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WBGT ANALYSIS OF THERMAL COMFORT OF THE AREA OF SEMBERIJA

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ABSTRACT

Thermal comfort of urban areas is a highly researched field of science, which is gaining more and more importance in the field of ecology. The research of the area from the aspect of the convenience of physical activities and outdoor life provides data that is also useful in the health sector. This research included the area of Semberija in Bosnia and Herzegovina, which is characterized by unfavorable conditions during summer, due to high temperatures, swampy land and increased artificial presence of construction and industries.

Not all areas have the same weather conditions, therefore other factors such as relief and presence of forests are important in the overall state of the area. Therefore, data from two meteorological stations, at a short distance from each other, but in a different natural and artificial environment, were analyzed. These are the station in the town of Bijeljina and the station within the Mine and Thermal Power Plant in Ugljevik.

Within this research, the WBGT bioclimatic model was used, which is widely used in the world for the purposes of calculating the time that the human body can spend in direct sunlight during work or exercise, without rest. Given that the same time period is not covered, an average of 14 years (period 2005 – 2018) was analyzed for the area of Bijeljina, and an average of 8 years (period 2015 – 2022) for Ugljevik. The period from 2015 to 2018, which covers both locations, was also analyzed in order to make a comparison and notice the differences and determine the factors that affect the thermal comfort of the space.

Keyword: *thermal comfort, WBGT, bioclimatic indices, urban environment, land use*

INTRODUCTION

Thermal comfort represents an interesting field of research from the aspect of people's comfort and their functioning in the area they live in, but also from the aspect of spatial planning in terms of the layout and intensity of construction. The uneven population of the area, the growth of the cities and the extinction of villages, leads to different microclimatic characteristics of several areas at close distances.

As a consequence of increasing development of the cities, appear many problems such as overcrowding of certain areas, which further leads to changes in space that affect the growth of temperature in urban environments, such as concrete and asphalt surfaces, lack of green areas, increasing number of cars, etc. Many cities have higher temperatures than the environment due to the level of urbanization that modifies land use, creating a specific phenomenon, urban heat islands [1,2].

According to the audit of the world perspective of urbanization from 2018, 68% of the population will live in urban areas by 2050 [2,3]. The quality of urban living conditions often depends on the thermal comfort of the open urban spaces, which are used on a daily basis [4]. In order to understand the conditions of certain area, especially conditions that are affecting everyday human life, thermal comfort is used.

Human thermal comfort is defined as a condition of mind which expresses satisfaction with the surrounding environment, according to ANSI/ASHRAE Standard 55 [5]. High temperatures and humidity provide discomfort sensations and sometimes heat stress. People react differently to environmental elements, depending on their physical and mental health and their adaptation to certain conditions. Common for everyone is that they are not immune to meteorological conditions, especially air temperature and humidity [6].

Due to the influence of external factors, a person is in constant danger of accumulating heat in the body. Heat is constantly produced in the human body due to metabolic reactions, which is also constantly lost in the immediate environment. When the degree of heat in the body is equal to the degree of heat loss, thermal equilibrium occurs, also known as Human heat balance [7].

The amount of heat produced and delivered by a person depends on physical activity, clothing, gender, age, body weight, diet, mental and health status, external conditions, etc. Heat generated by metabolic processes is given off by humans using basic heat transfer mechanisms. These are: radiation, conduction, convection and evaporation. All these processes, that are shown on figure 1, depend on atmospheric conditions [7,8].

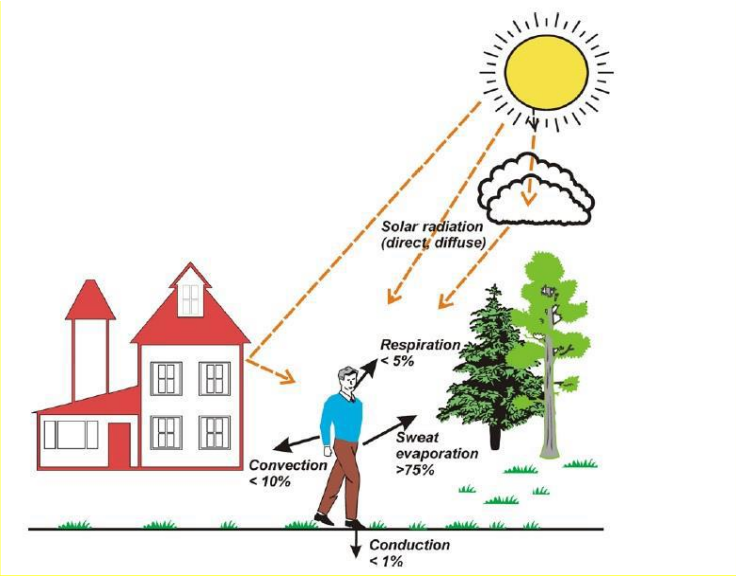


Figure 1. Ways of heat release in the environment

LOCATION

The area of Semberija is located on the northeast part of Bosnia and Herzegovina, in the entity of Republic of Srpska. The location is at the crossroads between Serbia, Croatia and internal Bosnia and Herzegovina, which has enabled this area accelerated development and increase of the population since the beginning of the 21st century.

Total researched area is 904.43 km^2 [9]. It consists of two municipalities: The City of Bijeljina and municipality Ugljevik. Total number of inhabitants is 123 425 [9]. Population density varies within the area, with lowland parts being more populated than the mountainous. For the purposes of this research, data from two meteorological stations were used, one in the city of Bijeljina named Station 1 and one in the area of Mine and Thermal Power Plant in Ugljevik town named Station 2 (figure 2). Air distance between the stations is around 20 km [10].

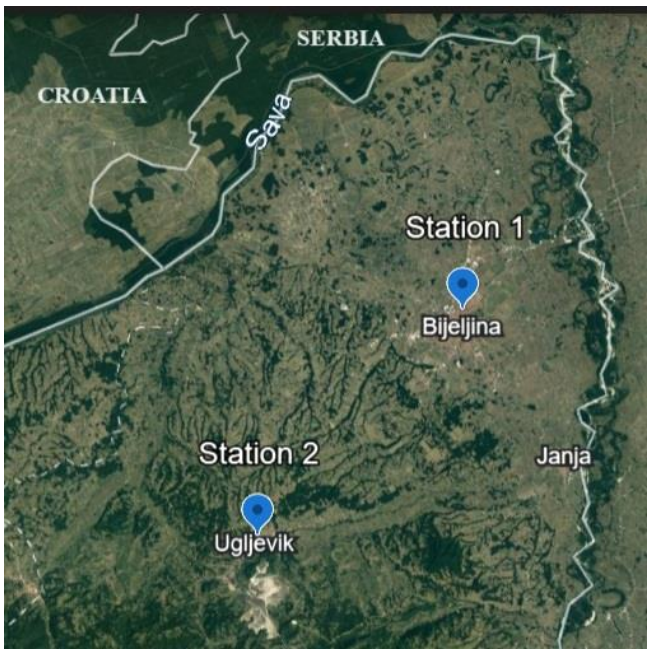


Figure 2. Location of weaher stations on the researched area

Bijeljina is a characteristic example of heat island in Bosnia and Herzegovina. Construction of facilities since the beginning of the 21st century made a complete transformation of the space and created from small town an urban environment [11,12]. According to the last Census in 2013, the city of Bijeljina has 42 278 inhabitants, which is 16 1 % more than in the year 1991 [13]. According to the previous research, the city of Bijeljina shows unfavorable characteristics of thermal comfort, which are pronounced during the warmer part of the year (especially months Jun, July and August) [6,12,14,15]. The weather station from which the data were obtained is located about 1.5 km by air from the city center, at the altitude of around 90 meters [10].

The second station is located at the location within the Ugljevik Mine and Thermal Power Plant, in the Ugljevik settlement. The characteristics of this station are that it is located within the industrial complex, in the immediate vicinity of the forest cover. Despite its small population, the municipality of Ugljevik is considered a more developed municipality in Bosnia and Herzegovina. The reason for this is the exploitation of coal. Station is at altitude of around 170 meters [10]. Previous research that used data from this weather station are scarce and do not give a concrete picture of the state of thermal comfort in the narrow area of the Ugljevik settlement [16].

METHODOLOGY

There are a lot of different bioclimatic models and indices that are used today for the analysis of thermal comfort of certain areas. For the purpose of this paper was used bioclimatic model, Wet bulb globe temperature (hereinafter referred to as WBGT). It has a total of five thermal stress categories. Those are: Unlimited, Possible heat stress, Heat stress at unacclimated, Heat stress at acclimated and All activity should be stopped.

According to National weather service [17] WBGT is a measure of heat stress in direct sunlight, which takes into account: temperature, humidity, wind speed, sun angle and cloud cover (solar radiation). WBGT was developed by Yaglou and Minard in 1957 and is regarded as one of the main experimental indices for measuring heat stress [18]. It was first used during the 1950s as a component of a successful campaign to reduce heat-related illnesses in the training camps of the US Army and Marine Corps [19].

WBGT is commonly used index of heat stress today, especially by military, universities and sports organizations. One of its purposes is to keep people safe while performing outdoor activities at high

temperatures. For these reasons, athlete organizations are using this bioclimatic index, so the athletes could reach a full potential without being put in health danger. WBGT addresses the physical activities that human body can stand in different climatic conditions regarding different seasons in the area of Semberija on two researched locations in this paper. In table 1 are presented values of WBGT and recommendations for involvement in outdoor activities for every value of the index [20].

Table 1 Recommendations for outdoor activities for wet bulb globe temperature (WBGT) values

	VALUE	DESCRIPTION
Unlimited	< 18	Unlimited
Possible heat stress	18 – 23	Keep alert for possible increases in the index and for symptoms of heat stress
Heat stroke at unacclimated	23 – 28	Active exercise for unacclimatized persons should be limited
Heat stroke at acclimated	28 – 30	Active exercise for all but the well-acclimated should be limited
Activity should be stopped	≥30	All training should be stopped

Data from two meteorological stations were used for calculation of thermal comfort of the two location within the area. Values, obtained from the meteorological station in the city, are calculated in software program Bioklima 2.6 [21]. This study included data for a period of 18 years in total, 14 years from the station in Bijeljina (2005 – 2018) [22] and 8 years from the station in Ugljevik (2015 – 2022) [23]. Only summer months were observed, June, July and August, because they have the least favorable conditions that affect human comfort. Years that overlap were compared in order to obtain more effective understanding of differences and similarities between these two observed locations on a small researched area.

According to Köppen's climate classification, Semberija belongs to the Cfb type – where the climate is moderate continental, with moderately cold winters and warm summers [22]. Heat waves appear every few years. 2019 was one of the warmest in the last 100 years on the research area. August had an average of 2° C higher mean air temperature [24], November was one of the 5 warmest in the last 150 years, with an average monthly temperature of 11.3°C [25] and December was the tenth warmest since the year 1861 [26]. Higher parts of Semberija have lower temperatures during the summer months, therefore are more pleasant.

WGBT is widely used for the presentation of possible heat stress for workers whose activities are carried out outside. The International Standard for heat stress uses WBGT to recommend work – rest limits for work in hot environments in order to ensure that average core body temperatures of worker populations do not exceed 38°C. Chapter 8.1.2 of the standard states that workers should be allowed sufficient time to acclimatize to an extremely hot or cold environment, including major changes in climatic conditions [27]. Many countries have national standards based on this international standard for WBGT limit values [28].

If the value of WBGT is within Heat stroke at unacclimated level, body is stressed after 45 minutes of working out. It is necessary to take breaks of 15 minutes. If the value of WBGT is within Heat stroke at acclimated level, body is stressed after 20 – 30 minutes of working out. It is necessary to take breaks of 30 – 40 minutes. Finally, if the value of WBGT is within Activity should be stopped level, body is stressed after 15 minutes of working out and should have at least 45 minutes breaks [17]. These recommendations should be followed in order to preserve health and obtain comfort of human body while carrying out outdoor activities (table 2).

Table 2. Suggested actions and Impact Prevention

EFFECTS	PRECAUTIONARY ACTIONS
None	None
Working or exercising in direct sunlight will stress your body after 45 minutes	Take at least 15 minutes of breaks each hour if working or exercising in direct sunlight
Working or exercising in direct sunlight will stress your body after 30 minutes	Take at least 30 minutes of breaks each hour if working or exercising in direct sunlight
Working or exercising in direct sunlight will stress your body after 20 minutes	Take at least 40 minutes of breaks each hour if working or exercising in direct sunlight
Working or exercising in direct sunlight will stress your body after 15 minutes	Take at least 45 minutes of breaks each hour if working or exercising in direct sunlight

Increased heat exposure raises the core body temperature of the human body. While some increase in core temperature above 37°C is acceptable, an increase beyond 39°C creates health risks, which vary from person to person, depending on ethnic group, age, gender, the duration of high heat exposure, and the degree of acclimatization. The core body temperature of all humans is maintained close to 37°C. The main mechanism of internal heat gain is the heat generated by muscles that work at approximately 20% efficiency [17,29].

Physical readiness is different for people of certain groups, but everyone is affected by meteorological factors, especially those that are new and that human organism of certain area is not used to them [14]. All categories of people are considered while researching and analyzing the results of WGBT. Some however, are more prone to experience heat stress. Discomfort and heat stress reduce productivity of workers and may lead to more serious health problems, especially for aged persons.

RESULTS

In this research all five categories are present on both locations, during the summer months. However, the number of each category varies between the locations. The categories show an uneven presence, with the largest number of days within the categories belonging to categories Possible heat stress and Heat stress at unacclimated.

For the human body, the most favorable days are within the category Unlimited, with values lower than 18. During those days human organism can have as the name says it, unlimited period of exercise and work without feeling exhausted in direct sunlight. This category has the least number of days on both location during observed period, with location Ugljevik showing higher numbers for every month and year (figure 3).

Category Possible heat stress, with values between 18 and 23, has the biggest presence of all categories during the summer months on location Ugljevik. This category represents the first warning towards the hot summer days that are characterized with unfavorable thermal comfort for human organism. On both locations this category counts between 10 to 15 days a month, with the least number of days in July (figure 4).

Category Heat stress at unacclimated, with values between 23 and 28, has the biggest number of all categories during summer months on Bijeljina location. It counts between 10 to 15 days on both locations, although it frequently goes up to 20, especially during the month of August, on location Bijeljina (figure 5).

Category Heat stress at acclimated, with values between 28 and 30, and category All activity should be stopped, with values higher than 30, has bigger presence at the Bijeljina location (figures 6 and 7). These two categories present the biggest threat for human organism and thermal comfort of the area.

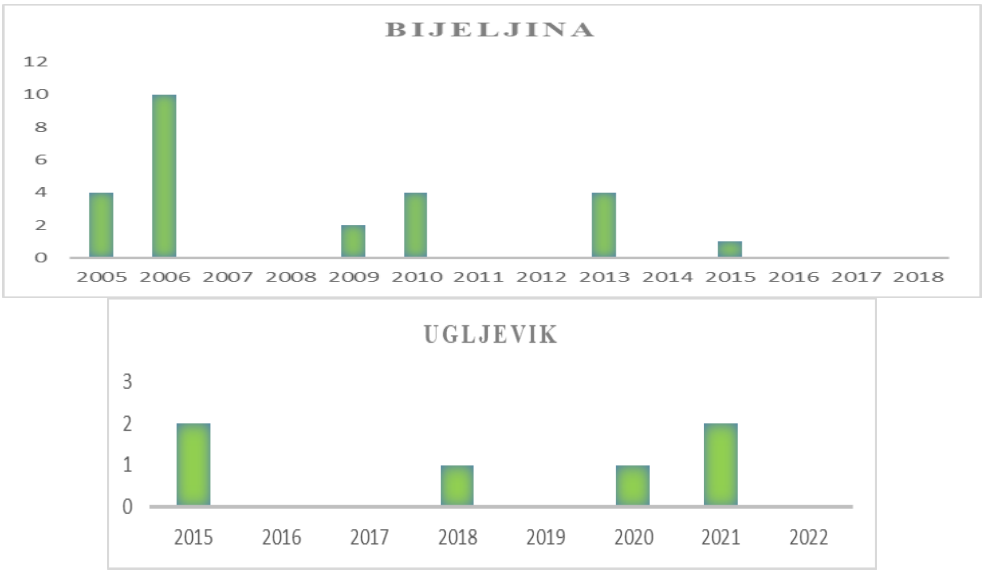


Figure 3. Number of days in the category Unlimited on both locations

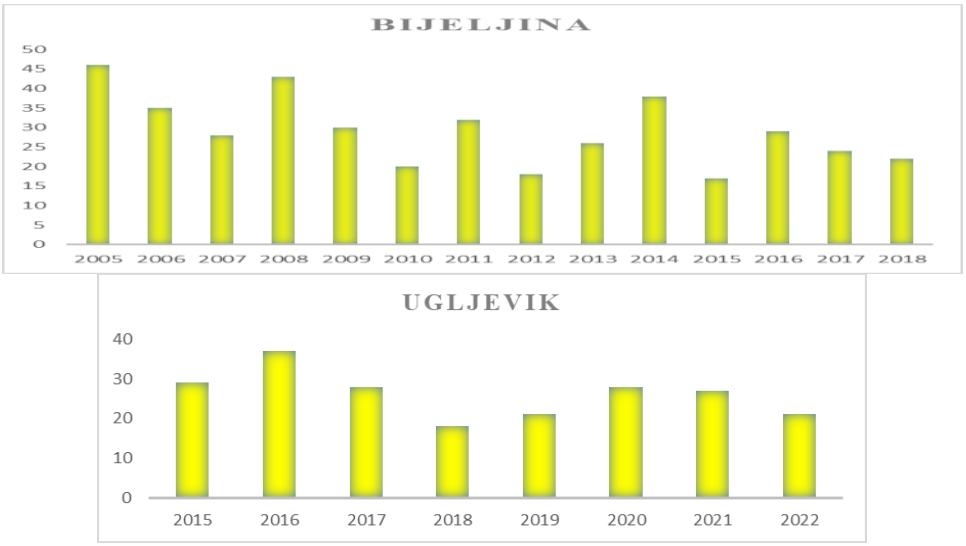


Figure 4. Number of days in the category Possible heat stress on both locations

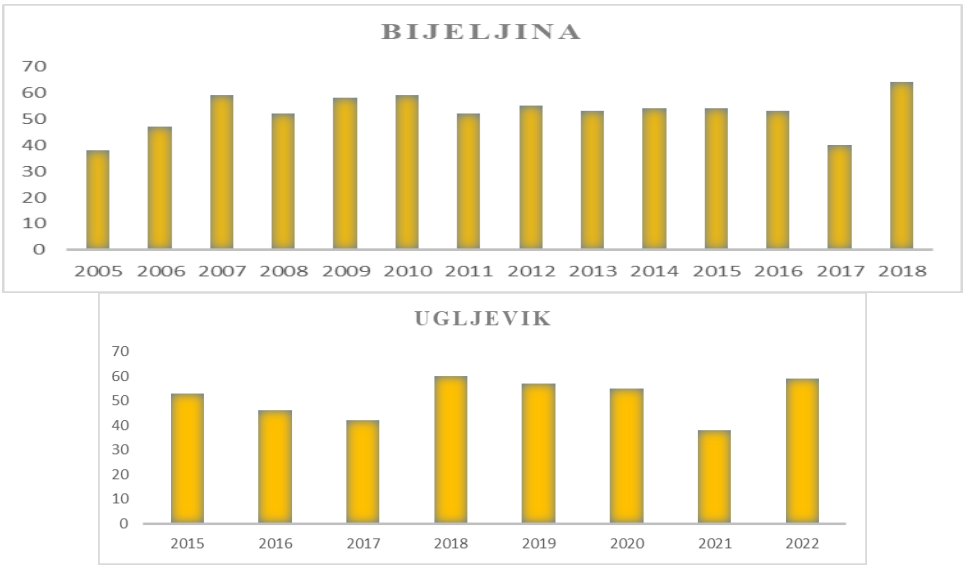


Figure 5. Number of days in the category Heat stress at unacclimated on both locations

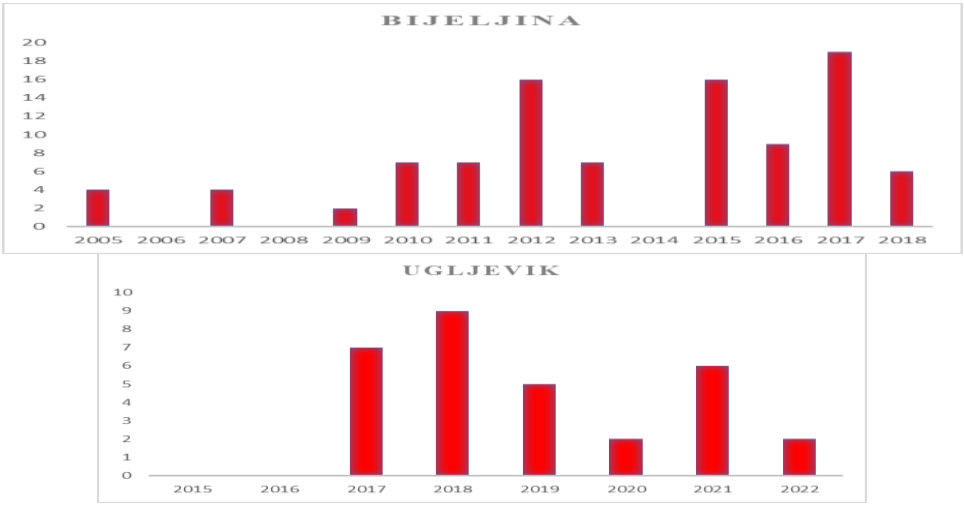


Figure 6. Number of days in the category Heat stress at acclimated on both locations

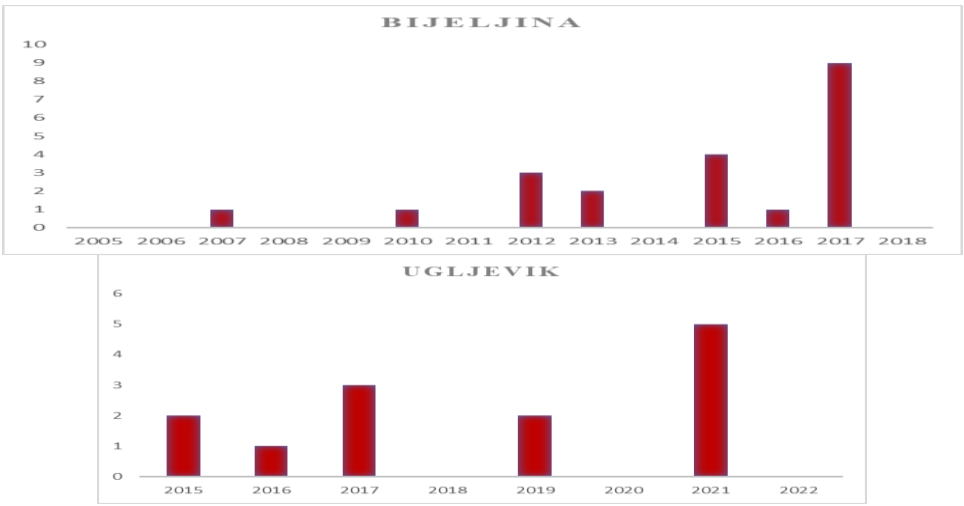
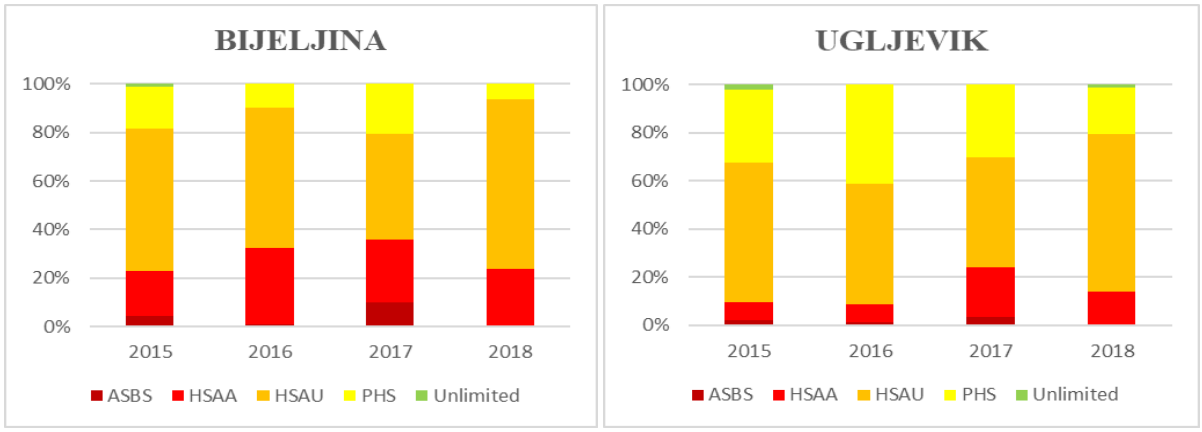


Figure 7. Number of days in the category All activity should be stopped on both locations

From the above data it is obvious that the location Bijeljina has more days that belong to the unfavorable categories regarding thermal comfort. However, since the years observed and the longevity of the research do not match on these two location, in the following chart are shown the ratios of all categories, but only for the years that overlap for both locations, from 2015 to 2018, four years in total (figures 8 and 9).



Figures 8 and 9. Ratio of all WBGT categories on both locations for the period 2015 – 2018

The ratio of categories within the summer months goes in favor of categories with pronounced thermal stress, especially on the location Bijeljina. As such, summer months have adverse thermal comfort which is poorly reflected on the state and health of the human body and it is necessary to take care of the activities of that place during such days.

DISCUSSION

Two observed locations gave similar, yet different results. In general, location Bijeljina has less days with favorable conditions for outdoor activities during summer months. On contrary, location Ugljevik, even though it has the presence of days in Activity should be stopped category, has overall better days suitable for pleasant thermal comfort for human organism, ie suitable for work and excercise in direct sunlight during the day.

Bijeljina, as a developing center of Republic of Srpska has an increase in construction, lack of green areas and a high influx of inhabitants. All this, plus the geographical conditions, such as swampy ground, lack of wind and trees has led to very unpleasant summers on this location. Thermal comfort during summer months is very harsh and it represents difficulties for people with heart and lung conditions, as it is very hard to breath. If we include work and exercise in this equation, it can be said with certainty that summer months are very unfavorable for outdoor activities during the day.

The second location, Ugljevik, has better conditions regarding thermal comfort, and allows people to work and exercise longer during summer days. The station from which meteorological data were used is places inside Mine and Thermal Power Plant Ugljevik complex which is a location prone to infrastructural works, transport and mining and as such is not favorable for human comfort. However, observing only WBGT values, it has the presence of more favorable days than the location Bijeljina. This is mostly due to forest cover that is present around the industrial complex and higher altitude in which the station is placed (figure 10) [31].

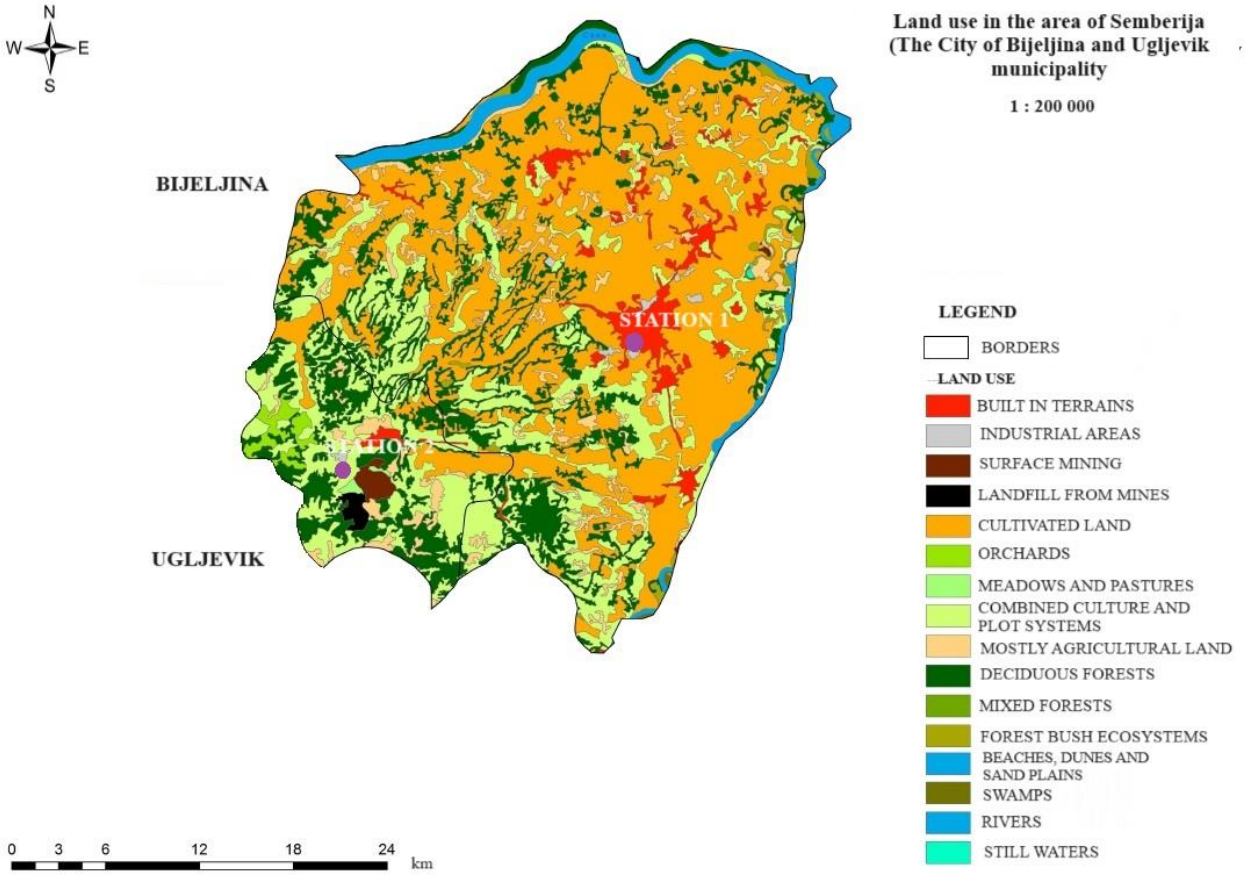


Figure 10. Location of stations in relation to land use of the area of Semberija

Observed in general, Semberija area has unfavorable days regarding thermal comfort that reflect negatively on people's health and wellbeing. Summer months in this area are characterized with high temperature and a lack of wind. The most uncomfortable conditions during summer are present in the area of the city of Bijeljina due to artificial factor that supplement natural negative elements. Going towards higher altitude, forest cover thickens and therefore gives the pleasant felling to human organism, that helps reduce poor thermal comfort.

All positive effects of calculated data can be attributed to the fact that area of Ugljevik, even though it has poor artificial elements, has better natural ones, that contribute to better thermal comfort and the state of human organism during summer months, than in Bijeljina and as such are suitable for work and exercise more than location Bijeljina. Different use of land has an impact on thermal comfort in general and contributes to overall feeling of human organism in space.

CONCLUSION

This research included the analysis of data of two meteorological stations in the area of Semberija. Data used were calculated through program BioKlima, where bioclimatic model WBGT was obtained for two locations, Bijeljina city and Mine and Thermal power plant Ugljevik.

Semberija is the area that has the highest population influx, since the civil war in Bosnia and Herzegovina in the 90s. This has led to intense infrastructural building, pollution, noise and lack of green areas, faster way of life which all have an effect on thermal comfort of people. In combination with unfavorable meteorological elements, it can have dangerous effect on human organism [6]. This is particularly expressed in the area of the city of Bijeljina.

The location within Mine and Thermal power plant Ugljevik showed more favorable days suitable for outdoor work and exercise in direct sunlight during the day. This is mostly due to its surroundings that are covered with forests, and are at a higher altitude.

In general, the area has unfavorable days during summer months that are not suitable for outdoor activities and represent days with poor thermal comfort that has negative effect on human organism and can lead to different health problems. It is necessary to apply proposed measures in order to protect the wellbeing of health and obtain heat balance in the organism.

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