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GIS BASED VULNERABILITY ASSESSMENT OF ILLEGAL WASTE DISPOSAL – CASE STUDY EAST SARAJEVO

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ABSTRACT

This research represents the results of field work conducted in the period from March 29 to May 29. 2020, to determine and record the location of illegal waste disposal sites in the municipalities of Istočno Novo Sarajevo and Istočna Ilidža. The location of illegal waste disposal sites was analyzed based on two groups of factors: space exposure and space sensitivity. The analysis included following exposure factors: distance from urban settlements, distance from roads and population density and sensitivity factors: land cover, hydrogeological characteristics of the substrate, distance from springs and watercourses and land slope. In addition to the location of illegal waste disposal sites, it was analyzed the potential vulnerability of space based on both groups of factors. Final map of spatial vulnerability was created using multi-factor analysis.

This work emphasizes the possibility of using easily accessible devices for recording the locations of illegal waste disposal sites, as well as the importance of geographic information systems in the analysis and monitoring of the state of the environment. Based on the example presented in the work, the possibility of applying a similar model on the territory of other municipalities is given, with the aim of preventing the negative consequences of pollution on human health and the environment.

Key words: *illegal waste disposal sites, spatial vulnerability, multi-factor analysis, GIS, B&H*

INTRODUCTION

Solid waste management in Bosnia and Herzegovina is characterized by numerous difficulties: inadequacy of waste disposal sites, inefficiency of waste collection systems, poor coverage of organized waste collection systems (especially in rural areas), low percentage of recycled waste, small number of recycling centers, uncontrolled waste disposal, low awareness of the population about proper waste disposal, etc.

According to the report on solid waste management in the countries of South-east Europe [1], approximately one quarter of the generated waste in Bosnia and Herzegovina is disposed at illegal waste disposal sites, i.e. illegal waste dumps. Some of the consequences are: direct pollution of land and surface water, potential vulnerability of public health due to possible groundwater contamination, impairment of flora and fauna due to habitat disturbance, pollution (air) due to waste incineration, vulnerability of water and soil by microorganisms and bacteria as a consequence decay, appearance of unpleasant odors, disturbance of landscape characteristics of the area [2]. In 2012, there were 590 illegal waste disposal sites on the territory of B&H, although it is assumed that this number is twice as larger [3]. The problem of dumping waste in illegal waste disposal sites (illegal waste dumps) is especially evident in rural areas where there is no system of organized waste collection. Thus, in 2012, the service of waste collection and disposal covered 68% of the territory of B&H. A particularly big problem is the disposal of waste of animal origin, the disposal of construction waste, electronic and electrical devices [4].

According to the data presented in the Waste Management Strategy in RS until 2026, there are 51 registered municipal waste disposal sites for the waste in the Republic of Srpska and approximately 216 illegal waste disposal sites. The RS Waste Management Strategy envisages action plans that define activities, goals and waste management measures in the period from 2017 to 2026. As one of the goals, rehabilitation and closure of municipal and illegal waste disposal sites is envisaged, while as a measure of realization of this goal it is stated: „Periodically update the existing database of municipal and illegal waste disposal sites in the Republic using modern methods for their identification, mobile applications" [4].

According to the United Nations Strategy for Reducing Local Disaster Risks and Strengthening Resilience [5], disaster risk refers to potential injuries or loss of life as well as damage or destruction of goods occurring in a system, society or community over a period of time. Disaster risk depends on 4 factors: probability of occurrence of harmful activities, factors of exposure of nature, people, infrastructure, housing and human property to disaster-prone areas, disaster susceptibility factor and capacity to act adequately in case of negative circumstances and catastrophic events.

Many authors investigated this issue, especially the health impact of landfills and uncontrol dumping sites on the human health [6,7]. Authors Triassi et al. (2015) [8], investigated scientific papers dealing with the effects of illegal landfills in the region of Campania in Southern Italy in relation to human diseases. At the conclusion, authors pointed out a possible long-term role of waste, according to positive correlation results, with outcomes as liver and lung cancer mortality, in addition to a short-term effect waste-related, confirmed by association with congenital malformation, which is compatible with the lack of remediation of the polluted sites and persistence of waste mismanagement (pp.1232). Musmeci at al. investigated the impact of solid waste management on human health [9]. Many researchers studied the impact of illegal landfills on environmental components such as land degradation [10,11], water contamination [12,13], degradation of soil and vegetation [14].

Considerable number of studies were based on the appliance of geographic information systems such as research of the Seror and Portnov (2018) [15], which have investigated the area with potential risks of illegal construction and demolition waste dumping using GIS. Fazzo et al. (2020) [16], used GIS-based Indicator of Waste Risk to Investigate the Health Impact of Landfills and Uncontrolled Dumping Sites. Authors Critto, Carlon & Marcomini (2003) [17], applied GIS and kriging method with principal component analysis for characterization of contaminated soil and groundwater surrounding an illegal landfill. Many studies applied combined methods of mapping and spatial analytical tools of GIS with other investigation methods such as remote sensing, statistical methods and multicriteria assessment for investigation of the risk of illegal landfilling on people's health and the environment [18,19,20].

This work presents an inventory of illegal waste disposal sites and an analysis of the location of illegal waste disposal sites in relation to exposure and sensitivity factors. The aim of this work is to point out the possibility of applying simple GPS technologies and geographic information systems for the purposes of collecting information and monitoring the state of the environment. In this work, an illegal waste disposal site (illegal landfill) is considered to be an unregistered area where waste is disposed and whose area is larger than $1m^2$. Based on these criteria, an assessment of the most vulnerable areas in the municipalities of Istočno Novo Sarajevo and Istočna Ilidža (extended to the territory of the settlement of Kijevo in the municipality of Trnovo RS) is given.

WASTE DISPOSAL IN MUNICIPALITIES

Organized collection and disposal of waste on the territory of the municipalities of Istočno Novo Sarajevo and Istočna Ilidža is performed by the utility companies „Rad” a.d. Istočno Novo Sarajevo and Public Utility Company „Komil” a.d. Istočna Ilidža. The percentage of coverage by the organized waste disposal system in both municipalities is about 80%. The lowest coverage is in rural settlements, due to poor accessibility and smaller number of users [21,22]. There is not a single regulated waste disposal sites on the territory of the municipalities of Istočno Novo Sarajevo and Istočna Ilidža, and all waste is deposited in a joint, unregulated waste disposal site „Krupacke stijene” on the territory of Kijevo, in the neighboring municipality of Trnovo RS. Given the population density, which is many times higher than the average in the Republic of Srpska (in the municipality of Istočna Ilidža the population density is almost 10 times higher than the average in the Republic of Srpska), this area is particularly exposed to potential threats to public health and environmental pollution due to improper disposal and treatment of waste. There are numerous problems of waste management in these two municipalities, and some of them are: lack of adequate waste disposal sites for waste disposal, insufficient coverage of municipalities with organized waste collection system, non-implementation of waste separation and selection, lack of recycling centers, lack of animal waste collection operators, non-existence of operators for collecting medical waste (on the territory of the municipality of Istočna Ilidža), there is the Public Health Institute „Srbija“ [21].

According to the Republic Waste Management Plan [23], the construction of a regional waste disposal sites for municipal waste in the Republic of Srpska is planned on the territory of the municipality of Foča, which would cover 13 municipalities of the Republic of Srpska, including the municipalities of Istočna Ilidža, Istočno Novo Sarajevo and Trnovo RS. Due to the lack of regulated waste disposal sites and low awareness of the population about the potential pollution and harmful consequences for the environment and health of the population, waste is often disposed improperly in illegal waste disposal sites or „illegal waste dumps”. This work presents an analysis of the location of illegal waste disposal sites in relation to exposure factors and sensitivity factors as well as a GIS analysis of the potential threat to the environment due to improper waste disposal. The analysis covers the territories of the municipalities of Istočna Ilidža and Istočno Novo Sarajevo. The territory of the settlement of Kijevo in the municipality of Trnovo RS was added to this area, since there is a common unregulated waste disposal sites „Krupačke Stijene” (Figure 1). The municipalities are in the central part of the Republic of Srpska and Bosnia and Herzegovina and occupy the southern and southeastern parts of the Sarajevo valley with the territory at the mountains Trebević, Igman and Bjelašnica.

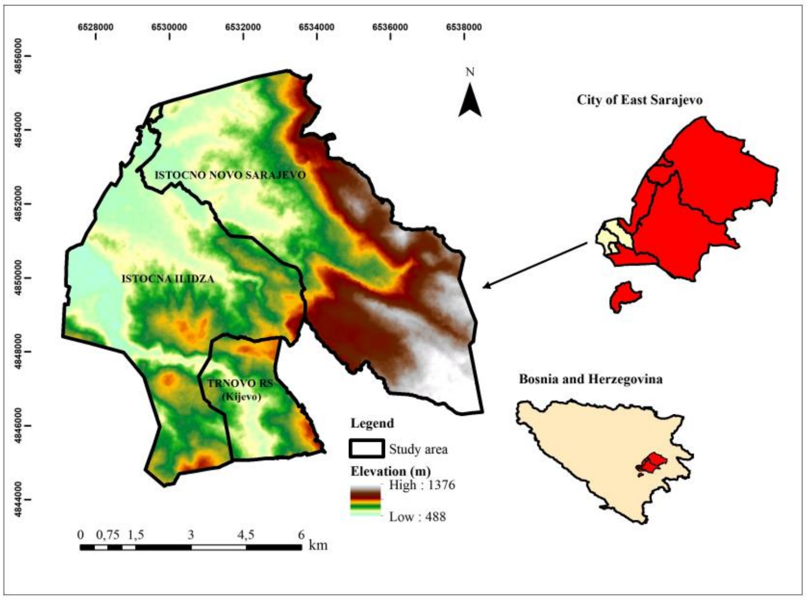

Figure 1. Location of study area

The municipality of Istočna Ilidža is located at an average altitude of 500 m, while most of the territory of Istočno Novo Sarajevo is above 600 m above sea level. Administratively, these municipalities belong to the territory of the City of Istočno Sarajevo and together with the settlement of Kijevo (Trnovo RS) they cover an area of 74.1 km^2 or 5.1% of the territory of the city. There are 25107 inhabitants in the analyzed territory. The average population density in the municipality of Istočna Ilidža is 493 inhabitants per km^2, while in the municipality of Istočno Novo Sarajevo the average population density is 274 inhabitants per km^2. In this work the territories of these municipalities are considered as a single spatial unit, given the relatively small spatial coverage and administrative boundary that intersects the spatially compact urban unit.

MATERIALS AND METHODS

To analyzing the locations of illegal waste disposal sites („illegal waste dumps"), field research was conducted in the period from March 29 to May 29.2020. Field research included identification of illegal waste disposal sites, determination of the exact location by GPS measurements and photography, to determine the structure of the waste at illegal waste disposal sites. The devices used for positioning are the GPS Garmin eTrex 30. Location mapping and analysis of potential spatial vulnerability due to the location of illegal waste disposal sites was performed using geographic information system, the QGIS [24]. For the analysis of locations in relation to the slope was used DEM model [25], and for needs of the analysis of locations in relation to watercourses was used a topographic maps 1:25 000 [26], with corrections according to the Open Street Map [27]. Data on the water permeability of the substrate were obtained by vectorization of the Hydrogeological Map of B&H 1:500 000 [28], and data on land usage were obtained from data in CORINE Land Cover 2018 [29]. Data on population density were obtained based on the 2013 Census of Population, Households and Dwellings in the Republic of Srpska [30]. The administrative boundaries of the settlement were obtained by vectorization of maps.

The analysis was performed using GIS spatial tools. GIS and data modelling are powerful tools for calculating and describing some data of hazard effects. There are many methods which can be used for the purpose of risk or vulnerability assessment as semi-kriging [31,32], multicriteria decision making [33,34,35,36], aggregation methods such as weighted linear combination [37,38,39], using geostatistics and GIS [15], multi-factor analysis [18,40] and other. For this research multi-factor analysis is applied, considering two groups of factors: environmental exposure and environmental sensitivity factors. The term exposure refers to an inventory of potential factors that may influence the probability of occurrence of negative consequences in a given area [40]. The exposure of the space is the probability that the space will be exposed to the illegal landfill siting.

For the spatial exposure assessment three factors were analyzed: distance from road infrastructure, distance from urban settlements and population density. Raster of distance buffer zones were obtained using Euclidean distance buffering [41]. According to research on the influence of social factors on the location of waste disposal sites [42,43], waste disposal sites should not be in populated areas or in immediate vicinity of them. A higher concentration of the population per area unit indicates a higher probability that the environment and the health of the population will be endangered. In this work, the most endangered areas are considered to be settlements whose population density is higher than the average in the Republic of Srpska (47 inhabitants/km^2).

Based on the factor of distance from urban settlements, the most endangered areas are located next to the most urban parts of the analyzed area. As moving away from urban settlements, the likelihood of waste being dumped in a given area decreases due to rising transportation costs. In relation to the factor of distance from the road infrastructure, the most exposed areas are in the immediate vicinity of the road routes. The accessibility of the space contributes to the greater likelihood that it will be exposed to illegal waste disposal.

The second group of analyzed factors in the work are sensitivity factors. Sensitivity refers to the physical properties of the space that determine the predisposition that in the case of exposure to negative influences, pollution and environmental hazards will occur in the area [44,40]. The vulnerability of groundwater and surface water is especially emphasized, since this area is rich in watercourses that are used both for economic purposes and for water supply of households [45,13]. Sensitivity factors analyzed are soil cover, hydrogeological properties of the substrate, land slope and distance from watercourses.

In the second part of the work, the potential vulnerability of space is analyzed based on exposure and sensitivity factors. The first step was to create raster maps for all factors (criterion layers) with sub-criteria. Based on a review of the literature [46,47,48], all criterion layers with sub-criteria are standardized on a scale from 1 to 5, with a higher value indicating higher exposure / sensitivity. Sub-criteria with their assigned values are presented in Table 1. Creation of raster of exposure and raster of sensitivity is based on aggregation method according to formulas below (1 – 3), using raster calculator. All criteria for the assessment of exposure and sensitivity had an equal impact on the final score obtained in the spatial vulnerability raster.

Based on the values shown in Table 1, the reclassification of the criterion layers was performed. The spatial exposure raster E_i is obtained by summing the assigned values of all three criterion layers (maps) using a raster calculator and according to the formula:

$$1)\quad E_i = D_u + G_n + D_P$$

D_u - distance from urban settlements, G_n - population density category, D_p - distance from road infrastructure

The spatial sensitivity (Si) raster is obtained based on:

$$2)\quad S_i = F_{lc} + H_g + S_p + D_w$$

F_{lc} - land cover, H_g - hydrogeological properties of the terrain, S_p - land slope, D_w - distance from watercourses.

In the final part of the analysis, a raster of potential vulnerability of space was created, V_s. The raster of spatial vulnerability represents the final assessment of vulnerability of space based on the factors of spatial exposure and spatial sensitivity. It contains a score of numerical values, obtained by dividing the sum of the values of all factors of group E_i and all factors of group S_i, for each raster cell, with the total number of analyzed factors (7 in total). The raster of spatial vulnerability was obtained by using a raster calculator according to the formula:

$$1)\quad V_s = (E_i + S_i)/n; \;\; n = 1\ldots 7$$

V_s – Spatial vulnerability, n – total number of analyzed factors

All the factors (criteria) applied in this analysis were of equal importance in assessing the vulnerability of the area to potential location and pollution caused by illegal waste disposal. In the final phase, the classification of potential vulnerability of space was performed in three levels of spatial vulnerability: slightly vulnerable, vulnerable and highly vulnerable. The classification was performed using the „Jenks natural breaks classification method".

Jenks natural breaks classification method is used to group data sets into a number of homogeneous groups. The method was specially developed for the needs of geographic data analysis and represents a standard geographic classification algorithm in GIS software [49,50].

The grouping is based on reducing the square deviation from the mean value within the group. Breakpoints are determined by selecting the limit values (ranges) of the group so that differences in values within one group are minimal, while the difference to other groups is being maximized [51]. Finally, by reclassifying the spatial vulnerability raster, three categories of spatial vulnerability were obtained.

Table 1. Standardized criteria values with sub-criteria and frequency of illegal disposal sites exposure

Exposure			
Factor (Criterion layer)	Sub-criteria	Weight value of sub-criterion	Illegal waste disposal cites
Distance from road	d < 50 m	5	12
	50,1 < d < 100	4	7
	100,1< d <150	3	2
	d > 150	2	8
Distance from urban settlements	Within urban area	5	9
	d≤1 km from urban area	5	8
	1 km < d < 2 km	4	11
	d ≥ 2 km	3	1
Population density of the settlement (Population per km^2)	1-50	2	5
	50,1-150	3	6
	150,1-500	4	9
	500,1-1500	5	7
	G >1500	5	2
Land cover	discontinuous urban fabric	5	2
	Deciduous forests/coniferous forests/ mixed forests	4	18
	complex cultivation patterns	5	8
	land principally occupied by agriculture, with significant areas of natural vegetation	5	1
	Barren land/sparse vegetation	1	0
Hydrogeological characteristics	Low permeability rocks without aquifers	1	0
	Low permeability rocks with possible local aquifers	2	0
	Semi - permeable rocks	3	21
	Permeable rocks	5	8
Distance from watercourse	d <50	5	15
	50,1 - 100	5	3
	100,1 - 150	4	1
	d> 150	3	10
Slope (º)	0-3	1	2
	3,1-5	2	3
	5,1 – 7	3	3
	7,1-10	4	6
	n >10	5	15

RESULTS AND DISCUSSION

During field research 29 locations of illegal waste disposal sites were mapped. On the territory of the municipality of Istočno Novo Sarajevo there are 16 waste disposal sites, while 11 illegal waste disposal sites were mapped on the territory of the municipality of Istočna Ilidža. This group is joined by two waste disposal sites located on the territory of the municipality of Trnovo, in the settlement of Kijevo, in the immediate vicinity of the administrative border with the municipality of Istočna Ilidža. These are illegal waste disposal sites in the valley of the river Željeznica, whose coordinates are y = 43.774380, x = 18.39160, at an altitude of 583 m and the waste disposal sites for municipal waste „Krupacke stijene", with coordinates y = 43.7736799, x = 18.3910699, at an altitude of 635. Waste disposal sites „Krupacke stijene" is a mutual waste disposal site of waste collected in municipalities: Istočno Novo Sarajevo, Istočna Ilidža and Trnovo (RS). According to the spatial distribution in relation to the altitude, illegal waste disposal sites are most present in the lowest part of the analyzed area, in valleys and river valleys with an elevation below 800 m. Only two illegal waste disposal sites were found in the altitude above 800 m (Figure 2).

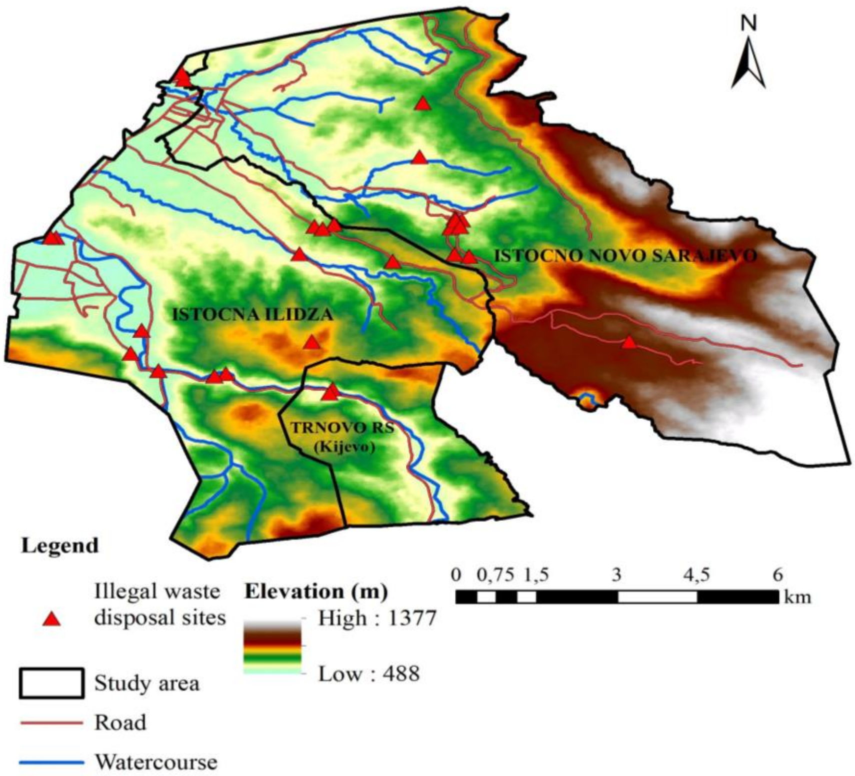

Figure 2. Locations of illegal waste disposal sites in the municipalities of Istočno Novo Sarajevo and municipality of Istočna Ilidža

Waste structure

Construction materials, furniture, electrical waste, plastic packaging, car tires and glass are most often disposed items at illegal waste disposal sites. The structure of waste is dominated by recyclable waste such as glass and plastic. Waste management on the territory of the municipalities of Istočna Ilidža and Istočno Novo Sarajevo is further complicated by the lack of waste separation at the source, the lack of vehicles for waste collection, the lack of transfer stations and recycling centers.

Illegal waste disposal sites in relation to exposure and spatial sensitivity factors

The emergence of illegal waste disposal sites is favorably influenced by factors such as quality access roads and proximity to urbanized space. These factors affect the likelihood that a site will be selected for illegal waste disposal. In the Table 1 is presented the distribution of illegal waste disposal sites in relation to the distance from the road infrastructure (in meters), in relation to the distance from urban settlements and in relation to the population density.

Approximately 60% of illegal waste disposal sites are located at the maximum distance up to 100 m from the road, while the largest number is located directly in the zone up to 50 m distance. This shows that illegal waste disposal is most prevalent in accessible areas, right next to roads. Analyzing the distribution of illegal waste disposal sites in relation to urban settlements, almost 1/3 of illegal waste disposal sites are located directly on the territory of urban settlements, while at a distance of 1 km from urban settlements there are 8 more illegal waste disposal sites located.

Therefore, more than 50% of illegal waste disposal sites are in the urbanized parts of the municipalities of Istočno Novo Sarajevo and Istočna Ilidža. Analyzing the distance categories individually, the largest number of waste disposal sites is located at distance 1 to 2 km in relation to the urban settlement (Figure 3). This indicator is further supported by the analysis of waste disposal site's locations in relation to population density. Almost 60% of illegal waste disposal sites are in settlements with a population density between 150,1 and 500 inhabitants per km^2 and 500,1 and 1500 inhabitants per km^2.


Figure 3. The waste disposal sites next to the road R-446 (Lukavica-Jasik-Pale)

These are settlements of the suburban type, at a short distance from the most densely populated, urban settlements: Lukavica (municipality of Istočno Novo Sarajevo) and settlements Sarajevo part - Ilidža and Sarajevo part - Sarajevo Novi Grad (municipality of Istočna Ilidža). The most of illegal waste disposal sites are located on the territory of the settlement of Toplik, where 9 illegal waste disposal sites are located, while in the settlement of Sarajevo - Ilidža and settlement Kasindo, there are 6 illegal waste disposal sites by each. Approximately 70% of illegal waste disposal sites are in three settlements that occupy 34% of the analyzed territory.

The environmental sensitivity is the likelihood that locating an illegal waste disposal site in a given space will cause harmful consequences for human health and the environment. The location of illegal waste disposal sites in relation to the type of land cover indicates that waste is illegally disposed mostly in the suburban zone, next to urban parts of municipalities. Land cover with combined systems of crops and plots and land with a larger share of natural vegetation are represented here. Almost 50% of the observed illegal waste disposal sites are located on this type of land cover. In the area of the Municipalities of Istočno Novo Sarajevo and Istočna Ilidža, illegal waste disposal sites are often located in the immediate vicinity of the residential zone. Of particular concern is the fact that other waste disposal sites are mostly located in the deciduous forest belt, which further degrades the rural area.

Particularly worrying situation is with the waste disposal sites located on a permeable rock and within the urban settlements of Lukavica, Sarajevo Part - Ilidža and in the suburban zone, the settlement of Toplik. There are 8 illegal waste disposal sites on the permeable rocks, at a distance of less than 50 m in relation to the watercourses. These waste disposal sites, with intense rainfall, threaten groundwater and surface flows by potential leachate. Approximately 70% of mapped illegal waste disposal sites are located on a semi-permeable geological substrate. The deployment of the illegal waste disposal sites in relation to the proximity of watercourses indicates regularity, given that most illegal waste disposal sites are in river valleys. More than 50% of the mapped locations are located at less than 50 m in relation to watercourses.

The location of illegal waste disposal sites in the immediate vicinity of the riverbed increases the potential threat to watercourses and the possibility of pollution by solid waste, which is transported over longer distances through watercourses. Around 30% of the analyzed illegal waste sites are located further from 200 m from the watercourse. Analyzing the slope criterion, larger slopes indicate a potential risk of pollution, since the slope surface has an impact on the atmospheric precipitation runoff coefficient, which, together with different leachate, reaches the substrate polluting the soil, groundwater and surface water.

Only two waste disposal sites are located on land with a slope of up to 3 degrees while approximately 70% of the mapped sites are located on land with a slope greater than 7 degrees. Observing the categories of land slope, the largest number of analyzed illegal waste disposal sites is in the category of land with a slope greater than 10 degrees.

In the first part of the analysis, individual raster of environmental exposure (Figure 4a) and environmental sensitivity (Figure 4b) were obtained. The spatial exposure raster contains a score of values for exposure factors obtained by simply summing the standardized values of the factors: distances from urban settlements, distances from road infrastructure and population density categories. The spatial sensitivity raster was obtained by summing the standardized values of all sensitivity factors: soil cover type, hydrogeological substrate, distance from watercourses and land slope (Table 2).

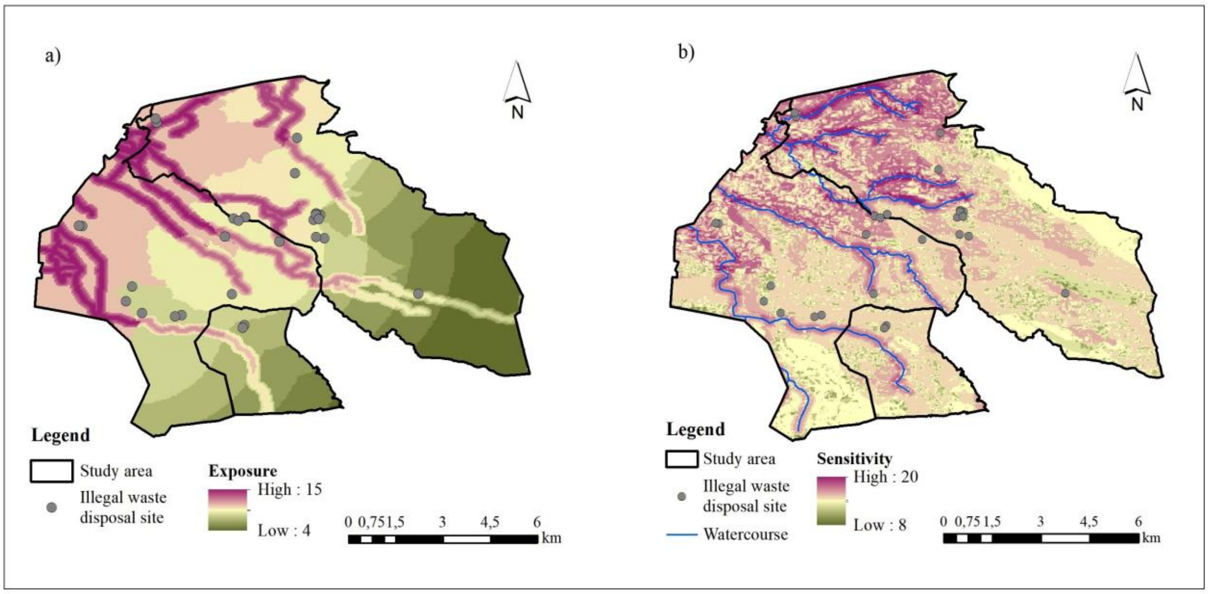

Figure 4. a) Environmental exposure and b) Environmental sensitivity

The highest score of values according to the factors of environmental exposure have urban areas, river valleys and areas next to the road infrastructure. The exposure is determined by the accessibility and close proximity to densely populated zones. The potential location of illegal waste disposal sites in this area can cause significant environmental degradation, primarily due to soil pollution, groundwater and surface flows pollution. These processes indirectly have a negative impact on the living world and can significantly endanger biological processes in this area.

Table 2. Categories of spatial vulnerability

Score	Category	Surface area (km^2)	Surface area %
1,86 – 3,00	Slightly vulnerable	19,30	27,34
3,10 – 3,70	Vulnerable	28,16	39,89
3,71 – 5,00	Highly vulnerable	23,13	32,77

The lowest exposure of the area for potential disposal of illegal waste disposal sites is in the peripheral, rural parts of the municipalities, which are characterized by a relatively large distance from urban centers as waste generation sites and poor infrastructural connectivity. Based on the considered factors of exposure and sensitivity, an analysis of the spatial vulnerability due to illegal waste disposal sites was performed.

The results of the analysis of the spatial vulnerability of the explored area indicate a high degree of vulnerability of the area due to high probability for illegal waste disposing and spatial sensitivity (Figure 5).

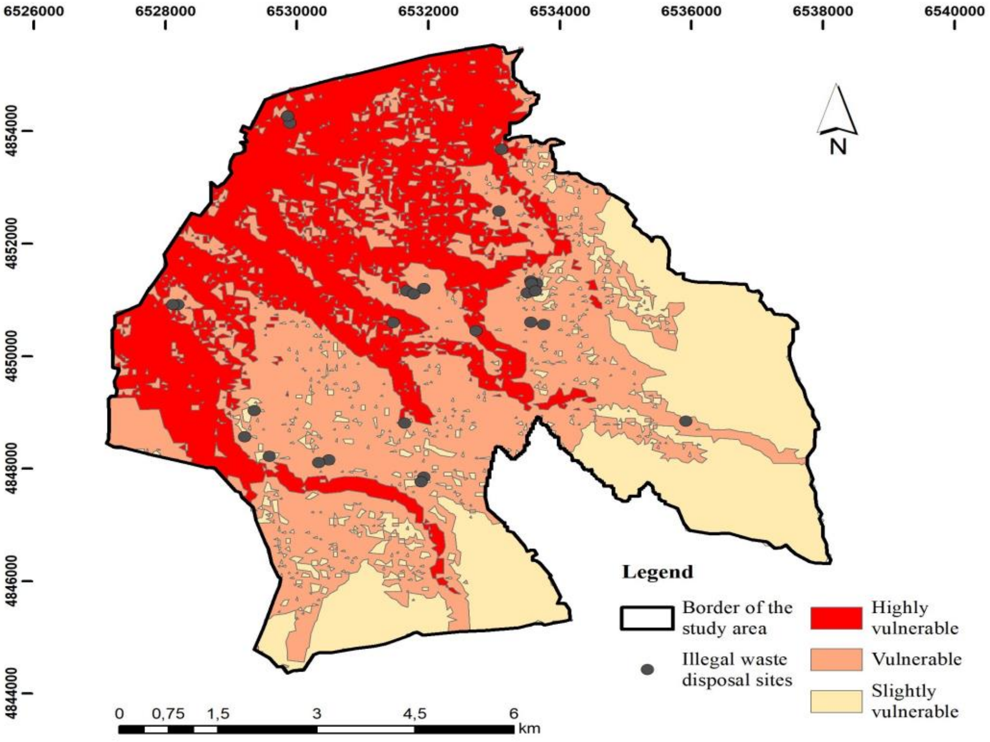

Figure 5. Spatial vulnerability of the area due to locations of illegal waste disposal sites

Approximately 33% of the territory of the explored area belongs to the category of highly endangered area. This area is potentially the most endangered category in both groups of analyzed factors and considering its predispositions (water permeability of the substrate, relative proximity of watercourses, slope of land higher than three degrees, high concentration of population) there is a high probability of pollution and endangerment of the environment.

There are six illegal waste disposal sites in the most endangered part of the explored area. These waste disposal sites pose a danger as they usurp and pollute the soil, affect potential groundwater contamination by the substrate seepage and potentially endanger the health of residents.

Almost 40% of the analyzed area belongs to the category of endangered area. This is predominantly a suburban type of area, where its proximity to urban zones affects its predisposition to become an illegal waste disposal site. In addition to location features that affect the choice of a given space for locating illegal waste disposal sites, this area is also characterized by a higher degree of spatial sensitivity, since these zones are relatively close to watercourses, with sporadic agricultural areas and a higher percentage of land with natural vegetation. These areas are characterized by permeable and semi-permeable geological base.

The observed location of the identified illegal waste disposal sites also testifies to the vulnerability of this area. There are 20 illegal waste disposal sites in the category of vulnerable area (70% of the total number of analyzed). In the third category, low-risk areas, there are areas that are characterized by a low score of vulnerability, both in terms of exposure factors and sensitivity factors. Peripheral, rural parts of the analyzed area belong to this area. 27.3% of the territory belongs to the category of low-risk area, and 3 illegal waste disposal sites are located in this area.

CONCLUSION

The waste management process in Bosnia and Herzegovina is characterized by numerous difficulties: imprecisely defined powers in the process of waste management and treatment, uneven system of financing the waste management process in different municipalities, lack of a single information system / database on the amount and type of waste disposal sites, lack of recycling centers and centers for the treatment of hazardous waste, a large number of unregulated waste disposal sites, frequent disposal of waste in illegal waste disposal sites, etc.

For efficient waste management, it is necessary to create a unique database on waste management. One of the steps is the introduction of simple technologies and systems such as smartphones and geographic information systems, which would enable the collection of information on waste disposal site's locations and regular monitoring of changes in the environment. Field work on the territory of the municipalities of Istočno Novo Sarajevo, Istočna Ilidža and the settlement of Kijevo (Trnovo RS) recorded the location and determined coordinate points for 29 illegal waste disposal sites.

The analysis of the locations of illegal waste disposal sites showed that the largest number is located at less than 2 km from urban settlements, while more than 60% is located at a distance of less than 100 m in relation to roads. According to the population density factor, the largest number of waste disposal sites is in densely populated areas, with an average population density of 150,1 to 500 and 500,1 to 1500 inhabitants per km^2. In relation to the type of land cover, 45% of illegal waste disposal sites are in the forest belt. All other illegal waste disposal sites are in the discontinuous urban area (scattered populated areas) and the area of agricultural production with a higher share of natural vegetation. Approximately 50% of recorded illegal waste disposal sites are located at less than 50 m from watercourses, while over 70% of illegal waste disposal sites are located on slopes greater than 3 degrees.

The analysis of the spatial vulnerability due to illegal waste disposal, showed that the urban zone in the area of the municipalities of Istočno Novo Sarajevo and Istočna Ilidža is highly vulnerable because six illegal waste disposal sites have been recorded there. Densely populated suburban areas are also in the category of vulnerable. These settlements are located near the area of the largest amount of waste generation and are well infrastructurally integrated with the urban zone. The location of registered illegal waste disposal sites shows that this zone is the target area for improper waste disposal, with 70% of illegal waste disposal sites.

The results of the analysis indicate the possibility of applying these methods for recording and creating a database on illegal waste disposal sites, which would enable simple and efficient monitoring of the situation on the field. The assessment of potentially vulnerable areas can be successfully used for the purposes of recording the most vulnerable categories of space, which creates the preconditions for preventive action and special supervision over the most endangered spatial categories. These methods can serve as a good basis for creating local waste management plans and with some corrections, they can be successfully applied to the territories of other municipalities in Bosnia and Herzegovina.

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REFERENCES

[1] DG Environment of the European Commission (2017). A comprehensive assessment of the current waste management situation in Southeast Europe and future perspectives for the sector including options for regional cooperation in recycling of electric and electronic waste. Bristol, United Kingdom: Eunomia Research & Consulting, Report for Maja Mikosinska DG Environment of the European Commission

[2] Nenković-Riznić, M., Pucar, M. & Simonović, S. (2009). Regional concept of environmental protection and waste management, with case studies of South Morava region. „Arhitektura i urbanizam" („Architecture and Urbanism"), (26), 77-87.

[3] Ministry of Foreign Trade and Economic Relations of Bosnia and Herzegovina (2012). Report on the State of the Environment in Bosnia and Herzegovina in 2012. Fund for Achieving the Millennium Development Goals and the United Nations Environment Program (UNEP).

[4] Government of Republic of Srpska (2017). Waste Management Strategy for the period 2017-2026, Banja Luka: Ministry of Spatial Planning, Construction and Ecology.

[5] United Nations office for Disaster Risk Reduction - UNDRR (2019). Words into Action guidelines: Implementation guide for local disaster risk reduction and resilience strategies, authors: Authors: Hardoy, Jorgelina; Filippi, María Evangelina; Gencer, Ebru; Morera, Braulio Eduardo; Satterthwaite, David.

[6] Kuehn, C. M., Mueller, B. A., Checkoway, H. & Williams, M. (2007). Risk of malformations associated with residential proximity to hazardous waste sites in Washington State. Environmental Research, 103(3), 405–412. doi:10.1016/j.envres.2006.08.008

[7] Grant K., Goldizen F.C., Sly P.D., Bruné M.N., Niera M., van den Berg M. & Norman R.E. (2013). Health consequences of exposure to e-waste: A systematic review. Lancet. doi: 10.1016/S2214-109X(13)70101-3.

[8] Triassi, M., Alfano, R., Illario, M., Nardone, A., Caporale, O. & Montuori, P. (2015). Environmental Pollution from Illegal Waste Disposal and Health Effects: A Review on the „Triangle of Death." International Journal of Environmental Research and Public Health, 12(2), 1216–1236. doi:10.3390/ijerph120201216

[9] Musmeci, L., Bellino, M., Cicero, M. R., Falleni, F., Piccardi, A. & Trinca, S. (2010). The impact measure of solid waste management on health: the hazard index. Annali dell'Istituto superiore di sanità, 46, 293-298.

[10] Vaverková, M. D., Maxianová, A., Winkler, J., Adamcová, D. & Podlasek, A. (2019). Environmental consequences and the role of illegal waste dumps and their impact on land degradation. Land Use Policy, 89, 104234. doi:10.1016/j.landusepol.2019.10

[11] Solomun, M.K., Barger, N., Cerda, A., Keesstra, S. & Marković, M. (2018). Assessing land condition as a first step to achieving land degradation neutrality: a case study of the Republic of Srpska. Environ. Sci. Policy 90, 19–27. https://doi.org/10.1016/j.envsci.2018.09.014

[12] Sotirov, A., Savova, S., Yordanov, S., Taseva, R., Kulkina, L., Yerusalimova, M. & Eftimova, M. (2015). Influence of river water contamination on distribution of fish species. СБОРНИК, 118.

[13] Golijanin, J., Ćulafić, G., Petronić, S. & Matović, O. (2017). Groundwater vulnerability in karst of Jahorina. Archives for Technical Sciences, No 16 (1), 9–17.

[14] Belabed, S., Lotmani, B. & Romane, A. (2014). Assessment of metal pollution in soil and in vegetation near the wild garbage dumps at Mostaganem region. J. Mater. Environ. Sci, 5(5), 1551-1556.

[15] Seror, N. & Portnov, B. A. (2018). Identifying areas under potential risk of illegal construction and demolition waste dumping using GIS tools. Waste Management, 75, 22–29. doi:10.1016/j.wasman.2018.01.027

[16] Fazzo, L., De Santis, M., Beccaloni, E., Scaini, F., Iavarone, I., Comba, P. & Airoma, D. (2020). A Geographic Information System-Based Indicator of Waste Risk to Investigate the Health Impact of Landfills and Uncontrolled Dumping Sites. International journal of environmental research and public health, 17(16), 5789. https://doi.org/10.3390/ijerph17165789

[17] Critto, A., Carlon, C. & Marcomini, A. (2003). Characterization of contaminated soil and groundwater surrounding an illegal landfill (S. Giuliano, Venice, Italy) by principal component analysis and kriging. Environmental Pollution, 122(2), 235-244.

[18] Biotto, G., Silvestri, S., Gobbo, L., Furlan, E., Valenti, S. & Rosselli, R. (2009). GIS, multi-criteria and multi-factor spatial analysis for the probability assessment of the existence of illegal landfills. International Journal of Geographical Information Science, 23(10), 1233–1244.

[19] Suleymanov, A., Abakumov, E., Zakharenko, I. & Suleymanov, R. (2021). Assessment and mapping of landfills on soils in the Serpukhov district (Moscow region). Geodesy and Cartography, 47(4), 181-185.

[20] Quesada-Ruiz, L. C., Rodriguez-Galiano, V. & Jordá-Borrell, R. (2019). Characterization and mapping of illegal landfill potential occurrence in the Canary Islands. Waste Management, 85, 506-518.

[21] Municipality of Istočna Ilidža (2011). Local Environmental Program LEAP 2012-2018, Istočna Ilidža.

[22] Municipality of Istočno Novo Sarajevo (2011). Local Environmental Program LEAP 2012-2018, Istočno Novo Sarajevo-

[23] Republic Waste Management Plan in the Republic of Srpska (2019). Regional Center for Environment - REC: Ministry of Spatial Planning, Construction and Ecology of the Republic of Srpska.

[24] QGIS 3.4. QGIS Development Team, 2018.

[25] ASTER Global Digital Elevation Model, version 2, ASTGTM2_N43E018, ASTGTM2_N43E019, ASTGTM2_N44E018 & ASTGTM2_N44E019. Ministry of Economy, Trade, and Industry (METI) of Japan and NASA, https://earthexplorer.usgs.gov/, (accessed on 06.02.2019.)

[26] Military Geographical Institute (1986). Topographic maps 1:25 000, Sheets Sarajevo 525 2 - 3 Ilidža, Sarajevo 525 2-4, Sarajevo 525 4-1, Bjelašnica, 525 4-2 Ilovice

[27] OpenStreetMap. Import/Catalogue. Available online: https://wiki.openstreetmap.org/wiki/Import/Catalogue (accessed on 15 May 2020).

[28] Institute for Geological Research of the Republic of Srpska „Geozavod" and the Federal Institute for Geology: A fragment of the Hydrogeological Map of the SFRY. (1980) Hydrogeological map of the territory of BiH, 1: 500 000, Zvornik, Sarajevo.

[29] The European Environment Agency - EEA (2018). CORINE Land Cover (CLC), Version 2020_20u1

[30] Institute of Statistics Republic of Srpska (2017). Census of population, households and dwellings in the Republic of Srpska in 2013. Banja Luka: Institute of Statistics Republic of Srpska.

[31] Valjarević, A., Djekić, T., Stevanović, V., Ivanović, R. & Jandziković, B. (2018). GIS numerical and remote sensing analyses of forest changes in the Toplica region for the period of 1953–2013. Applied Geography 92:131-139. https://doi.org/10.1016/j.apgeog.2018.01.016.

[32] Valjarević, A., Srećković-Batoćanin, D., Valjarević, D. & Matović, V. (2018). A GIS- based method for analysis of a better utilization of thermal-mineral springs in the municipality of Kursumlija (Serbia). Renewable and Sustainable. Energy Reviews. 92, 948–957. https://doi.org/10.1016/j.rser.2018.05.00

[33] Chen, K., Blong, R. & Jacobson, C. (2001). MCE-RISK: integrating multicriteria evaluation and GIS for risk decision-making in natural hazards. Environmental Modelling & Software, 16(4), 387-397.

[34] Linkov, I., Satterstrom, F. K., Kiker, G., Batchelor, C., Bridges, T., & Ferguson, E. (2006). From comparative risk assessment to multi-criteria decision analysis and adaptive management: Recent developments and applications. Environment International, 32(8), 1072–1093.

[35] Hongoh, V., Hoen, A.G., Aenishaenslin, C. et al. (2011). Spatially explicit multi-criteria decision analysis for managing vector-borne diseases. Int J Health Geogr 10, 70.

[36] Liu, Y. G., Wang, N. L., Wang, L. G., Zhao, Y. Q. & BoWu, X. (2013). Application of GIS in regional ecological risk assessment of water resources. Environmental Engineering & Management Journal (EEMJ), 12(7).

[37] Malczewski, J. (2000). On the Use of Weighted Linear Combination Method in GIS: Common and Best Practice Approaches. Transactions in GIS, 4(1), 5–22. doi:10.1111/1467-9671.00035

[38] Deepak, S., Gopika, R. & Jairaj, P.G. (2020). Geospatial approach for assessment of vulnerability to flood in local self governments. Geoenvironmental Disasters volume 7, Article number: 35. https://doi.org/10.1186/s40677-020-00172-w

[39] Sujatha, E. R. & Rajamanickam, G. V. (2014). Landslide Hazard and Risk Mapping Using the Weighted Linear Combination Model Applied to the Tevankarai Stream Watershed, Kodaikkanal, India. Human and Ecological Risk Assessment: An International Journal, 21(6), 1445–1461. doi:10.1080/10807039.2014.920222

[40] Seeboonruang, U. (2016). Geographic information system – based impact assessment for illegal dumping in borrow pits in Chachoengsao Province, Thailand. Geological Society of America Special Papers, 520, 393-405.

[41] Li, D. (2018). Geocoding and Reverse Geocoding. Comprehensive Geographic Information Systems, 95–109. doi:10.1016/b978-0-12-409548-9.09593-2

[42] Dion, N. P., Alvord, R. C., Olson, T. D., Geological Survey (U.S.) & Washington (State). (1986). Geologic, hydrologic, and cultural factors in the selection of sites for the land disposal of wastes in Washington.

[43] Matsunaga, K. & Themelis, N. (2002). Effects of affluence and population density on waste generation and disposal of municipal solid wastes, matsunaga-njt1-june7total-1, 1-28.

[44] Wisner, Ben, Adams, John & World Health Organization. (2002). Environmental health in emergencies and disasters: a practical guide / edited by B. Wisner, J. Adams. World Health Organization. https://apps.who.int/iris/handle/10665/42561

[45] Malinowski, M. & Wolny-Koładka, K. & Jastrzębski, B. (2015). Characteristics of illegal dumping sites - case study: watercourses. Infrastructure and Ecology of Rural Areas. 2015 / IV. 1475–1484. doi:10.14597/infraeco.2015.4.4.106.

[46] Domazetović, F., Šiljeg, A., Lončar, N., & Marić, I. (2019). GIS automated multicriteria analysis (GAMA) method for susceptibility modeling. MethodsX, 2553-2561. doi: 10.1016 / j.mex.2019.10.031.

[47] Mihai, F.C., Ursu, A., Ichim, P. & Chelaru, D.A. (2015). Determining rural areas vulnerable to illegal dumping using GIS techniques. Case study: Neamt county, Romania. 13th International Multidisciplinary Scientific GeoConference on Ecology, Economics, Education and Legislation, SGEM 2013 Conference Proceedings, Jun 2013, Albena, Bulgaria. pp. 275-282

[48] Da Paz, D. H. F., Lafayette, K. P. V., Holanda, M. J. de O., Sobral, M. do C. M., & Costa, L. A. R. de C. (2018). Assessment of environmental impact risks arising from the illegal dumping of construction waste in Brazil. Environment, Development and Sustainability. doi:10.1007/s10668-018-0289-6

[49] North, M. (2009). A Method for Implementing a Statistically Significant Number of Data Classes in the Jenks Algorithm. 6th International Conference on Fuzzy Systems and Knowledge Discovery, FSKD 2009. 1. 35-38. 10.1109 / FSKD.2009.319.

[50] Chen, J., Yang, S., Li, H., Zhang, B. & Lv, J. (2013). Research on Geographical Environment Unit Division Based on the Method of Natural Breaks (Jenks). ISPRS - International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences. XL-4 / W3. 47-50. 10.5194 / isprsarchives-XL-4-W3-47-2013.

[51] ESRI (2008). ArcGIS Desktop Help 9.3. Cited at: http://webhelp.esri.com/arcgiSDEsktop/9.3/index.cfm?TopicName=Natural_breaks_(Jenks)