough flexibility to accommodate a wide range of geometric operations at the expense of modelling, optimization, and dynamic simulation functions (Jankowski, 1995). The second perspective on improving the decision support capabilities focuses on the expansion of GIS descriptive, prescriptive, and predictive capabilities by integrating GIS software with other general software packages (e.g., statistical software) and with specialized analytical models such as environmental and socio-economic models (Goodchild 1987, Dangermond 1987, Burrough et al. 1989, Birkin et al. 1990, Nyerges 1993, Maidment 1993). According to this view, mapping, query, and spatial modelling functions of GIS can provide data display at different scales, preprocessing, and data input for environmental and statistical models.

Different levels of integration between GIS and analytical models can be considered, starting from a loose integration where GIS and models are linked using a file exchange mechanism, through a tighter integration with a common user interface and user-transparent file exchange process, to a fully integrated GIS modelling system with shared memory and a common file structure (Fedra 1993). Remote Sensing (RS) and Geographic Information Systems (GIS) are becoming powerful tools in spatial planning processes, which, among others, include mapping of meteorological and hydrological components. Through Remote Sensing process it is very easy to identify the cold or hot land surface in real time (Sailesh et. al., 2011), while GIS can be used for spatial modeling and mapping of climatological variables, like-temperature, precipitation, air pressure, humidity, insolation etc. Different interpolation or extrapolation methods can be conceived to map meteorological and hydrological variables in the process of regional and spatial planning. Over the last few decades, geostatistic interpolation methods (Li&Heap, 2008) became commonly used and recognized to have several advantages (Goovaerts, 1993) over non-geostatistic methods such as Thiessen polygon, inverse distance weighting, or isohyetal methods. Many research studies have used geostatistic techniques which consider topographic variations in mapping climatological variables on mountains terrain. Studies exemplifying these approaches are the best choice for precipitation (Mair&Fares, 2011) and for evapotranspiration (Martinez, 1996).

However, most of these interpolation techniques do not take into account the effect of relief and other geographic factors. For that reason, GIS interpolation techniques should take into account the potential effects of topographical factors on the spatial distribution of meteorologicaland hydrological variables. Such interpolation techniques (universal techniques) use geographic information systems (GIS) and digital elevation models (DEMs) for spatial analyses (Chapman, 2003). Several researchers have demonstrated the potential of universal techniques on mapping precipitation (Daly et. al, 1994), temperature (Gómez et. al, 2008) and evapotranspiration (Vicente-Serrano et. al, 2007). In these regression-based techniques, geographic and topographic factors that control the spatial distribution of climate are used as independent variables (Basist, A. et. al, 1994), and dependence models are created between the climate data and independent variables. The main advantage of this technique is that maps are compiled from weather stations and auxiliary information that describe geographic and topographic variables which improves the accuracy and spatial detail of the maps.(MMbando & Kleyer, 2018).

Regarding a GIS application in hydrology, approaches for integrating GIS with hydrological modelingused in previous decades were essentially technology-driven without adequately addressing the conceptual problems involved in the integration. The conceptualizations of space and time embedded in previous generations of GIS were not conceptually compatible with those in the hydrological models (Sui et. al, 1999). This incompatibility implicitly imposes constraints on the type of hydrological models that can be developed. However, current GIS generation along with Remote Sensing Technologies, reframed such research agenda, as hydrological models are more compatible with GIS modeling technologies. By reframing the future research agenda from the emerging geographic information science (GIScience) perspective, the authors contend that the integration of hydrological modeling with GIS should proceed with the development of a high-level common ontology that is compatible with both GIS and hydrological models.

On the other side, a significant number of scientific studies on the meteorological and hydrological interpolation involved with the factors that modeled them in Sarajevo have not been published. Traditionally, the applied method had been the linear interpolation between stations and the drawing of isolines based in the researcher knowledge of the studied area. There are recent works that search statistical relationships between geographical variables and climatological as well as studies that use Remote Sensing GIS (geographical information systems) techniques to modeled these climatological variables (Miquel et al. 2000). A goal of this research study is to apply universal interpolation methods and GIS modeling technologies in mapping precipitation, temperature, and evapotranspiration of the City of Sarajevo.

2. Study area

The City of Sarajevo is located in the central part of Bosnia and Herzegovina, in the valley of the same name, which represents the southern end of a larger morphostructure, the Sarajevo-Zenica valley. In mathematical-geographical terms, the City of Sarajevo extends between 43°57'11" and 43° 27'99" N, ie 18°31'0.2"and 18°15'24" E, occupying a total area of 135.30 km^2 (Author's calculation, according to GIS data). Total area is determined by a very strong dynamics of relief, ie the change of high mountains and river valleys in a relatively small area. Almost the entire area of the city of Sarajevo is located in the basin of the river Bosna (Figure 1). According to Koppen's climate classification, the Sarajevo valley is dominated by the temperate climate type Cfb, expressed through the formation of four clearly differentiated seasons, slightly lower average temperatures compared to most other cities in Bosnia and Herzegovina, and average annual precipitation between 900 and 1000 millimeters. In the mountains surrounding Sarajevo, the climatic conditions have changed significantly due to the influence of altitude, and are characterized by significantly lower temperatures and slightly higher precipitation.

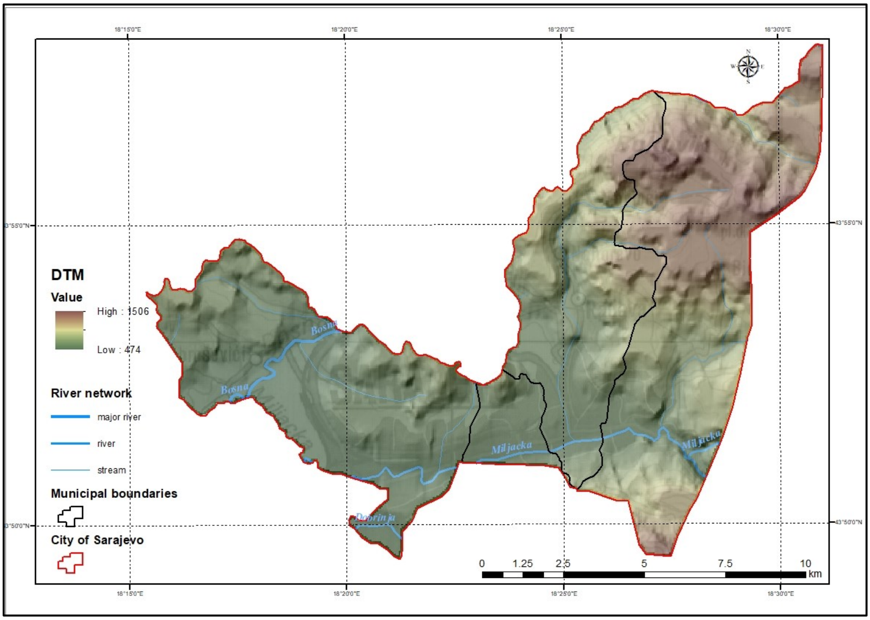

Figure 1: Digital terrain model and hydrographic network of City of Sarajevo.

3. Materials and methodology

By analyzing the data taken from the official website and available meteorological yearbooks of the Federal Hydrometeorological Institute of Bosnia and Herzegovina, for a period of 10 years, more specifically from 2000-2010, from two meteorological stations: Bjelave (altitude 630 meters above sea level) and Bjelašnica (altitude 2,067 meters above sea level), the basic regularities of climatic parameters of the area of the City of Sarajevo were determined. Detailed analysis of the parameters was provided by GIS interpolation of the data using the available metherological and hydrological data of the aforementioned meteorological stations. The interpolation method was used to more precisely estimate the climatic parameters for a more specific area of the city by hypsometric zones. This was followed by a geovisualization process, which was also performed using GIS software. GIS technology facilitates a comprehensive presentation of the evaluation, assessment and valorization of all relevant specifics of geospace important in its regional and spatial planning. An important part of such specificities are all interpreted climate and hydrological data. Spatial interpolation techniques predict values for cells in a raster from a limited number of sample data points. These were used to predict unknown values for any geographic pointdata.

Additionally, interpolation methods were used to estimates values using a mathematical function that minimizes overall surface curvature, resulting in a smooth surface that passes exactly through the input points. Conceptually, the sample points are extruded to the height of their magnitude. The ArcGIS spatial analyst is used for spatial interpolation of the high resolution meteorological and hydrological variables. Average monthly meteorological and hydrological data was driven from official yearbooks of Federal Hydrometeorological Institute of Bosnia and Herzegovina. The obtained data was very precise and continuous and therefore used to estimate accurately using data from nearby meteorological and hydrological stations.

4.Results and discussion

Meteorological components

By analyzing the data of an average January, July and annual air temperature of Sarajevo, a regularity decline in temperature with altitudewas observed, so that the maximum average temperatures occur at altitudes of 400 and 500 meters, while the lowest air temperatures are registered at altitudes of 1100-1500 m. Interpolation of data registered at the meteorological stations Bjelave (630 mamsl) and Bjelašnica (2,067 mamsl) determined the real thermic gradient or real lapse rate of temperature is the average lapse rate of temperature of 0.6138°C/100 meters (Figure 2).

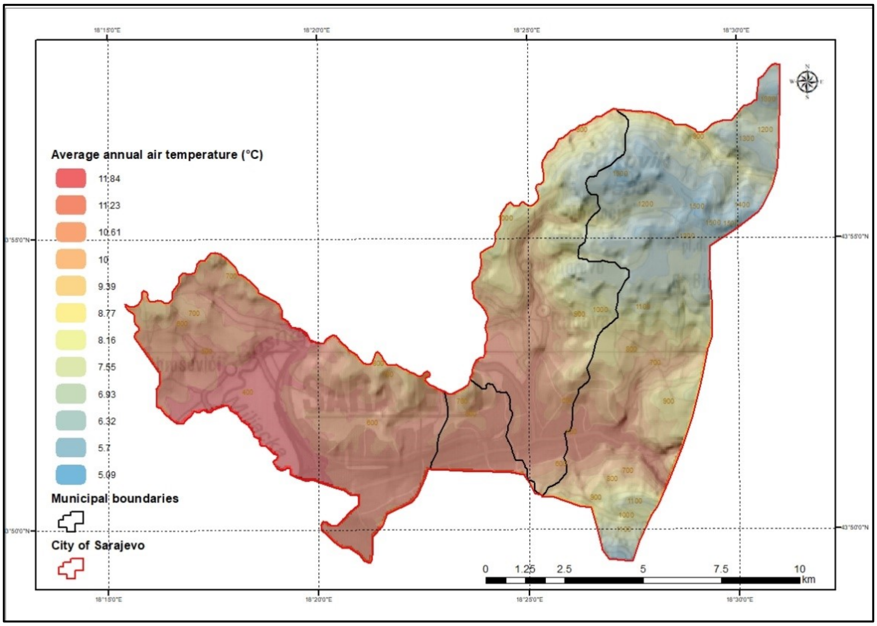

Figure 2: Average annual temperatures of the City of Sarajevo.

Many factors are responsible for air temperature differences. Our study proved the well-known thesis that air temperature decreases with increasing altitude. The lapse rate is defined as the rate of decrease with height for an atmospheric variable. In general, a lapse rate is the negative of the rate of temperature change with altitude change. An interpolation of an average January, July and annual precipitation, the regularity of its increase with the rise in altitude was observed. Higher altitudes receive a higher amount of precipitation, with an annual average of 1500 mm at an altitude of 1500 mamsl (Figure 3). By integrating the obtained data, it was found that the amount of precipitation increases on an annual average by 2.20 mm for every 100 m of altitude. The amount of precipitation is higher in the summer period, especially in July, which coincides with the main precipitation period of the continental regime, which is positioned at the end of spring - the first half of the summer climatic season (May-July), but changed significantly due to orographic barriers in the area of Sarajevo valley. Analysis of interpolated data on average January, July and annual insolation in the City of Sarajevo, showed that the average duration of insolation during the winter period increases with altitude (especially if we take into account the fact that the Sarajevo valley during the same period is often characterized by temperature inversions and dense layer of smog and radiation fogs that further reduce average insolation). During the summer period, insolation is higher (longer) at lower altitudes, while on an annual average, the average duration of insolation is still longer in the lower parts of the city (Figure 4).

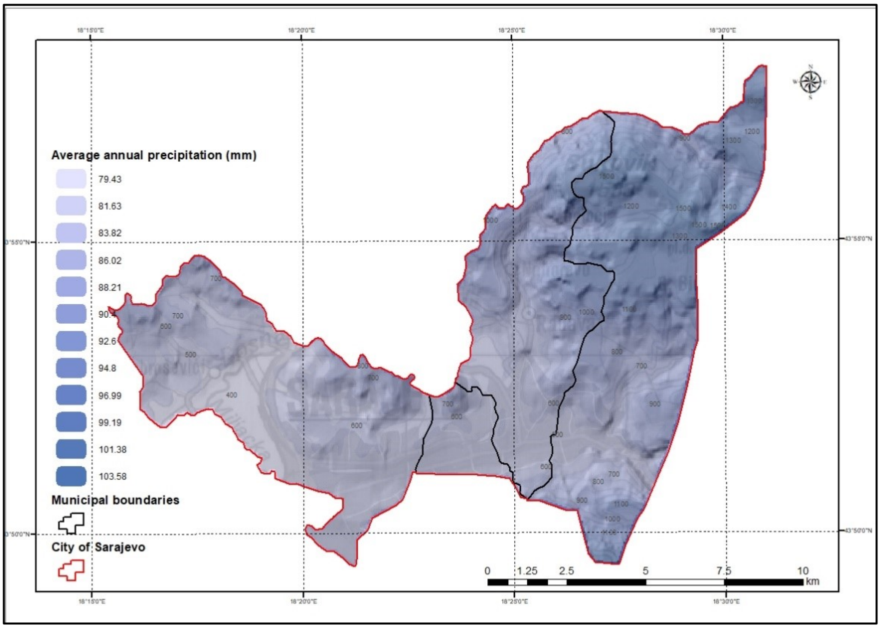

Figure 3: Average annual precipitation of the City of Sarajevo.

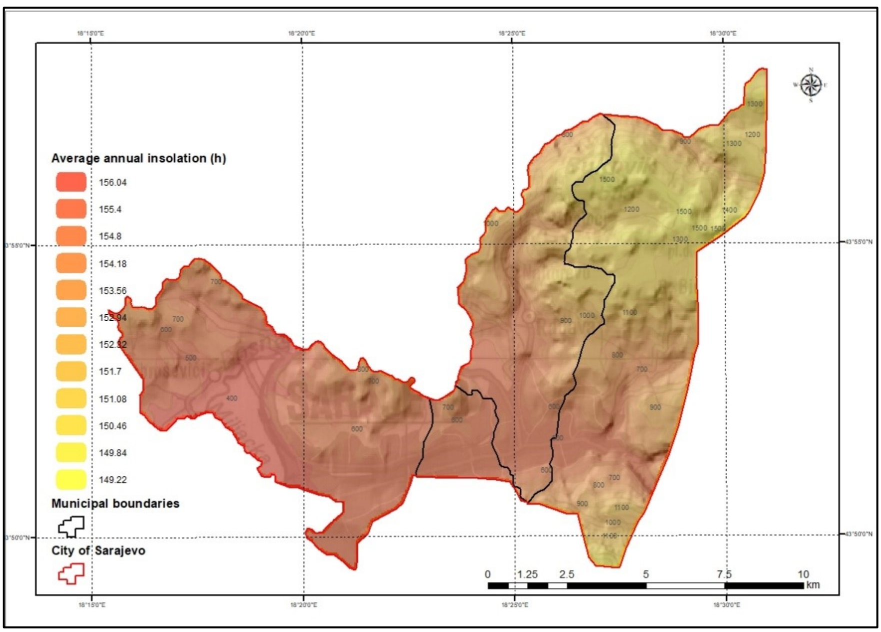

Figure 4: Average annual insolation of the City of Sarajevo.

An analysis of cartographic contributions of the average January, July and annual air humidity shows a similar pattern, which is expressed in the data on the average amount of precipitation for the relevant periods. Values increase with increasing altitude, so that the annual average humidity in the city increases by 0.63% / 100m altitude (Figure 5).

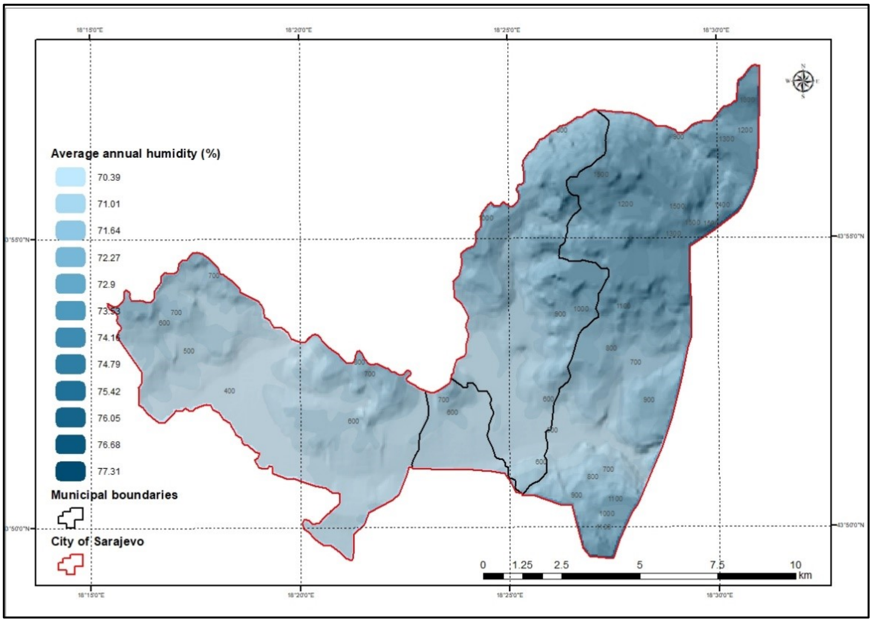

Figure 5: Average annual humidity of the City of Sarajevo.

The aforementioned regularities of the increase of average values for the amount of precipitation and humidity, with the increase of altitude, were registered and are in line with the increase of the parameters of average cloudiness during January, July and the year above the City. The observed regularity is in line with the reduced average insolation during January and the annual average. According to the obtained and interpolated data, it can be concluded that the values reflect the average cloud cover of the area, according to the annual average (0 - clear - 10 - sky completely covered with clouds) (Figure 6). By analyzing the data on the average January, July and annual air pressure, it was noticed that the values decrease with the increase in altitude, in the annual average of 10.47 Pa for every 100 m of altitude (Figure 7). By comparing the maps, it can be noticed that the average air pressure values are slightly higher at lower altitudes during January, which is in line with the cold air pressure and climatological season. Furthermore, our study shows that the value of air pressure gradually decreases with the rise of an altitude, which is in line to higher value of cloud cover, air humidity and precipitation and more unstable weather conditions in general.

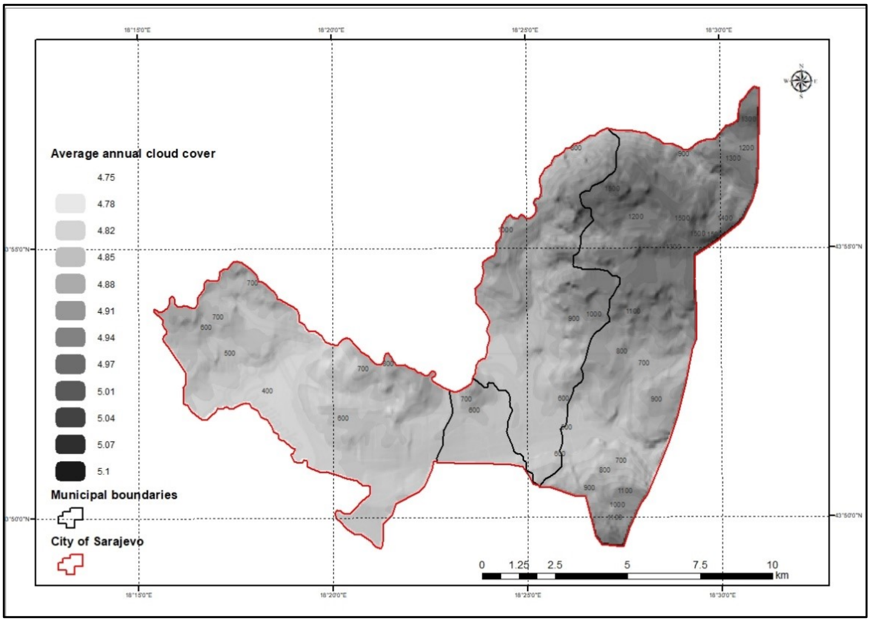

Figure 6: Average annual cloud cover of the City of Sarajevo.

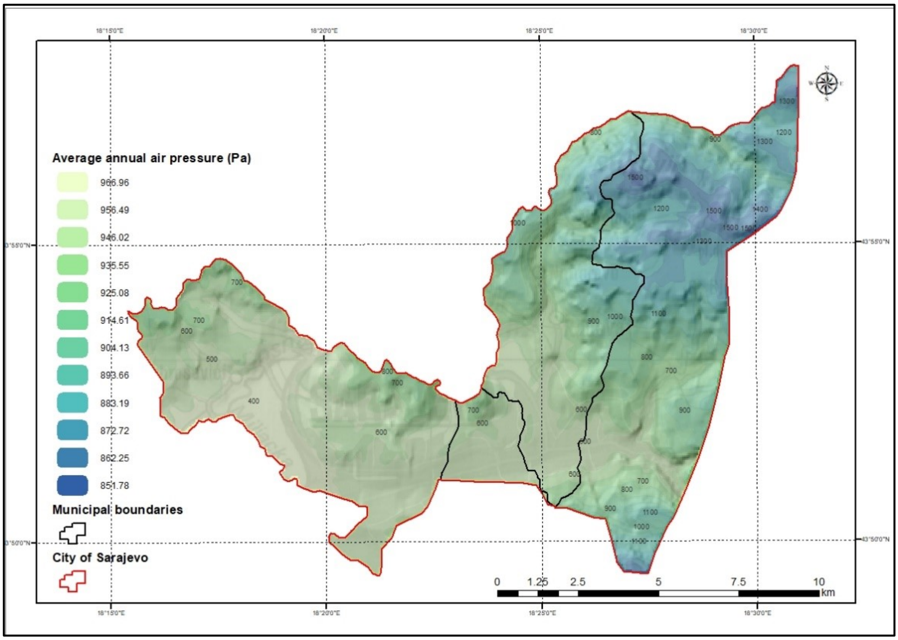

Figure 7: Average annual air pressure of the City of Sarajevo.

Hydrological components

The river network of Sarajevo is primarily represented by the main watercourse - the river Bosna. Additionally, a larger watercourse and recipient of the city area is the river Miljacka with a series of tributaries in the form of streams, whose riverbeds are cut in precipitation areas and elevations around the City valley. Described and river network watercourses were ranked according to the Straher method. The lowest, first rank consists of tributaries without tributaries that have a dominant presence in the complete river network of the city area; these are the Sušica stream, Lješnica, Babin stream, Lučica, Grabovica / Grončica, the tributary stream Moščanica, Lapišnica, Lepenica, Rječica and the tributary stream Trnava (Figure 8).

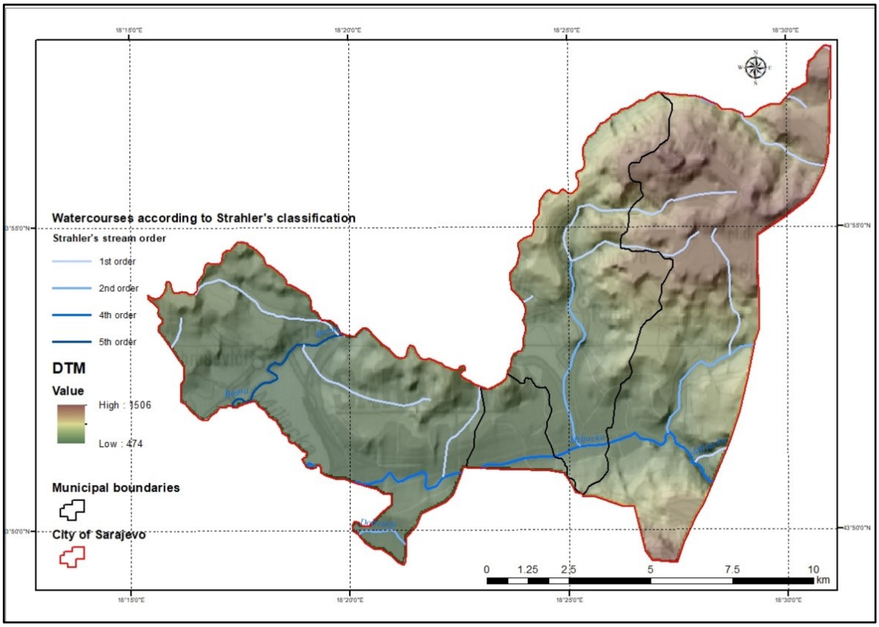

Figure 8: Watercourses of the City of Sarajevo according to Strahler's classification.

According to the "top down" system devised by Strahler, rivers of the first order are the outermost tributaries. If two streams of the same order merge, the resulting stream is given a number that is one higher. If two rivers with different stream orders merge, the resulting stream is given the higher of the two numbers (Strahler, 1957, 1964). The Strahler order is designed to reflect the morphology of a catchment and forms the basis of important hydrographical indicators of its structure, such as its bifurcation ratio, drainage density and frequency. Its basis is the watershed line of the catchment. The flows of the second order are: Mošćanica, Koševski potok and Dobrinja. By merging Pljanska and Mokranjska Miljacka, a course of the fourth order was created - Miljacka, also the main recipient of the City area.

The watercourse of the highest order is the main stream of the area of the City, which in this part is the stream of the fifth order. Determining the share of flows by orders in an analyzed area of the City was performed by measuring the lengths of each of the listed by hypsometric zones (Figure 9).

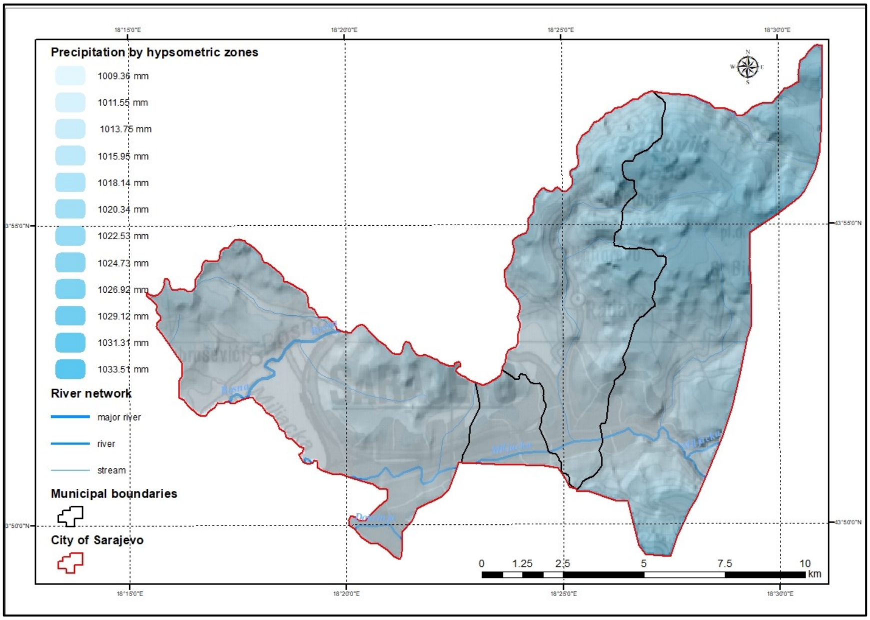

Figure 9: Average precipitation by hypsometric zones of the City of Sarajevo.

The presented map is the result of a calculation made between the average annual amount of precipitation and the real precipitation gradient previously determined by interpolation of data, which is 2.20 for every 100 meters. The amount of precipitation per hypsometric zones increases with increasing altitude for the same amount. The Figure 10 shows the amount of water that evaporates on average from each hypsometric zone of the City. Higher evaporation from surfaces at lower altitudes of the city is evident.

Effective rain or excess precipitation is part of the total amount of precipitation that flows from the basin surface. Data on the amount of precipitation by hypsometric zones participating in the runoff were obtained by subtracting the amount of water, previously obtained actual evapotranspiration from the total amount of precipitation excreted on each zone. A calculation was then performed in relation to the area of each digitized hypsometric zone. The effective amount of precipitation in the city area varies greatly by hypsometric zones, the largest amounts are in the lowest hypsometric zones, also the largest total area and vice versa (Figure 11).

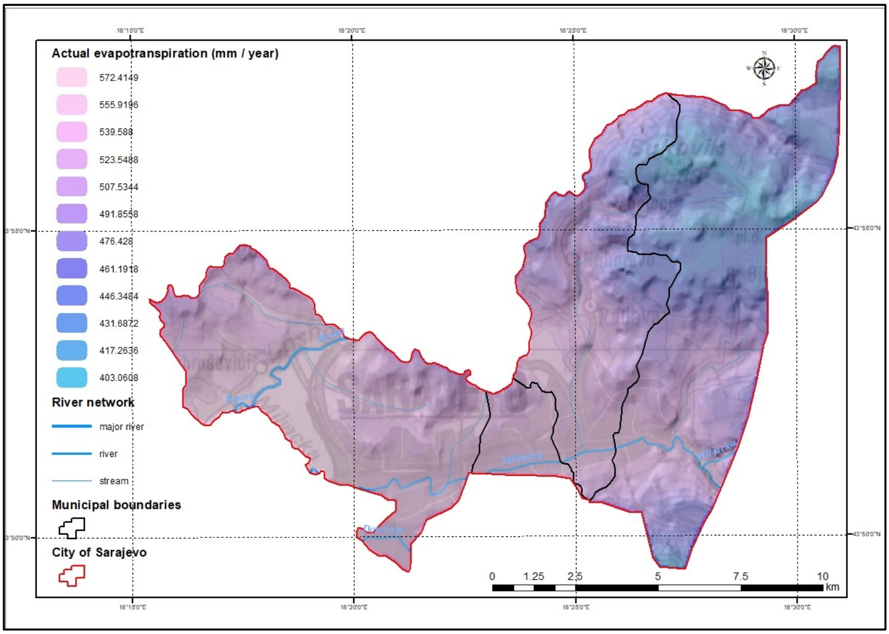

Figure 10: Actual evapotranspiration of the City of Sarajevo.

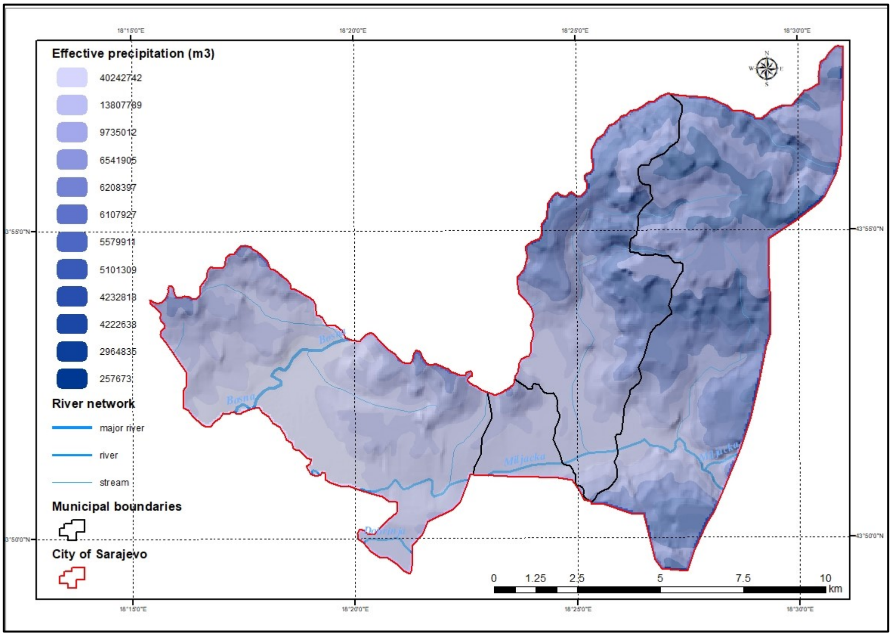

Figure 11: Effective amount of precipitation by hypsometric zones of the City of Sarajevo.

Steady or autochthonous flow consists of those waters which generate from precipitation that is discharged to the appropriate hypsometric zone (Korjenić & Temimović, 2016). Accordingly, the values of this parameter are higher at lower hypsometric levelsof an analyzed area, since they are characterized by a higher effective value of precipitation as well (Figure 12). The calculation also includes the influence of the unit of time, so that the effective amount of precipitation per unit of time are higher in the lower hypsometric levels. The transit flow consists of waters that come to the same zones from higher altitudes, and in this regard, the higher values were recorded in lower hypsometric zones and vice versa (Figure 13).

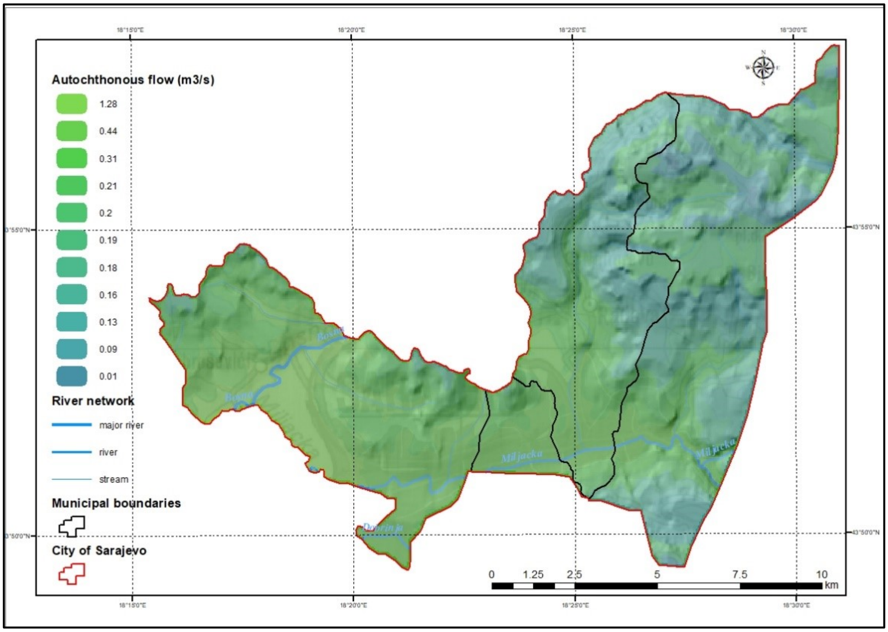

Figure 12: Autochthonous flow through hypsometric zones of the City of Sarajevo.

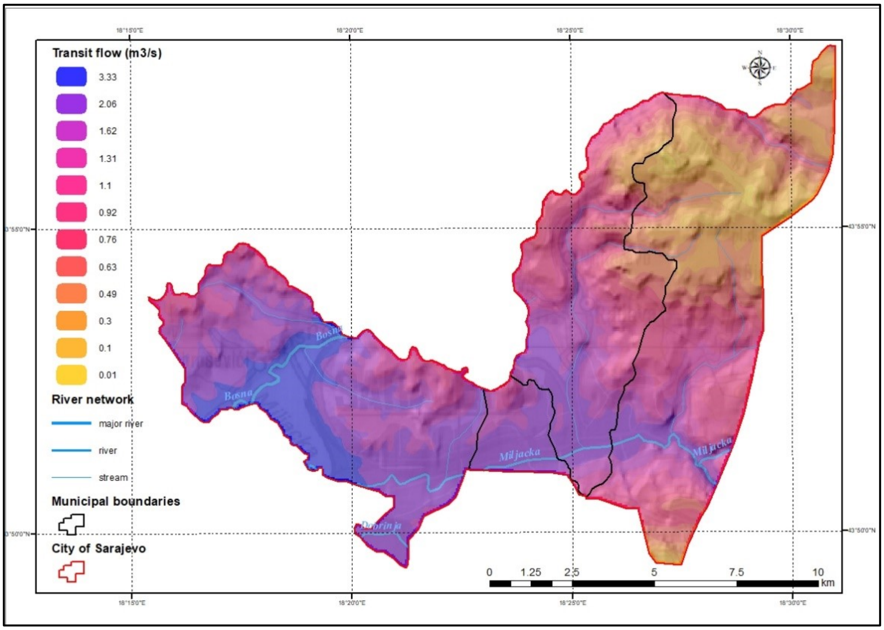

Figure 13: Transit flow through hypsometric zones of the City of Sarajevo.

5. Conclusion

Spatial interpolation of meteorological and hydrological variables can be broadly used in spatial planning process. Our study underlines the importance of different variables in this process. For the purposes of GIS modeling, we interpolated data on average monthly values of all available meteorological and hydrological data from several meteorological stations in the analyzed area, for a period of 10 years. Furthermore, a digital elevation model data set was used. Expectedly, some standard deviation errors are likely to crop up in our study, but if other variables like latitudinal location, continentality, solar radiation, permanent wind directions and cloudiness factor, aspect etc, then the suggested model may predict even more accurate result. As the result suggest, these two variables are likely to be major factors to control the temperature. We can run this model for calculating the mean monthly temperature for other areas as well provided the weightaged of the parameters are calculated for respective area. The previous procedure of data analysis of meteorological and hydrological variables of the City of Sarajevo served as a basis for a more detailed analysis of important geographic parameters in the spatial planning process of an analyzed area.

According to the results of our study, some important specifics of the area in the assessment of meteorological and hydrographic potentials for spatial planning were recognized, such as: total precipitation on hypsometric zones, actual evapotranspiration, effective precipitation, indigenous flow and transit flow.All these, described and cartographically presented parameters are an important part of the field of Physical Geography, which are of great importance in the development of the basis of spatial plans of each area. The spatial basis with the contained elements of climatic and hydrographic characteristics gives a precise view of the current situation and leaves the possibility to assess improvements and future procedures aimed at improving the overall spatial development on the principles of environmental protection and meeting the needs of the population

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