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IMPACT OF POPULATION ON THE KARST OF EAST SARAJEVO (BOSNIA AND HERZEGOVINA)

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Abstract: Research of human settlements on the karst area of East Sarajevo starts with a brief overview of the City's characteristic traits and the influence of relief on the distribution of the population. The karst terrain was mapped using GIS tools, after which the percentage of the population and its concentration on the karst area of the East Sarajevo was determined. Karst areas have a low population density caused by difficult living conditions due to the vertical and horizontal dissection of relief, lack of mineral resources, geodynamic disasters, water shortages, specific climate conditions, degraded land, and vegetation. The consequences are the fragmentation of property, migration and aging of the population, lack of labor, weakening of the economy, etc. The research focus is to determine the degree of the anthropogenic impact on the karst environment and to apply the suitable methodology in the determination of the settlements categories according to the degree of karst environment vulnerability.

Keywords: vulnerability of karst; population; karst environment; settlements; East Sarajevo

Introduction

The City of East Sarajevo is located in the eastern part of Bosnia and Herzegovina and consists of six municipalities: Istočno Novo Sarajevo, Pale, Istočna Ilidža, Istočni Stari Grad, Sokolac, and Trnovo (Figure 1). There are 216 settlements, covering a total area of about 1,447 km². According to the hypsometric distribution, the settlements are located from 500 to 1,916 m above sea level.

Through previous research (Lukić Tanović, Golijanin, & Grmuša, 2014), the authors studied the impact of the morphometric features of the terrain on the distribution of the population of the City. Therefore, this paper represents a continuation of the research with a review of the hypsometric zoning and distribution of the population (applying the final results of the 2013 Census, which were not available at the time of the earlier research). In the researched areas, four hypsometric zones are evident: the southeast part of Sarajevo Polje, altitude 510 m and more; hill relief with plains and plateaus 800–1,000 m; middle mountain relief with 1,000–1,500 m; and high mountain relief with peaks: Jahorina (1,916 m), Treskavica (1,776 m), Romanija (1,652 m), Trebević (1,629 m), Ozren (1,453 m) and Devetak (1,424 m).

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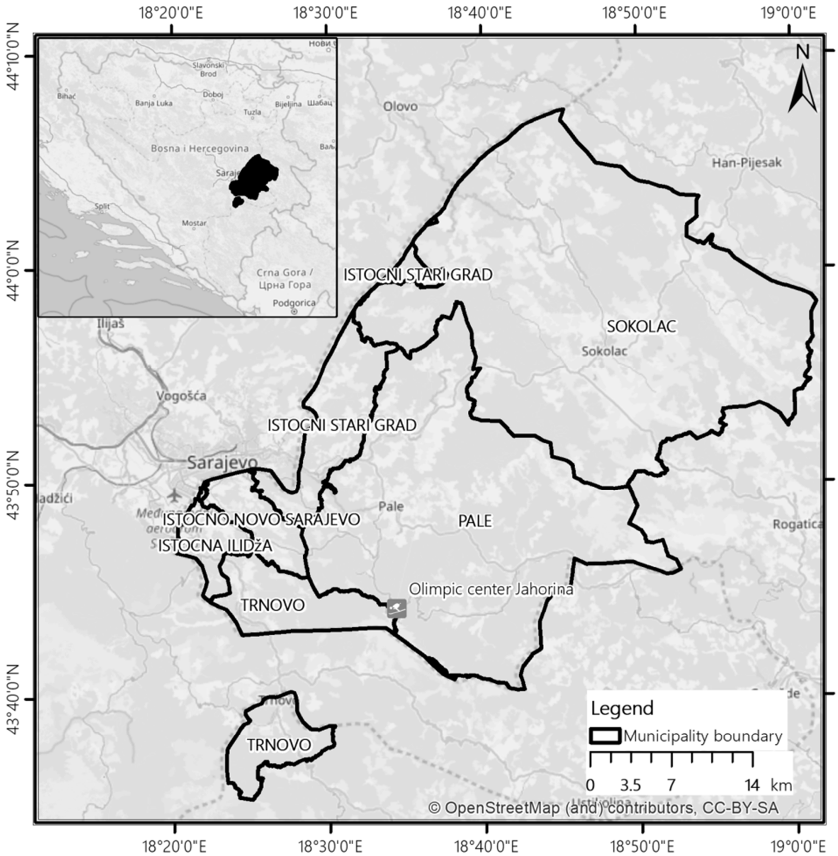

Figure 1. The municipalities of the City of East Sarajevo - geographical position in Bosnia and Herzegovina

Inspecting the distribution of the settlements (Figure 2), it can be noticed that the largest number of the settlements or 29.6% (64 settlements) are located at a hypsometric zone between 900 to 1,000 m. There are 19% of the settlements (41 settlements) in hypsometric zone between 800 to 900 m. Two urban settlements, Pale and Sokolac, are also located within this hypsometric zone. Analyzing the relations between relief and population, according to the latest population census, it was noticed that, in East Sarajevo, the lowest hypsometric zones are not the most populated.

The space belonging to Sarajevo Polje, the largest part of the municipalities of Istočna Ilidža and Istočno Novo Sarajevo, is lower and more favorable for settlement and urbanization. The population inhabiting the lowest hypsometric belt in the investigated area is 25,014 inhabitants, which makes up 41.7% of the population of the City. In the second hypsometric belt, the conditions for settling are also favorable, judging by the largest number of inhabitants in this zone (49.1% or 29,428 inhabitants). Almost half of the population of East Sarajevo lives in this area. Middle mountain relief dominates this zone and a number of inhabitants is rapidly decreasing causing these parts to have lower population density (5,453 or 9.1% of the population live in settlements located at altitudes from 1,000 to 1,500 m), while the highest parts of the city's territory are almost uninhabited (Lukić Tanović, 2018). Further, the subject of this research will be the distribution of settlements on karst terrain in the area of East Sarajevo.

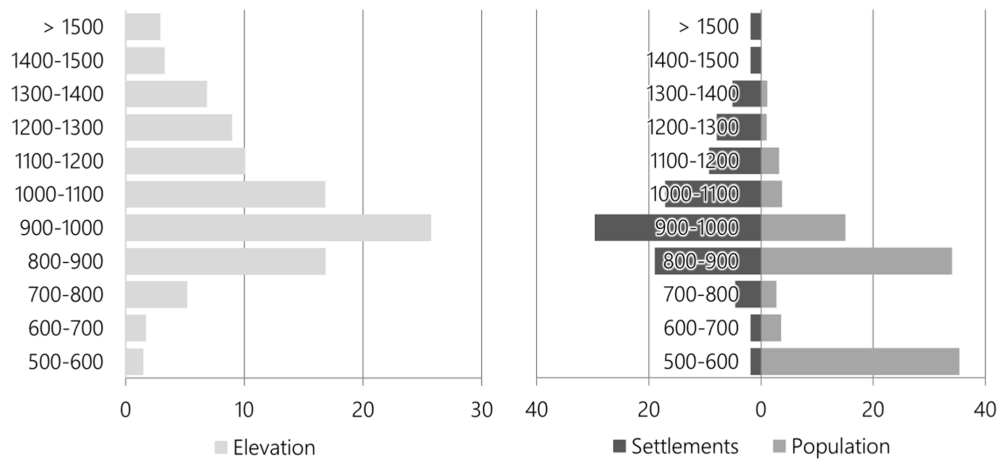

Figure 2. Distribution of settlements and population (%) by elevation zones of East Sarajevo (2013)

The karst rocks of East Sarajevo are Triassic limestones with smaller area covered with dolomites. Limestones of Middle and Lower Triassic form the basis of the explored area, where dominate thick-bedded (banked) limestones and massive limestones and dolomites of Middle Triassic (in particular the layers of Anisian with a share of over 35%). Lower Triassic karst is represented at a lower rate, mainly as thick-bedded (banked) Megaladon limestones and thin-bedded (striped) limestones 18% (Golijanin, Ćulafić, Petronić, & Matović, 2017).

Conditions for living on the karst are difficult due to: the vertical and horizontal dissection of the relief, poor mineral resources, geodynamic disasters, water shortages, specific climatic characteristics. That is why these terrains are usually less populated, with property fragmentation, emigrations, aging of the population, lack of labor, weakening of the economy, population concentration in the areas with fertile land or where industrial or tourist centers are located.

The karst areas are significantly more vulnerable than others, especially if we consider factors such as: geomorphology, hydrogeology, biodiversity, etc. The most frequent risks associated with karst are sinks, floods and slope movements, but also anthropogenic impacts such as karst groundwater pollution (Gutiérrez, Parise, De Waele, & Jourde, 2014; Ravbar & Goldscheider, 2007; Telbisz, Bottlik, Mari, & Kőszegi, 2014). For the proper reduction of negative effects and the promotion of sustainable development it is necessary to do the evaluation of natural and anthropogenic impacts (biological and chemo-physical) (Bain, Harig, Loucks, Goforth, & Mills, 2000). In addition to papers that deal with the problem of dissolution kinetic of the carbonate systems interacting with the rainfall (e.g. Kaufmann & Dreybrodt, 2007; Palmer, 2007), a great number of papers deal with the interaction of natural and anthropogenic effects on karst, in particular from the point of karst vulnerability (e.g. Butscher & Huggenberger, 2009; Calò & Parise, 2009; Day, 2010; Gutiérrez et al., 2014; Iván & Madl-Szőnyi, 2017; Ravbar & Goldscheider, 2007; Telbisz, Botllik, Mari, & Petrvalska, 2015; Telbisz et al., 2014; Telbisz, Imecs, Mari, & Bottlik, 2016; Telbisz, Stergiou, Mindszenty, & Chatzipetros, 2019). Some papers deal with the topic of population trends and movements in the karst areas, and they indirectly analyze the anthropogenic impact on the karst (Pejnović & Husanović-Pejnović, 2008).

The expansion of urban areas (including roads and industrial facilities) in karst, changes in the way of land use, etc. lead to the increasing degradation and karst pollution, with serious consequences for karst ecosystems and the quality of groundwater (De Waele & Follesa, 2004). The situation is even more complicated in the post-conflict scenarios, as it is in the Balkans karst areas (Calò & Parise, 2009). Therefore, activities must be undertaken to assess the negative impacts of the increased pressure on the fragile karst environment, as well as to find solution how to reduce them.

The main goal is to determine the degree of endangerment of karst area based on the ratio between population density and the area under the karst, and to make classification of the City settlements by the degree of vulnerability. The threats to karst terrains, as well as the population on the karst areas were processed earlier in scientific papers (Golijanin et al., 2017; Ravbar & Goldscheider, 2007; Tolmachev, 2013; etc.).

Data and Methods

The karst is represented in a large area of East Sarajevo, and the main working hypothesis is that the karst environment is endangered due to the negative anthropogenic impact. Karst terrains were identified and mapped using QGIS 3.4 (2018) processing tools after which the degree of population density and concentration of population on karst were determined. Geological data was obtained using Basic Geological Map SFRY in scale 1:100000, where karst terrains were separated from other terrains of East Sarajevo (Jovanović, Mojićević, Tokić, & Rokić, 1978; Mojićević & Tomić, 1982; Olujić & Karović, 1985; Strajin et. al, 1978; Vujnović & Marić, 1982). The percentage of karst terrains was calculated within the administrative boundaries of the settlements of the City of East Sarajevo. Population data for each settlement was obtained by the last census data (Republika Srpska Institute of Statistics, 2017). Elevation data was derived from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) Version 2 (Ministry of Economy, Trade, and Industry [METI] of Japan & United States National Aeronautics and Space Administration [NASA], 2011). Data processing was performed using Version 18.20.2018 of V–Analyitcs (2018) software.

The main aim of this analysis is to examine the relation between two parameters: percentage of the karst terrain in settlements and the population density within those settlements. We assumed that settlements with larger population density and with middle to high percentage of karst terrain are more vulnerable than less populated ones. In order to perform this analysis both variables were categorized by its significance for this statement.

In the first step, settlements of the City of East Sarajevo were categorized in 5 categories by the percentage of the karst terrain. Each of these categories has the assigned value according to its significance, where the lowest value (1) is assigned to settlements where karst terrain is presented in the range between 1 to 20%. The highest value (5) is given to settlements with the most significant percentage of karst terrain, ranging from 81% to 100%.

The second variable, population density, is also categorized into 5 categories according to its significance for the karst environment vulnerability. The lowest value (1) is assigned to settlements with the lowest population density ranging from 0 to 10 people per square kilometer. The highest value is assigned to the group with the population density higher or equal to 500 people per square kilometer. The categorization of the settlements by population density is carried out according to Friganovic model (Friganović, 1978). Each variable was categorized in the equal number of categories (5), because it allows easier comparison and examination of the relationship between the variables. Category range, assigned values and basic statistical parameters for the variables of the karst terrain and the variables of population density are presented in Table 1.

Table 1
Categories, values and main statistical parameters of the karst terrain variable and population density variable

No.	Variable	Categories	Value	*f* (No. of settlements)	Cumulative frequency	*M*	*SD*
1	Karst terrain in %	1–20	1	25	25	3.52	1.396
		21–40	2	23	48		
		41–60	3	37	85		
		61–80	4	43	128		
		81–100	5	65	193		
2	Population density (people per km²)	1–10	1	131	131	1.47	0.836
		11–50	2	44	175		
		51–100	3	10	185		
		101–500	4	5	190		
		≥ 501	5	3	193		

Note. *f* = Frequency; *M* = Mean value; *SD* = Standard Deviation.

In the second step, correlation was used in order to examine the relationship between the categorized variable of karst terrain and categorized variable of population density. Spearman's correlation between categorized karst terrain variable and population density is equal to –0.391 ($p < .01$). The results of the correlation between these variables indicate that there is negative medium correlation between the percentage of karst terrain and population density in the settlements of the City of East Sarajevo.

In the third step, the composite variable *Vk* was calculated. Variable *Vk* was calculated as an arithmetic mean of the value of karst terrain variable and the value of population density variable for each settlement in the City of East Sarajevo.

$$Vk_i = 1/2 \cdot (a_i + b_i)$$

$$i = 1 \text{ to } 193$$

Vk is a new composite variable (arithmetic mean), a_i represents the value of the karst terrain variable for certain settlement, assigned after categorization, b_i represents the value of the population density variable for certain settlement after categorization.

Composite variable *Vk* for 193 settlements has 7 classes, whose values are ranging from 1 to 4. A class whose values of the *Vk* equal 4 contains only one settlement, while the largest class contains 75 settlements and has the value of *Vk* variable equal to 3. The second largest class has the value of *Vk* 2.5 and there are 47 settlements within this class (Figure 3).

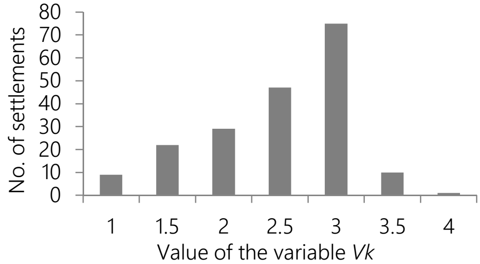

Figure 3. Number of settlements by value of the variable *Vk*

In the fourth step, we defined three classes of settlements: highly vulnerable, medium vulnerable and low vulnerable karst environment according to the value of variable *Vk*, using the model of cumulative frequency curve and the method of equal intervals. This method emphasizes the distribution of variable *Vk* on horizontal axis into approximately equal intervals (3 intervals). These intervals represent the range of value *Vk* within a class, while point projected from a cumulative curve to Y axis represents cumulative % of settlements for a specific class. The peculiarities of *Vk* variable distribution can be perceived from the shape of the curve. This classification was performed using V-Analytics software proposed by authors of the model (Andrienko & Andrienko, 2004, 2009). In order to perform the final settlements classification, it was necessary to reduce the number of classes of variable *Vk* from 7 classes to previously defined 3 classes. The results of the classification can be perceived from Figure 6.

Results and Discussion

The karst terrain in the City of East Sarajevo

The analysis of the karst distribution (Table 2) shows that these terrains occupy 835.3 km², or 57.7% of the territory of East Sarajevo. The largest percentage of karst areas is in Sokolac municipality (78.7%), and the smallest percentage of karst is in the municipality of Pale (29.5%).

Table 2
Karst areas (in km² and %) by municipalities of the City of East Sarajevo

Area	Karst km²	Karst %
Sokolac	544.8	78.7
Istočni Stari Grad	58.1	66
Trnovo	57.3	52.2
Istočno Novo Sarajevo	17.5	46.2
Istočna Ilidža	12.7	43.4
Pale	144.8	29.5
City East Sarajevo	*835.3*	*57.7*

Table 3 shows many more settlements are located in predominantly limestone area, but there are fewer inhabitants. Further, 10.6% of the settlements have no karst terrain on their territory, and in 2013, 22.6% of the population lived in this area.

Table 3
Settlements and population living on the karst terrains of the City of East Sarajevo (censuses 1991 and 2013)

Karst %	No. of settlements		Population 1991		Population 2013	
	absol.	%	absol.	%	absol.	%
0	23	10.6	5,202	10.9	13,566	22.6
1-20	25	11.6	13,542	28.5	18,335	30.6
21-40	23	10.6	8,386	17.6	12,437	20.8
41-60	37	17.1	10,624	22.3	9,482	15.8
61-80	43	19.9	4,847	10.2	3,782	6.3
81-100	66	30.1	4,939	10.4	2,314	3.9

Note. Adapted from *Census of population, households, dwellings and agricultural holdings 1991*, by Institute for statistics Federation of Bosnia and Herzegovina, 1998, Sarajevo; *Census of population, households and dwellings in Republic of Srpska 2013*, by Republika Srpska Institute of Statistics, 2017, Banja Luka.

Compared to the previous census of 1991, the number of inhabitants in this area doubled. The reason for this is the increase in the number of inhabitants in the intercensus period, and the positive intercensus dynamics is a result of the war migration and the positive migration balance of internal migrations.

The majority of settlements (30.1% of settlements or 65 settlements) are located on terrains with karst ranging 81 to 100%. More than half of the settlements in the City area or 50.5% of them are located on terrain with over 60% of karst, but these are mostly less populated rural settlements, with lower population density, limited economic activity and low impact on the karst environment.

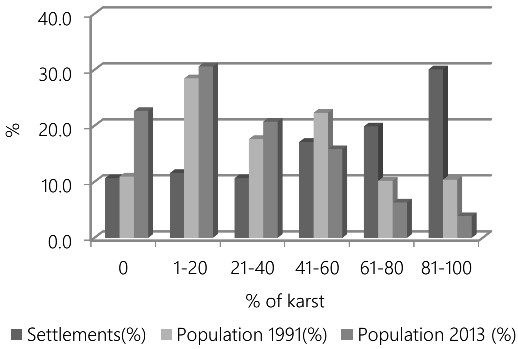

Figure 4. Share of population and settlements located on the karst terrains of the City of East Sarajevo

Specific settling processes occur in the City of East Sarajevo, mainly due to population decrease in the area with greater karst covering. In 1991, there was 42.9% of population living on 40% of the territory, while in 2013, 26% of the City population lived in this area.

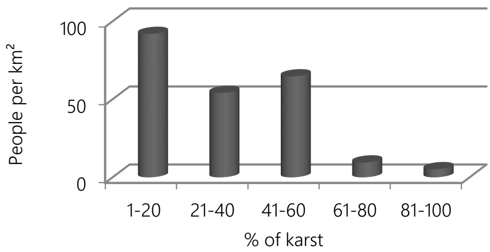

Figure 5. Population density on karst terrain of the City of East Sarajevo

There are 29 settlements with limestone covering 100% of the territory, with 753 inhabitants, or 1.3% of population. The average population density in these settlements is 5.68 people per km², which confirms the hypothesis that karst terrains are not suitable for settling due to poor living conditions. The highest percentage of the population (30.6%) lives on karst terrain, up to 20% (in 1991 there was 28.5% of population).

The vulnerability of the karst environment in the City of East Sarajevo

The karst vulnerability analysis in the settlements of the City of East Sarajevo is based on the following criteria: percentage of karst areas and population density. According to these criteria, settlements were categorized in three categories: highly vulnerable, medium vulnerable, and low vulnerable karst. High population density increases potentially negative impact on the karst environment. Also, high percentage of karst terrain in settlements increases vulnerability of karst due to higher probability for possible contamination. Settlements with low population density and small percentage of karst terrain are the least vulnerable due to low population impact on the karst and smaller probability for karst terrain contamination. The results of the settlements classification by method of equal intervals on the cumulative frequency curve can be perceived from Figure 6.

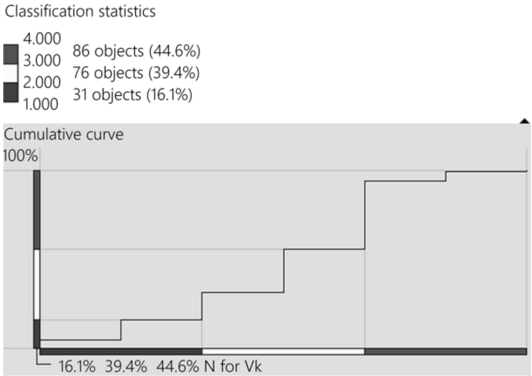

Figure 6. Cumulative frequency curve and settlement classification by method of equal intervals (V-Analytics, 2018)

Table 4
Settlements in the City of East Sarajevo by karst terrain vulnerability

Group	Range of *Vk*	No. of settlements	Settlements in %
Low vulnerable	1–1.5	31	16.0
Medium vulnerable	2–2.5	76	39.4
Highly vulnerable	3–4	86	44.6

The results of the settlement classification (Figure 6) by the method of equal intervals indicate there are three classes of settlements. From cumulative curve we can perceive two class breaks, representing the beginning of a new class of settlements. The first class break is at value 2 and the second at value 3 of variable *Vk* (Classification statistics). The final results of the classification are shown in Table 4.

There are 31 settlements or 16.0% in a group of low vulnerable karst settlements. These settlements are defined by low vulnerability due to its low value of variable *Vk*, ranging 1–1.5. These results show that karst terrain occupy less than 20% of the territory, with the lowest population density ranging from minimum 1 to maximum 50 people per km². Low percentage of the karst terrain and small, sparsely dispersed population decreases a potentially harmful anthropogenic impact in these settlements (Figure 7).

In the group of settlements with medium vulnerable karst terrain there are two types of settlements where variable *Vk* ranges 2–2.5. The first type are the settlements that mostly have medium to high percentage of karst terrain, ranging from 20% to 80% of the territory. These settlements are not considered highly vulnerable due to their sparsely populated territories. Although it is small population density, the karst in this area may become vulnerable due to very low awareness of the population on the preservation of the environment. The second type within the same group of medium vulnerable karst are the settlements with small % of karst terrain but considerably high population density. This type of settlement is Miljevići with 1,265 people and population density of 414 people per km² and 14% of the area under the karst. High concentration of people increases a potentially harmful effect on the karst terrain.

The third group of settlements are highly vulnerable settlements, within variable *Vk* ranging 3–4. There are 44.6% or 86 settlements in a group of highly vulnerable karst settlements. The percentage of karst terrain in these settlements has a range from 41% to 100% and 67 settlements have the highest percent of karst terrain (81–100%). The population density in these settlements has a range from the lowest to the highest value, while there are 3 settlements: Sokolac, Sarajevo Dio-Ilidža, and settlement Pale, where the population density is higher than 500 people per km². The settlements which are classified within the class of highly vulnerable mostly have the highest percent of karst terrain with medium to high population density.

The results of the analysis show that the most vulnerable karst environment is in municipality Sokolac, where 58 settlements with highly vulnerable karst are located, representing 67.4% of all the highly vulnerable karst settlements of the City of East Sarajevo. The most vulnerable karst environment is in settlement Sokolac. This settlement is the only urban settlement located on mainly karst terrain where limestone covers 57.5% of the area, with 5,562 people and the population density of 1,733.5 per km² (also the most densely populated area of East Sarajevo). The settlement Istočna Ilidža is only partially located in karst terrain but it is in a group of highly vulnerable karst settlements due to high population density. There are 10,243 people living on a limestone terrain, covering 28% of the area with the population density of 833 people per km².

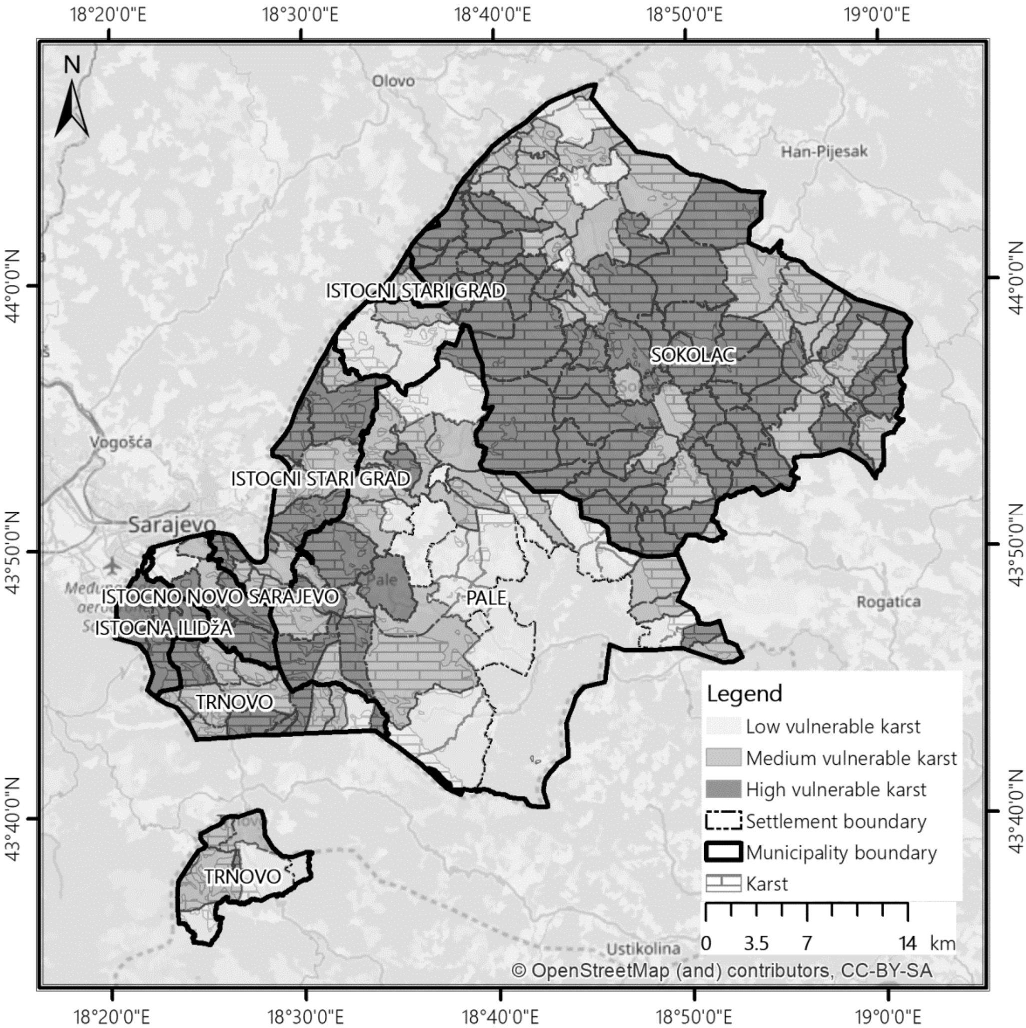

Figure 7. Settlement categorisation by the vulnerability of the karst environment

Even though less populated, some settlements are categorized as highly vulnerable (Brejakovići, Čavrine, Kaljina, Kusače) because the karst terrain covers 100% of the territory. Village of Brejakovići has 218 inhabitants and population density of 41.5 people per km². Settlements Nehorići, Sarajevo dio Stari Grad, Gornje Biosko and Vidrići are placed in the category with highly vulnerable karst environment due to high percentage of karst terrain (over 80%) although population density is lower than 30 people per km². This category also includes two settlements vulnerable by City dumps located in settlement Krupac (65.5% of the area under the karst and the population density of 31.2 people per km²) and Donja Ljubogošta (42.3% of the map with the population density of 49.1 people per km²).

The influence of population and settlements on the karst environment in East Sarajevo becomes obvious through their impact on water pollution and problems with waste disposal sites. Local ecological action plans for the individual municipalities of the City were used in the analysis of the karst environment.

Water is a very important resource on the karst terrains due to its insufficiency. Any deterioration of water quality highly affects principal life functions of the population on karst terrain (Lješević, 2005). Water management in the area of East Sarajevo is inefficient. Main causes for this are: uncontrolled discharge of wastewater from industrial facilities and households, lacking the purification processes. In Sokolac municipality is the largest karst area (over 78%) so authors are focusing the attention on the situation in this municipality. The limestone terrain and underground karst forms make the highest impact on a water regime of Sokolac municipality causing loss of atmospheric water below the karst surface. That is why this area is poor with watercourses and springs (except in northwest part of the municipality) (Municipality of Sokolac, 2011). In the urban part of the municipality there are sewage and rainwater drainage systems. However, there is no wastewater treatment plant in this municipality so the wastewaters are discharged directly into watercourses. The wider suburban and rural areas are not connected to the sewage system, so there are more septic tanks in this area that are not impermeable and which are endangering the karst underground with potential contamination. The situation with wastewaters is the same in all the municipalities of the City differing only by number of pollutants. High water pollutants are metal industry plants, slaughterhouses and meat processing plants, auto-repairing stations, car washes etc. Water quality is also affected by forest cuttings within sanitary protection of spring area, which is the case in the municipality of Pale (Municipality of Pale, 2011). Low ecological awareness of the population about the importance of water protection deteriorates the situation due to various types of waste being disposed in watercourses and karst springs. The karst underground area is highly sensitive to wastewaters from households and industrial plants. These wastewaters contain different forms of pathogenic microorganisms, viruses, parasites, chemical substances, organic matter, fats, oils, acids, salts, metals while on the other hand, karst terrains are characterized by low capability of self-treatment of polluted water (Lješević, 2005).

Karst relief forms are often endangered by waste disposal, especially in rural areas, as it is in East Sarajevo, where there is very low ecological awareness about the protection of the environment. Waste is deposited in ponors and caves, so that various types of infection spreading endanger the karst underground. Waste collecting and removing is organized only in the urban parts of the City. There are no proper systems for waste collecting in rural areas, what causes improper waste disposal and vulnerable of the karst environment. There are two solid waste disposal sites in the City and a large number of wild waste disposal sites in East Sarajevo. There are no municipal waste disposal sites in Sokolac municipality and waste is classified and disposed into a waste disposal site in the municipality of Rogatica. Problems with waste disposal are huge such as the problem of transportation financing, inadequate and unsafe transport, etc. Large part of the area of the municipality of Sokolac lacks the waste collection system. Waste is often disposed in watercourses, along roads, on agricultural and forest land. The municipalities of Trnovo, Istočna Ilidža and Istočno Novo Sarajevo use the city's waste disposal site Krupačka stijena. The waste disposal site is located in the territory of the municipality of Istočna Ilidža, in a settlement where the karst environment is highly vulnerable. There is no waste sorting and the waste disposal sites should be repaired and closed (Municipality of Istočno Novo Sarajevo, 2011). Rural places from these municipalities are not included in the waste collection system. Among these are the settlements with the vulnerable karst environment. The second waste disposal site Stanišić Dolovi is located in the rural area of the municipality of Pale where significant area is covered with limestone terrain. Underground waters are highly vulnerable since the waste disposal site is unprotected from atmospheric impacts and without systems for isolating water percolating in karst underground (Municipality of Pale, 2012).

Conclusion

The results of the analysis of the vulnerability of karst environment confirm the hypothesis that karst occupies a significant part of the studied area, or precisely 57.7% of the studied territory (835.3 km^2). The largest percentage of karst is in the municipality of Sokolac (78.7%), while the least percentage is in Pale municipality (29.5%). Settlements density is higher on the terrain with a greater presence of limestone while the reverse situation is with the number of inhabitants. Around 50% of settlements in the City are located on terrains with more than 60% of karst. However, these are mostly rural settlements with small population, low population density and limited economic activity and impact on the environment of the karst. The highest percentage of the population (30.6%) is placed in the area covered with karst up to 20% of the territory.

Three classes of settlements were identified, according to the karst environment vulnerability: settlements with the highly vulnerable environment of karst, representing 45% of settlements; settlements with medium vulnerable karst, taking up 39%; settlements where the karst vulnerability is low take up 16%.

The analysis of environmental conditions in the area of the City of East Sarajevo concerning air and water threats as well as waste disposal systems, shows that the environment of the karst is vulnerable. Municipal authorities do not pay enough attention to the problems of environmental protection. There are many examples for this conclusion as inadequate urban waste disposal sites and illegal waste disposal sites, as well as the discharge of wastewater into watercourses. Low awareness of people about the environmental protection enhances these negative effects not only on the karst terrain but also on the environment as a whole.

Ecological problems associated with the karst have a negative impact in many parts of the world. Carbonate and evaporite rocks cover more than 20% of the continental ice-free Earth area, and around a quarter of the world's population depends on water supply from the karst zones. The real significance of these problems is usually greater than those perceived, mainly due to the hidden and sometimes dispersive character of the negative effects. Future activities need to be focusing on the processes of modernization and alignment with standards in environmental protection systems as well as on education about the importance of environmental protection.

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