Árvízre vonatkozó városi árvízveszély értékelése GIS alapú AHP megközelítés használatával

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Urban flood hazard Assessment to flood using GIS based AHP approach

A városi árvizek nagy figyelmet kaptak az elmúlt években, mivel a városi területek lakossága egyre sérülékenyebbé vált a szélsőséges éghajlati jelenségekkel szemben. A városi árvizek aránya világszerte megnőtt főképp a klímaváltozásnak betudhatóan. A növekvő árvízproblémával való megbirkózáshoz egyre nagyobb erőfeszítéseket tettek a városi területek árvízvédelme érdekében. A védekezés gyakorlati megvalósítása érdekében elsősorban azonosítani kell az árvízveszélynek kitett területeket. Ebben a tanulmányban, hasonlóképpen, egy kísérletet tettünk arra, hogy Győr városában az árvíz szempontjából potenciálisan veszélyeztetett területeket azonosítsunk. A Rába, a Rábca, a Mosoni-Duna, a Marcal és a Duna összefolyásánának közelsége miatt Győr különösen veszélyeztetett település. Az árvízveszélyt úgynevezett Analitikus Hierarchikus Folyamat (angolul: "AHP") technikával mértük kiválasztott paraméterek alapján, azaz a tengerszint feletti magasságot, a felszín borítottságot/földhasználatot, a görbületi számot (Cn háló) és a lejtést figyelembe véve, úgy, hogy minden egyes tényezőnek meghatározott jelentősége van. Az eredményül kapott kockázati térkép megmutatja, hogy árvízkockázati szempontból a külvárosi területek kifejezetten magas, míg a város nagy része magas kockázati övezetben helyezkedik el. A belvárosi terület alacsony árvízkockázatú övezetben található, míg a déli városrésznek csak egy kisebb része helyezkedik el nagyon alacsony árvízi övezetben. A tanulmány eredménye nagyon hasznos a jövőbeni kutatások szempontjából, amely kutatások a kitettség, az érzékenység és árvízzel szembeni ellenálló képesség mechanizmusának integrálásával foglalkoznak.

Introduction

Floods in urban area are one of the most frequently occurring and widespread disasters affecting the urban morphology worldwide *(Zhongming et al. 2012)*. The evidence from across the world shows that in the last decades the frequency and severity of urban flooding has increased significantly *(Miller – Huntchins 2017)*. Urban flooding could be initiated by either natural activity like heavy rainfall intensity or human activities such as urban encroachment along river banks or flood plains, poor urban infrastructure, lack of a proper drainage system, deforestation and interference in natural waterways *(Huang et al. 2018; Song et al. 2019, Adekola – Lamond 2018)*. The flooding in the urban areas is mainly triggered when surface runoff exceeds the capacity of drainage systems, coinciding with the situation when sewers having a limited capacity and poorly planned or operated drainage system is unable to get along with heavy rainfall occurrence or increase in the river and streams water level that runs through the affected urban areas *(GETIRANA et al. 2020)*. The rapid change in climate and its resulting consequences has led to an increased focus on research, planning, and action on different aspects of urban environment *(RIGNOT et al. 2013, SZENTO et al. 2015)*.

Urban systems are very complex as they function as a realm that provides different services for the residents *(BATICA – GOURBESVILLE 2014)*. The sustainability of the urban areas and the interventionist policies to maintain the livelihood are the main emphasis of today's urban issues *(ANTOGNELLI – VIZZARI 2016, BUSH – DOYON, D'ACCI 2019, GHADI – TÖRÖK)*. In near future, the cities that are located on the river floodplains and coastal deltas are expected to become more vulnerable to the risk of urban flooding mainly because of the impacts of climatic change *(MACITYRE et al. 2018)*. There is a growing debate among researchers and policymakers about the necessity to strengthen the resilience of urban areas as these are struggling regularly in confronting the climatic extremes *(HENSTRA 2012)*.

The climate change has two levels of direct impacts: shocks and sudden impacts such as typhoons, storms, drought heat waves, and frequent flooding events; and slow ramifications that build gradually over time such as average temperature increase, sea level rise, and long-term changes in rainfall patterns *(KIM – LIM 2016)*. In recent past the world has witnessed a significant increase in communities affected from the flood processes to the extent that the threatening level of direct and indirect destruction has a direct impact on the associative structure of urban communities *(DOUXCHAMPS et al. 2017)*. The resulting impacts of these disturbances are mostly felt by vulnerable people i.e., socially or economically marginalized population, due to their low level of ability to adapt and respond *(BULL-KAMANGA et al. 2003)*. Therefore, for a sustainable urban development, it is essential that the urban framework must be well built for adaptation to a climate change including frequent flooding *(EVANS 2011)*.

The urban flood is a hydrological hazard, which has the potential to cause damages in urban settlements *(FRIEND – MOENCH 2013)*. The maps of these hazards are usually designed to assist authorities in making proper decision mechanism by identifying the areas that have high probability of flooding over space and time by incorporating various parameters *(MIGUEZ – VERÓL 2017)*. By incorporating various factors that contribute to the flood hazard, a conceptual map of flood hazard can be established.

MATERIANS AND METHODS

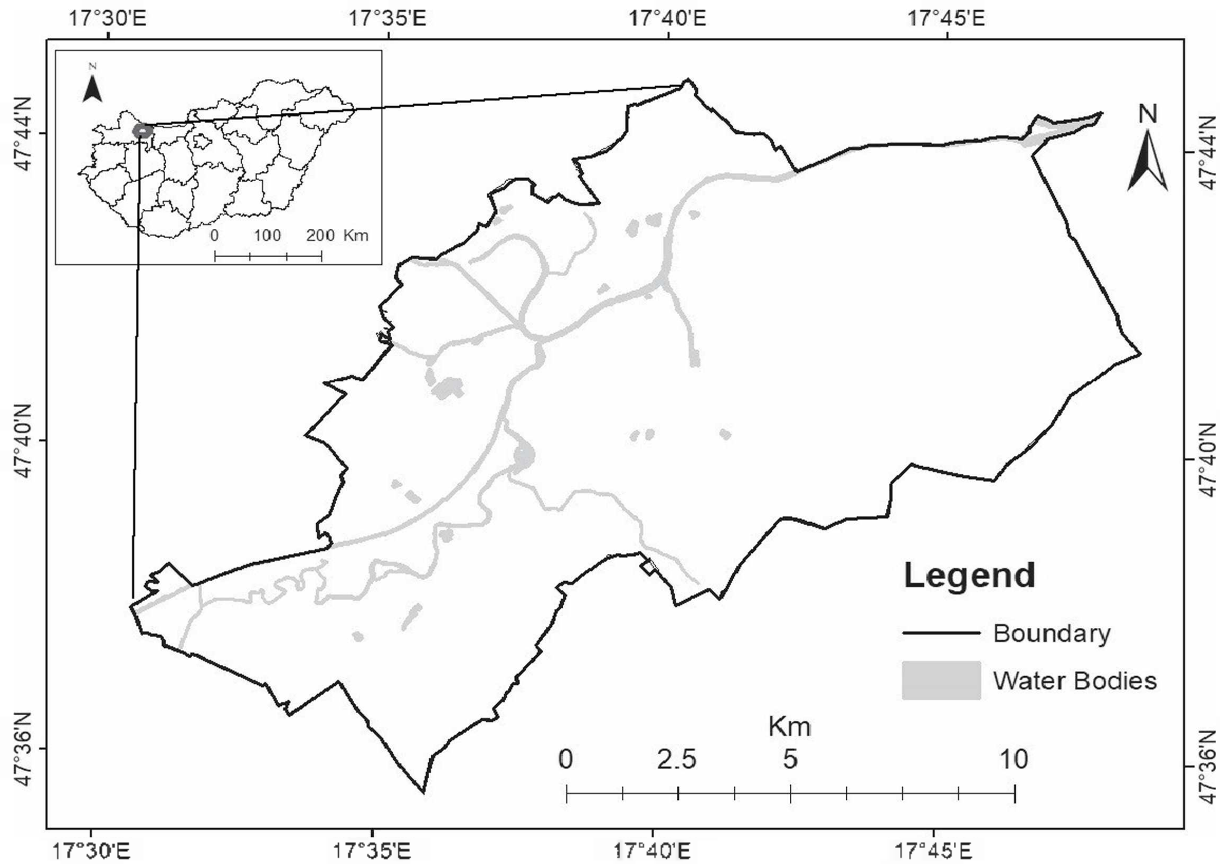
1. STUDY AREA

The city of Győr is chosen for the research study as it is the most important city in North-Western Hungary and historically been frequently affected by flooding

(Figure 1). The city is at the junction of four major local rivers i.e., Mosoni-Danube, Rába, Rábca and Marcal. Besides these four, the Great Danube is at only 10 km distance from the city center. The combination of all these rivers exerts great sway on the water regime in the city, hence any disturbance in the water level of these rivers result in the direct impact on the city infrastructure and local communities. The average water level has seen a steady rise of about 3.5 meters for the last two hundred years which now stands at 7.5 meters resulting in the flood defenses to be constantly raised by the authorities. This research study will be a useful attempt to analyze the impacts the changes in flood levels, watercourses and riverbeds on the local urban areas and to build a resilient framework to mitigate the harmful impacts of the floods to Győr city.

In this study we have selected four criteria for investigating flood hazard susceptibility in the study area. These four criteria are Elevation, Land use and Land cover (LULC), Curve Number grid (CN Grid) and Slope. The data were acquired from secondary sources mainly through the respective Government departments and literature.

Figure 1: Location Map of Study Area
1. ábra: A kutatási terület elhelyezkedése



2. Flood hazard

Flood is one of the key parts of natural hazards that can severely impact the development of an area *(Rehman et al. 2019)*. In recent times, owing to the negative impacts of climate change, the world has seen a significant increase in the flooding events in the urban areas *(Lin et al. 2020)*. The severity of these flooding varies from place to place depending on the nature of flooding, i.e. depth, extent, duration, uprising rate of floodwaters and velocity, physiography and local flood management *(Bruwier et al. 2020)*. In this study, we have generated a map of flood hazard for Győr city by assigning four criteria that are relevant in identifying hazard prone areas i.e., Elevation, Land use and Land cover (LULC), Curve Number grid (CN Grid) and Slope. These parameters were selected based on their importance and the local geographical features of the study area and play a significant role in determining the susceptibility of an area to the flood hazards. Each sub-factor was given weight using the expert opinion and literature review and normalized through Analytic Hierarchy Process (AHP) approach.

2.1. Analytical Hierarchy Process (AHP)

The analytical hierarchy process is a multicriteria method used in situations where there is complexity in determining the selection of the most suitable alternative *(Amanathan 2004)*. It is one of the most efficient weightage methods widely used worldwide to assess the urban flooding – Dahri, & Abida, (2017); Gupta & Dixit, (2022) –, in which each criterion is assigned with a specific value.

In AHP method the basics of AHP in this study is the pair-wise comparison of each Criterion. In this regard, the weights were assigned to each Criterion based on the knowledge and the literature review. The scale values are used from equal importance to extreme importance having numerical values of 1 to 9 *(Table 1)*.

The preference matrix *(Table 2)* was obtained using Table 1. The judgment of the appropriate values for each criterion is critical. The elevation factor obtained the highest importance to measure flood hazard, while the LULC and CN Grid received moderate values. In addition, slope acquired the lowest value.

In order to obtain the weightage average, the pair comparison is processed through normalized matrix resulting in the percentage weightage of each parameter. The weightage average shows that the elevation obtained the highest weight (37%) followed by LULC (27 %), CN Grid (26%) and the slope gets the least weight (10%) *(Table 3)*.

Table 1. Pair-wise comparison scale
1. táblázat: Alkalmazott skálák páronkénti összehasonlítása

Scale	Numerical Rating	Reciprocal
Equal importance	1	1
Moderate importance	3	1/3
Strong importance	4	¼
Very strong importance	7	1/7
Extreme importance	9	1/9
Intermediate values	2,4,6,8	1/2, 1/4, 1/6, 1/8

Table 2. Pair-wise comparison Preference matrix
2. táblázat: Preferencia mátrix páronkénti összevetés

Criteria	Elevation	LULC	CN Grid	Slope
Elevation	1	2	2	2
LULC	1/2	1	2	3
CN Grid	1/2	1/2	1	4
Slope	1/2	1/3	¼	1
Total	2.5	3.83	5.25	10

Table 3. Normalized matrix of Pair wise comparison of parameters for Hazard Analysis
3. táblázat: A veszélyelemzés-paraméterek páronkénti összevetésének normalizált mátrixa

Criteria	LULC	CN Grid	Slope	Average	Weight (%)
Elevation	0.522	0.387	0.166	0.37	37
LULC	0.261	0.387	0.25	0.27	27
CN Grid	0.130	0.193	0.5	0.26	26
Slope	0.086	0.032	0.083	0.10	10
Total/Sum	3.83	5.25	10	1	100

3. COMSISTENCY RATIO

The evaluation of calculated weights is validated through a numerical index called the consistency ratio (CR). The CR is defined as the ratio between the consistency index (CI) and the random index (RI).

It is given as

CR = CI/RI.. (Eq. 1)

The CI is given by the formula

CI = λmax - n/n – 1................................. (Eq. 2)

Where λmax represents the largest eigenvalue which is calculated as 4.24 *(Table 4.)*, while 'n' is the number of perimeters used in the AHP method. Putting values in the equation:

CI = 2.24 – 4/4 -1 = 0.08

CI = 0.08

Table 4. Consistency Index (CI) Calculation
4. táblázat: Konzisztencia index számolása

Sum of criteria (Table 1)	**Criteria Average**	**Product of both column**
2.5	0.37	0.94
3.83	0.27	1.09
5.25	0.26	1.2
10	0.10	1
		λmax = 4.24

Similarly, the RI is a constant value which is obtained through *(Table 5.* As the number of parameters in the study are 4, so the value of RI for n=4 is 0.9.

Table 5. Consistency indices (RI) for a randomly generated matrix
5. táblázat: Konzisztencia index értékei a generált mátrixmérethez

Criteria Value (n)	2	3	4	5	6	7	8
RI	0	0.52	0.9	1.12	1.24	1.32	1.41

Now, putting the values of CI and RI in Eq.1,

CR= 0.08/0.9 ⟹ CR= 0.088

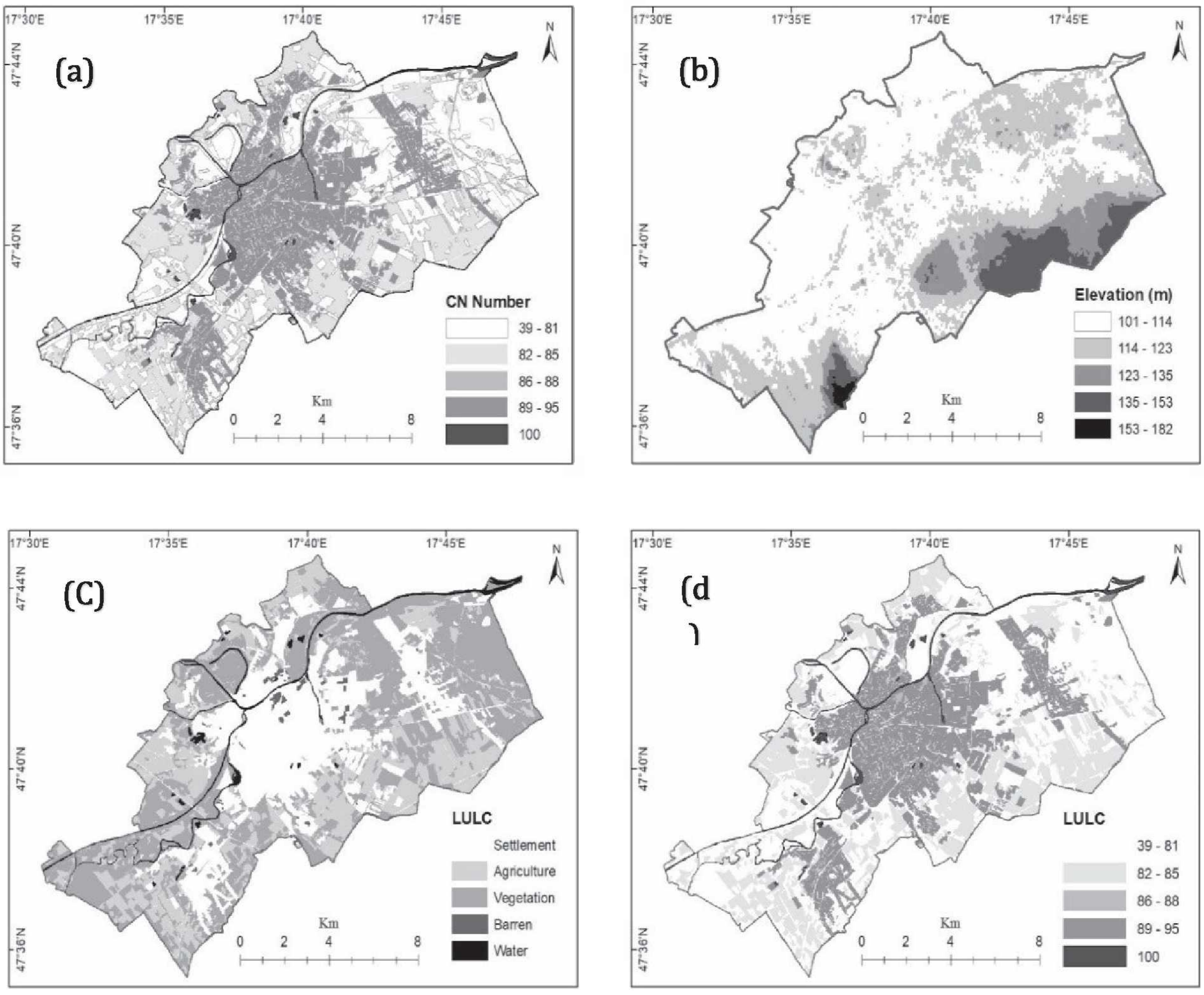
Now, the value of RI only accepts a matrix as a consistent one if CR < 0.1 i.e., if the CR exceeds the value of 0.1 then it will be taken as non-reliable and all the exercise must start again until the resultant CR value becomes less than 0.1. Hence, our resultant value of CR is 0.088 which is less than 0.1, hence it proves that the preferences and the weights applied in this study are reliable.

4. GIS BASED WEIGHTED OVERLAY METHOD

The statistical measures are then processed using the raster weighted overlay method in Arc GIS software 10.8. Each of the four parameters was mapped separately *(Figure 2)* and afterwards reclassified using "Weighted Overlay" in the "Spatial Analyst Tool". The Weighted Overlay is a geoprocessing tool that helps in calculating multi-criteria analysis between several rasters using a common measurement scale and weights, each according to its importance. The influence percentage value of each parameter was obtained from Table 3. of each of level of hazard was calculated in weighted overlay method.

Figure 2: (a) CN Grid, (b) Elevation, (c) LULC, (d) Slope

2. ábra: CN háló (a), magasság (b), LULC (c), lejtés (d)

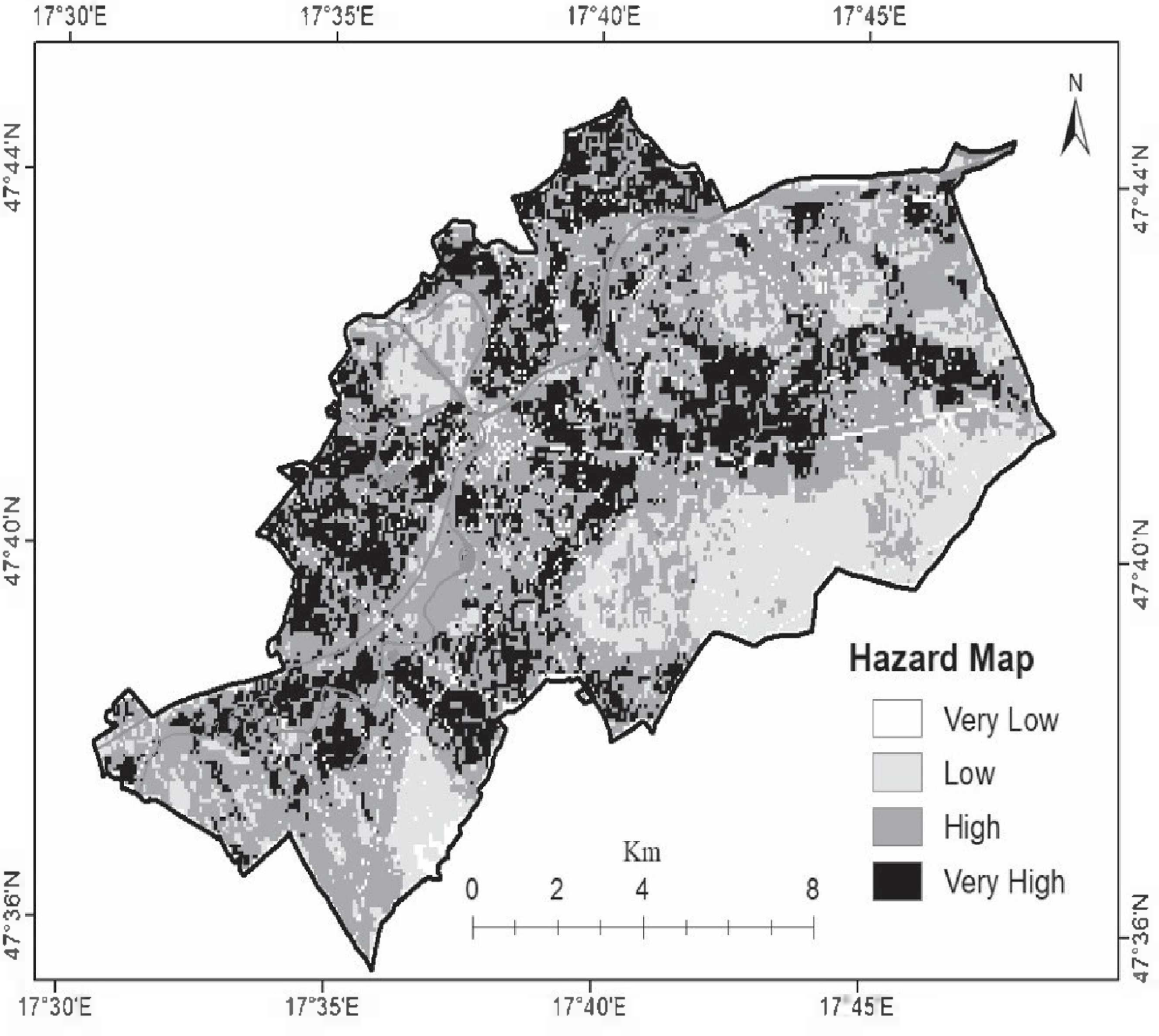


5. RESULT

The final hazard map was obtained with four level levels of hazard situation, i.e. very low, low, high and very high hazard prone zone (Figure 2). The percentage

The highest percentage of hazard level was 32.7% obtained by 'very high' hazard zone, 31.6% in 'low' level, 31.2 % has 'high' level while the lowest percentage was obtained by 'very low 'level', i.e. 4.5. The resultant percentage of hazard zones shows that almost two-thirds, i.e. 63.9% of the study area is subjected to either high or very high flood hazard zones.

Figure 3. Hazard map of the study area.
3. ábra: A kutatási terület árvízveszély térképe



The resultant weightage map of the study area shows a mixture of areas falling into different zones of the four classes (very high, high, low, very low) *(Figure 3)*. The resultant map shows that mainly the low-lying flat areas of the eastern and western parts of the study area have a very high possibility of urban flooding, followed by the downtown area of Győr into high potential of urban flooding. The prominent aspect of the map is the old city next to the confluence of the rivers which falls into low potential of urban flooding owing to its relatively high elevation compared to the neighboring areas. Other parts of the city also have low potential of urban flooding, particularly the north-eastern and southern parts of the city. The areas that are relatively far from the rivers, especially the southern part, give a low possibility to be affected by floods. The very low potential urban flooding hazard areas are only present on the south-eastern part of the city that are at the highest elevation in the study area. These area's elevation ranges from 130 m to 182 m with a clear variation from the average elevation of the city, i.e. 118m making these areas to be the least affected by a possible flooding event.

SUMMARY

In this study an attempt was made to identify the flood hazard zones in Győr city using Analytic Hierarchy Process (AHP) approach. Győr city has a history of frequent flooding due to its proximity to the Rába, Rábca, Mosoni-Danube and Marcal rivers, while the great Danube River is located only 10 km from the downtown area. Four parameters were selected that are most relevant in identifying the hazard situation of the study area, i.e. elevation, land cover/land use, curve number (Cn Grid) and slope. Each parameter was assigned a specific value using expert opinion and literature knowledge. The parameters were then processed by statistically measuring AHP approach which were then visualized using Arc GIS software and a final map of flood hazard was obtained. The resultant hazard map shows that the majority of the study area is subjected to flood hazard situation, i.e. 63.9%, while the main city area is located in either high or very high flood hazard zones. This study provides a useful tool in assisting the authorities to identify those areas which are vulnerable to future flooding. Furthermore, incorporating other factors like exposure, susceptibility and coping capacities with assigned parameters like precipitation, water discharge, settlement structure, economic capacity, population density etc., an urban resilient mechanism can be constructed to better deal with future flooding situations.

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